Resonant Acoustic Mixing (RAM) for Coated Explosive Material Manufacturing (Abstract #22241)

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Project **Objectives**

- Laboratory evaluation of Resonant Acoustic Mixing (RAM) to manufacture CXM-AF-7 Premix
  - CXM-AF-7 incorporated into AFX-795 for use in Mk 80 series General Purpose Bomb for U.S. Air Force
- Determine advantages of RAM technology over traditional Premix manufacturing Techniques
  - Safety evaluation of RAM technology with explosive powder beds
  - Reduction in coating cycle time
  - Elimination of Slurry Water for process stream

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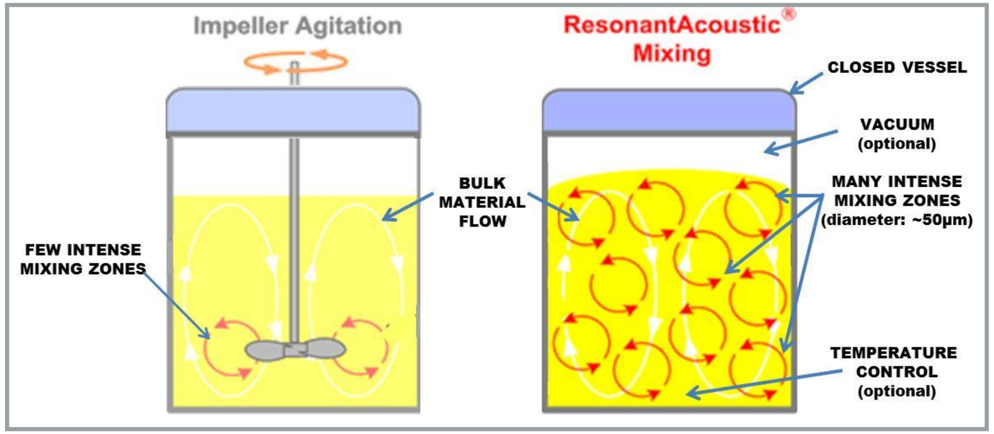
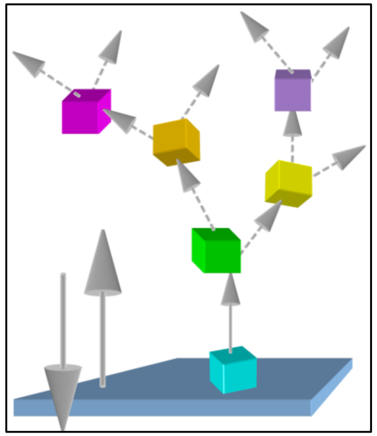
Resonant Acoustic **Mixing**

- RAM Technology
  - Non-Contact mixing at low frequency (60Hz)
  - High Intensity: 100x's the acceleration of gravity
  - Efficient energy distribution with uniform micro-mixing
- Primary Mixing
  - Mechanism is from collisions driven by inter-particle redistribution
    - Mixing increases with higher acceleration
  - Creates several intense mixing zones





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Explosive **Premix**

- RDX/HMX based Premixes have been traditionally manufactured by two methodologies
  - Aqueous Slurry
    - Water/Explosive slurry is agitated while a plasticizer (i.e. DOA, IDP, DOS) is dispersed onto the crystalline explosive
      - Up to 2,100 Gallons of water utilized per batch of product
      - Requires downstream cycles of dewatering and drying
    - Utilized slurry water represents a waste stream for treatment prior to discharge
    - Products: CXM-3, CXM-7, CXM-9, CXM-11, CXM-AF-X
  - Kettle Coating
    - Water wet explosives are introduced to a steam heated kettle
    - Agitation and steam heat are utilized to dry and coat the premix in-situ

Safety Assessment **Constraints**

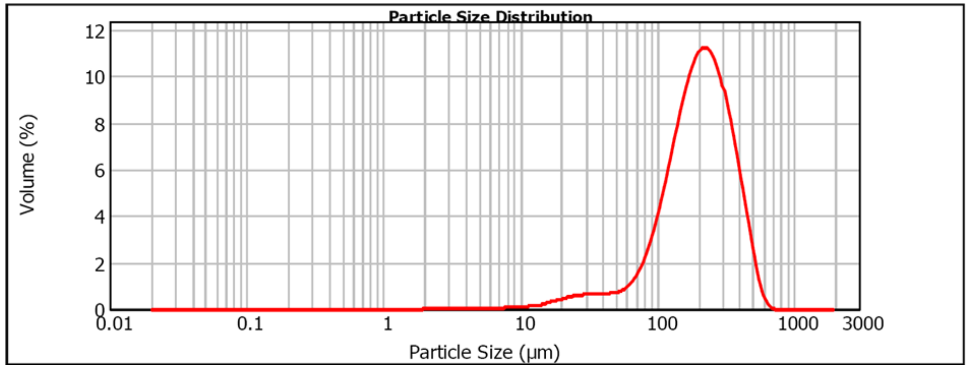
- Preliminary experimental plan was to mix RDX FEM and RDX Class 1 utilizing RAM
- Plan required data assessment of voltages of the powder bed to determine risk factors
  - Voltage measured at powder surface and subsurface - Allow for charge density calculation
  - Assumption of voltage was constant throughout powder bed – powder behaves as a capacitor
- Discharge of the powder bed could be calculated and compared with ignition energy of RDX classes

- Assumption lead to conservative estimates, but also leads to a project of its own!

