RDECOM

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Development, Optimization, and Application of Combined Effects Explosives

12 May 2009

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Outline

- Objectives
- CHEETAH Calculations
- Cylinder Expansion Results
- Optimization of Formulation
- Other Testing
- Conclusions
- Future Plans

"Distribution A: Unlimited Distribution"

Objectives

Develop and Demonstrate an aluminized explosive where the aluminum fully reacts in the early time of detonation and substantially contributes to the metal pushing energy of the explosive formulation and enhances blast.

- High Energy Explosive (LX-14)
  - Meet metal pushing performance
  - High nitramine content
  - High early work output (before 7V/V0)
- High Blast Explosive (PAX-3)
  - Meet blast performance
  - Typically aluminum and additional oxidizer
  - Later work output (after 7V/V0)
- Combined Effects Explosive
  - Meet LX-14 (metal pushing) AND PAX-3 (blast) performance with one explosive
  - Nitramine with fine aluminum: micron size
  - Aluminum reaction occurs very early and contributes to early work

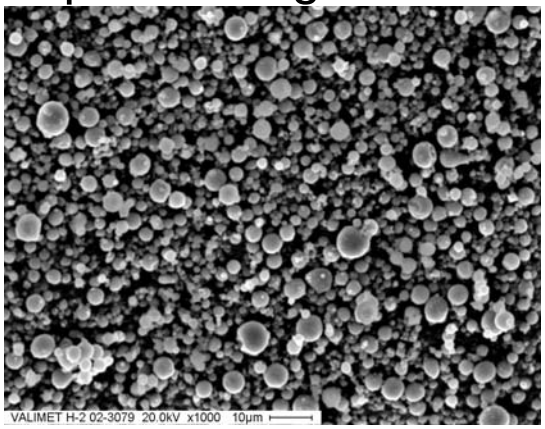
"Distribution A: Unlimited Distribution"

Aluminum Particle Size

- Nano-Aluminum
  - Advantages
    - May react quickly and completely in a detonation for a complete release of energy
    - Claimed higher heat of formation than normal aluminum
  - Possible disadvantages
    - Oxide coating may decrease performance.
    - Reactivity with air or water
    - Aging and stability in formulations not yet established.
    - Potentially higher cost
    - Requires modified processing methods

Micron Size Aluminum

- Advantages
  - Eliminates most of the disadvantages of the nano aluminum
- Possible disadvantages
  - Larger particle size may prevent fast enough reaction
  - Requires modified processing methods



"Distribution A: Unlimited Distribution"

Formulations

	LX-14	PAX-29	PAX-29n	PAX-30	PAX-3	PAX-3a	PAX-42
HMX	95.5			77	64	64	
RDX							77
CL-20		77	77				
Al		15	15 (nano)	15	20 (39μm)	20 (3.5μm)	15
BDNPA/F		4.8	4.8	4.8	9.5	9.5	4.8
CAB		3.2	3.2	3.2	6.5	6.5	3.2
Estane	4.5						

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PAX-29 (CL-20) CHEETAH 3.0 Calculations

COMPOSITION: **Aluminized CL-20** 3.2% CAB, 4.8% BDNPA/F 92% (CL-20 + Aluminum)	**Density** 99%TMD (g/cc)	**CJ Pressure** GPa	**Detonation Velocity** (km/s)	**Expansion Energy** @V/V0=6.5 $E_{6.5}$ (kJ/cc)	**Total Mechanical Energy** E_{tot} (kJ/cc)
0% Al (PAX-22)	1.938	40.7	9.36	9.82	11.34
10% Al	1.984	39.6	8.98	10.55	13.26
13% Al	1.998	38.6	8.84	10.69	13.81
15% Al (PAX-29)	2.008	37.7	8.72	10.75	14.18
17% Al	2.018	36.5	8.60	10.76	14.55
20% Al	2.033	34.5	8.37	10.65	15.20
25% Al	2.058	32.2	8.04	10.28	15.92
30% Al	2.083	28.7	7.92	9.28	15.31

- $E_{6.5}$ optimizes at 15-17% Al
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 25% Al

"Distribution A: Unlimited Distribution"

