

AVT-340 Research Workshop on Preparation and Characterization of Energetic Materials

Resodyn Acoustic Mixing as an Advanced Process for the Preparation of Energetic Materials

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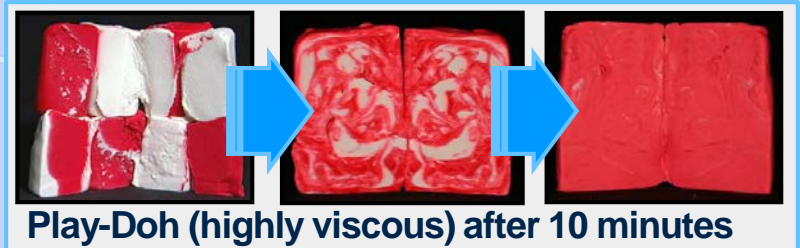
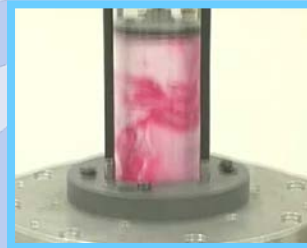


Resodyn Acoustic Technology for Processing Energetics Overview from 10,000 feet and from Various Perspectives



RAM Mixing Attributes and Capabilities

- Rapid mixing
- Thorough, uniform, repeatable mixing
- Universal mixing technology
 - Solid-Liquid
 - Liquid-Liquid
 - Solid-Solid
 - Liquid-Gas
 - All Combinations thereof
- Unique attributes
 - Easily scales from laboratory to production
 - No internal mixer hardware
 - Unparalleled performance creates new product development opportunities



Solid-Liquid



Liquid-Liquid



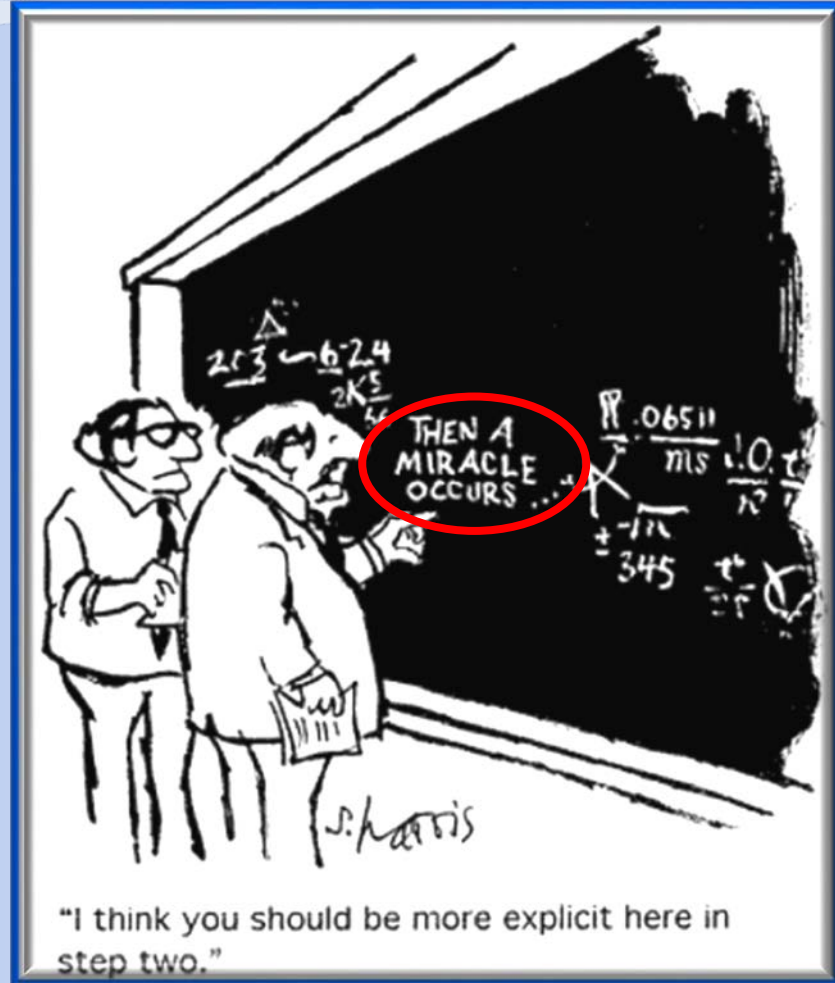
Solid-Solid



Liquid-Gas

ResonantAcoustic[®] Mixing Phenomena

- First Pass Explanation on How ResonantAcoustic[®] Mixing Works



Pay Attention to Information “Behind the Curtain”



ResonantAcoustic[®] Resonator Technology Unveiled



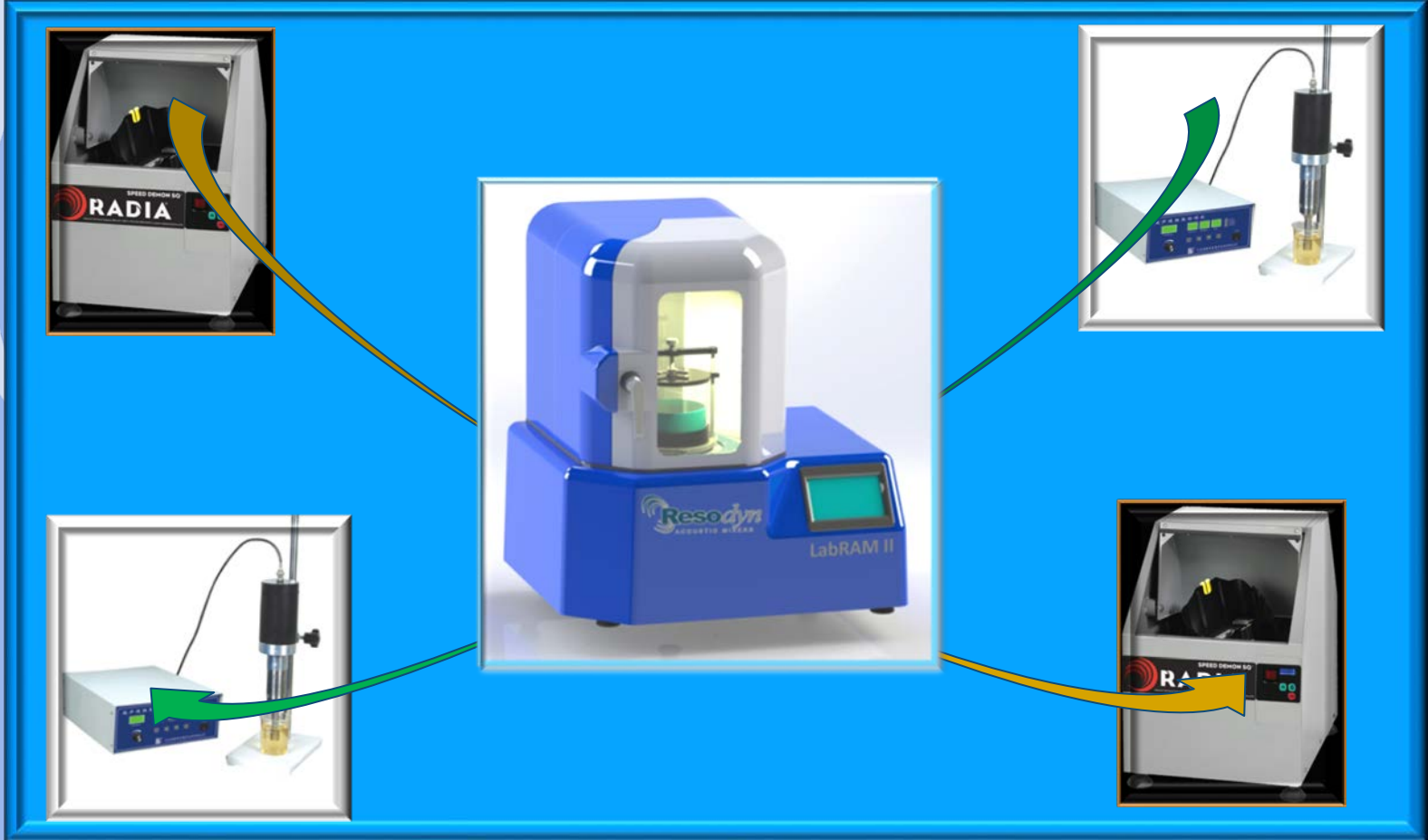
ResonantAcoustic[®] Technology Core Features