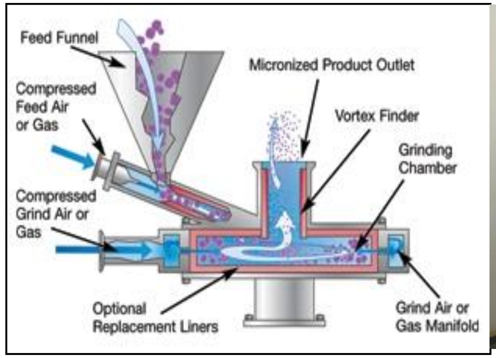
- This lead to conducting a Failure Modes and Effects Analysis (FMEA) where the following items addressed the test plan:
  - Polystyrene container was chosen as it offered much lower voltages on the container and powder
    - Required to witness the mixing on the RAM stage
    - Polystyrene breakdown voltage was calc. to be 20kV. Energetic powder not expected to reach this limit
  - ESD prevention allotted for using RDX with DOA present. No dry powder beds were evaluated

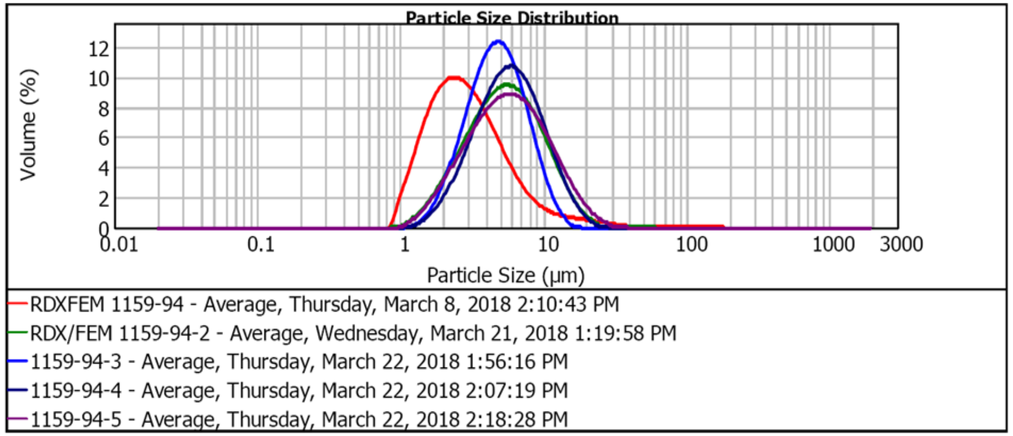
RDX Product **Verification**

- RDX Class 1 (7RC118-88A2) was used for this project
  - ~200 pounds (90kg) was obtained



- RDX Class 1 processed through Fluid Energy Mill unit
  - Particle Size Reduction

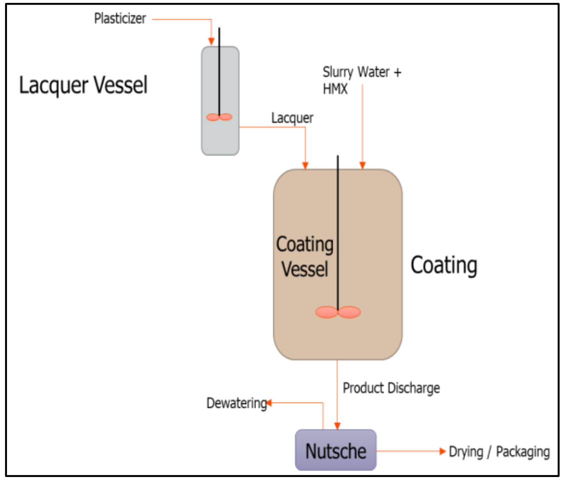




Laboratory **Slurry Coating**

- CXM-AF-7
  - Slurry coated at the BAE Systems R&D Laboratories at HSAAP
  - 10L Slurry Coat Vessels
    - Solids Loading
    - Volume
    - Agitation Rate
    - Temperature

  - None uniform distribution of the plasticizer
    - DOA/Water are immiscible
    - Particles not uniformly distributed in powder bed