PAX-30 (HMX) CHEETAH 3.0 Calculations

COMPOSITION: Aluminized HMX 3.2% CAB, 4.8% BDNPA/F 92% (HMX + Aluminum)	**Density** 99%TMD (g/cc)	**CJ Pressure** GPa	**Detonation Velocity** (km/s)	**Expansion Energy** @V/V0=6.5 $E_{6.5}$ (kJ/cc)	**Total Mechanical Energy** E_{tot} (kJ/cc)
0% Al	1.821	33.8	8.77	8.54	10.15
10% Al	1.874	32.6	8.43	9.37	12.03
15% Al (PAX-30)	1.902	31.3	8.16	9.70	12.98
18% Al	1.919	30.9	8.04	9.83	13.56
19% Al	1.925	30.7	8.02	9.84	13.77
20% Al	1.931	30.4	8.01	9.83	13.99
25% Al	1.960	28.4	7.99	9.62	14.95
28% Al	1.978	27.0	7.96	9.33	15.20
30% Al	1.991	26.2	7.94	9.00	15.09

- E6.5 optimizes at 18-20% AL
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 28% Al

"Distribution A: Unlimited Distribution"

PAX-42 (RDX) CHEETAH 3.0 Calculations

COMPOSITION: **Aluminized RDX** 3.2% CAB, 4.8% BDNPA/F 92% (RDX + Aluminum)	**Density** 99%TMD (g/cc)	**CJ Pressure** GPa	**Detonation Velocity** (km/s)	**Expansion Energy** @V/V0=6.5 $E_{6.5}$ (kJ/cc)	**Total Mechanical Energy** E_{tot} (kJ/cc)
0% Al	1.745	30.7	8.51	8.06	9.66
10% Al	1.802	29.7	8.19	8.91	11.55
15% Al (PAX-42)	1.832	28.7	7.94	9.24	12.50
18% Al	1.851	28.6	7.84	9.37	13.07
19% Al	1.857	28.4	7.82	9.38	13.29
20% Al	1.863	28.1	7.80	9.37	13.50
25% Al	1.896	26.3	7.75	9.19	14.46
28% Al	1.915	25.0	7.70	8.89	14.67
30% Al	1.923	24.1	7.67	8.56	14.56

- E6.5 optimizes at 18-20% AL
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 28% Al

"Distribution A: Unlimited Distribution"

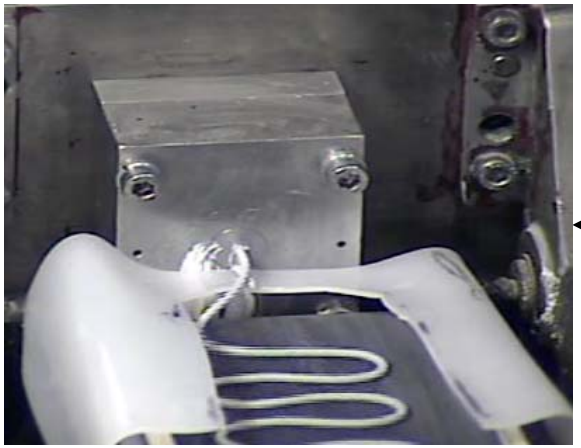
PAX-3 (HMX) CHEETAH 3.0 Calculations

COMPOSITION: **PAX-3 Variations** 6.4% CAB, 9.6% BDNPA/F 84% (HMX + Aluminum)	**Density** 99%TMD (g/cc)	**CJ Pressure** GPa	**Detonation Velocity** (km/s)	**Expansion Energy** @V/V0=6.5 $E_{6.5}$ (kJ/cc)	**Total Mechanical Energy** E_{tot} (kJ/cc)
0% Al	1.760	29.7	8.34	7.74	9.39
10% Al	1.810	28.3	7.99	8.52	11.13
15% Al	1.835	27.4	7.73	8.83	12.01
18% Al	1.851	27.1	7.65	8.94	12.58
19% Al	1.857	26.9	7.64	8.95	12.78
20% Al (PAX-3)	1.862	26.6	7.63	8.94	12.98
25% Al	1.890	24.8	7.58	8.73	13.86
28% Al	1.906	23.5	7.51	8.47	14.10
30% Al	1.918	22.6	7.47	8.17	14.01

