Resonant Acoustic Mixing of Cast Composite Propellant and PBXN

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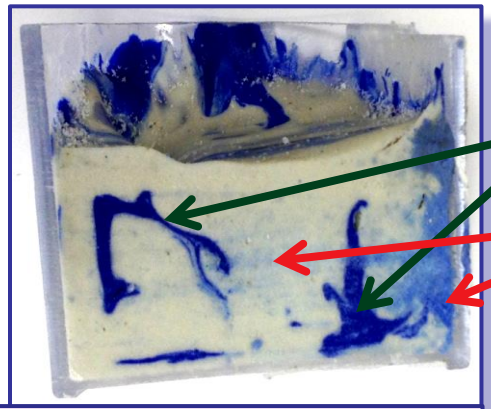
Resonant Acoustic Mixing: Shaking up the future of energetic mixing

Overview

- What is Resonant Acoustic Mixing
- RAM at NSWC IHEODTD
- Energetic mixing, PBX and Propellant
  - End item mixing
  - Physical properties
  - Mix quality
- Mix process studies
- Other formulations

Resonant Acoustic Mixing

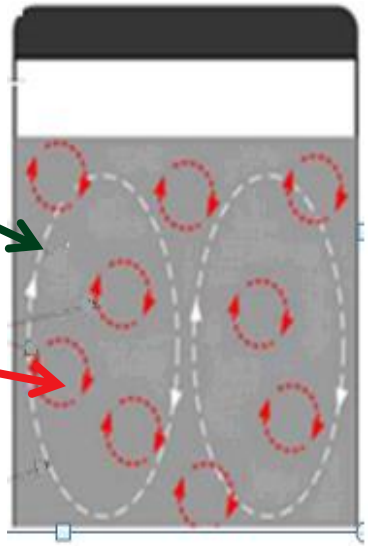
- What is Resonant Acoustic Mixing (RAM)
  - Non-contact mixing
  - Low-frequency (approximately 60 Hz)
  - High-intensity (up to 100g)
  - Uniform & simultaneous micro-mixing



There was a 3/8 inch layer of Blue simulant 45 Seconds Prior

Bulk Distributive Mixing

Intense Dispersive Mixing



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Resonant Acoustic Mixing- Benefits

- **Safety: No moving parts!**
- Cost Savings
  - Efficiency
    - Reduce mix/cast labor
    - Reduce cure times: overnight, ambient cure
    - Reduce cycle times
  - Reduce Footprint
    - Potential to replace larger horizontal and vertical mix facilities
    - Reduce or eliminate cure ovens

NSWC IHEODTD RAM Overview

- Two LabRAMs (1st generation: 500g capacity) operating
  - HTPB propellant and PBX formulations
    - Mechanical properties testing
  - Mixed in end units
    - Small rocket motor and grenade
    - Both successfully test fired
- RAM-5
  - Installed
  - Have run with inert PBX simulant
  - Approval for energetic use pending possible site approval evaluation

RAM Mixing at IHEODTD

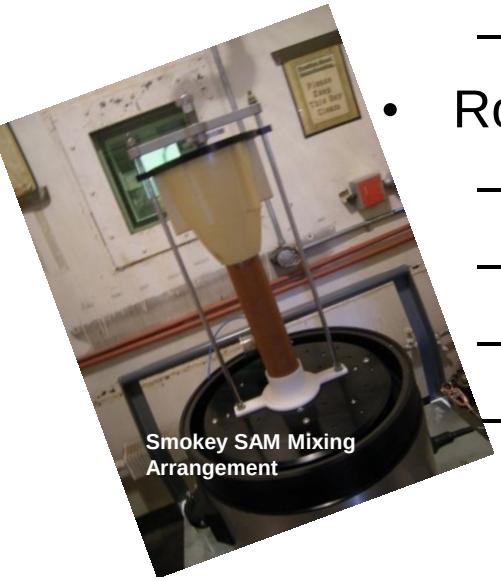
Energetic Mixing

- PBX Explosives
  - PBXN-109
  - PBXN-110
- AP Propellants
  - N-60
  - Other composite propellant
- End-unit Mixing
- Other Formulations