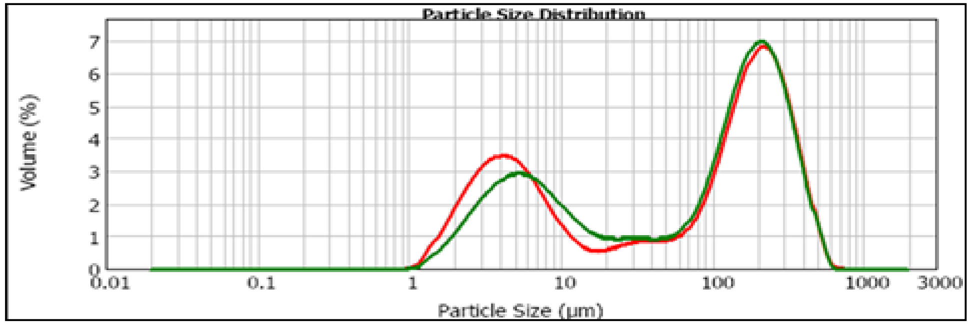


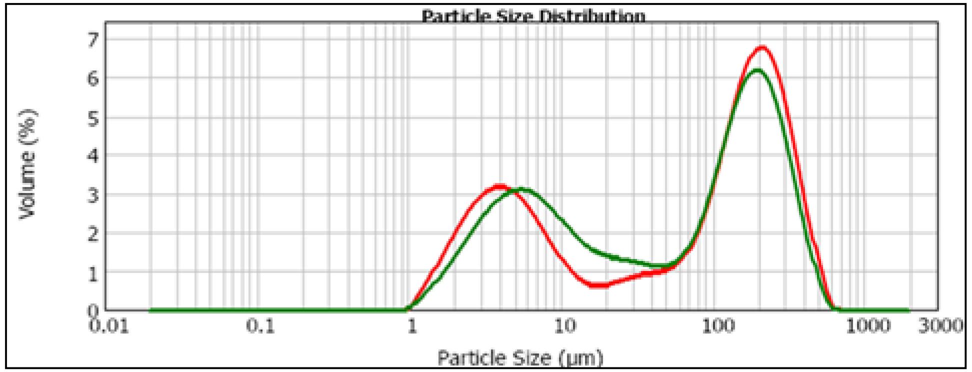
CXM Batch	FEM Input Batch	D10, µm	D50, µm	D90, µm
1159-107	1159-94-4	3.0	114	326
1159-108	1159-94-1	2.3	128	330
1159-109	1159-94-2	2.9	111	317
1159-110	1159-94-2	2.9	111	317
1159-111	1159-94-2	2.9	111	317

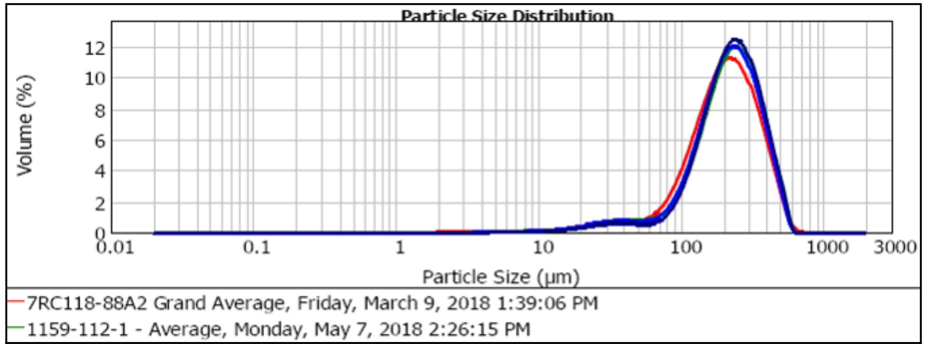
Attrition Study **Slurry Coating** vs. **RAM**

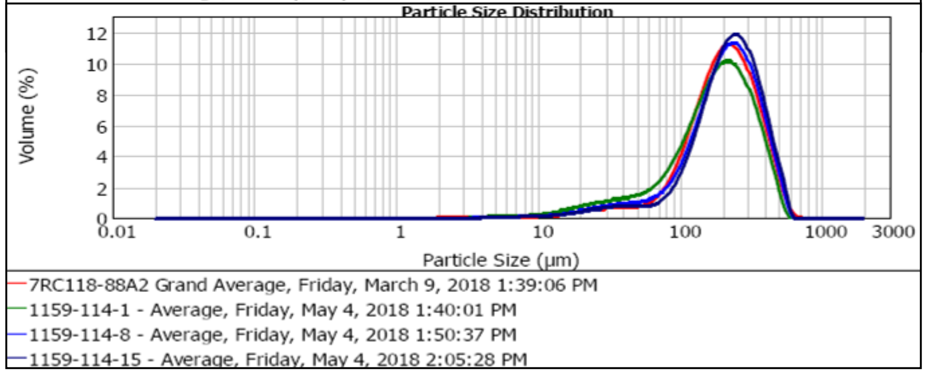
- PSD of Slurry coated RDX
  - Green = slurry coated
  - Red = RDX input blend
- No PSD Reduction from Input Material