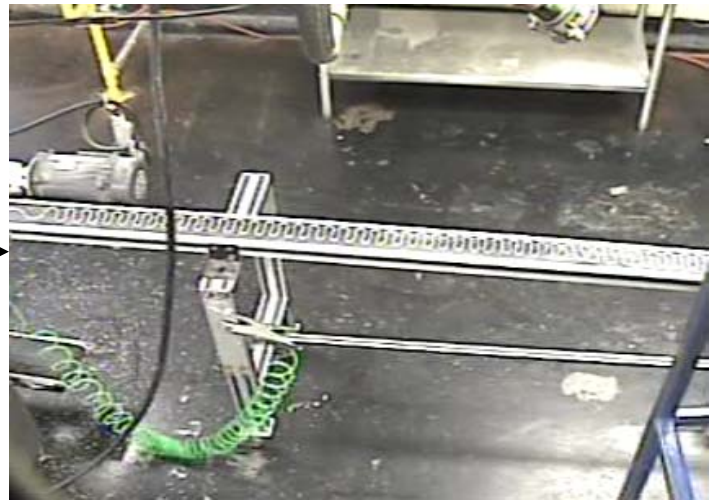
- E6.5 optimizes at 18-20% AL
- CJ pressure optimizes at 0% Al
- Total mechanical energy optimizes near 28% Al

"Distribution A: Unlimited Distribution"

Extrusion of PAX-3 MANTECH Funding

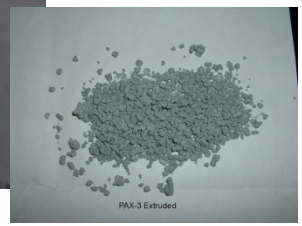


Extruded PAX-3



Final End Product PAX-3

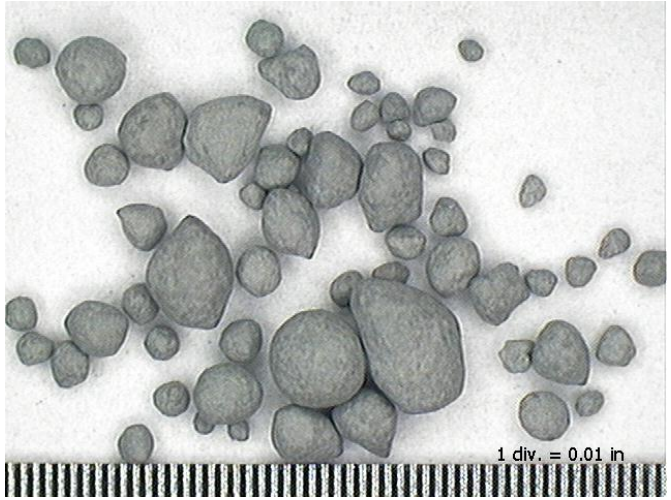
Granulated PAX-3



PAX-30 and PAX-42 are about to start development in twin screw extruder

"Distribution A: Unlimited Distribution"

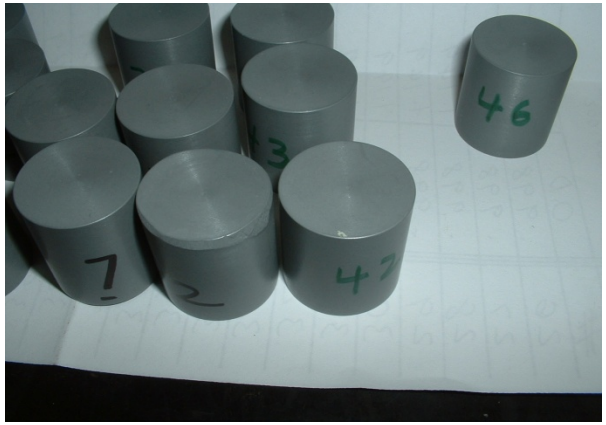
Molding Powder & Pressed Pellets



PAX-30 Powder made with vertical mix process

PAX-42 Powder made with vertical mix process

PAX-30 Cylinder Expansion Pellets



PAX-42 Cylinder Expansion Pellets

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LSGT Results

	LX-14	PAX-29	PAX-29n	PAX-3a	PAX-3	PAX-42
LSGT (cards)	193	135	130	128	124	110
Pressed Density (g/cc) (% TMD)	na	2.009 99.0%	2.005 98.3%	1.878 99.8%	na	1.842 99.5%

PAX-30 LSGT		
Vertical Mix	Slurry Mixed	Vertical Mixed
162/165 98.2% TMD	160/161 98.5% TMD	161/162 97.9%TMD

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Metal Pushing & Blast Energy Compared to LX-14

Percent Change compared to LX-14		
HE	Metal Pushing/Unit Volume (Experimental)	Blast (Calculated)
LX-14 (HMX)	0 (Baseline)	0 (Baseline)
PAX-29c (CL-20)	17 %	43 %
PAX-29n (CL-20)	17 %	38 %
PAX-3 (HMX)	-28 %	32 %
PAX-30 (HMX)	6 %	30 %
PAX-42 (RDX)	3 %	24 %

- PAX-30 and PAX-42 maintain metal pushing energy but exceed blast with 18.5% less explosive fill
- CL-20 increases sensitivity and cost – not ready for development
- Excellent candidates for multi-purpose warhead!