End Unit Mixing Demonstrations

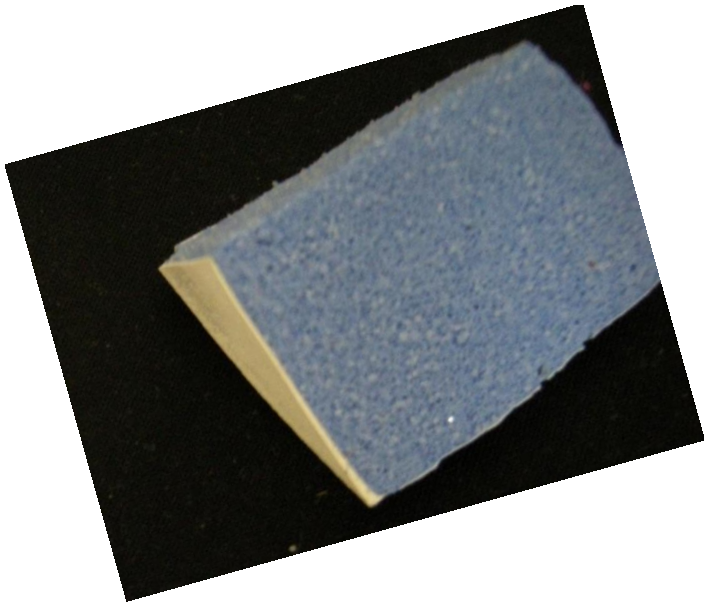
- Two-part premix method for volume considerations
- Small items mixed individually on LabRAM
- Neither item requires liner
- Grenade
  - PBXN-109
  - 3 grenades fired with production LAT
  - Passed requirements
  - Indistinguishable from production units
- Rocket Motor
  - N-60
  - 3 rocket motors fired with production LAT
  - Passed requirements
  - Indistinguishable from production units


Sectioned Inert Grenade


Smokey SAM Mixing Arrangement

End Unit Mixing

- Lined unit mix test; inert material mixed in lined beaker
  - Sectioned for visual inspection
  - Liner undisturbed
  - “Release coat” between liner and mix was disturbed (undesirable)
    - Ability to mix in lined container may be dependent on liner properties



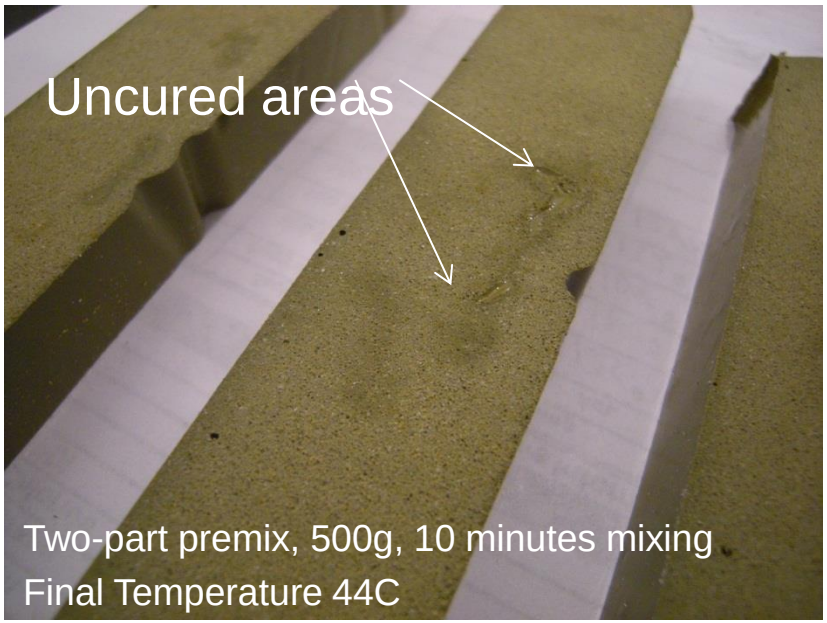
End Unit Mixing

- FY16-17 Funded Project
  - Investigate rocket motor end unit mixing
  - Liner integrity
  - Motor case durability
  - Mix geometry effects
    - Motor case and mandrel shape effect on mixing
    - “Overfill” fixture for ingredient addition
  - Successful project will demonstrate mix in case of lined motor on RAM-5