- ResonantAcoustic[®] Mixing and Processing has one Common Element -- “Resonator”
- The ResonantAcoustic[®] Technology Embodies 3 Key Features
 1. Sound Generator
 2. Operates at Large Displacements and at Modest Frequencies
 3. Operates at Mechanical Resonance
- ResonantAcoustic[®] Mixing and Processing Technology Requires one to  Mindsets on Several Fronts

ResonantAcoustic® Technology Enabling Operational Features

DISPLACEMENT ↑

↑ FREQUENCY



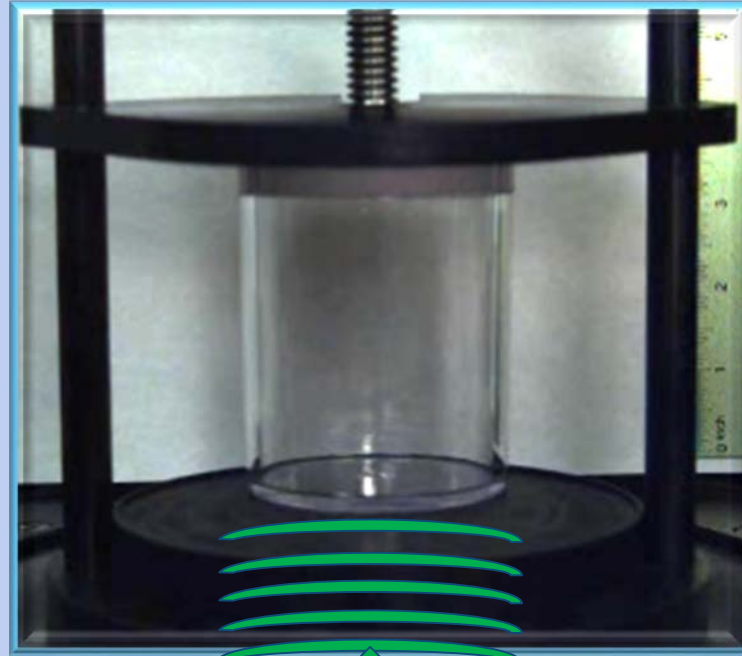
Not a Paint Shaker, nor an Ultrasonic Technology
RAM uses Modest Frequency and Large displacements

ResonantAcoustic® Technology Core Feature

Number 1 -- Sound Generator

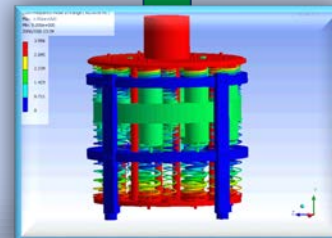
- ResonantAcoustic® Mixers Operate at ~60 Hz

A Sub-Woofer is an acoustic energy generator designed to produce low-frequency (20 to 200Hz) sounds



Empty container at 100 g of acceleration 3,600 fps

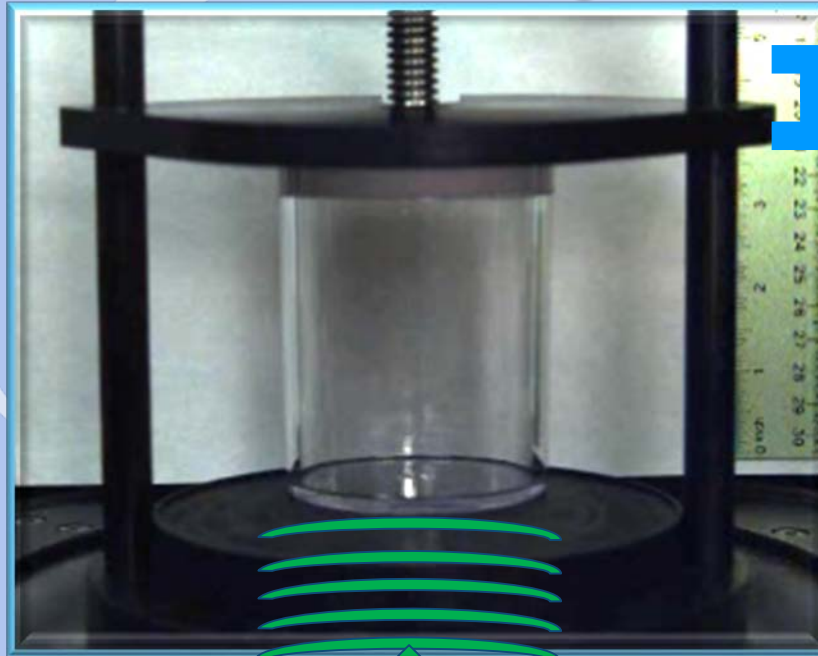
SOUND ENERGY



ResonantAcoustic[®] Technology Core Feature

Number 2 – Operates at a Large Displacement

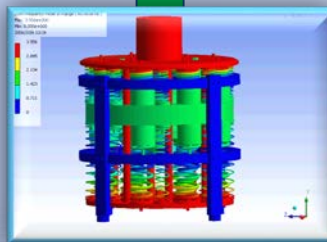
- ResonantAcoustic[®] Mixers Create Up to 0.55 Inch Oscillating Displacements at ~60 Hz and at 100 g of Acceleration