"Distribution A: Unlimited Distribution"

Cylinder Expansion Test Data (Gurney Energy)

Comparison of Predicted and Actual Cylinder Expansion Results (V/V0=7)				
Formulation	**Wall Velocity *v* (mm/μs) actual/predicted**	**Gurney Constant $\sqrt{2E}$ (mm/μs)**	**Predicted Gurney Constant (mm/μs)**	**Modified Gurney Constant (mm/μs) actual/predicted**
PAX-29n	1.965/1.944	3.078	3.046 (-1.0%)	3.135/3.102
PAX-29	1.976/1.968	3.102	3.089 (-0.4%)	3.159/3.146
PAX-29 (repeat)	1.976/	3.098		3.156
PAX-30	1.855/1.890	2.968	3.023 (+1.9%)	3.022/3.078
PAX-42 (EXP6 eos)	**1.873/1.844 /1.790**	**3.045**	**3.002 (-1.4%) 2.914 (-4.3%)**	**3.101/3.057 /2.967**
LX-14	1.848/	3.014		

PAX-42 (an RDX version) meets LX-14 performance and has significant blast at a lower cost

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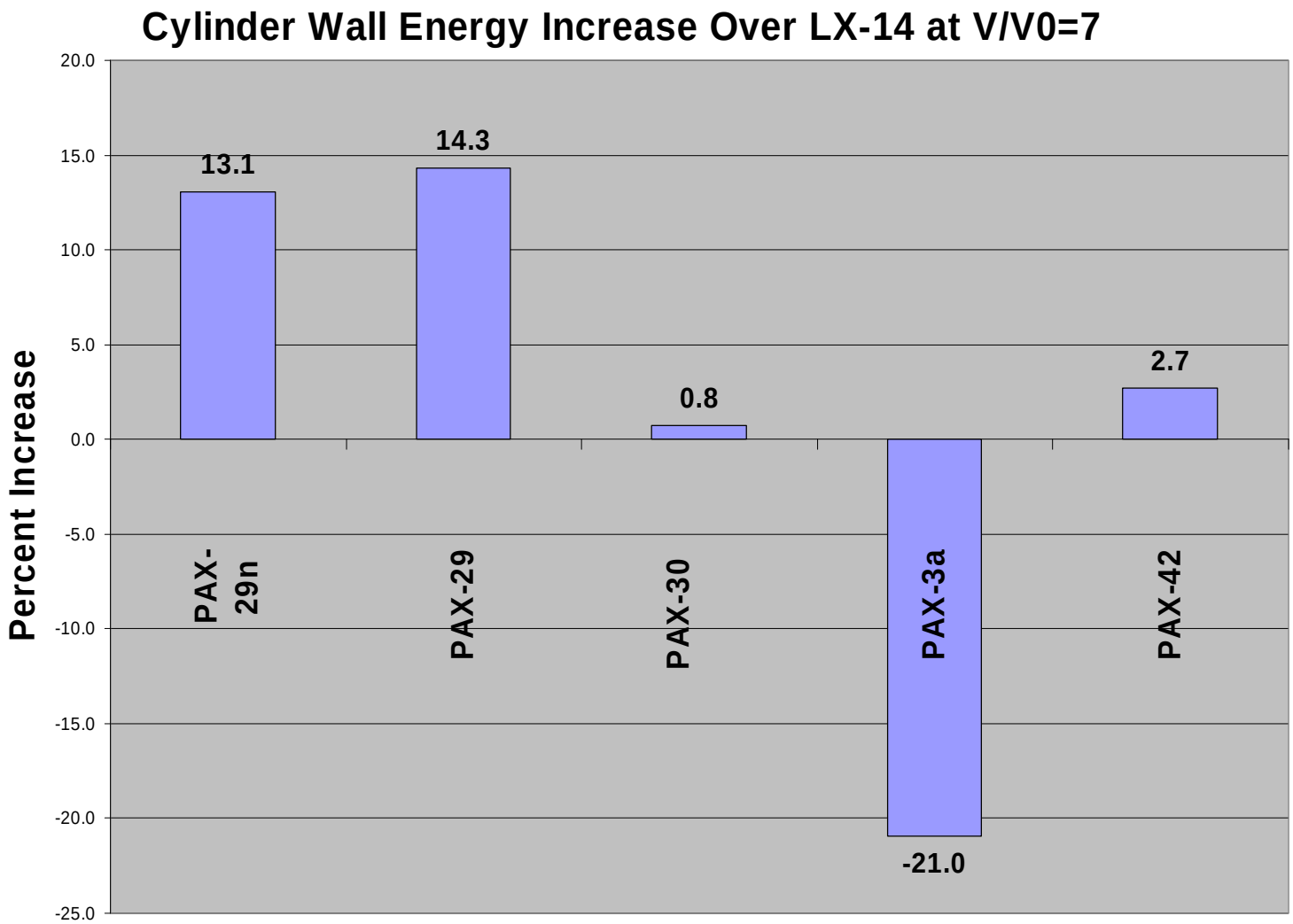
Metal Pushing Compared to LX-14