Physical Properties

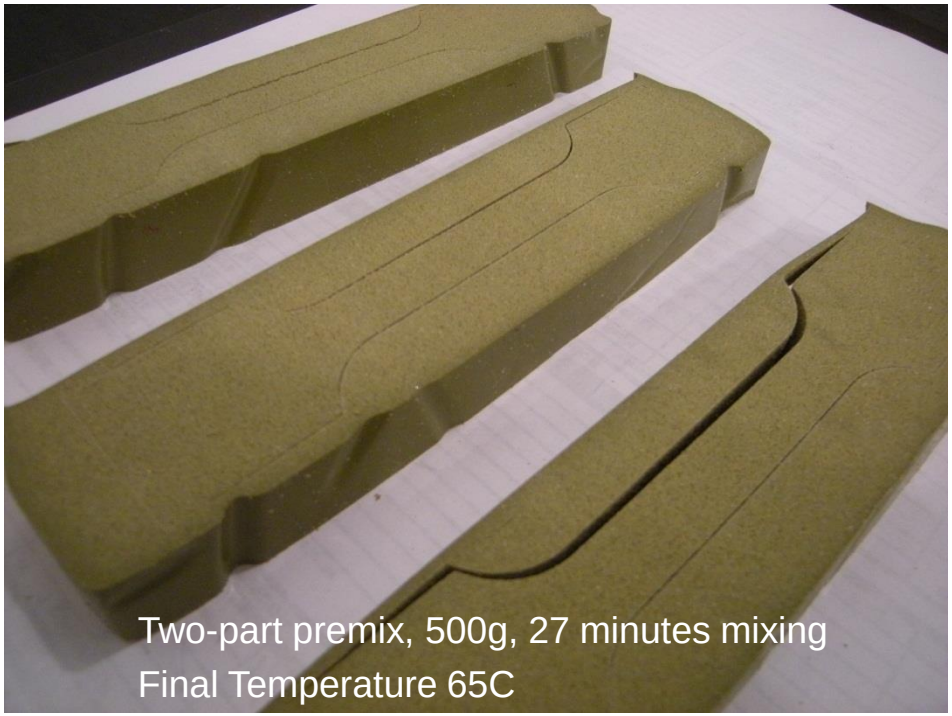
- PBXN-109
  - Two mix methods; premixes and from raw materials
  - Mechanical properties, density
- PBXN-110 Type 2
  - Mix from raw materials
  - Accelerated cure (increased catalyst level)
  - Mechanical properties, density, sensitivity, vacuum stability
- N-60
  - Mix from premixes*
    - *Settling of zinc in premix was observed
  - Mechanical properties, density
- All formulations met specification physical properties requirements, within range of historical data
  - *One N-60 sample failed density