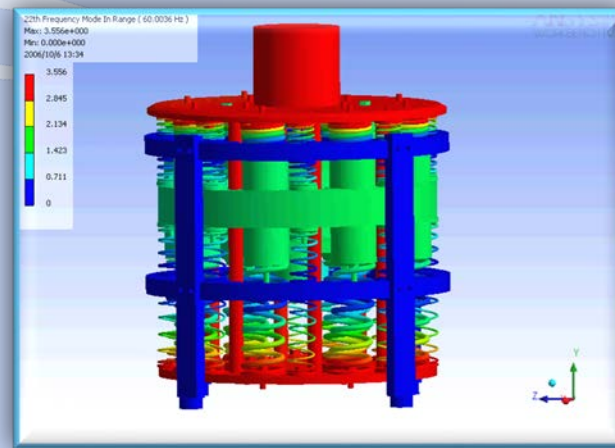
0.55 inch
Peak-to- Peak
Displacement
at 100 g

Empty
container at
100 g of
acceleration
3,600 fps

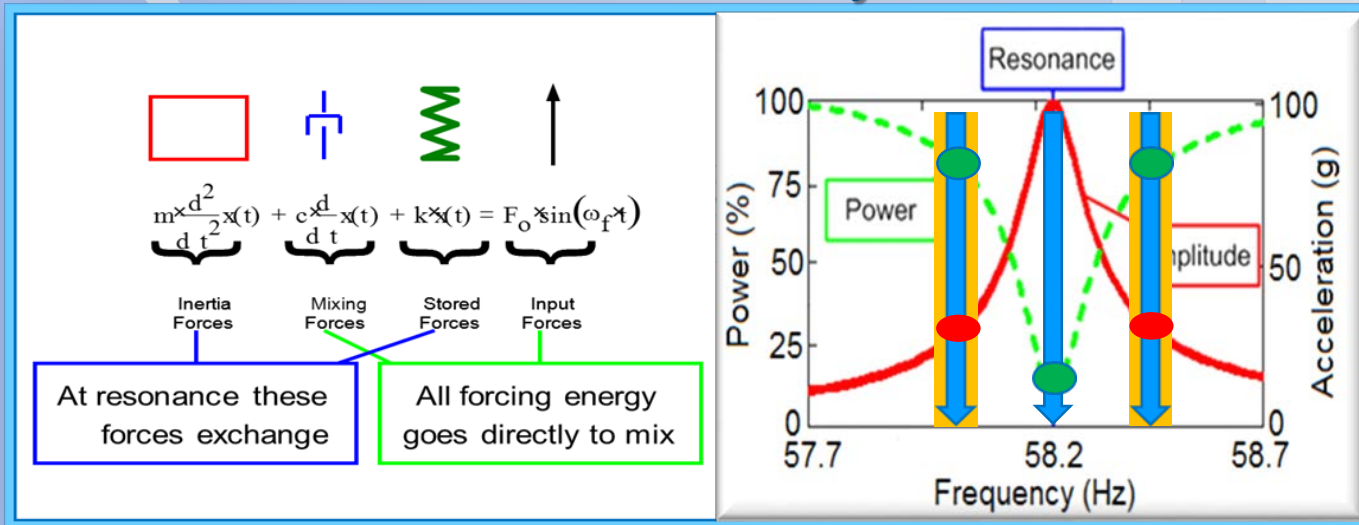
SOUND ENERGY



ResonantAcoustic® Technology Core Feature Number 3 – Operates Mechanical Resonance



Resonator Platform and Dynamics



Maximum Resonator
Amplitude at Minimum
Power

Energetics Competencies, Formulation and RAM Process Support

- **Propellants**
 - Cast-curable, in particular
 - Chemistries based on urethane-cure
 - Examples: High Solids AP/Al/HTPB, Highly Plasticized Minimum Signature Formulations, Energetic Thermoplastics, AP replacement technology, and more
- **Explosives**
 - As above, cast-curable compositions
 - Examples: PBXN -109, -110 and their simulants (Viscosity, Density, etc.)
- **Interactions of the above with formulation and IM outcomes**
 - Process improvements leading to benefits in FI, SCO, SCJ, these yet to be determined
- **Pyrotechnics or Pyrolants**
 - Advances in powder-powder mix capability, solventless process methods, powder coatings and encapsulants, co-crystallization or chemical entrainment – these for performance upgrades, hazards reduction
- **Continuous versus Batch Processing**
 - For all the above!

Examples of Energetic Manufacturing Applications for ResonantAcoustic[®] Technology

- Weapons Production Value Proposition
- Mix-in-Case Applications
- Continuous Mixing

RAM 5 Value Proposition Case Study: McAlester Army Ammunition Plant

- **Manufacture BLU-109 Bomb for the U.S. Air Force**
- **Current Process**
 - Cut and Machine from solid round extrusion
 - Previous Cost \$1,250 per part
- **ResonantAcoustic[®] Manufacturing Process**
 - Near-net-shape each part
 - Production capabilities of 500 per month
 - Current Cost of \$450 per part



McAlester Army Ammunition Plant RAM 5 Installation

- **Value Proposition --Net Economic Outcome/Gain**

- Saves ~\$800 per part
- Payback < 12 months
- Provides



**RAM Technology Saves ~\$800 Per Part
500 Parts Manufactured Per Month
Payback < 12 Months!
More than 15,000 Grains have been
Manufactured.
Savings ~ \$12 million to Date.**

RAMS Installed
September 2013

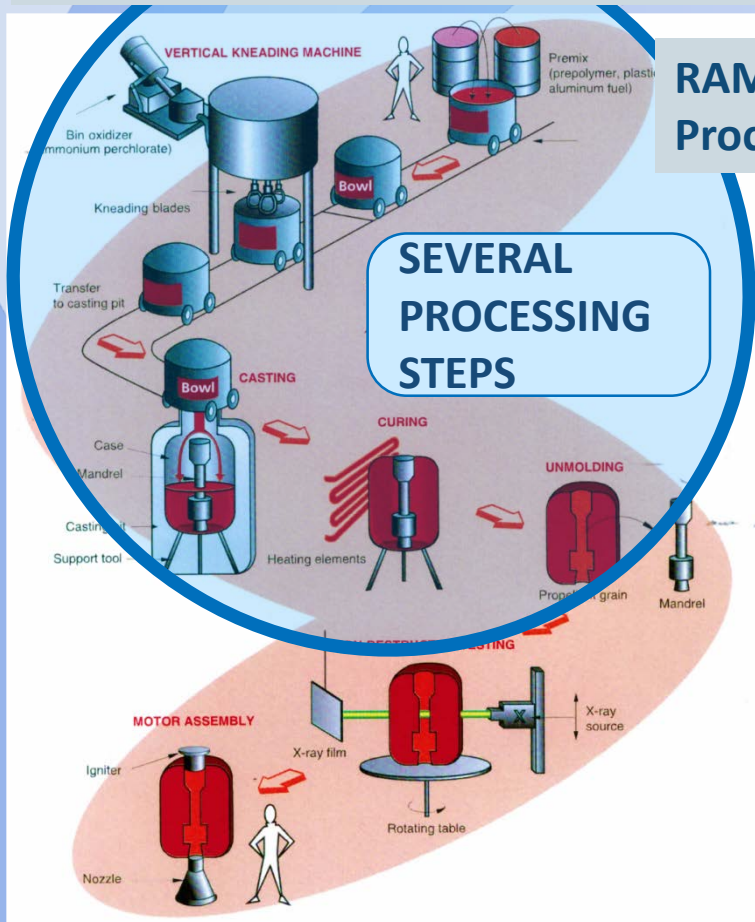
- Energetic Manufacturing Currently in Full Production