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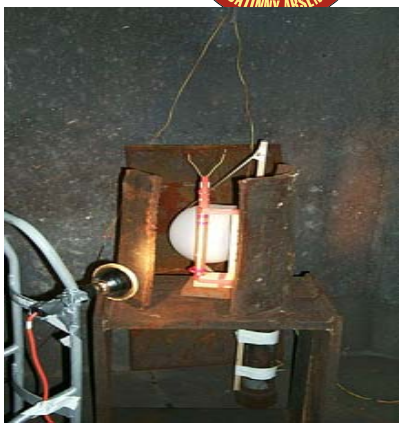
PAX-30 DOE (Metal Pushing)

- Aluminum reaction is excellent for Al particles sizes from 130 nm to 15 micron
- 15 micron aluminum gives best performance at early and late expansion (blast vs metal pushing)
- There is a clear drop in performance with 30 micron aluminum



Comparison of Predicted and Measured Cylinder Expansion Tests for PAX-30 PAX-30 DOE – Effect of Aluminum Particle Size (92% Solids, 15% AL)			
Aluminum Particle Size	**Density (g/cc)**	**Cylinder Wall Velocity (mm/μs)**	
		V/V0=2	**V/V0=7**
130nm	1.870 (96.8% TMD)	1.520 predicted 1.410 (92.7%) measured	1.838 predicted 1.830 (99.5%) measured
3.5μ	1.909 (99.3% TMD)	1.560 predicted 1.429 (91.6%) measured	1.888 predicted 1.855 (98.3%) measured
8μ	1.885 (98.1% TMD)	1.550 predicted 1.480 (95.5%) measured	1.881 predicted 1.856 (98.7%) measured
15μ	1.889 (98.3% TMD)	1.554 predicted 1.509 (97.1%) measured	1.883 predicted 1.887 (100.2%) measured
30μ	1.878 (97.7% TMD)	1.546 predicted 1.398 (90.4%) measured	1.874 predicted 1.791 (95.6%) measured

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PAX-30 DOE (Metal Pushing) Solids Level

- All 15 micron
- Moderate increase in theoretical performance with solids level
- Significant increase in measured performance with solids level
- 100% aluminum reaction efficiency at 92% solids

Comparison of Predicted and Measured Cylinder Expansion Tests for PAX-30 PAX-30 Optimization – Effect of Solids Level (15% 15μ AL)			
Percent Solids	**Density (g/cc)**	**Cylinder Wall Velocity (mm/μs)**	
		V/V0=2	**V/V0=7**
86	1.863 (99.6% TMD)	1.504 predicted 1.339 (89.0%) measured	1.839 predicted 1.653 (89.9%) measured
88	1.868 (98.9% TMD)	1.516 predicted 1.397 (92.1%) measured	1.850 predicted 1.729 (93.5%) measured
90	1.871 (98.2% TMD)	1.526 predicted 1.458 (95.5%) measured	1.862 predicted 1.810 (97.2%) measured
92	1.889 (98.3% TMD)	1.554 predicted 1.509 (97.1%) measured	1.883 predicted 1.887 (100.2%) measured