Explosive Mixing
Temperature Rise vs. Mix Quality

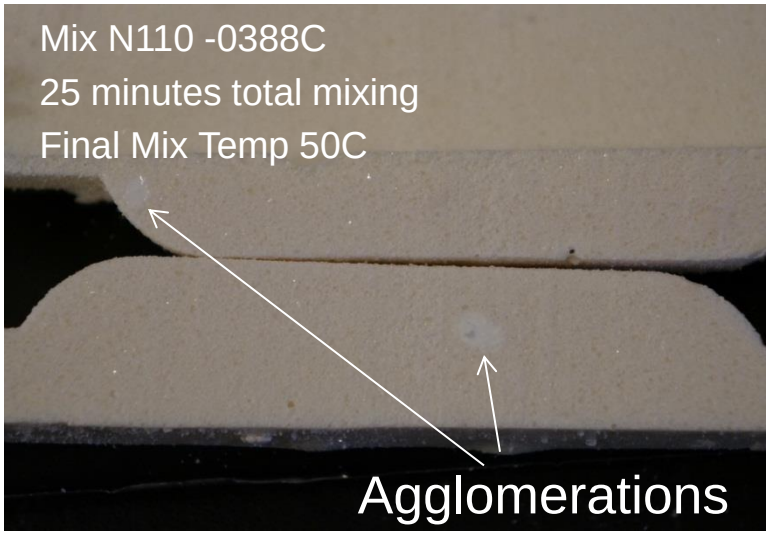


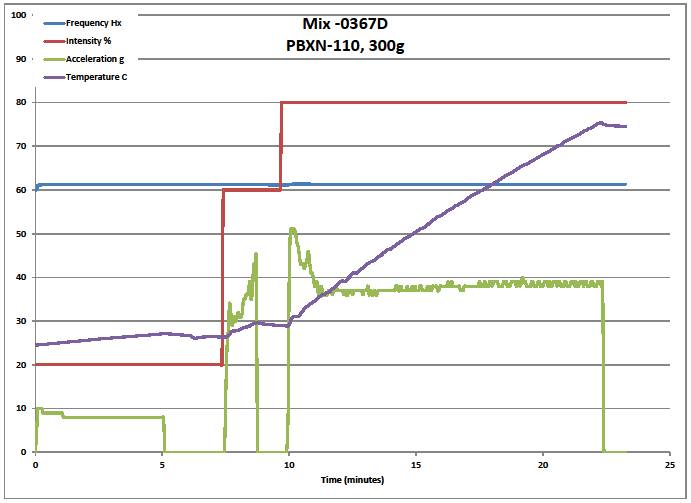
Poorly mixed N-60

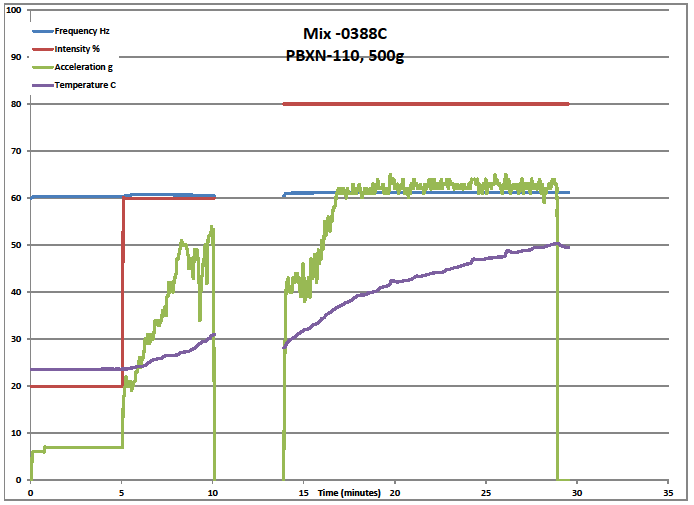
Well mixed N-60



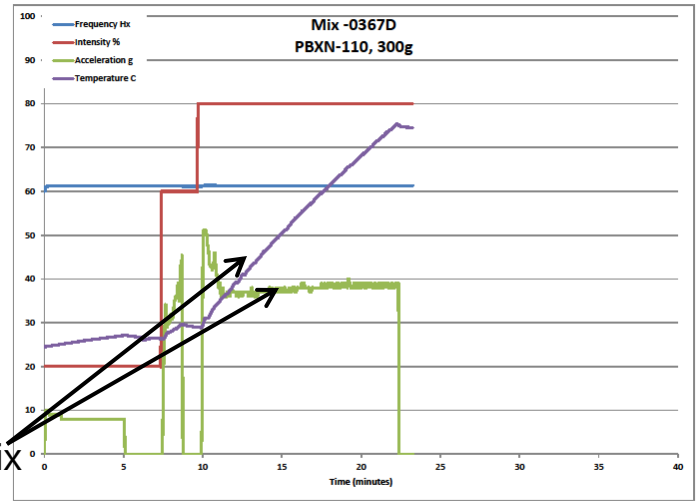
Explosive Mixing
Temperature Rise vs. Mix Quality