- PSD of RAM coated RDX
- Used Class 1 RDX containing 5% water









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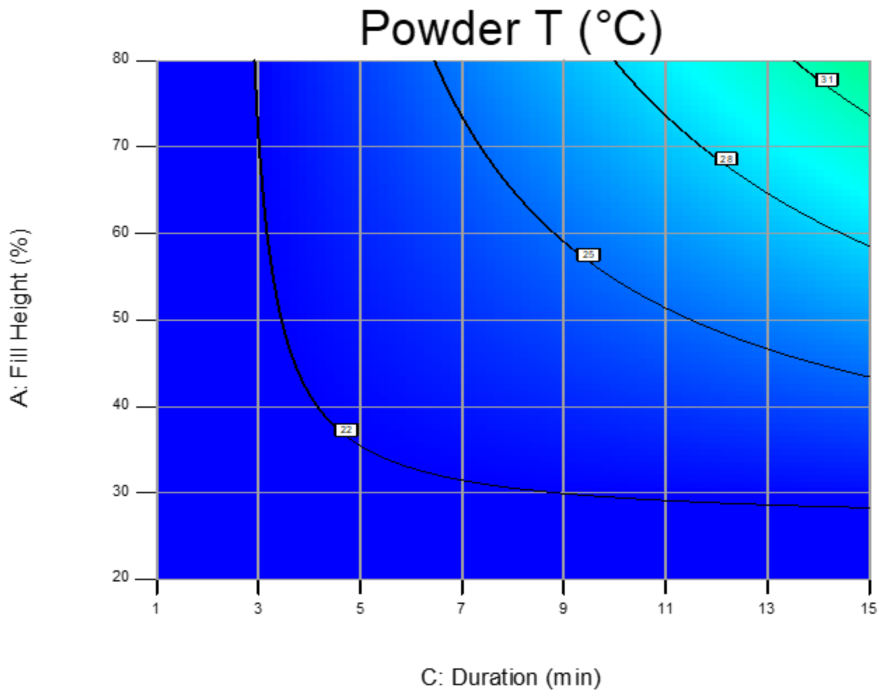
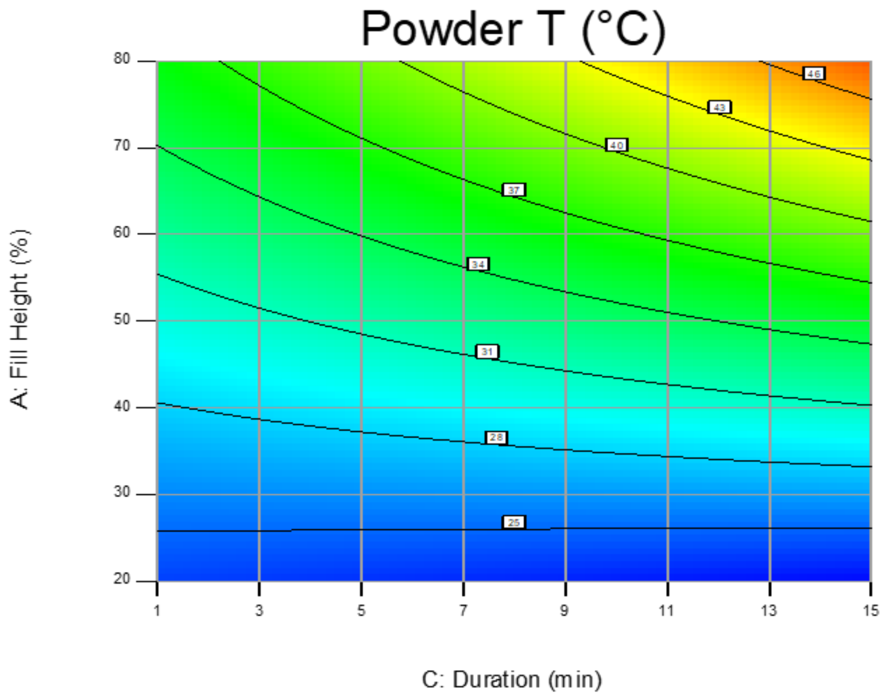
RAM – **Secondary Objective**

- Range of voltage encountered during mixing was -3 to 4.6kV, less than that measured on some formulations from storage
- Powder temperature behavior – 30G at left and 80G at right





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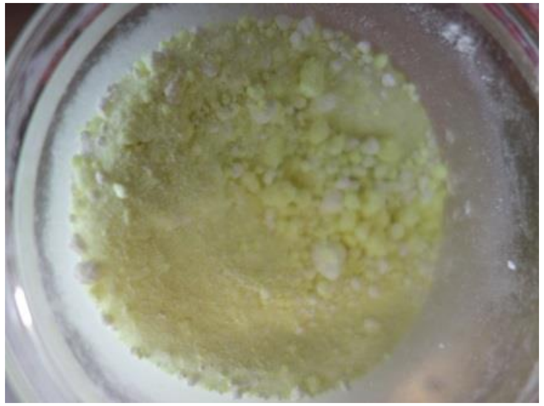
LabRAM CXM-AF-7 **Process Study #1**

- Slurry coated RDX with 3% DOA → FEM; used with dry Cl 1 and dyed DOA in 8 oz. PS jar
  - 16 experiments varying order of addition, mix acceleration and duration, pre-sieving of FEM RDX
- Mix cycles tended to be long, ranging from 2-17 minutes, as we monitored lump destruction/formation
- Mixing was periodically stopped to check voltage and temperature, which was essentially the same behavior as that seen for water-wet Cl 1 in the attrition study
- Composition was determined on top, middle and bottom samples
  - BET, impact and density by pycnometer were determined