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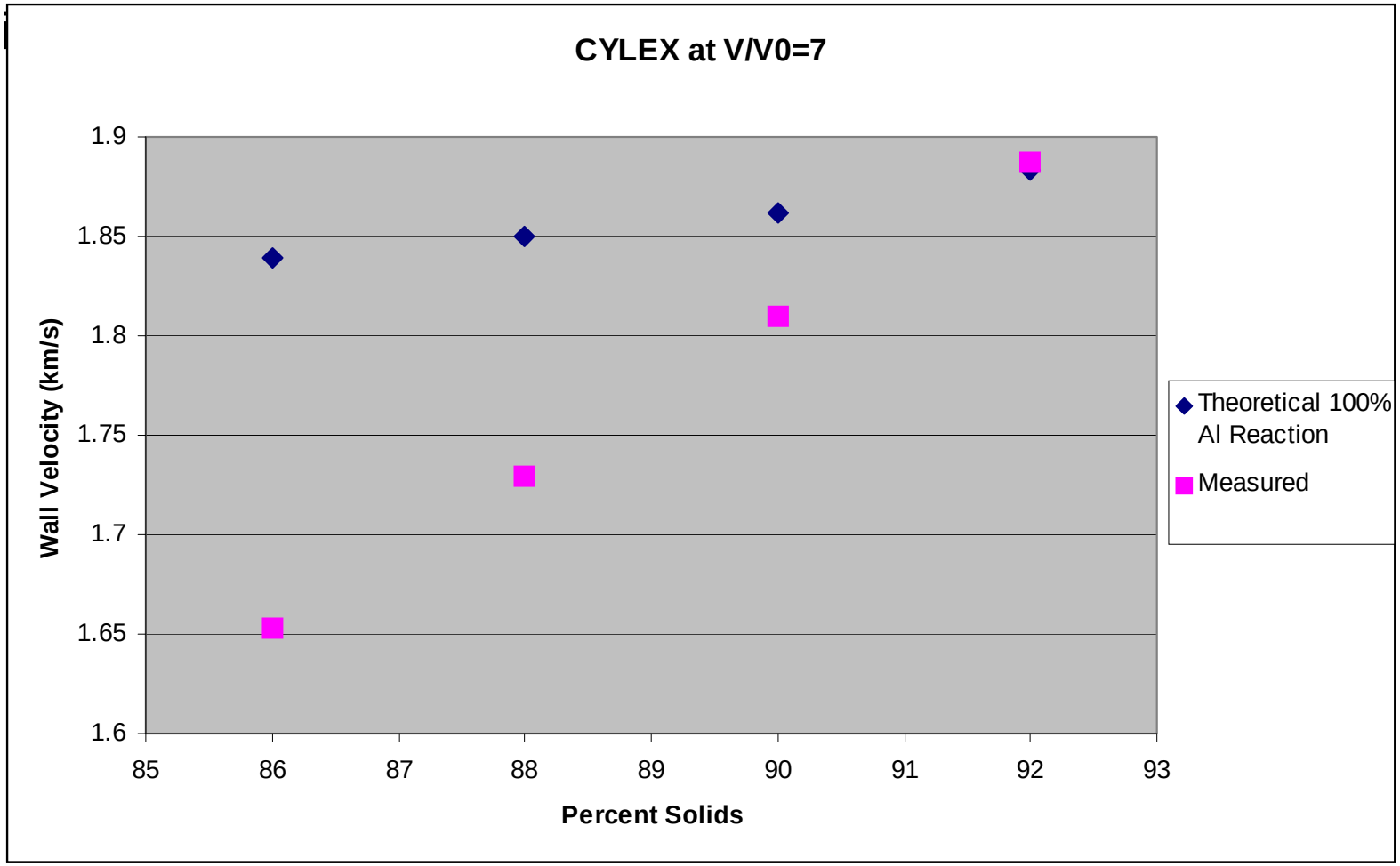
