54th Annual Fuze Conference

"The Fuzing Evolution – Smaller, Smarter, and Safer"

May 11 – 13, 2010
Kansas City, MO

Wednesday, May 12, 2010

Agenda
General and Open Sessions Agenda

GENERAL SESSION - SESSION II

- ***DTRA Overview*** *- Danny Hayles, Defense Threat Reduction Agency*
- ***ARDEC Overview*** *- Dr. Joseph Lannon, Director, Armament Research, Development & Engineering Center*
- ***AMRDEC Overview*** *- Mr. Shannon Haataja, Electronic Engineer, US Army, AMRDEC*
- ***Navy Overview*** *- Mr. John Hendershot, Fuze Branch Head, NSWC, Indian Head Division*

OPEN SESSIONS - SESSIONS IIIA

- ***High Reliability Fuzing Architecture for Cluster Munitions*** *- Karen Amabile, US Army ARDEC*
- ***Dynamic Impact Simulation of "High-G Hardened Fuzes"*** *- Dr. Paul Glance, Naval Air Warfare Center Weapons Division*
- ***Modelling the Interaction of a Laser Target Detection Device with the Sea Surface*** *- Gary Buzzard, Thales*
- ***Adaptive Imaging and Guided Fuze Technologies*** *- Ron Barrett, The University of Kansas*
- ***Design Challenges and Critical Technology Discovery for Hard Target Fuze Design*** *- Chad Hettler, Sandia National Laboratories*
- ***Systems Engineering in Hard Target Systems Design*** *- Patrick O'Malley, Sandia National Laboratories*
- ***M789 30mm Sensitivity Improvement*** *- John Geaney, US Army ARDEC*
- ***Optical System to Control Termination of Small & Medium Caliber Munitions*** *- Dr. Sergey Sandomirsky, Physical Optics Corp.*
- ***NavFire Guidance System – Integrated GPS and Mission Computer for Future Navigation Solutions*** *- Walter Trach, Rockwell Collins*
- ***Integrating Manufacturability into Fuze Development*** *- Stephen Redington, US Army ARDEC*

Thursday, May 13, 2010

OPEN SESSIONS – SESSION IVA

- ***XM1156 Precision Guidance Kit (PGK)*** *- Anthony Pergolizzi, Army Fuze Management Office*
- ***40mm Infantry Grenade PD Self-Destruct Fuze*** *- Michael Butz, JUNGHANS Microtec*
- ***New Safety Requirements: Fuzing System Solutions*** *- Max Perrin, JUNGHANS Microtec*
- ***Improved Energetic Materials as Fuze Ingredients*** *- Dr. David Price, BAE Systems*
- ***High Speed Digital Infrared Imaging of the M201A1 Grenade Fuze Initiation Train*** *- Dr. Ryan Olsen, Naval Surface Warfare Center - Crane, Detachment F*
- ***Safety Assessment of Fuzing Systems Using IEC 61508*** *- Dr. Ivo Häring, Fraunhofer EMI*
- ***Impact Switch Study*** *- Dr. Dave Frankman, L3 Fuzing and Ordnance Systems*
- ***Radio Frequency Programmable Signal Processor System for Fuze Programming*** *- Douglas Cox, Mixed Signal Integration*
- ***Programmable Initiators to Extend Functionality of Reserve Power Systems*** *- Carlos Pereira, US Army ARDEC*

OPEN SESSIONS- SESSION VA

- ***MEMS Retard and Impact Sensors*** *- Walter Maurer, Naval Air Warfare Center Weapons Division*

- ***60KG MEMS Sensor,*** *Robert Sill, PCB Piezotronics Inc*
- ***Development of Low-Cost, Compact, Reliable, High Energy Density Ceramic Nanocomposite Capacitors*** *- Todd Monson, Sandia National Labs*
- ***Non-Lethal Fuzing Requirements*** *- Tim Mohan, Armament Research, Development & Engineering Center*
- ***Results from Preliminary Testing of a NewGeneration of High-Shock Accelerometers with Extreme Survivability Performance*** *-Randy Martin, Meggitt Sensing Systems, North America*
- ***Use of Conductive Adhesive in Fuze Applications*** *- Dr. Jakob Gakkestad & Per Dalsjo, FFI*
- ***The Impact Switch Investigation*** *- Sam Tuey, Naval Air Warfare Center Weapons Division*
- ***Low-Cost MEMS Initiators*** *- Chopin Hua, MicroAssembly Technologies*
- ***Inkjet Printing High-Explosive Materials for Direct Write Fuzing*** *– Daniel Stec, SAIC*

NDIA National Defense Industrial Association

54th Annual Fuze Conference

May 12, 2010 - General Session (AM)

Session I

- **8:00** Introduction/Admin Remarks – Dr. Barry Neyer
- **8:05** NDIA Opening Remarks – MG Barry Bates, USA (Ret)
- **8:10** ~~Keynote – Robin Stubenhofer~~

Session II (Chair: Jim Sharp, Asst: Dr. Barry Neyer)

- **8:40** DTRA Overview – Danny Hayles
- **9:00** ARDEC Overview – Dr. Joseph Lannon
- **9:20** AMRDEC Overview – Mr. Shannon Haataja
- **9:40** Break
- **10:00** Navy Overview – John Hendershot
- **10:30** ~~Air Force S&T Strategy – Tim Tobik~~
- **11:00** ~~Fuze IPT Perspective – Charles Kelly~~
- **11:15** ~~Joint Fuze Technology Program – Lawrence Fan~~
- **11:35** Lunch

AFEI NTSA PSA WID

May 12, 2010 - OPEN Session (PM)

Session IIIA (Chair: Ken Kelly, Asst: Bob Hertlein)

- **1:00** High Reliability Fuzing Architecture for… - K. Amabile
- **1:20** Dynamic Impact Simulation of "High-G…" – Dr. P. Glance
- **1:40** Modeling the Interaction of a Laser Target… - G. Buzzard
- **2:00** Adaptive Imaging and Guided Fuze… - R. Barrett
- **2:20** Design Challenges and Critical Tech… - C. Hettler
- **2:40** Systems Engineering in Hard Target… - P. O'Malley
- **3:00** Break
- **3:20** M789 30mm Sensitivity Improvement – J. Geaney
- **3:40** Optical System to Control Termin… - Dr. S. Sandomirsky
- **4:00** NavFire Guidance System – Integrated… - W. Trach
- **4:20** Integrating Manufacturability into Fuze… - S. Redington
- **4:40** Conference Adjourned for the Day
- **5:30** Grand Reception

54th Annual Fuze Conference

May 13, 2010 - OPEN Session (AM)

Session IVA (Chair: Telly Manolatos, Asst: Lawrence Fan)

- **8:00** XM1156 Precision Guidance Kit (PGK) – A. Pergolizzi
- **8:20** 40mm Infantry Grenade PD Self-Destruct… - M. Butz
- **8:40** New Safety Requirements: Fuzing System… - M. Perrin
- **9:00** Open
- **9:20** Improved Energetic Materials as Fuze… - Dr. D. Price
- **9:40** High Speed Digital Infrared Imaging… - Dr. R. Olsen
- **10:00** Break
- **10:20** Safety Assessment of Fuzing Systems… - Dr. I. Häring
- **10:40** Impact Switch Study – Dr. D. Frankman
- **11:00** Radio Frequency Programmable Signal… - D. Cox
- **11:20** ~~High Energy Self-Integrated Piezoelec… - Dr. A.V. Carazo~~
- **11:40** Programmable Initiators to Extend Func… - C. Pereira
- **12:00** Lunch

May 13, 2010 - OPEN Session (PM)

Session VA (Chair: Eric Roach, Asst: Tim Bonbrake)