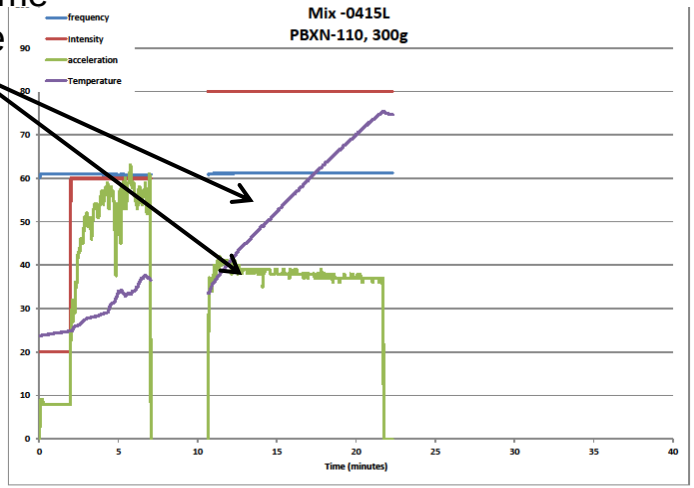




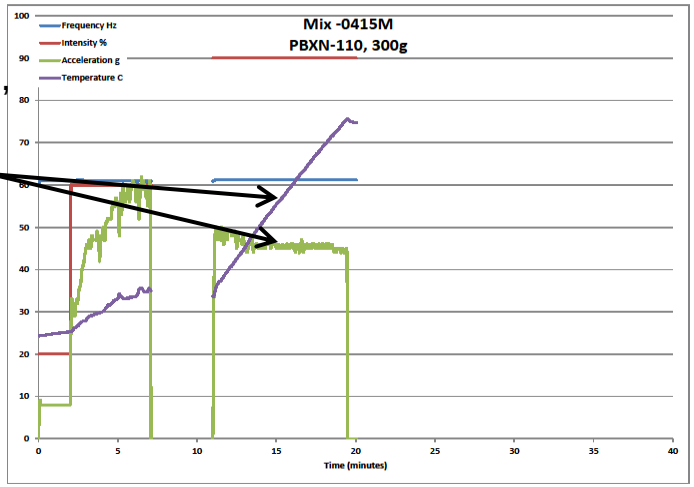
Repeatability and Variability



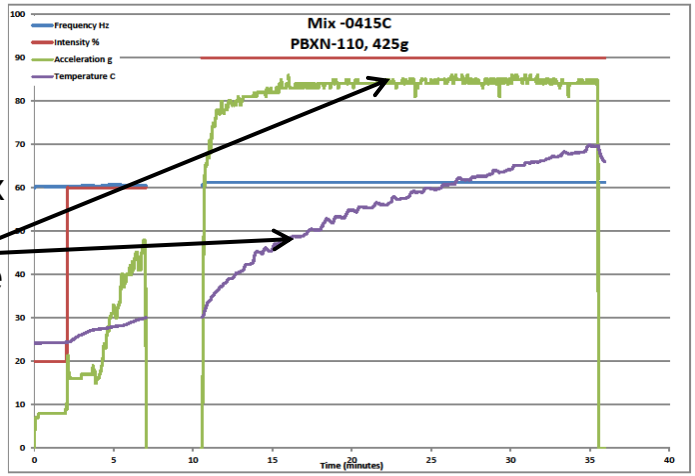
Same mix process yields same response



Same mix size, similar mix process, similar mix response



Changed mix size and vessel, same mix process, much different response



LabRAM Mix Variable Screening Study

Factors

- Mix characteristics
  - Viscosity
  - Density
- Mix size/shape
  - L/D
  - Mass
- Mixer parameters
  - Intensity (Acceleration)
  - Vacuum

Responses

- Mixing Power
  - Power Equation from Resodyn
- Mixing Power/ $Mass_{mix}$
  - Correlates to temperature rise

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LabRAM Mix Variable Screening Results

- Acceleration, L/d, Vacuum important variables
- Density, viscosity, mass not important (for range studied)
- Significant unexplained variance
- Desirable range (high power values) not described by derived model
  - Considered that higher 500g level for mass may have been poor choice (at edge of machine limits)

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LabRAM Mix Variable "Optimization" Study

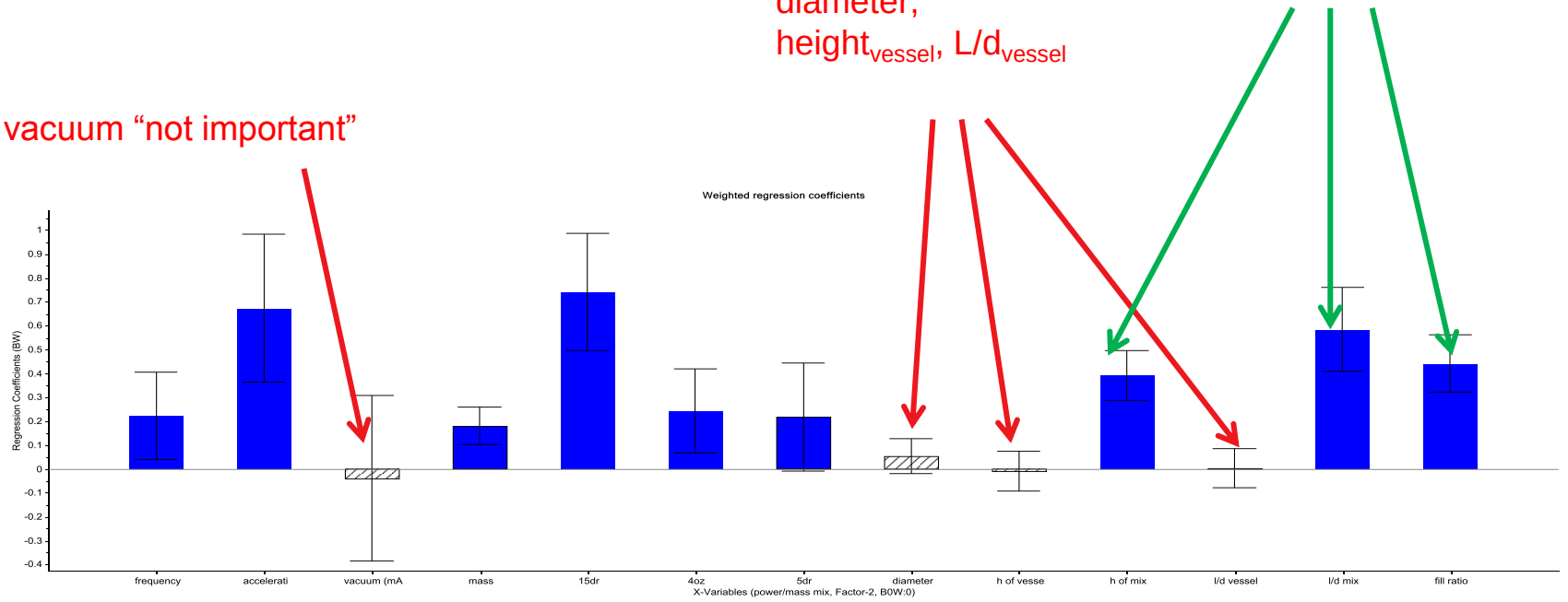
- Focus on important variables from screening study
  - Acceleration (Intensity), L/d, Vacuum
- Viscosity and density constant
- Additional (higher) L/d Levels
  - Included other dimensional variables in analysis
    - (diameter, $height_{mix}$, $height_{vessel}$, L/d_{mix}, L/d_{vessel}, fill ratio)
- Lower mass levels
  - Avoid possible equipment limitations
  - Smaller vessels: 5 dram, 15 dram, 4 ounce