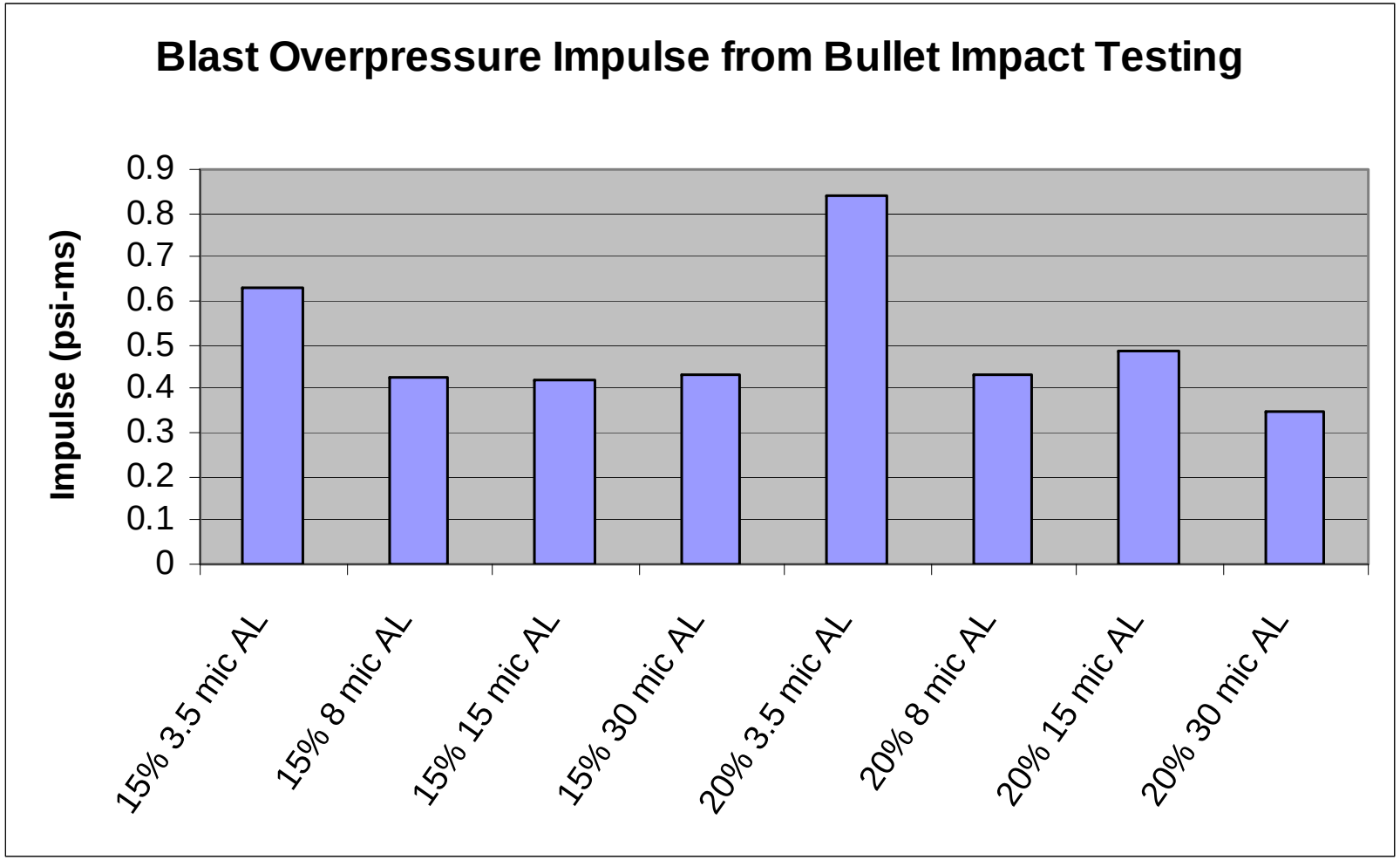
PAX-30 Cylinder Expansion Optiization