Resodyn New Initiatives - Overview

- **Mix-in-Case (MIC)**
 - Waste Reduction
 - Reduced Processing Steps
- **CAM, Continuous Acoustic Mix**
 - By Comparison, Makes Batch Processing Inefficient, Costly
 - Improves Quality, Minimizes QD, Enables Large Motor Operations Using RAM Technology
- **CIP, Clean in Place**
 - Minimize Cleanup Associated with Energetics Processing
 - Waste Reduction Yields Environmental and Cost Benefit

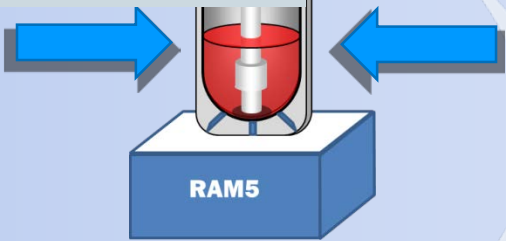
Mix-in-Case Process Transformation

Conventional Composite Propellant Manufacturing Process



SEVERAL PROCESSING STEPS

RAM Consolidated Process



RAM - ONE CONSOLIDATED STEP

Pre-mix
Oxidizer
Mixing
Net Shape
Cure

Significant Savings Potential

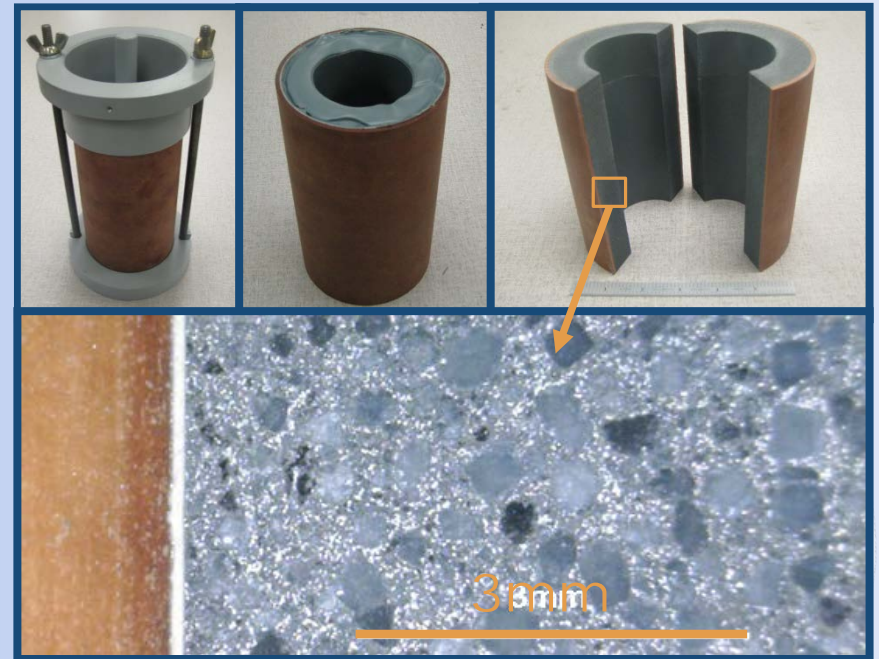
- Processing Steps and Equipment
- Cost Reduction
- Waste Reduction
- Safety Improvements

Resodyn Technology

- **Several Mix in Case (MIC) Projects Reported to be Completed or Underway**
- **Notable Examples**
 - **NAWCWD China Lake**
 - **Surrogate and Live Materials, Both Successful**
 - **Two Projects Completed**
 - 2.75 inch warheads
 - Shaped Charge Jet (SCJ) warheads
 - **Picatinny Arsenal**
 - **Surrogate Materials**
 - **M-67 Grenade**
 - **International Energetics Producer Sponsored Project**
 - **Development work using surrogate materials ongoing**
 - **Demonstrated on single asset using surrogate HDPB materials using acrylic shape in order to observe and record mixing processes**
 - **Being demonstrated on actual assets using surrogate HDPB materials**
 - **RAM 5 H ordered to take process into production**
 - **Resodyn (Surrogate Energetic Mixes)**
 - **Completed investigative work on three shape charges using surrogate Propellant materials**
 - Phi motor
 - Complex rocket motor shape on RAM 5
 - Complex rocket motor shape on RAM 55
 - **International Energetics Producer Purchasing RAM 5 to include Multiple Shape Charge Mix Capabilities**

Mix-in-Case

- **Benefits**
 - Eliminate manufacturing steps
 - No air voids are introduced by pouring into the mold
- **Bates Motor Example (Shown Right)**
 - 3 lbm rocket motor
 - Mixed in case under vacuum
 - Total mixing time - 15 minutes

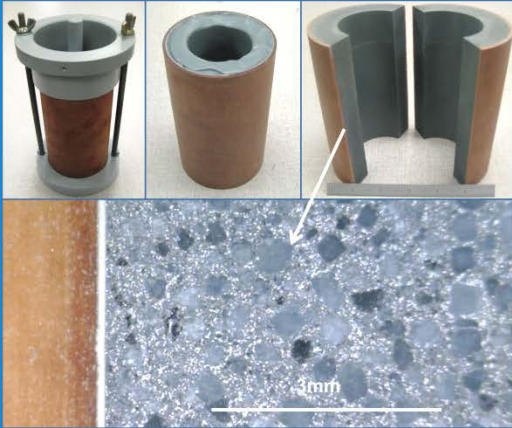


Mix-In-Case Solid Propellant Results

Small Scale Mix-In-Case

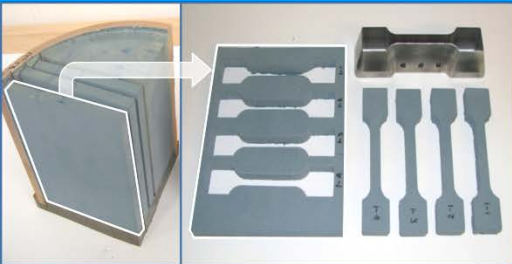
3# Mix-in-Case Product

- Cured Motor Inspection



40# Mix-In-Case Product

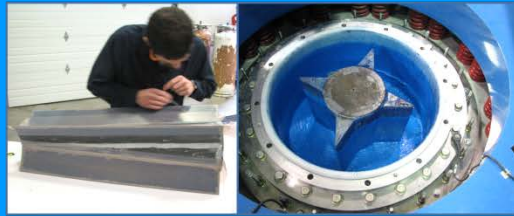
- Test Specimens obtained from cured Mix-In-Case product to demonstrate material uniformity