LabRAM CXM-AF-7 **Process Study #1**

- WORST

→



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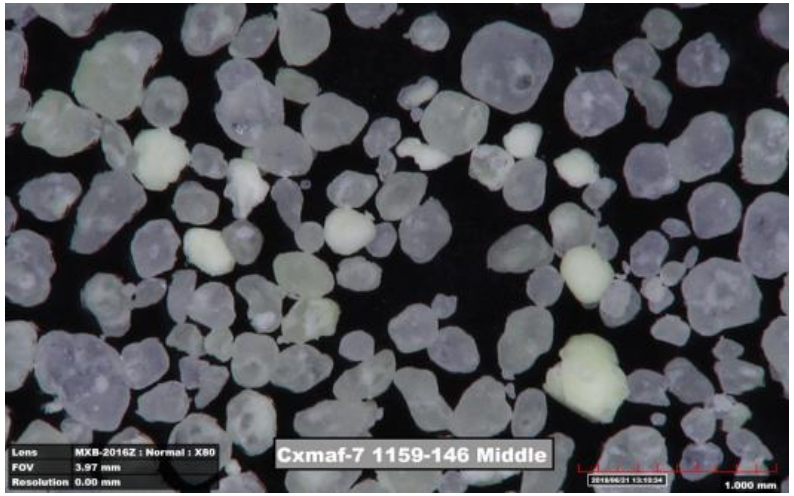

- BEST

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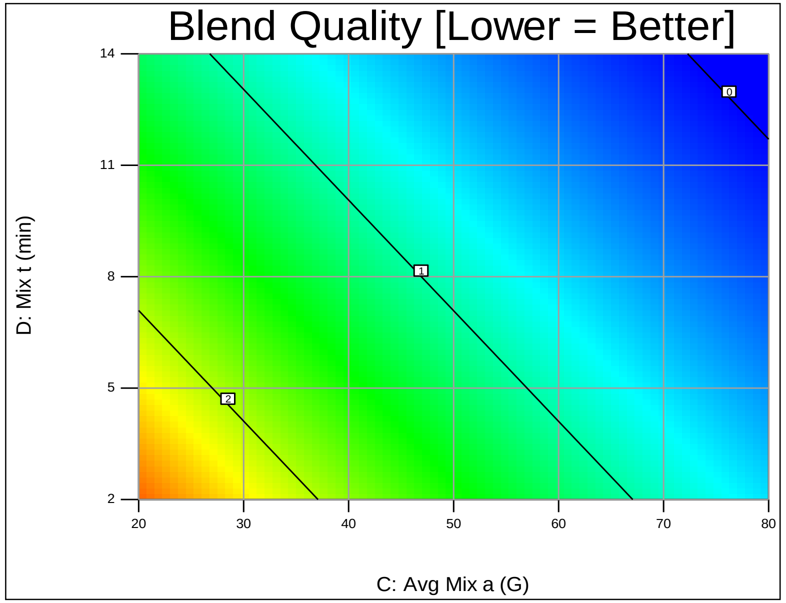
LabRAM CXM-AF-7 **Process Study #1**

- 2% DOA isn't sufficient quantity to coat all particles in the powder bed, as evidenced by number of particles without dye
- Voltage during mixing ranged from -0.7 to 6.9kV
  - Comparable to the voltages measured during the RAM attrition study with 5% water present
- Inclusion of initial "wetting" step did not play a major role in the resulting blend quality.
- Settled on DOA – RDX addition order
- Batches with the best visual blend quality exhibited low BET values
- Visual blend quality was effected by three main factors: acceleration, mix time and pre-sieving FEM RDX



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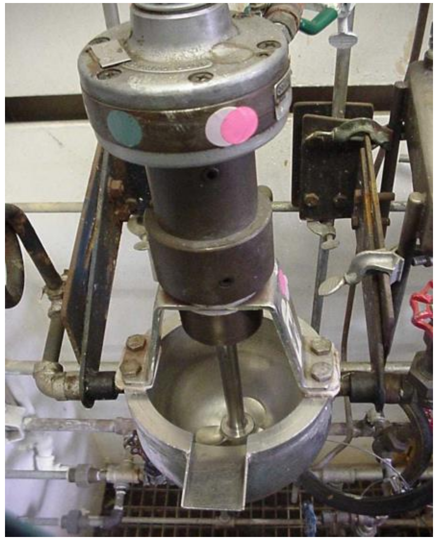
Laboratory **Kettle Coating**

- 5 Pound (2.2kg) Steam heated kettle
- RDX/DOA processing to provide Premix feedstock
  - Coating/Drying in-situ
    - Eliminates slurry water waste stream
- Experimentation conducted at:
  - 1% DOA
  - 3% DOA
- RDX/DOA coated material
  - FEM process to provide input material
- RDX Class 1, RDX FEM, DOA processed in RAM



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LabRAM CXM-AF-7 **Process Study #2**