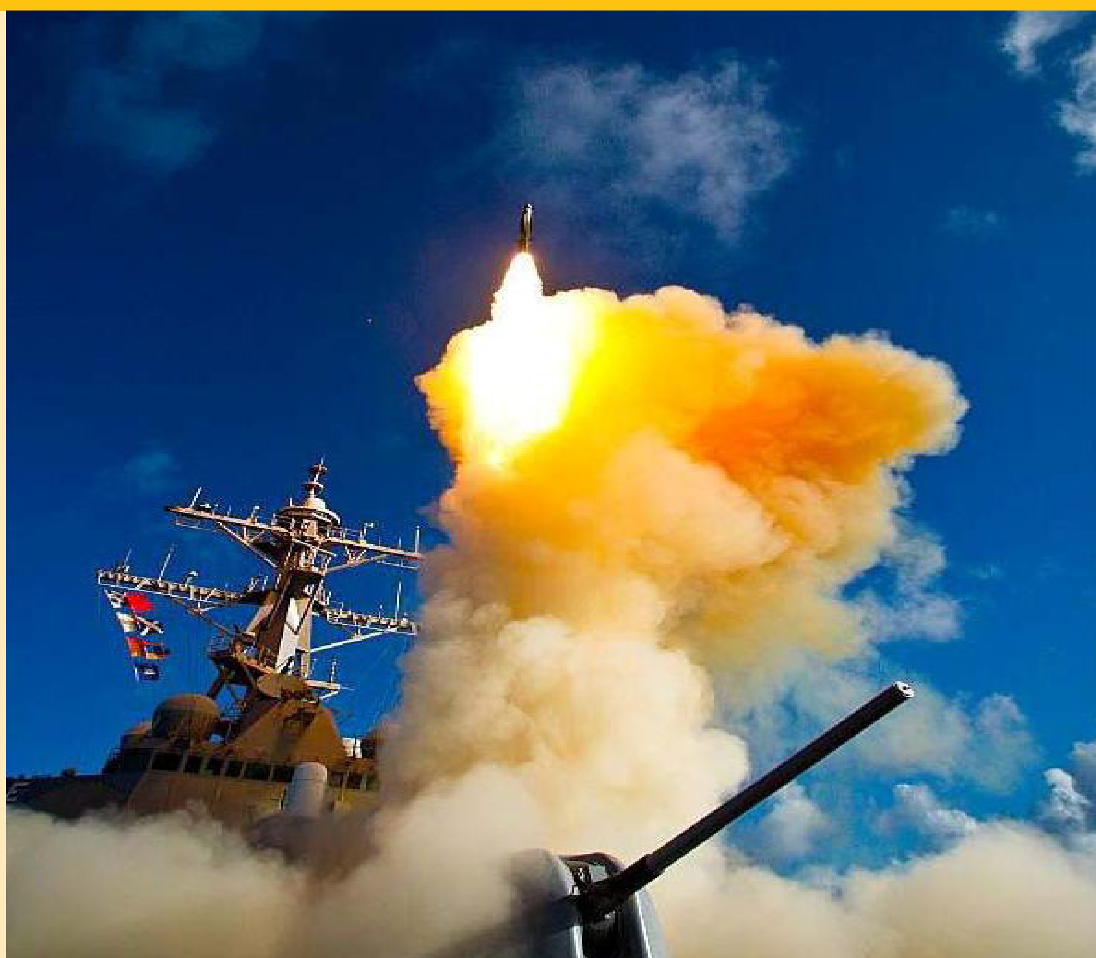
- **1:00** MEMS Retard and Impact Sensors – W. Maurer
- **1:20** ~~Strengthening and Miniaturizing the Res… - T. Benschop~~
- **1:40** 60KG MEMS Sensor – R. Sill
- **2:00** Development of Low-Cost, Compact, Rel… - T. Monson
- **2:20** Non-Lethal Fuzing Requirements – T. Mohan
- **2:40** Results from Preliminary Testing of a New… - R. Martin
- **3:00** Break
- **3:20** Use of Conductive Adhesive… - Dr. J. Gakkestad/P. Dalsjo
- **3:40** The Impact Switch Investigation – S. Tuey
- **4:00** Low-Cost MEMS Initiators – C. Hua
- **4:20** Inkjet Printing High-Explosive Materials… - D. Stec
- **4:40** Wrap-Up & Conference Adjourned

Event # 0560

PROMOTING NATIONAL SECURITY SINCE 1919

54TH ANNUAL FUZE CONFERENCE

"The Fuzing Evolution-Smaller, Smarter, and Safer"



May 11-13, 2010

KANSAS CITY, MO

AGENDA

New This Year

Visit the following company Table Top Displays in the Regency Ballroom Prefunction area:

- Bennington Microtechnoogy
- DTS, Inc.
- EnerSys
- NNSAs National Secure Manufacturing Center
- PCB Piezotronics
- US Army Yuma Proving Ground

Keep this in mind for your company in 2011!

TUESDAY, MAY 11, 2010

3:00-6:30 pm - Onsite Registration

5:00-6:30 pm - Opening Reception

WEDNESDAY, MAY 12, 2010

GENERAL SESSION

Session I

7:00 am Onsite Registration/Continental Breakfast

8:00 am Introduction/Administrative Remarks
Dr. Barry Neyer, Chair, Fuze Division
Director of Engineering, Defense, PerkinElmer

8:05 am NDIA Opening Remarks
MG Barry Bates, Vice President, Operations
National Defense Industrial Association

8:10 am Keynote
Robin Stubenhofer, Vice President of Operations,
Kansas City Plant

Session II

CHAIR: JIM SHARP ASSISTANT: DR. BARRY NEYER

8:40 am DTRA Overview
Danny Hayles, Defense Threat Reduction Agency

9:00 am ARDEC Overview
Dr. Joseph Lannon, Director, Armament Research, Development & Engineering Center

9:20 am AMRDEC Overview
Mr. Shannon Haataja, Electronic Engineer, US Army AMRDEC

9:40 am BREAK

10:00 am Navy Overview
Mr. John Hendershot, Fuze Branch Head, NSWC Indian Head Division

10:30 am Air Force Fuze Strategy
Tim Tobik, Chief, Fuze Branch, Air Force Research Laboratory

11:00 am Fuze IPT Perspective
Charles Kelly, OUSD (AT&L)

11:15 am Joint Fuze Technology Program
Lawrence Fan, NSWC Indian Head Division

WEDNESDAY, MAY 12, 2010 (PM)

OPEN SESSIONS

Session IIIA

CHAIR: KEN KELLY **ASSISTANT:** BOB HERTLEIN

1:00 pm High Reliability Fuzing Architecture for Cluster Munitions
Karen Amabile, US Army ARDEC

1:20 pm Dynamic Impact Simulation of "High-G Hardened Fuzes"
Dr. Paul Glance, Naval Air Warfare Center Weapons Division

1:40 pm Modelling the Interaction of a Laser Target Detection Device with the Sea Surface
Gary Buzzard, Thales

2:00 pm Adaptive Imaging and Guided Fuze Technologies
Ron Barrett, The University of Kansas

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Dr. Sergey Sandomirsky, Physical Optics Corp.

4:00 pm NavFire Guidance System – Integrated GPS and Mission Computer for Future Navigation Solutions
Walter Trach, Rockwell Collins

4:20 pm Integrating Manufacturability into Fuze Development
Stephen Redington, US Army ARDEC

4:40 pm Conference Adjourned For the Day

5:30 pm - 7:00 pm Grand Reception

US ONLY SESSIONS

Session IIIB

CHAIR: TOM BAGINSKI **ASSISTANT:** ED COOPER

1:00 pm The Demands of Supersonic Penetrator Weapons on the Safety and Survivability of Ordnance Fuzing Systems
Laurie Turner, Thales

1:20 pm Joint Fuze Technology Panel (JFTP) Hardened Miniature Fuze Technology (HMFT) Development
Jefferson Oliver, AFRL/RWMF

1:40 pm Universal Smart Fuze for Unmanned Aerial Vehicle and Other Remote Armament Systems
Daniel Vo & Lloyd Khuc, US ARMY ARDEC

2:00 pm Army Selectable Yield Unitary (ASYU) Fireset Characterization
Don Limbaugh, US Army ARDEC

2:20 pm Command to Arm S&A for Mortar Fuze Application
Byron Lee, ATK

2:40 pm An Economically Produced Mechanical Command-to-Arm Fuze for 40mm Rifled Grenade Applications
James Wise, DSE, Inc.

3:00 pm BREAK

3:20 pm Multi-point Initiation Systems for Non-Ideal Explosives
Dr. David Lambert, Air Force Research Laboratory

3:40 pm Extremely Insensitive Detonating Substance (EIDS) Initiation System Progress
Brad Hanna, NSWC Indian Head Division

4:00 pm Conformal Detonation Devices using Direct Write Technologies
Dr. Anne Marie Petrock, US ARMY ARDEC

4:20 pm Based Roll Determination in Spinning Projectiles
Steve Alexander, L3

4:40 pm Photonic Sensors for Fuzing of Hardened Target Penetrators
Dr. Todd Meyrath, Aerius Photonics

5:00 pm Lithium/Thionyl Chloride (Li/SOCl2) Cell for Medium Caliber Ammunition
Paul Schisselbauer, EnerSys Advanced Systems

5:20 pm Conference Adjourned For the Day

5:30 pm - 7:00 pm Grand Reception

AGENDA

THURDAY, MAY 13, 2010 (AM)

REGISTRATION

7:00 am Onsite Registration/Continental Breakfast

OPEN SESSIONS

Session IVA

CHAIR: **TELLY MANOLATOS** **ASSISTANT:** **LAWRENCE FAN**

8:00 am XM1156 Precision Guidance Kit (PGK)
Anthony Pergolizzi, Army Fuze Management Office

8:20 am 40mm Infantry Grenade PD Self-Destruct Fuze
Michael Butz, JUNGHANS Microtec

8:40 am New Safety Requirements: Fuzing System Solutions
Max Perrin, JUNGHANS Microtec

9:00 am Testing Navy Electronically Settable Fuzes for Ordnance Assessment
Jason Koonts, NSWC Dahlgren

9:20 am Improved Energetic Materials as Fuze Ingredients
Dr. David Price, BAE Systems

9:40 am High Speed Digital Infrared Imaging of the M201A1 Grenade Fuze Initiation Train
Dr. Ryan Olsen, Naval Surface Warfare Center - Crane, Detachment F

10:00 am BREAK

10:20 am Safety Assessment of Fuzing Systems Using IEC 61508
Dr. Ivo Häring, Fraunhofer EMI

10:40 am Impact Switch Study
Dr. Dave Frankman, L3 Fuzing and Ordnance Systems

11:00 am Radio Frequency Programmable Signal Processor System for Fuze Programming
Douglas Cox, Mixed Signal Integration

11:20 am High Energy Self-integrated Piezoelectric Setback Generators for Smart Fuzing
Dr. Alfredo Vazquez Carazo, MICROMECHATRO ICS, Inc.