430# Mix-In-Case

Center-Perforation

- Star Pattern Mix-in-Case



- Preparing Star Pattern Mandrel Surface
 - Cut-away view
 - RAM 55 Processing



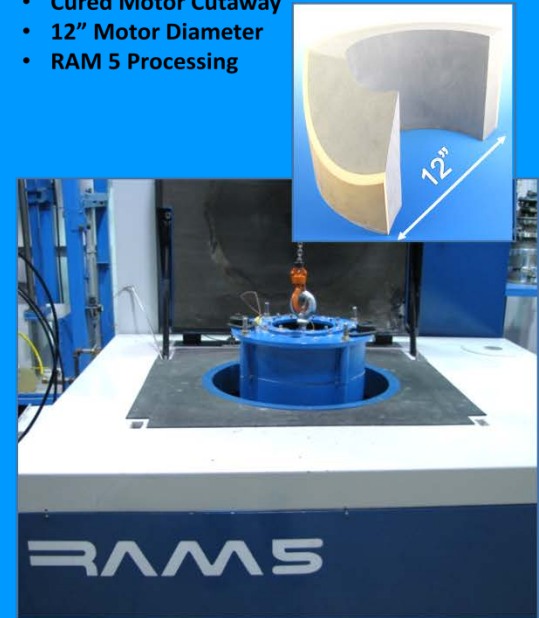
70# Mix-In-Case

BATES Motor

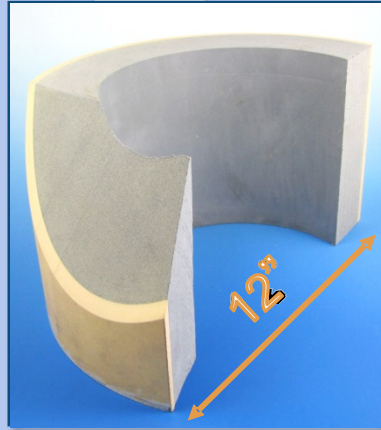
- Active Cooling



- Cured Motor Cutaway
- 12" Motor Diameter
- RAM 5 Processing



Client Specified Containers - - Mix in Case

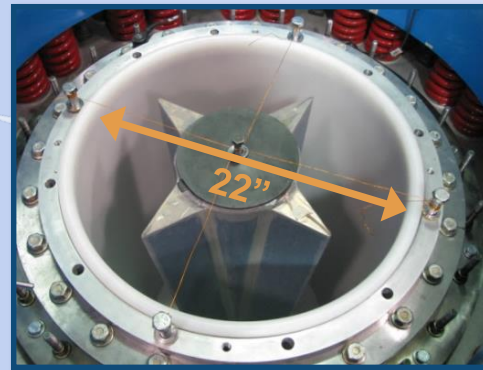


- **Bates Rocket Motor**

- 70 lbm RAM 5 mix
- Mixed in case under vacuum
- Thermally controlled
- Total mixing time - 20 minutes

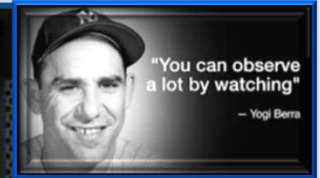
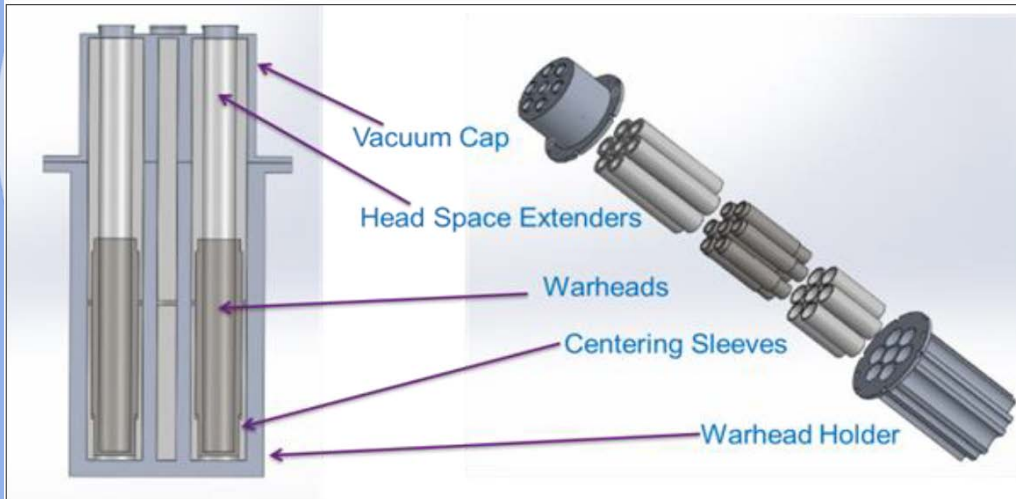
- **Complex Mandrel Proof of Concept**

- 430 lbm RAM 55 mix
- Mixed under vacuum
- Total mixing time - 20 minutes



NAWCWD China Lake Mix-in-Case

Warhead Mix-in-Case Demonstrations at NAWCWD China Lake
Dr. Andrew Nelson, et al, 2019 Technical InterChange, Butte, Montana



Video of
Resodyn Mix-in-Case
2.75 inch diameter, 13
inch long, acrylic
facsimile warhead

19% Powdered Sugar
58% Granulated Sugar
23% HTPB R45

Mixed at:
~50 Torr of Pressure
80 g of Acceleration



NAWCWD China Lake Mix-in-Case 18 Shaped Charge Jet (SJC) Warheads



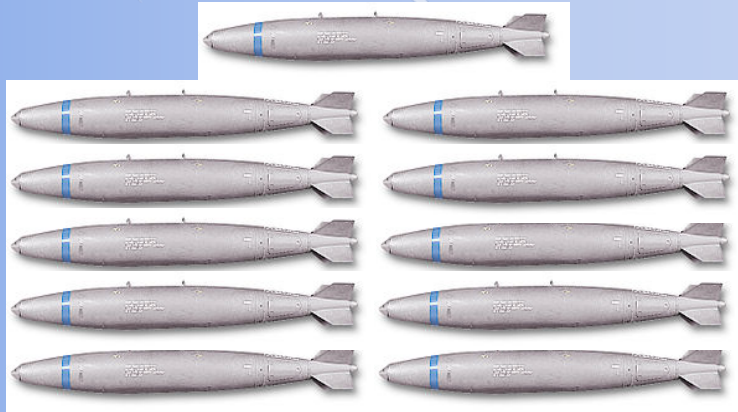
Dr. Andrew Nelson, et al, 2019 Technical InterChange, Butte, Montana