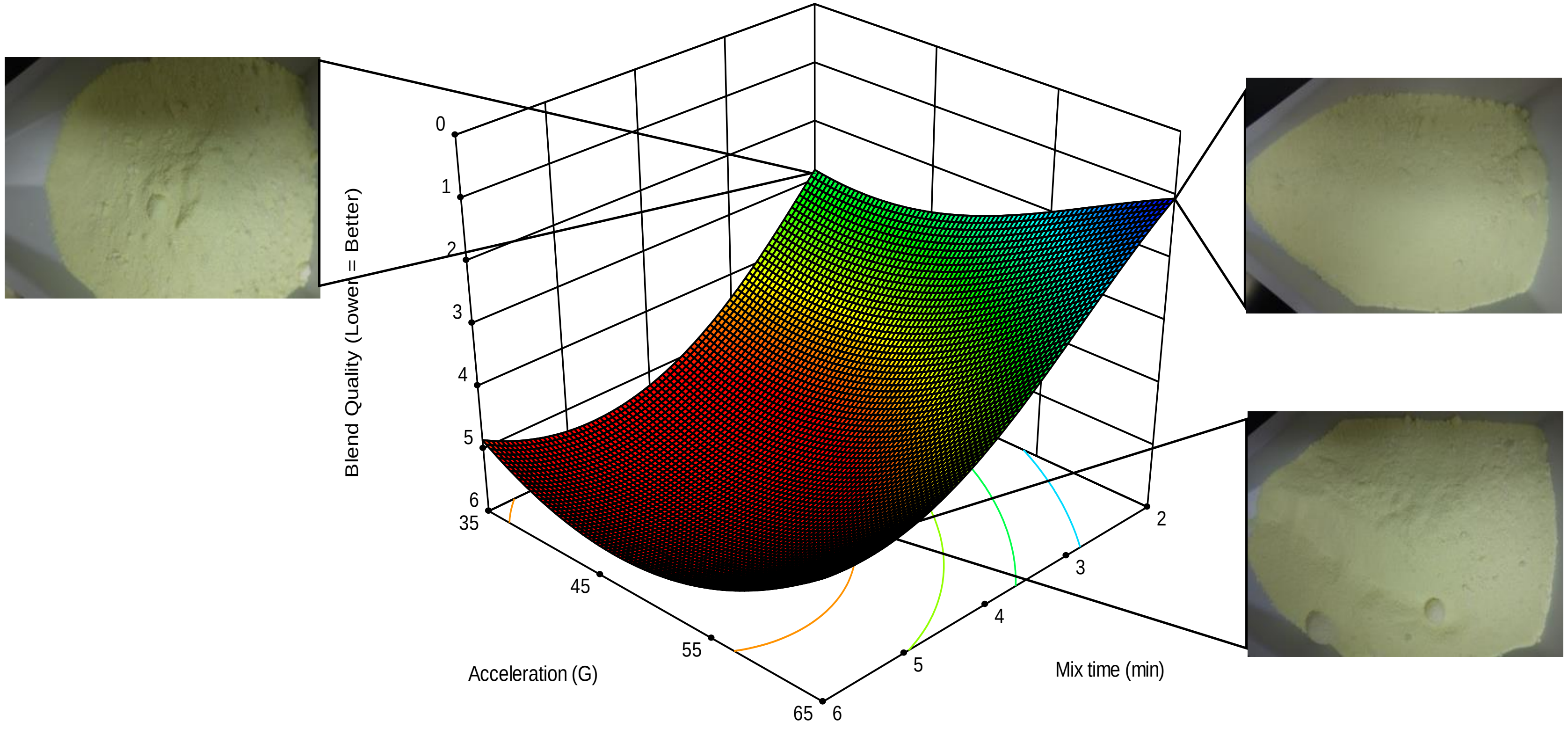
- Kettle coated Cl 1 RDX with 1% DOA → FEM
  - Used with precoated Cl 1 and dyed DOA in 8 oz. PS jar
- 14-run I-optimal quadratic experimental design with acceleration, mix time and pre-sieving step.

	Acceleration, G	Mix time, min	Sieve Size, mm
Low	35	2	1.68 (-12)
Mid	50	4	4.76 (-4)
High	65	6	9.51 (-3/8")

- Composition was determined on top, middle and bottom samples
  - BET, impact and density by pycnometer were determined at EOM

LabRAM CXM-AF-7 **Process Study #2**

- Contour plot showing blend quality, coarse screen.
- Competing processes at intermediate mixing conditions