LabRAM Mix Variable Study

"Important": height$_{mix,}$ L/d$_{mix,}$ fill ratio

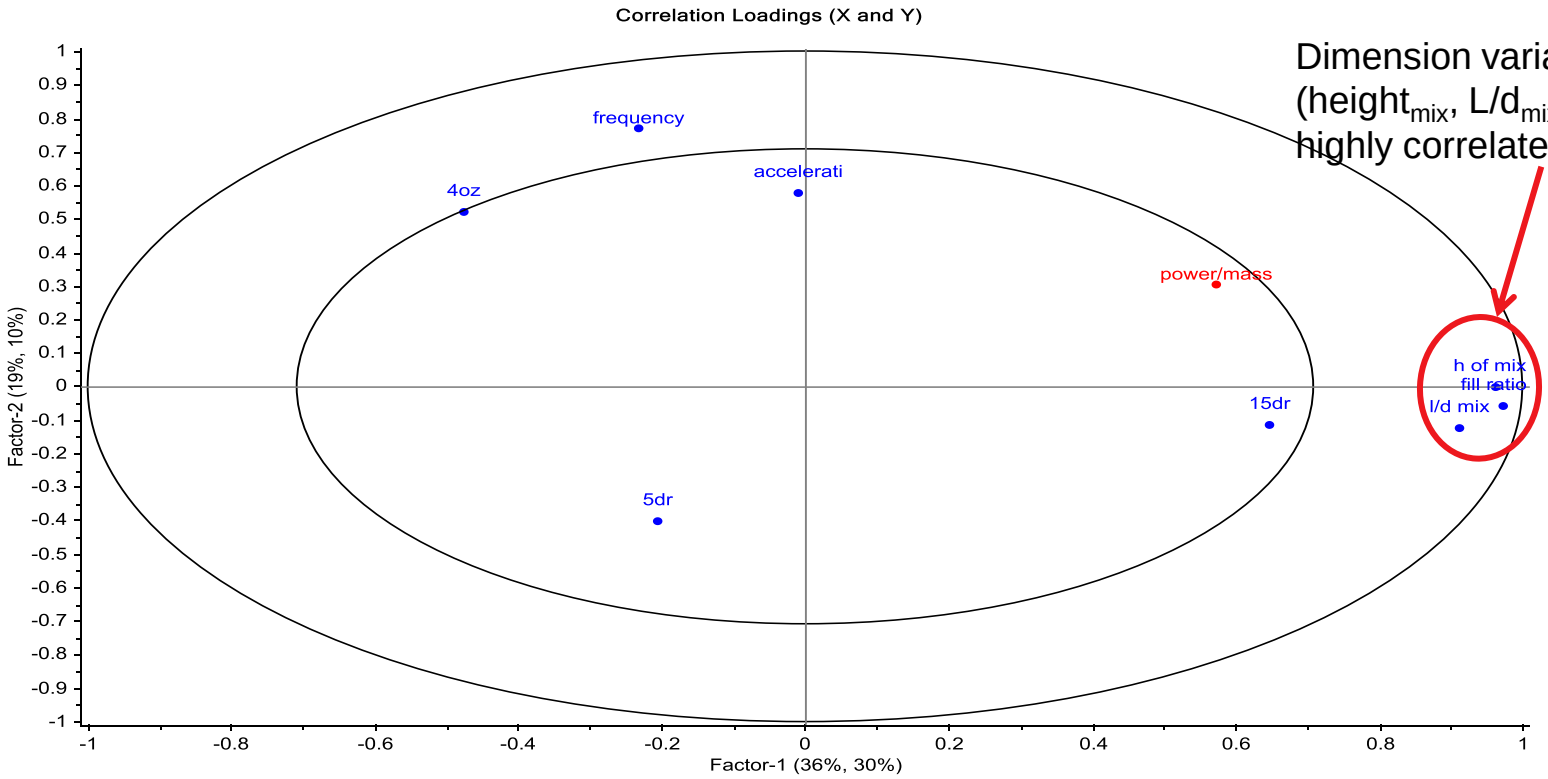
"Not important": diameter, height$_{vessel}$, L/d$_{vessel}$

vacuum "not important"



Regression Coefficients for Power/Mass (Full Model)