- Data shows consistent trends
- Modeling of phenomena does not match experiment



"Distribution A: Unlimited Distribution"

PAX-30 DOE – Bullet Impact (1/2lb bare billet)



"Distribution A: Unlimited Distribution"

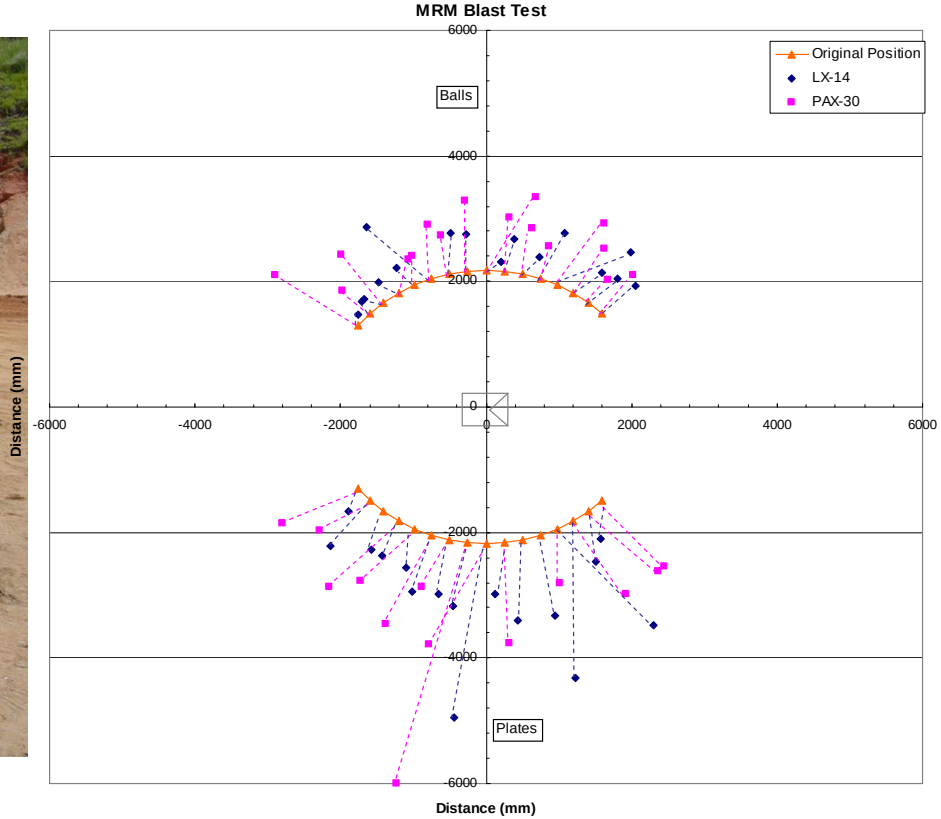
Summary - PAX-30 Formulation Studies

- PAX-30 DOE study shows that 15 micron aluminum at the 15% level offers the following benefits
  - Best performance
  - Better pressed density than smaller Al sizes
  - Better bullet impact response than 3.5 micron Al
  - Reduced cost compared to smaller Al
  - Reduced aluminum ESD sensitivity compared to smaller Al
- The PAX-30 optimization study shows that performance is greatly reduced at solids levels below 92%
  - Bullet impact improvement seen only at the lowest (86%) solids level

PAX-30 optimizes metal pushing and blast at 92% solids and 15micron Aluminum

"Distribution A: Unlimited Distribution"

MRM Stonehenge - PAX-30 and LX-14



- Blast capabilities outperformed LX-14 in the MRM configuration.
- PAX-30 maintained penetration equivalent to LX-14

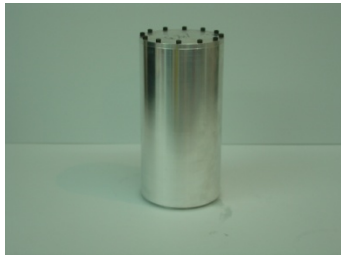
"Distribution A: Unlimited Distribution"

PAX-30 3.2" IM Testing MIL STD 2105C

Test	# of Tests	Reaction		
Explosive		LX-14	PAX-30	PAX-42
Bullet Impact	2	Type IV	Type III	Type IV
Fragment Impact	2	Type IV	Type III	Type III
FCO	2	Type IV, Type V	Type IV	Type 1, Type III
SCO	2	Type III, Type V	N/A	Type III, Type V

* Initial Assessment

Unreacted Material



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Unreacted Material PAX-30

BI

FCO

"Distribution A: Unlimited Distribution"

Summary

- High energy/high blast (combined effects) explosive formulations have been demonstrated; PAX-29 and PAX-30 and PAX-42 formulations have been tested and verified to exceed the metal pushing energy of the baseline explosive LX-14 while substantially exceeding the blast energy
- Several formulations were developed in which proper size aluminum was demonstrated to react completely in the very early time of detonation, which contributes to the metal pushing energy
- In this formulation it is not necessary to use nano aluminum to achieve early time reaction
- PAX-30 possesses over 30% more Gurney Energy with equivalent blast capability to other standard aluminized explosives such as Al Comp A3
- Eigen detonation theory used to explain behavior
- EOS equations have been developed

"Distribution A: Unlimited Distribution"