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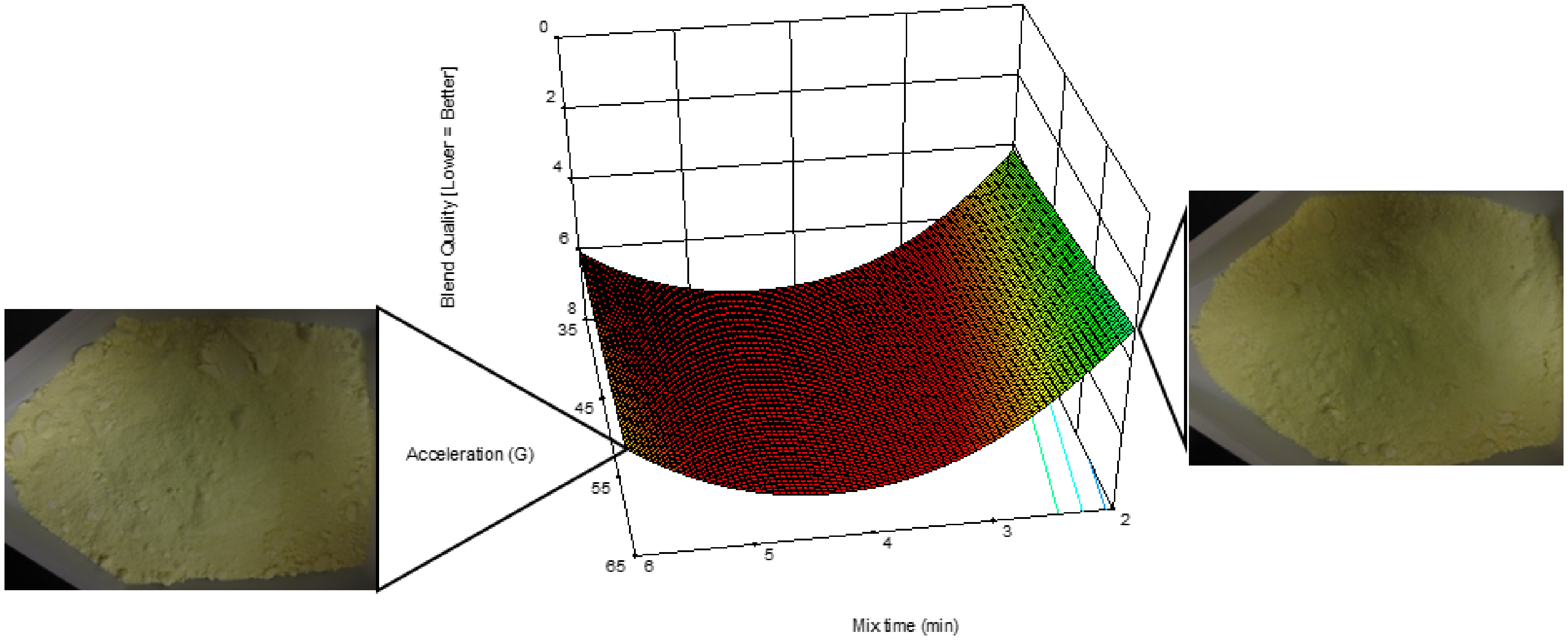
LabRAM CXM-AF-7 **Process Study #3**

- Kettle coated Cl 1 RDX with 3% DOA → FEM
  - Used with pre-coated Cl 1 and dyed DOA in 8 oz. PS jar
- Otherwise, duplicated the experiments run under study #2, which used inputs coated at the 1% DOA level.

	Acceleration, G	Mix time, min	Sieve Size, mm
Low	35	2	1.68 (-12)
Mid	50	4	4.76 (-4)
High	65	6	9.51 (-3/8”)

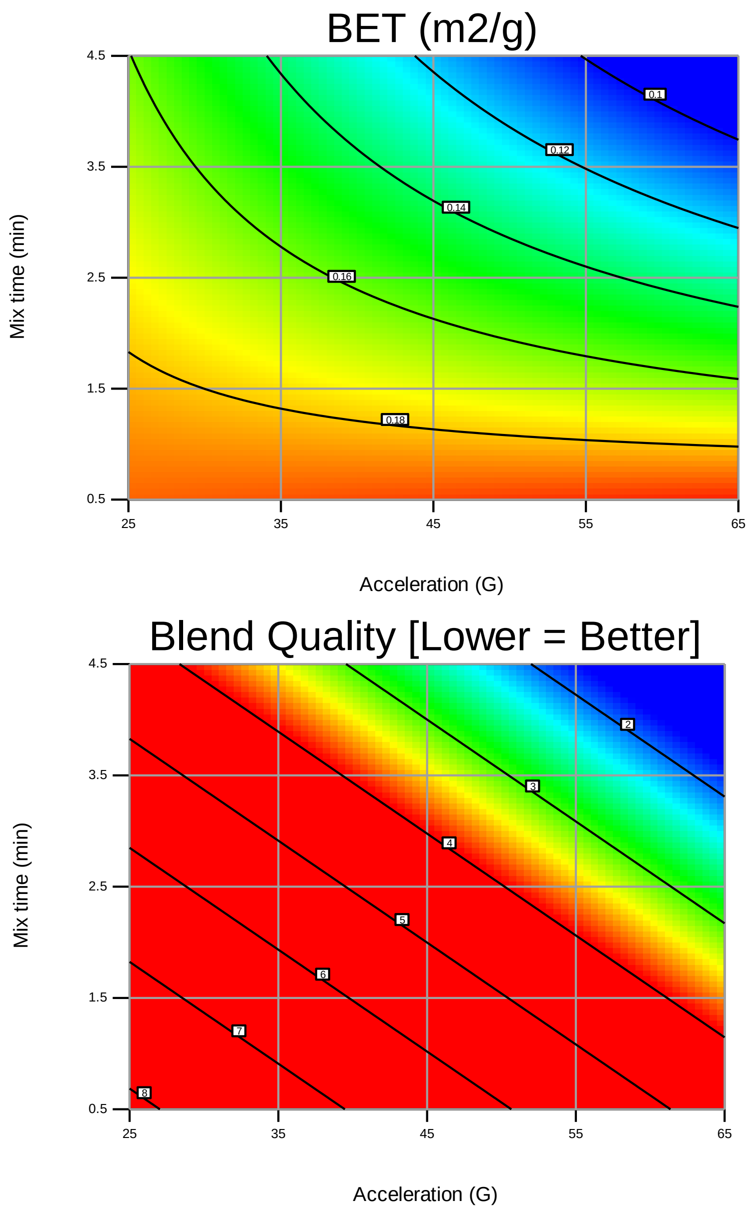
LabRAM CXM-AF-7 **Process Study #3**

- Mix quality degrading from the 2-4 minute range, and then recovered.
  - Pointing to competing processes
- Terms in model of differing order here, indicating course of mixing affected by extent of DOA pre-coat