Motivation for ResonantAcoustic[®] Technology Continuous Processing

- **RAM Product Line was Limited to Batch Mixing**
 - 1 kg – LabRAM II
 - 36 kg – RAM 5
 - 420 kg – RAM 55
- **Many Industrial Mixing Applications Require Higher Production Rates, or are Better Suited to Continuous Production**
- **To meet this Market Opportunity, Continuous Processing Methods have been Developed**

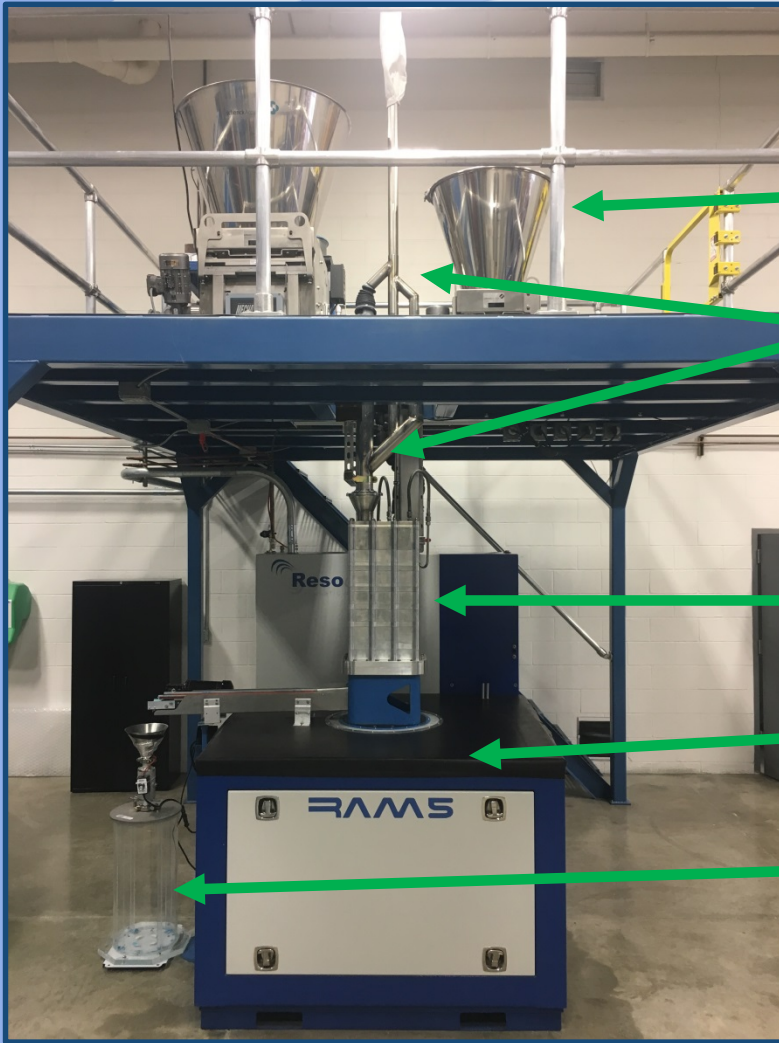
Resodyn Technology

- Standard Volume Vessel Continuous Acoustic Mixer (CAM) for RAM 5
 - At-cast viscosity: 250,000 cP at 25°C
 - Tested at: 2.0 kg/min;
120 kg/hr



> 11 Mk82 GP Bomb fill per 8hr shift, each with 87kg NEW
Similar to BLU 111/B, or JSOW Warhead NEW

NAWCWD China Lake -- The Overall Continuous Acoustic Mixer and Clean-in-Place Process

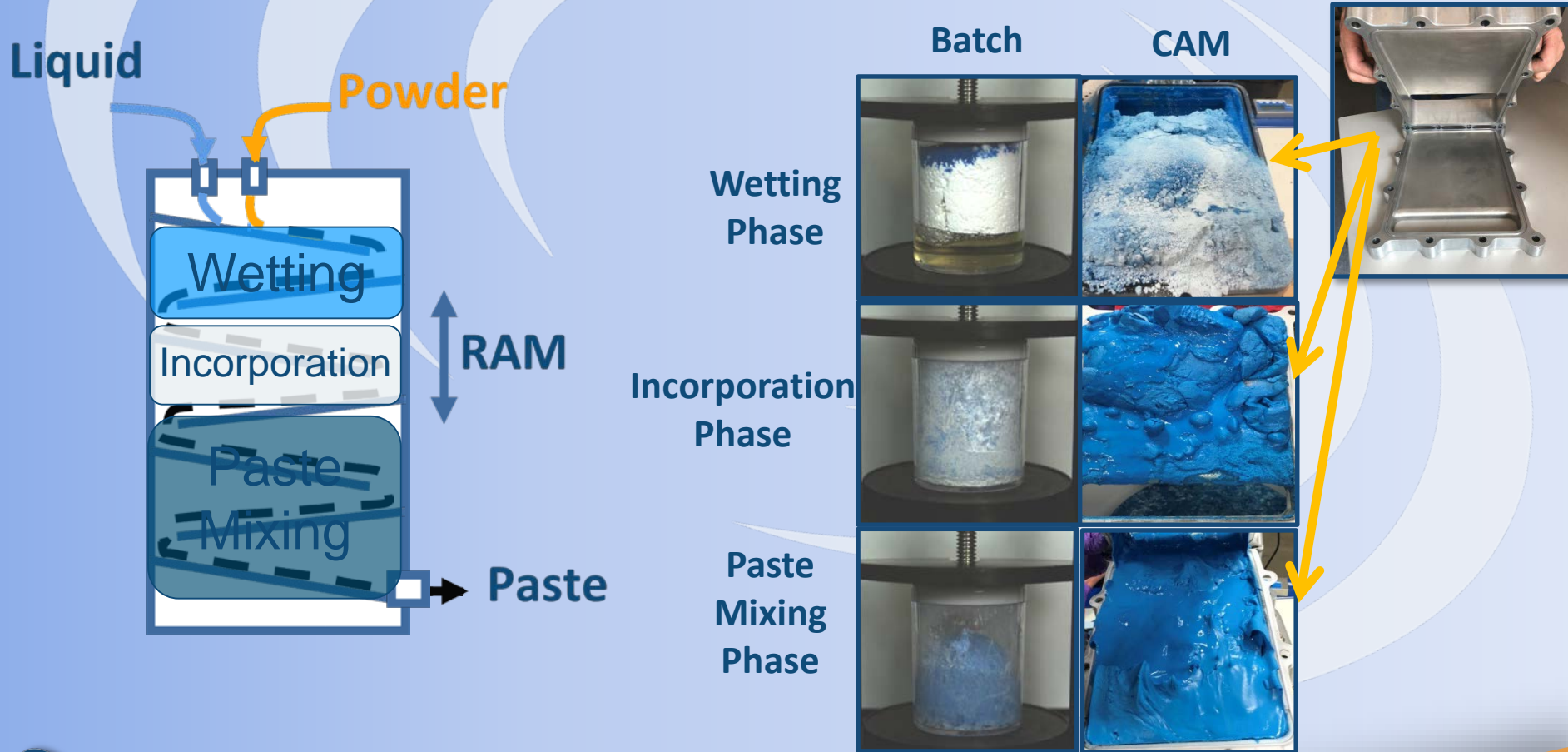


Unit Operations

- Loss-in-Weight Feeders
- Powder Delivery System
- Liquid Pumps (not shown)
- CAM
- RAM 5 Resonator
- Vacuum Degassing