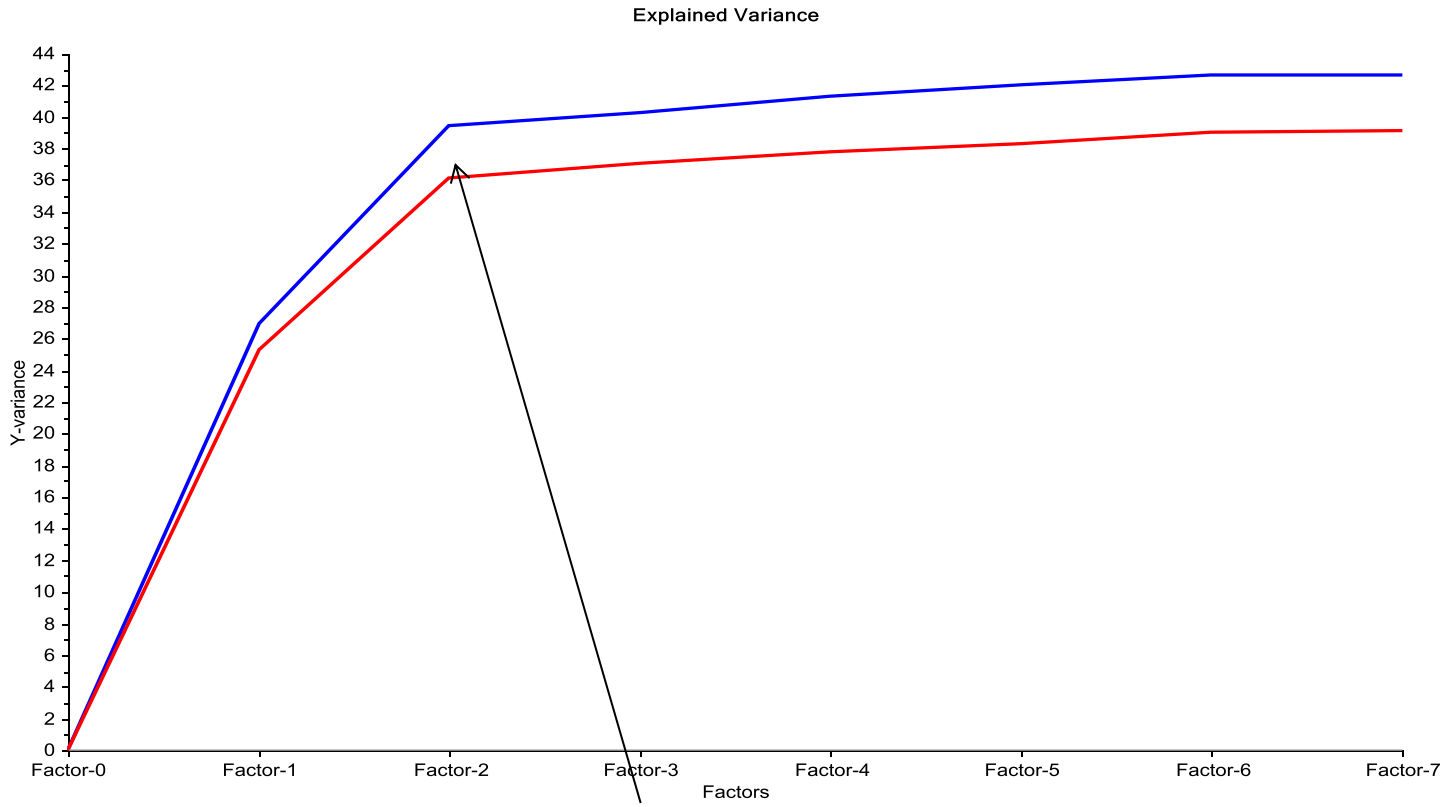
LabRAM Mix Variable Study



Dimension variables ($height_{mix}$, L/d_{mix}, fill ratio) highly correlated

Correlation Loadings of Reduced Model

LabRAM Mix Variable Study



A total explained variance of 40% is low, and may mean:

- There are other variables that are not included in the model
- The system has a high level of random variation normally
- A measuring tool/method that was used has a large amount of variation