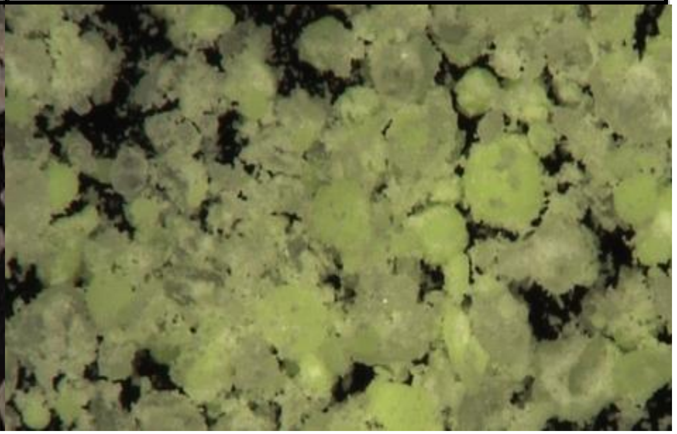
LabRAM CXM-AF-7
Optimal Process Dev to Support AFX-795 Trials

- Neat Class 1 RDX used to limit the amount of kettle coating
- 1% DOA precoated onto Cl 1 RDX to be milled
  - Alleviate FEM feeding challenges
  - Reduce static charge in initial RAM mixing
  - Possible improvement in FEM shelf life
- Stayed with DOA containing dye to aid in visual observation
- Shift to shorter mix times



AFX-795
Comparison of RAM and Slurry CXM Inputs

- RAM
  - 23 batches were blended into a composite
- Slurry Coat
  - 2 slurry batches were blended

	RAM CXM-AF-7	Slurry CXM-AF-7
BET, m^2/g	0.088	0.146 (weighted avg)
Microscopy		

AFX-795
Process and Observations

- Melt Pour Processing
  - Wax was melted in steam kettle under agitation
  - CXM-AF-7 was introduced and allowed to blend
  - Remaining DOA added
  - Introduced Al and lecithin components and allowed to mix to completion
  - Observations
    - Baseline CXM-AF-7 (Slurry Coated) caused a greater rise in viscosity during incorporation
    - Difficulty with pull down and incorporation of Al in mix with baseline CXM

AFX-795 **Data Comparison**

	LSGT, Cards	BAM Friction, N	ERL Impact, cm	ESD, J	DSC Peak, °C	VTS, ml/g
Baseline (Slurry)	**136-157***	**298.8**	**181.97**	**0.29**	**244.49**	**0.1649**
RAM	**134.5**	**288.0**	**213.79**	**0.40**	**243.62**	**0.1916**

*= BAE Systems Historical Data Range for AFX-795

Slurry Versus 55 Gal RAM
Elapsed Hours / 4,100 lbs. CXM-AF-7

Step	lbs.	**Elapsed Hours (%)**
Dry Cl 1 RDX	3,895	
Mill Cl 1 RDX	1,597	
Slurry Coat	4,100	
Dewater	4,100	
Kettle Dry	4,100	
Pack out	4,100	
	TOTAL	**100%**

Step	lbs.	**Elapsed Hours (%)**
Dry Cl 1 RDX	2,214	
Kettle coat / dry dewatered Cl 1 RDX with 1% DOA	1,681	
Mill Pre-coated Cl 1 RDX	1,698	
RAM	4,100	
	TOTAL	**56%**

^Gains in Cl 1 drying and kettle coating based on reduced weights needed
ᵓ Mill at 311 lbs / hour with slight penalty for DOA presence
*RAM batch size = 300lbs with blend time 3 min & cycle time 0.3hrs

Conclusions

- Laboratory experiments indicate that it is feasible to apply RAM technology as an alternative to the slurry coating process for the manufacture of CXM-AF-7 Premix
- Monitoring:
  - Maximum voltage of the product was not influenced by mix acceleration or time (with presence of DOA or water)
  - At low fill levels no temperature rise was observed; at production-scale fills, one would need to determine time-dependent temperature rise at conditions
- Mixing progress appears to be dependent on extent of DOA coating on inputs
- Early indications show moderate mixing times and accelerations can result in competing processes where the number of lumps are decreasing but size of a few lumps are growing larger
- RAM appears to result in agglomerates of DOA-coated FEM, which may account for the ease of incorporation into AFX-795
- BET was found to be a good predictor of extent of DOA distribution into the powder
- AFX products comparable

Thank you