11:40 am Programmable Initiators to Extend Functionality of Reserve Power Systems
Carlos Pereira, US Army ARDEC

12:00 pm LUNCH

US ONLY SESSIONS

Session IVB

CHAIR: **CURT POWELL** **ASSISTANT:** **FRAN MATTIA**

8:00 am MEMS Fuzing for High Reliability Systems
Dr. Michael Deeds, Naval Surface Warfare Center Indian Head Division

8:20 am Design and Testing of Low-G and Very Low-G Retard
Metal MEMS Sensors
Ryan Knight, US Army ARDEC, Fuze Division

8:40 am A Versatile Explosive Train Integrated into a MEMS Safety and Arm Device
Alex Parkhill, NSWC Indian Head Division

9:00 am Non-Inertial MEMS Mechanical Safety and Arming Device
Tim Hoang, US Army ARDEC Fuze Division

9:20 am MEMS Fuze in 40mm HEDP Cartridge Demonstration
Charles Robinson, US Army ARDEC

9:40 am Navy MEMS Fuze Technology for Marine Corp Flight Control Mortar Application
Dr. Daniel Jean, NSWC Indian Head Division

10:00 am BREAK

10:20 am Multi-Axial Pyroshock Fuze Testing
Dr. Janet Wolfson, Air Force Research Lab

10:40 am The Development of a Fuze Survivability Protocol for Hard Target Fuzes
Stephen Szczepanski, Air Force Research Lab

11:00 am Modeling of G-Switch Based Target Detection
Dr. Scott McEntire, Sandia National Laboratories

11:20 am Fuze Diagnostic Recording
Dr. Scott McEntire, Sandia National Laboratories

11:40 am The Multi Axis Shock Test (MAST) Program
Dr. John Thomas, Anyar, Inc.

12:00 pm LUNCH

THURSDAY, MAY 13, 2010 (PM)

OPEN SESSIONS

Session VA

CHAIR: ERIC ROACH ASSISTANT: TIM BONBRAKE

1:00 pm MEMS Retard and Impact Sensors
Walter Maurer, Naval Air Warfare Center Weapons Division

1:20 pm Strengthening and Miniaturising the Reserve Lithium Battery
Tonny Benschop, Thales Cryogenics BV

1:40 pm 60KG MEMS Sensor
Robert Sill, PCB Piezotronics Inc.

2:00 pm Development of Low-Cost, Compact, Reliable, High Energy Density Ceramic Nanocomposite Capacitors
Todd Monson, Sandia National Labs

2:20 pm Non-Lethal Fuzing Requirements
Tim Mohan, Armament Research, Development & Engineering Center

2:40 pm Results from Preliminary Testing of a New Generation of High-Shock Accelerometers with Extreme Survivability Performance
Randy Martin, Meggitt Sensing Systems, North America

3:00 pm BREAK

3:20 pm Use of Conductive Adhesive in Fuze Applications
Dr. Jakob Gakkestad & Per Dalsjo, FFI

3:40 pm The Impact Switch Investigation
Sam Tuey, Naval Air Warfare Center Weapons Division

4:00 pm Low-Cost MEMS Initiators
Chopin Hua, MicroAssembly Technologies

4:20 pm Inkjet Printing High-Explosive Materials for Direct Write Fuzing
Adrew Ihnen, Stevens Institute of Technology

4:40 pm Wrap- Up & Conference Adjourned

US ONLY SESSIONS

Session VB

CHAIR: DR. BARRY NEYER ASSISTANT: DON SHUTT

1:00 pm Evaluation Tools for Exploding Foil Initiators
1Lt Tim Ager, Air Force Research Laboratory

1:20 pm Deposition and Testing of Sub-Millimeter Energetic Materials
Alexander S. Tappan, Sandia National Laboratories

1:40 pm EFI Qual by Similarity
Brad Biggs, Raytheon

2:00 pm Reproducing System-Imposed Environments in Penetration Fuze Testing
Dr. Jason Foley, Air Force Research Lab

2:20 pm Pyroshock Testing of Fuzes in Penetrators
2nd Lt. Lashaun Watkins

2:40 pm Safety Considerations for Optical Firing Set Technology
Charles Treu, NNSA Kansas City Plant

3:00 pm BREAK

3:20 pm FUZION Smaller-Smarter-Safer
Ronald Persson, Mustang Technology Group

3:40 pm Development of a Miniaturized Electronic Safe & Arm Device
Noah Desch, L3 Fuzing and Ordnance Systems

4:00 pm 30mm STAR ATO Fuzing Integration
Richard Bottenberg, ATK

4:20 pm Design Verification Testing of an Electronic Fuze Assembly to Withstand High G Mechanical Loads During Target Penetration
Perry Salyers, L3 Fuzing and Ordnance Systems

4:40 pm Advanced Aft Closure and Fuzewell System for Hard and Deeply Buried Target Penetrating Warheads
Edward Lawrence, General Dynamics Ordnance and Tactical Systems

5:00 pm High-performance, small footprint: Low-cost Poco-sprytron Switches
Charles Walker, Sandia National Laboratories

5:20 pm Wrap- Up & Conference Adjourned

THANK YOU TO OUR BREAK SPONSOR!

L3

Fuzing & Ordnance Systems

L-3 Fuzing & Ordnance Systems (L-3 FOS) was formed on January 1, 2009 from the merger of two legacy L-3 divisions — KDI Precision Products and BT Fuze Products. L-3 FOS combines expertise in both fuzing and ordnance systems to facilitate response to warfighter requirements, while providing a broader range of solutions to both the government and prime contractors.

The L-3 Fuzing & Ordnance System team confronts today's formidable technological challenges by devoting ourselves and all of our resources to fuzing and ordnance systems for the U.S. and our international military allies. L-3 FOS is globally recognized as fuzing experts and ordnance systems integrators for tube-launched, air-dropped, infantry-employed and missile-driven ordnance products.

L-3 FOS is leading the way in the development of reliable and affordable fuzing, ESADs and ESAFs, safety & arming devices and proximity sensor products. L-3 FOS capabilities include: Artillery Fuzes - M739A1, M762A1/M767A1, M782 (MOFA), MK404, MK417, MK418, MK432, MK437 (MOFN); Excalibur, Missile & Rocket Fuzing - GMLRS, ATACMS, AIM-9X and NLOS-LS and Bomb Fuzes - FMU-139C/B, FMU-143B/B, SDB and JASSM. For more information on L-3 Fuzing & Ordnance Systems and our products and capabilities, please visit www.L-3com.com/FOS.

THANK YOU TO OUR MAY 12th LUNCH SPONSOR!

DSE

DSE, is one of the world's leading manufacturers of precision metal components, assemblies and ordnance products. We currently serve as a Prime contractor for a multi-year, fully integrated system contract under the U.S. Army for the 40mm family of ammunitions. DSE is a fully ISI 9001:2000 certified Small Business. It has the organizational strength of a large business while maintaining the flexibility and responsiveness of a small business. Our fully integrated on-site manufacturing offers: a comprehensive, dynamic quality program, Statistical Process Control system, engineering, project and configuration management, material and production control support functions, purchasing and fully equipped metrology and calibration laboratories.

Established since 1979, DSE consistently demonstrates its commitment to clients and employees through the company emphasis on integrity, excellence and ethical practices. We enjoy a strong tradition as an innovative, proven supplier. DSE's business approach is carefully designed to align client interests and ethical support. We believe in the enrichment and fulfillment of our commitments through disciplined growth, technological innovation and seamless execution. The ability to manage client relationships and make them our leading priority is among our greatest competitive assets.

DSE's commitment to product success and corporate social responsibility is our cornerstone. The implementation of corporate and individual initiatives helps to ensure that we contribute to the communities in which we live and work and drives our corporate logic. Our business model upholds the basic value of protecting the courageous men and women who serve to secure liberty for all.

THANK YOU TO OUR MAY 12TH RECEPTION SPONSOR!