Continuous Module Mix Regimes

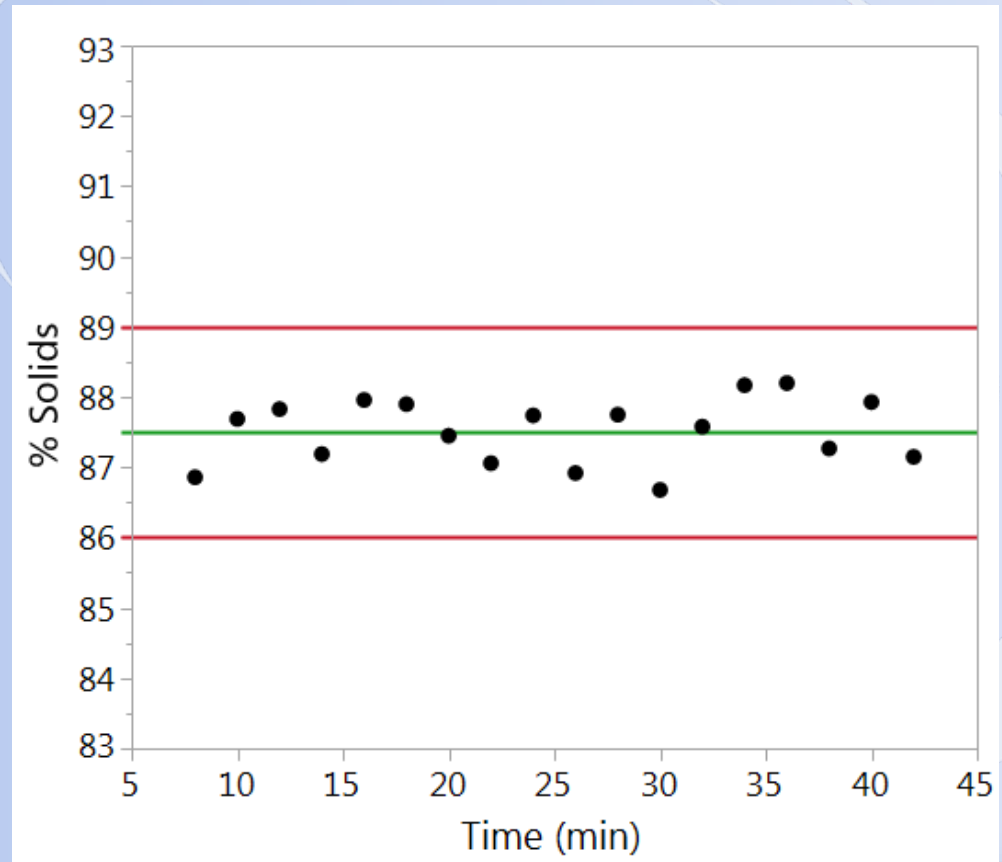
- Mix Regimes are the Same within the CAM as in Batch



Solid-Liquid: Inert PBX Surrogate Paste

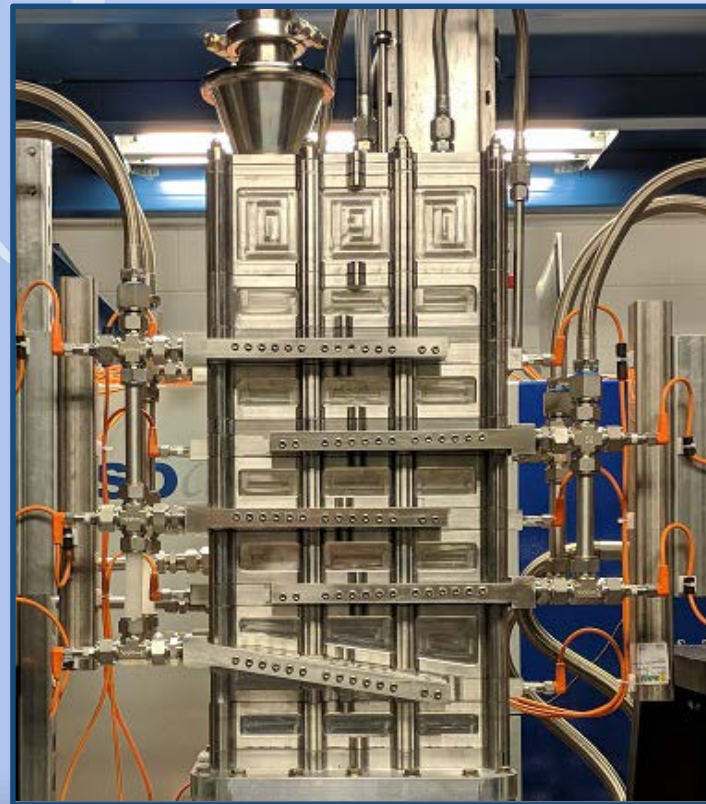
Thermal Gravimetric Analysis (TGA) Provides a Reliable and Reproducible Measure of Solids Loading **Consistency**

Produced Material Solids Loading is Well Controlled to Within ± 3 Standard Deviations



Temperature Control – Heating or Cooling

- Embedded Heat Transfer Channels Within CAM Modules
- A Single 1.5° Plate Resulted in ~350 Watts of Heat added to the Inert PBX Mixture (75°C, 0.85 gal/min)