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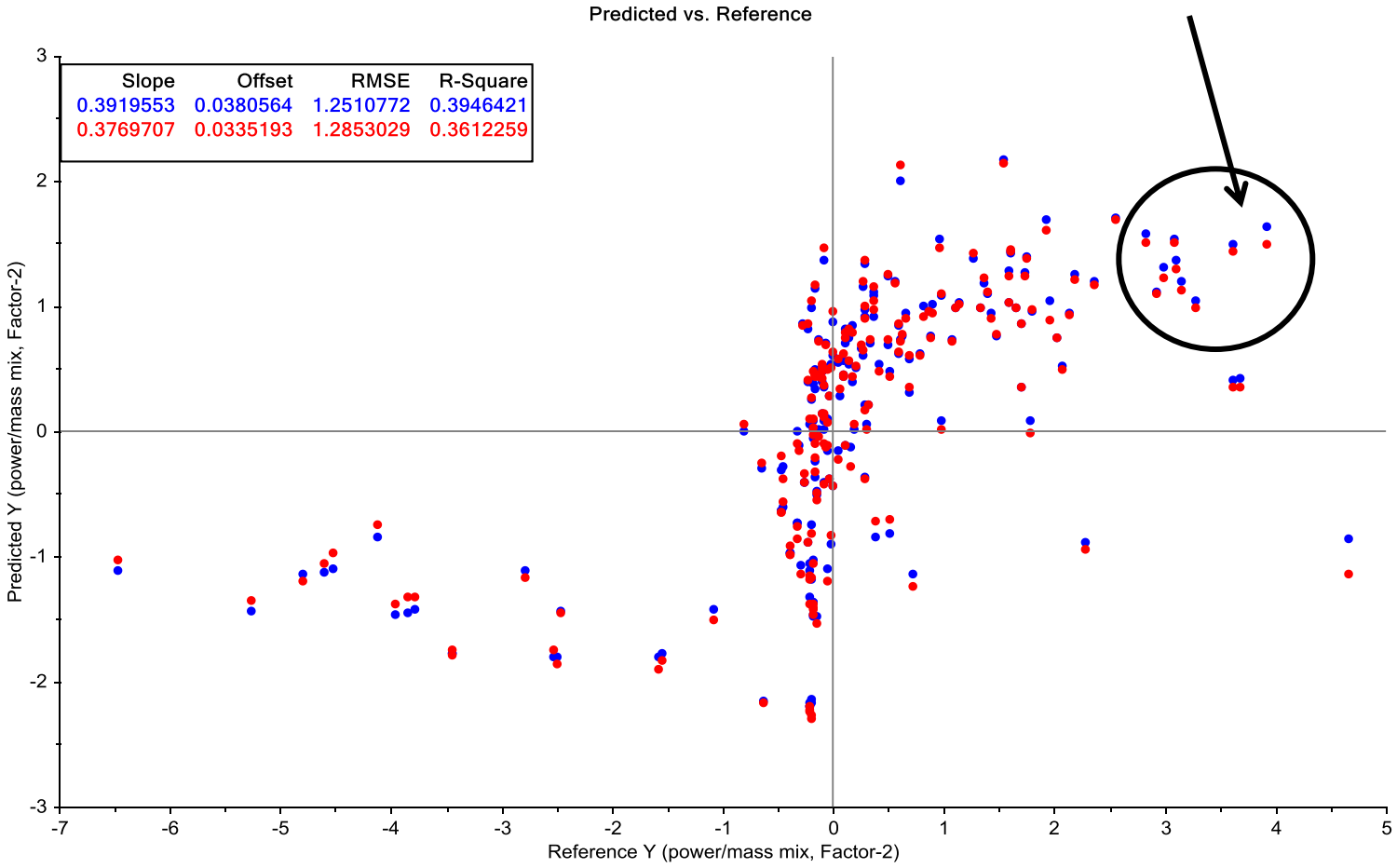
LabRAM Mix Variable Study

Another concern is that the derived model is not adequately predicting high power values.



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LabRAM Mix Variable Study

- In range studied (PBX simulant), viscosity and density of mix had negligible effect
- Vacuum and mix mass had little effect
  - Suggests we can use full vacuum w/o compromising mixing
  - Increasing mass with scale-up may not be a concern
- Geometry of mix is important
  - Diameter may not be important
  - Height of mix, L/d of mix, and/or “fill ratio” important
  - Factors to consider in scale-up to RAM-5

Other Formulations

- Pressed powder incendiary
  - 95% solids, Can be difficult to mix in traditional mixers
  - Good results on LabRAM
    - 7 minute RAM mix vs. 2 hours vertical mix
  - Burn test upcoming
- PBXN-110 Type 1
  - FY16-17 Funded Project
  - Qualification on RAM
  - PAPI curative
    - Fast and room temperature cure
    - Pot life problems in production, not currently used
  - One pint vertical mix cured in bowl
  - Same formulation on LabRAM successful mixes
    - 12 minute total mix time
    - Test results pending

Conclusions

- RAM Technology shows promise for energetics mixing
  - Performs well with current products
  - May solve some existing mixing problems
- Consistency in mixing when process held constant
  - More work necessary to understand how changes in process variables affect mixing
- End-unit mixing is viable
  - May not be suitable for all systems
- Accelerated cure is viable