ATK

Alliant Techsystems, Inc. (ATK) is a leading manufacturer of the fuzes U.S. and allied forces rely on today. The company is also pioneering the development of advanced fuze technology for tomorrow. ATK has delivered over 100,000 DSU-33 Proximity Sensors for weapons such as the Joint Direct Attack Munition (JDAM), and general purpose bombs. The company's Multi-Option Fuze for Artillery (MOFA) adds new flexibility to 105mm and 155mm artillery systems, and its Electronic Time Fuze for Mortars gives 60mm, 81mm, and 120mm shells improved timing accuracy and enhanced safety.

ATK's Precision Guidance Kit (PGK) affordably transforms existing 155mm artillery rounds into GPS-guided, one shot, one kill weapon systems, and its Hard Target Void-Sensing Fuze will enable precision bombs with penetrating warheads to detonate at precise points inside buried or reinforced concrete targets. The company is an industry leader in the development of advanced precision projectiles for naval and land forces applications.

ATK is the nation's largest producer of military small and medium-caliber ammunition, propellant and energetics, and Bushmaster chain gun systems. The company is also a leading manufacturer of 105mm and 155mm ammunition, airburst munition technology, and intelligent perimeter protection systems.

ATK is the world leader in solid propulsion systems and is the prime contractor on the first stage of NASA's shuttle-replacing Ares I vehicle. The company's booster motors provide much of the thrust for Delta-family of launch vehicles. In addition, ATK manufactures all three stages of the Minuteman III and Trident II missile systems. ATK is also a leading provider of components and subsystems for today's large satellites and it is pioneering the development of small constellations of satellites for tomorrow.

THANK YOU TO ALL THE SPONSORS!

ATK

DSE

KAMAN
PRECISION PRODUCTS
Where Value Meets Innovation

LOCKHEED MARTIN

L3

Fuzing & Ordnance Systems

NOTES

We hope to see you in 2011 & 2012!
Mark you calendars!

55th Annual Fuze Conference
Salt Lake City, UT - May 24-26, 2011

56th Annual Fuze Confernece
Baltimore, MD - May 14-16, 2012

National Defense Industrial Association

NATIONAL DEFENSE INDUSTRIAL ASSOCIATION
2111 WILSON BOULEVARD, SUITE 400
ARLINGTON, VA 22201-3061
(703) 522-1820
(703) 522-1885 FAX
WWW.NDIA.ORG

54th Annual Fuze Conference

"The Fuzing Evolution- Smaller, Smarter, and Safer"

US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

U.S. Army Aviation and Missile Research, Development, and Engineering Center Overview

Approved for public release; distribution unlimited.
Review completed by the AMRDEC Public Affairs Office (20 Apr 2010; FN4594).

AMRDEC
STRENGTH THROUGH TECHNOLOGY

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

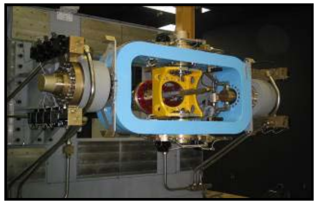
Presented to: **54TH Annual Fuze Conference**

Presented by: **Shannon Haataja**
AMRDEC

"The Fuzing Evolution – Smaller, Smarter, and Safer"

Date: **Wednesday, May 12, 2010**

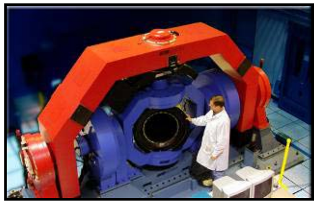
Agenda


- **Who are we?**

- **What do we do?**






TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

AMRDEC Overview

AMRDEC MISSION: Manage and conduct research, exploratory and advanced development, and provide one-stop life cycle engineering and scientific support for aviation, missile, and unmanned systems platforms

Aeroflightdynamics Directorate
NASA Ames–Moffett Field, CA
Aviation S&T

Maintenance Eng. Div. Aviation Engineering Dir.
Corpus Christi, TX
Aviation Sustainment Engineering

AMRDEC HQ
Redstone Arsenal Huntsville, AL
Missile R&D

Aviation & Missile Systems Eng.

Aviation & Missile Sustainment Eng. & Field Support

Aviation Applied Technology Dir.
Ft. Eustis, VA – Aviation R&D, Systems Eng / Special Operations Forces Support

Joint Research Program Office
NASA Langley, Hampton, VA - Aviation S&T

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Command Structure

- **U.S. Army Materiel Command**
  - **RDECOM** – Research, Development & Engineering Command
    - **AMSAA** – Army Material Systems Analysis Activity
    - **ARL** – Army Research Laboratory
      - **ARO** – Army Research Office
    - **AMRDEC** – Aviation & Missile Research, Development & Engineering Center
    - **ARDEC** – Armament Research, Development & Engineering Center
    - **CERDEC** – Communications Electronics Research, Development & Engineering Center
    - **ECBC** – Edgewood Chemical & Biological Center
    - **STTC** – Simulation & Training Technology Center
    - **NSRDEC** – Natick Solder Research, Development & Engineering Center
    - **TARDEC** – Tank Automotive Research, Development & Engineering Center

The U.S. Army Aviation & Missile Research, Development & Engineering Center

AMRDEC STRENGTH THROUGH TECHNOLOGY

FRONT OFFICE

Executive Director (Acting) *
Dr. Robin Buckelew
(SES)

Deputy Director
COL John Oxford, Jr.

Director for Missile Development *
Mr. C. Stephen Cornelius (SES)

Director for Aviation Development *
Dr. James Snider
(SES)

Director for System Engineering & Support (Acting) *
Mrs. Patricia Martin
(SES)

Updated: 09/22/09

* SES Position

Click on Directorate Boxes for details

DIRECTORATES

- Aviation Engineering *
- Advanced Science & Technology
- Software Engineering
- Weapons Development & Integration *
- Aviation Applied Technology
- Aeroflightdynamics
- Engineering *
- Weapons Sciences *
- Technical Management *
- System Simulation & Development
- Center Support

Other Activities

- Joint Tech. Ctr. / Systems Integration Lab (JTC/SIL)
- *Strategic Development Office (SDO)*
- Information Office

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Weapons Development & Integration Directorate

RDECOM | AMRDEC STRENGTH THROUGH TECHNOLOGY

ACTG DIRECTOR
Mr. James E. Hatfield

ST's & CHIEF SCIENTISTS
Dr. Paul Ruffin (ST), Dr. Jay Loomis (ST), Dr. Jamie Neidert

DIRECTOR FOR SYSTEMS
Dr. Mike Richman

- Advanced Technology — MeLisa Cannon, Chief
- Sys Dsn & Int Tech — Phil Jenkins, Chief
- EAPS ATO-D
  - Bill Nourse, PM
  - Dr. Jim Baumann, DPM
- CIAPS ATO-D
  - Don Lovelace, PM
- A-SLCMC ATO-D
  - Susan Dunbar, PM
  - Paige Walker, DPM
- CCNWS ATO-D
  - Susan Dunbar, PM
  - Greg Parker, DPM

ACTG DEPUTY DIRECTOR
Mr. Paul Turner

SAFETY & FACILITIES
Steve Caudill, Andrea Grisham, Fred Randall

ACTG ASSOCIATE DIRECTOR FOR P&S TECHNOLOGY
ROBERT HELEM

FUNCTIONS
- Systems & Warheads — Milton Henderson Jr., Chief
- Aerospace Materials — Bob Evans, Chief
- Missile Sustainment — Dr. Rob Little, Chief
- Propulsion Technology — Dr. Jay Lilley, Chief
- Platform Integration — Robert Helem, Chief
- Energetic Materials — Mike Morrison, Chief
- Controls & Electronics — Traci Ray, Chief (A)

ASSOCIATE DIRECTOR FOR SG&E TECHNOLOGY
Julie Locker

FUNCTIONS
- Infrared & Optical Tech — Ricky Hammon, Chief
- Image & Signal Proc Tech — Mike Wilson, Chief
- RF Technology — Jim Mullins, Chief
- Navigation Tech — Chris Roberts, Chief
- Electronics & Computer Tech — Roger Berry, Chief

Business & Administration

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Weapons Development & Integration Directorate (1 of 2)

Sensors, Guidance and Electronics Technology


Radar Operations Facility


Inertial Laboratory


Guidance Integration Facility


Russell Tower

CAPABILITIES:

- Guidance, navigation, and control solutions
- Infrared and RF sensors and seekers
- Image and signal processing
- Inertial and global positioning systems
- Real-time embedded hardware and software
- Automatic target recognition
- Hardware and software for fire control and platform integration
- Support and improvement for fielded systems
- Development and demonstration of new weapon systems

FUNCTIONS:

- Electronics and Computer Technology
- Image and Signal Processing Technology
- Infrared and Optical Technology
- Navigation and Control Technology
- RF Technology

FACILITIES:

- Embedded Processor Lab
- ATR/Tracker Laboratory
- Automated Infrared Sensor Test Facility
- LASER Countermeasures Lab
- Automated Laser Seeker Performance Evaluation System (ALSPES)
- Fiber Optics/MEMS Laboratory
- *Additional facilities pictured left*

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

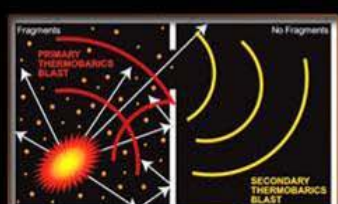
Weapons Development & Integration Directorate (2 of 2)

Propulsion & Structures Technology

- Design, Analysis, and Testing of Rocket Motors
  - Solid Propulsion Systems
  - Gas Generators
  - Gel Propulsion Systems
  - Variable Thrust Nozzles
- Processing & Loading of Energetic Compositions
- Enhanced Blast Evaluation
- Composite Structures and Materials
- Corrosion Prevention

- Active Protection Systems Against RPGs/ATGMs
- Survivable Modular Fuzing
- Multi-Mode Warhead
- Hypervelocity Kinetic Penetrators
- Insensitive Munitions
- Thermobaric Explosives
- Demilitarization
- Stockpile Reliability
- Service Life Assessment

- Weapon and Platform Integration
- Vehicle Mobility and Transportability
- Shock, Vibration and Modal Testing
- Structural Analysis (Static & Dynamic)
- Fatigue, Fracture, Hydraulics



RDECOM

Focus: Lifecycle Support

AMRDEC

STRENGTH THROUGH TECHNOLOGY

AMRDEC provides... Scientific & Engineering Expertise and Support to PEO's, PM's and Users <u>Across the Full System Lifecycle.</u>

DoD 5000 Life Cycle

S&T Program Development

Focused on identifying promising technologies & cutting-edge technology development to meet priority Warfighter needs

Future Systems Development

Focused on integrating cutting-edge technologies into systems to meet priority Warfighter needs

Fielded Systems Support

Focused on providing full-spectrum engineering support of fielded systems to enable the success of our PM customers and Warfighters

Support JCIDS / Materiel Development Decisions

Materiel Solution Analysis

Tech Development ATO / ATD

Engineering & Manufacturing Development

Production & Deployment

Opns & Support
Including Demil/Disposal

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Focus: Lifecycle Support
Science & Technology

Aviation Science & Technology Areas

- Structures
- Aeromechanics
- Survivability
- Engines/Transmissions
- Teaming/Autonomy
- Mission System Integration
- Modeling & Simulation
- Operations Support & Sustainment

Aviation ATOs
(Army Technology Objectives)


Intelligent Decision-Aiding for Aircraft Survivability


Aircrew Survivability Technologies (AST)


Capability-Based Operations & Sustainment Technologies - Aviation


Rotor Durability


Advanced Affordable Turbine Engine

Missile Science & Technology Areas

- Aerodynamics
- Composite Structures & Materials
- Computer Hardware/ Software
- Energetics & Warheads
- Guidance, Navigation & Control
- Image & Signal Processing
- Optical, IR, RF, and MEMS Sensors
- Propulsion Technology

Missile ATOs
(Army Technology Objectives)

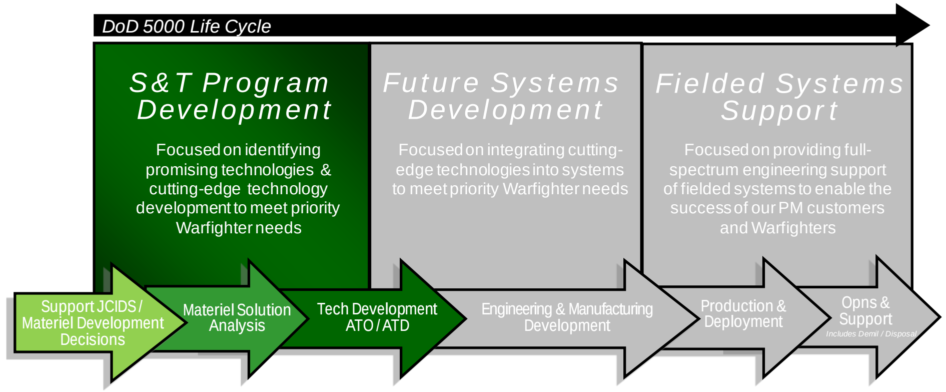

Extended Area Protection & Survivability (EAPS) Integrated Demo


Embedded Deeply Integrated Guidance & Navigation Unit (DIGNU) Tech Advancements


Kinetic Energy Active Protection System (KEAPS)


Applied Smaller, Lighter, Cheaper Munition Components


Close Combat Networking of Weapons & Sensors



AMRDEC Provides…

Next generation technology development of component-level, state-of-the-art aviation and missile technologies…

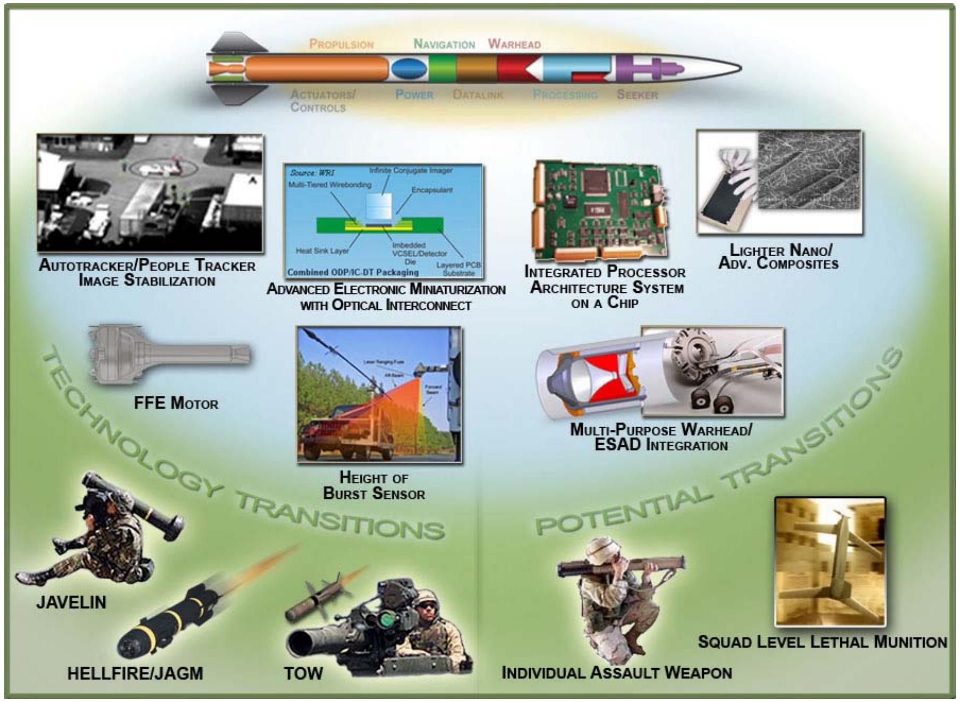
Providing payoff at the system level

AMRDEC Fuze Group
What we do?

- **Development Efforts**
  - **Miniaturization**
    - **ESAD and Fireset component evaluation and integration.**
  - **Survivability**
    - **System and component high G urban target survivability.**
  - **Tailored Effects**
    - **Selectable yield unitary.**
    - **Real time target classification.**

- **Program Office Support**
  - **Programmatic fuze safety certification guidance.**
  - **Conduct fault tree analyses.**
  - **Assist in requirements and qualifications development.**
  - **Active participation in fuze development as SME.**
  - **Participate in failure investigations.**

Smaller, Lighter, Cheaper Munition Components (SLCMC) ATO



SCHEDULE & COST

MILESTONES	FY09	FY10	FY11
Rqmts Analysis/Trades	3/4		
HW/SW Sys Engr/Design			
Development/Fabricate		4/5	
Integrate/Component Demos			6

Purpose:

Provide smaller, lighter, cheaper missile components & subsystems that enhance Javelin/TOW and Hellfire/JAGM capabilities and mature technologies for next generation small precision munitions

Products:

- Enabling components/designs ready for transition or system-specific tailoring
  - Lighter nano/adv. composite structures
  - Miniaturized guidance electronics
  - Advanced sensors (including image processing)
  - Electronic Safe & Arm Device for multipurpose warheads
  - Propulsion Technology