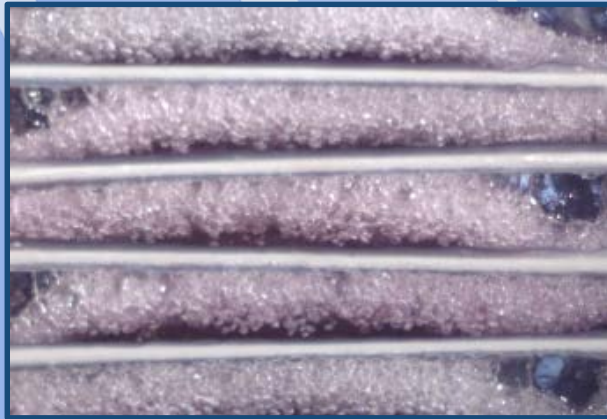
Thermowells

Temperature
Control Manifolds

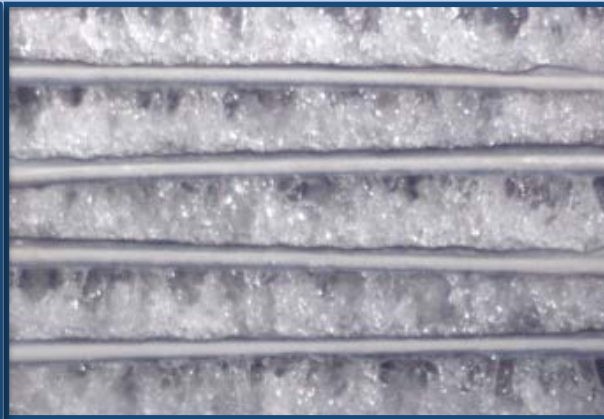
Through Plate Channels

Mechanical Cleaning Action

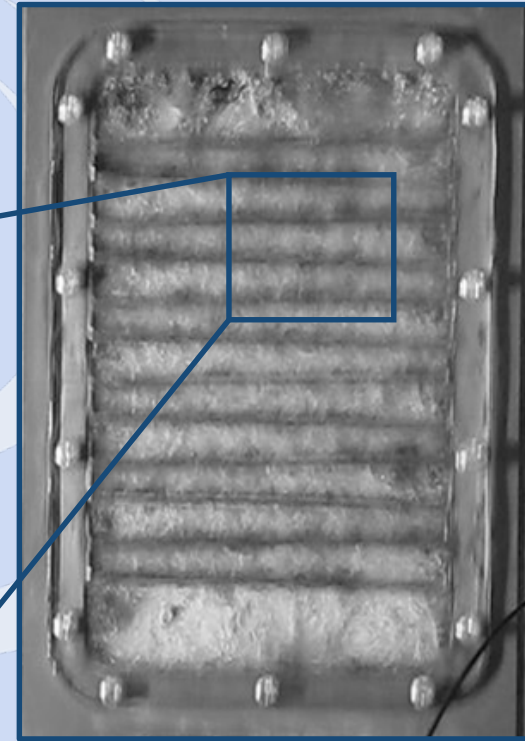
- **RAM Movement Imposes Strong Agitation that Creates Aggressive Cleaning Action that is Independent of Flow Rate, Allowing less Cleaning Agent to be Used**



**10 g
Acceleration**



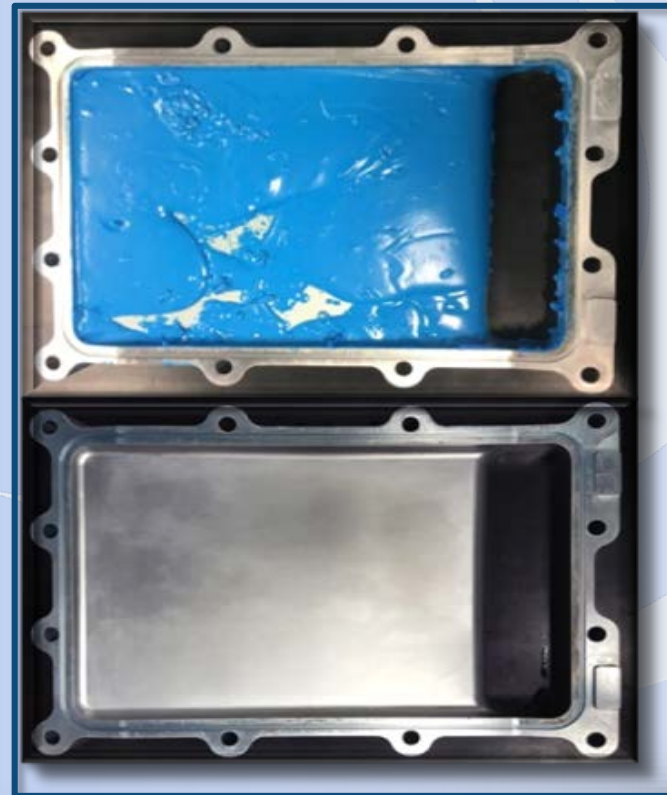
**50 g
Acceleration**



CAM Clean in Place (CIP)

- **Cleaning Inert PBX Surrogate from CAM using Clean-in-Place**
 - 5 kg of Material Wasted, less than 9 L of Aqueous Waste
 - 95g Acceleration Typically Used during Cleaning
 - 100% Removal Efficiency Achieved

After Runout
Before Cleaning



After Clean-in-Place

Value Proposition Cost Reductions

- **Equipment and Labor Reductions**
 - Reduced equipment stations
 - Reduced processing steps
 - Reduced processing time
- **One Step Ingredient Addition**
- **Mix-in-Mold or Mix-in-Case**
 - Near net shape to minimize post-cure machining
 - Final shape Mixing Capabilities has been Demonstrated
- **Energy Costs Reduced**
 - Reduced mix times
 - No mix vessel heat addition required
- **Reduced Waste**
 - Mix-in-Case
 - Continuous

Energetics Mixing Process of Choice

“ResonantAcoustic[®] Mixing”

Attributes

- **Reduce Cost of Manufacturing Energetics**
 - Reduce Manufacturing Time
 - Reduced Manufacturing Steps
- **Increased Safety**
 - Eliminates Blade Scraping Issues with Wall, or Foreign Objects
 - Low Shear, but Thorough Mixing of Highly Viscous Materials
- **Manufacturing Flexibility -- Reduced Batch Size Capability, but still Retain High Production Rate**
 - Ring of Safety Lessened for Large Batch Size Mixes
 - Reduced Constraints on Munitions Production Run Size (can accommodate small batch runs)

Summary

- **Resodyn Initiatives continue to demonstrate focus on energetic process equipment, and client success**
- **Advances in RAM technology are leveraged across all energetics industry needs: propellants, explosives, pyrotechnics**
- **Continuous Manufacturing, as Modular upgrade to RAM products, provides 'Game Changing' capability**

Resodyn Acoustic Mixer as a Universal Mixing and Processing Platform

- The Resodyn Acoustic Mixing (RAM) and Processing Technology is Arguably the Most Universal Mixing/Processing Technology of any Type Developed to Date
- The RAM Technology Employs a Single/Universal Platform to Mix and/or Process Materials
- The Underlying Foundation for the RAM Technology is the Use of an Oscillating Resonant Driver System to Transfer Energy to a Platform that Shakes a Mix Vessel, or Processing Container

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Innovative Mixing Technology

*Thank you for your
attention*

*A Veteran Owned
Small Business*