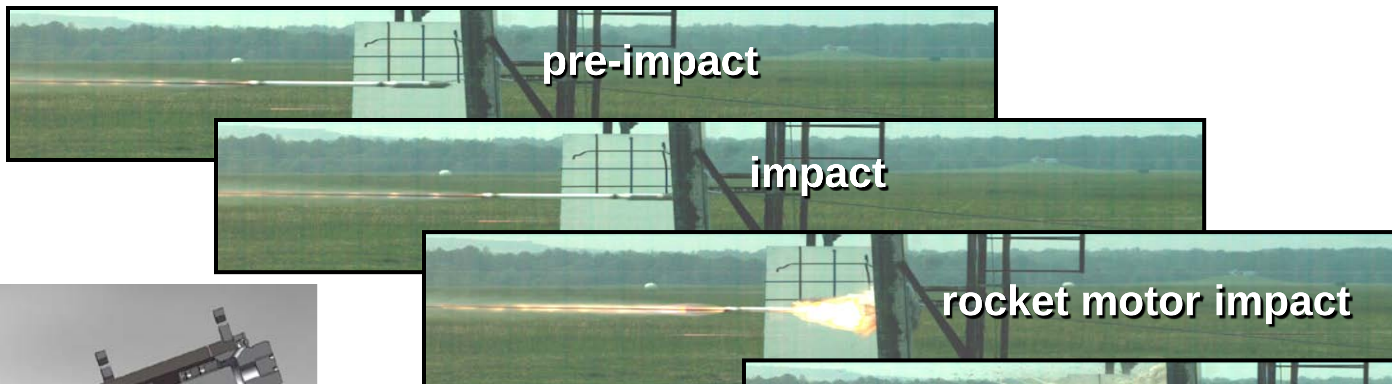
Payoff:

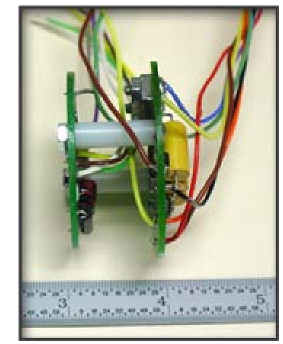
- Increased lethality
- Reduced logistics burden: smaller, lighter missiles with common components
- Reduced cost missiles

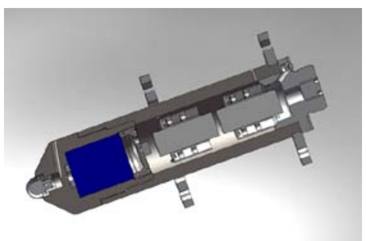
Survivable Modular Fuzing

ROCKET-ON-A-ROPE

Utilizes a 2.75-inch NDI rocket motor to propel a test article at supersonic speeds along dual high tensioned ropes for accurate hit point and missile orientation



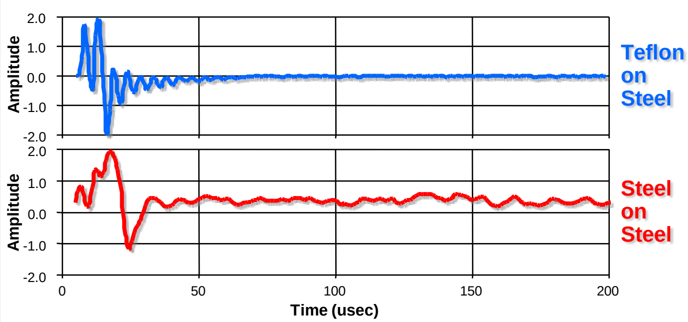




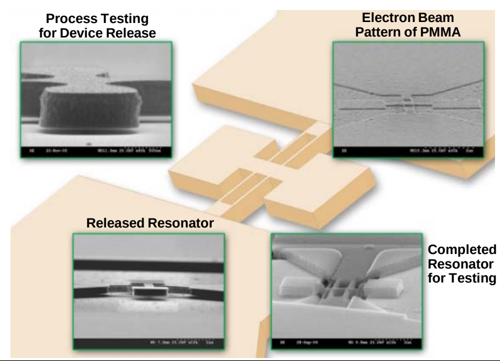
SWFTICE TECHNOLOGY:

- Enables "multi-mission" missile concept:
  - Simplifies logistics.
  - Increases stowed kills.
  - Enables expeditionary deployment.
- Decreases gunner workload by autonomous operation.
- Provides increased capability for legacy systems.
  - No launcher upgrades required for "smart missile" avoids platform retrofit costs.

TARGET IMPACT PHENOMENOLOGY PREDICTED THROUGH MODELING, VALIDATED THROUGH TESTS



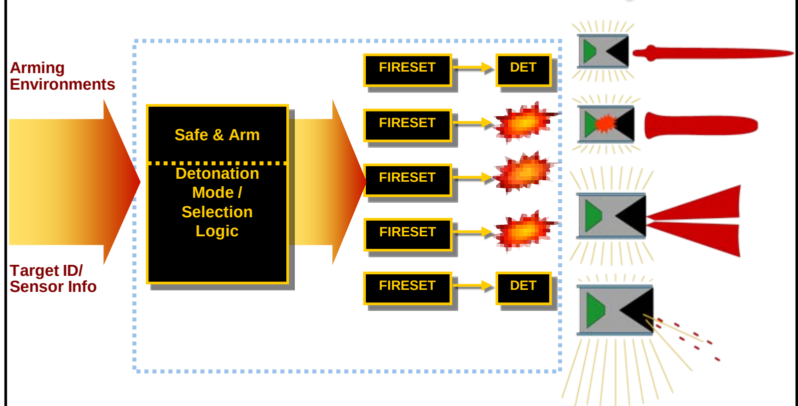
ADVANCED DESIGN ISTAR Transducers



INTEGRATED ISTAR SENSOR

- Leverages Army/DoD investments in:
  - Advanced Warhead Technology.
  - ESAD Technology.
  - Firing System Technology.
  - Energetics Technology.

Selectable Multi-Point Initiation System



SENSOR, WARHEAD & FUZE TECHNOLOGY INTEGRATED FOR COMBINED EFFECTS
SWFTICE ATO

Army Selectable Yield Unitary

Schedule & Cost

MILESTONES	FY08	FY09	FY10	FY11
Multi-output explosive & coupled Reactive Materials development	3	4	5	
Novel dynamic propellants & thruster development	3	4	5	
Advanced fuze & power development	3	4	5	
Warhead scaleable/selectable performance against multiple targets		4	5	6
Integrated Demos of Prototype Adaptive Munitions		4	5	6

Purpose:
- ***Provide capability for scalable, selectable, and adaptive lethal effects against platforms and personnel to selectively destroy target function and/or neutralize attributes while limiting damage to surrounding structures/personnel***

Products:
- ***Demonstration of agile technologies for scalable, selectable & adaptive lethal effects in large, medium, and small diameter munitions & missiles***
- ***Development of controlled lethal effects, multi-purpose energetics & formulations, reactive materials and advanced fuzing and power technologies***

Payoff:
- ***Improved weapon effectiveness/lethality***
- ***Reduced collateral damage***
- ***Rapid mission execution with less ammunition expended (reduced logistics)***
- ***Tech transition to PEOs, AMMO, M&S, Soldier: 155 VAPP, Javelin, TOW, JAGM, XM1069, MAPAM, M430***
- ***Demos: 250mm (GMLRS), 155mm (Excalibur), 30mm (M789/Mk238)***

AMRDEC Support Efforts PEO-MS SDD (or other) Programs

Precision Fires Rocket and Missile Systems (PFRMS) PMO

- GMLRS DPICM ESAD
- GMLRS Unitary ESAF
- TACMS Unitary Fuze(s)

Precision Fires for Current and Future Forces

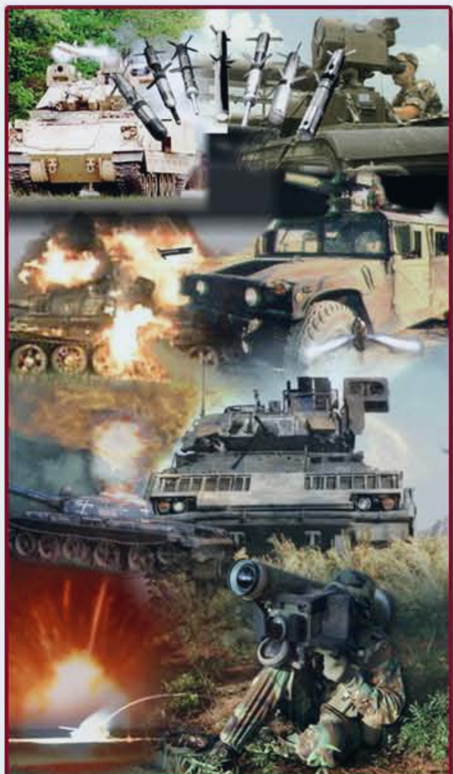
Non-Line Of Sight (NLOS) PMO

- Electronic Safe & Arm Device
- Inline Ignition Safety Device
- Note: Joint Development with USN

Unmanned Fire Support

AMRDEC Support Efforts PEO-MS SDD (or other) Programs

Close Combat Weapon Systems (CCWS) PMO



- TOW Fuze (In-house design transitioned to PMO)
- Javelin ESAF

Anti-Armor and Target Acquisition for the Front-Line Warfighter

Joint Attack Munition Systems (JAMS) PMO

- Hellfire ESAF
- JAGM ESAF
- 2.75" Rocket Common Fuze

Aviation Rockets and Missiles for the Joint Force

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

AMRDEC " Community " Participation

- Fuze Engineering Standardization Working Group (FESWG)
- U.S. Army Fuze Safety Review Board (AFSRB)
- U.S. Army Ignition System Safety Review Board (ISSRB)
- DOD Fuze IPT
- Defense Ordnance Technology Consortium – Fuze Subgroup
- Joint Fuze Technology Program
- Technical Coordinating Group X (TCG-X) – Firing Systems

The U.S. Army Aviation & Missile Research, Development & Engineering Center

AMRDEC
STRENGTH THROUGH TECHNOLOGY

Questions

DTRA Counter WMD Technologies Fuzing & Instrumentation Technology Overview

Presented at 54th Annual NDIA Fuze Conference May 2010

Danny R. Hayles

Outline

- Mission
- Requirement for Hard Target Fuzing
- Current Fuzing and Instrumentation Technology Thrusts
- Summary

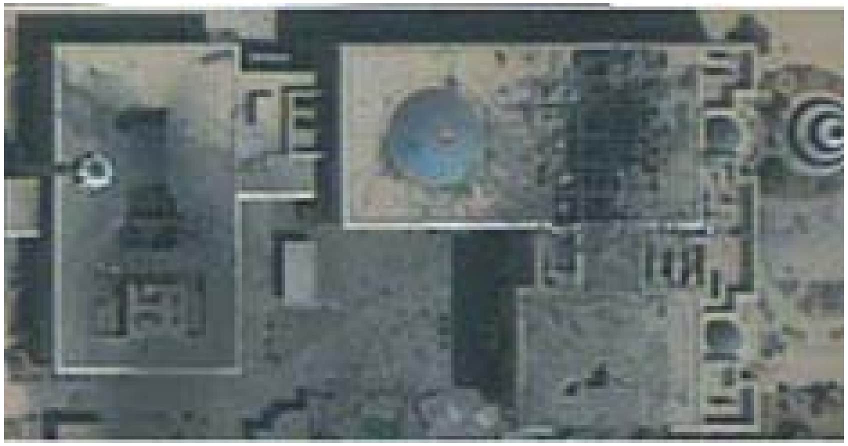
DTRA Mission

- Mission:
  - …reduce the threat to the United States and its allies from Weapons of Mass Destruction (CBRNE) by providing capabilities to reduce, eliminate, and counter the threat, and mitigate its effects.
- Functions:
  - Conduct RDT&E programs…in areas related to WMD and designated advanced weapons to include…WMD-related targets and the entire class of hard and deeply buried facilities.
- Vision:
  - Develop, test, and demonstrate to the Warfighters reliable and effective solutions to defeat WMD and WMD-related functions protected in Hard and Deeply Buried Targets

Hard & Deeply Buried Target (HDBT) Defeat Critical to Counter WMD Mission

- **Use of HDBTs is widespread among both hostile states and terrorists to protect WMD and WMD-related functions including:**
  - **Production, storage, research**
  - **Delivery systems**
  - **Command and control**
  - **National/terrorist leadership**

MOST VALUABLE ASSETS

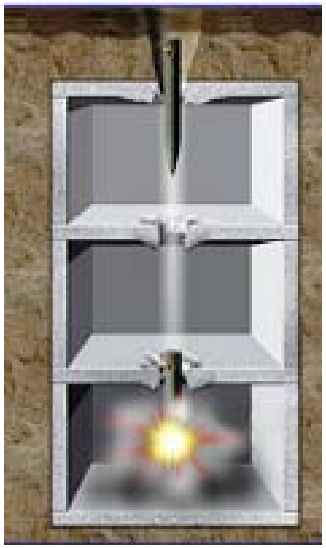


You can't defeat WMDs, if you can't defeat HDBTs!!

You can't defeat HDBTs, if the fuze does not survive!!

Fuzing and Instrumentation Technology Vision

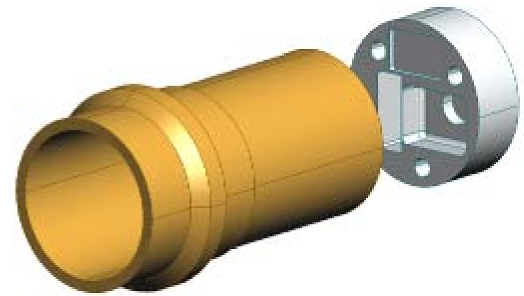
- Develop and demonstrate innovative **SURVIVABLE fuze technologies** to support the defeat of WMD related facilities
  - Fuze Harsh Environment Characterization
  - Sub-Scale Survivability Test Protocol
  - Micro-DEMON
  - Fuze Diagnostic Recording

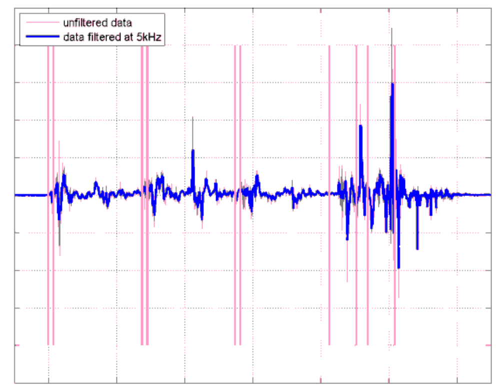


- Develop **SURVIVABLE instrumentation packages** to support development of new fuze/fuze technologies
  - Robust Fuzewell Instrumentation System (RFIS)
  - 3-Axis DTRA Data Recorder (3DDR)

Fuze Harsh Environment Characterization

- Fundamental understanding of forcing functions on the fuze and fuze components
- System level aspects being pursued within the larger Community





Bottom Line: Need to be able to predict and test the multi-axis loads on fuzes & fuze components

Sub-Scale Survivability Test Protocol

- Collaborating with AFRL/RW to establish test methodologies for replicating desired shock spectrum
- Establish survivability test protocol utilizing various lab & field apparatus

Notional Shock Spectrum

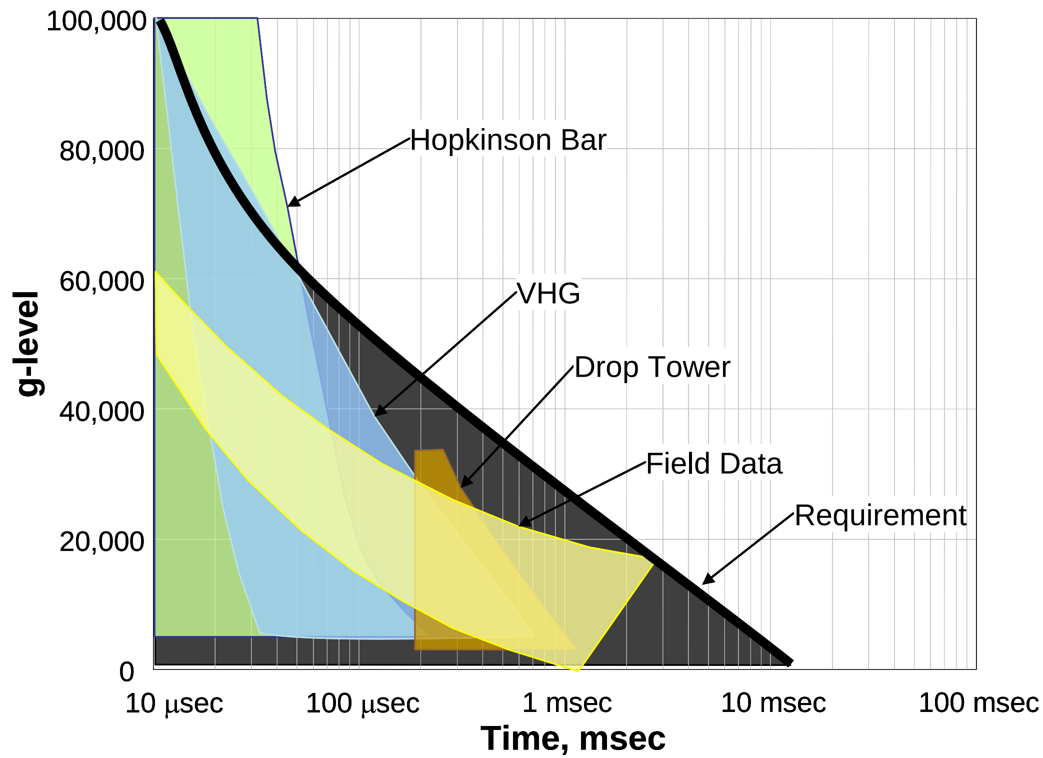


Photo Courtesy of AFRL/RWMF
Public Releasable: AAC/PA 03-496

FMU-152 Baseline Sub-Scale Test Survivability Assessment

- Collaborating with AFRL/RW and Kaman to establish an FMU-152 baseline survivability for sub-scale test protocol
- FMU-152 sub-scale test survivability limits will be utilized as qualitative baseline for future fuze/fuze components

Photos Courtesy of AFRL/RWMF (VHG Machine)
Public Releasable: AAC/PA 03-496 and
Kaman's Website: http://www.kamanaero.com/fuzing.html

DEMoN (Design for Efficient Miniaturization of Novel Fuzing)

- Collaborating with Sandia to explore level of miniaturization achievable for electronic in-line fuzing using COTS components, architectures and packaging technologies
- Miniature post-impact module benefits
  - Increased survivability
  - Increased reliability through redundancy
  - Common fuze components
  - Distributed architectures

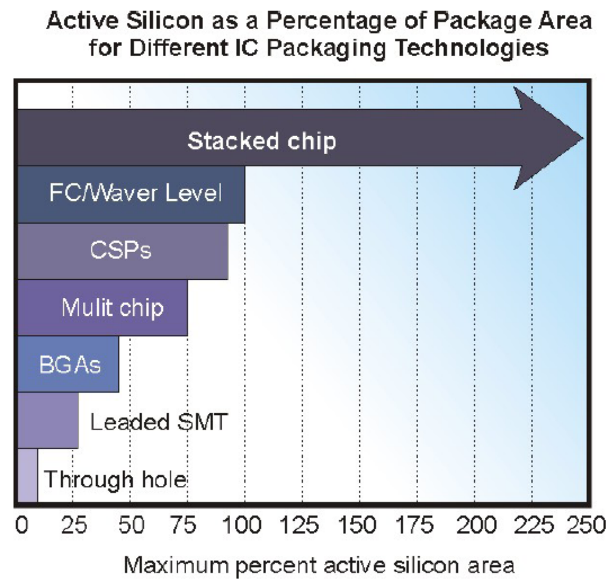
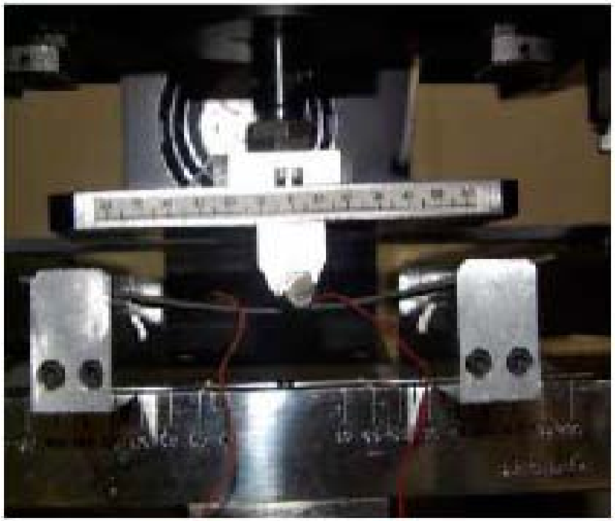


Photo courtesy of http://www.smta.org/files/Pan_Pacific_2007_Fjelstad.pdf

Fuze Diagnostic Recording (FDR)

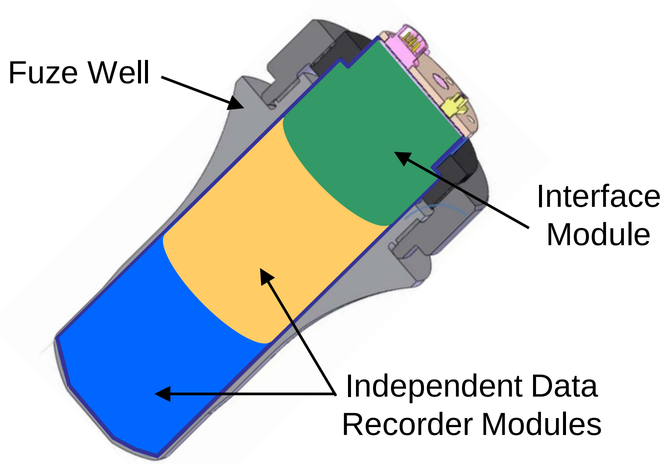
- Collaborating with Sandia to improve reliability and survivability of hard target fuzes by developing scientific understanding of mechanical & electro-mechanical behavior of critical components under high shock
  - Performance characterization for nominal environments and relevant functions
  - Repeat testing through gradually increasing stress (high-g) environments
  - Develop models of component performance to reflect high-g effects
- High voltage firing capacitors selected as initial component to assess/model



Photos Courtesy of http://www.amd.com/us-en/assets/content_type/DownloadableAssets/Pb-free_Board-level_reliability_study.pdf

Robust Fuzewell Instrumentation System (RFIS)

- **Collaborating with AFRL/RW to develop a robust data recorder instrumentation package with redundant internal data recorders to fit in standard 3” fuzewell**
  - **BAA Announcement Posted 10 Feb 2010**
  - **Solicitation Number: BAA-RWK-10-0004**



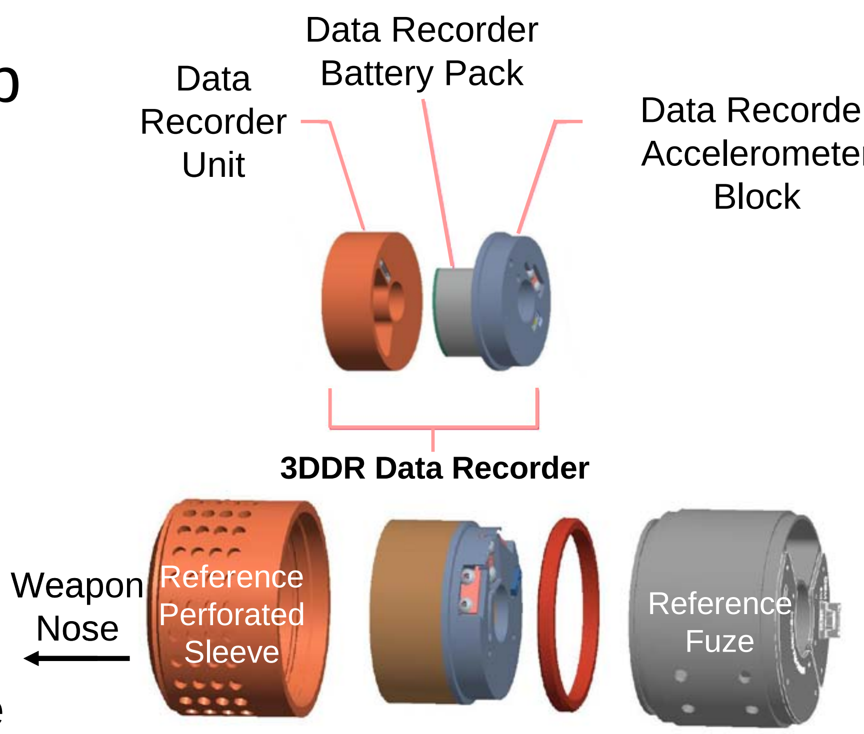
Notional RFIS Concept

<u>RFIS General Features</u>

- 3” Data Recorder Instrumentation Package
- Size & weight of current legacy fuzes
- Standardized Robust/Reliable Interfaces
- Cantilever or Compression Mounted
- Independent Data Recorders
  - Threshold of 2
  - Goal of 3

3-Axis DTRA Data Recorder

- Collaborating with Sandia to develop survivable booster cup recorder
  - 1st Generation 3DDR Design
    - 3 Unit Design
    - Replaceable accelerometers
    - Successful laboratory and field testing
  - 3DDR-Advanced Miniaturization (3DDR-AM)
    - Utilize DEMoN philosophy to achieve miniaturization
    - Universal Booster Cup Compatible
    - Retain full 3DDR functionality
    - Smaller and lower power
    - Provides foundation for 3-AMP replacement



Photos Courtesy of Sandia National Laboratory
Public Releasable: SAND # 2009-0918 P

Summary

- Hardened or deeply buried facilities are becoming:
  - More important to potential adversarial nations and non-national organizations
  - Harder to defeat
- Capability to defeat HDBTs is critical to Counter-WMD mission
  - Fuze survivability is essential to defeating HDBTs
  - Smart post-impact burst point control required
- Fuze harsh environment characterization is essential
  - Predictive capability for fuze/fuze component survivability
  - Development of robust sub-scale multi-axis test protocol
  - Defining robust full-scale tests compatible with limited resources
- Focused on fuze & instrumentation survivability in harsh environments
  - Developing novel fuze diagnostic recording capability
  - Efficient miniaturization for novel fuzing

The Fuzing Evolution – Smaller, Smarter, Safer, and more Survivable"

NDIA's 54th Annual Fuze Conference

NAVY OVERVIEW

John Hendershot

john.hendershot@navy.mil

301-744-1934

For Dr. Robert Gates

Technical Director, NAVSEA Indian Head Division

NEE IPT Lead

Outline

- Naval Energetics Enterprise Overview
- Fuze Safety Review Process & Panel
- Navy Fuze Acquisition
- Navy Fuze Work Highlights
- Summary

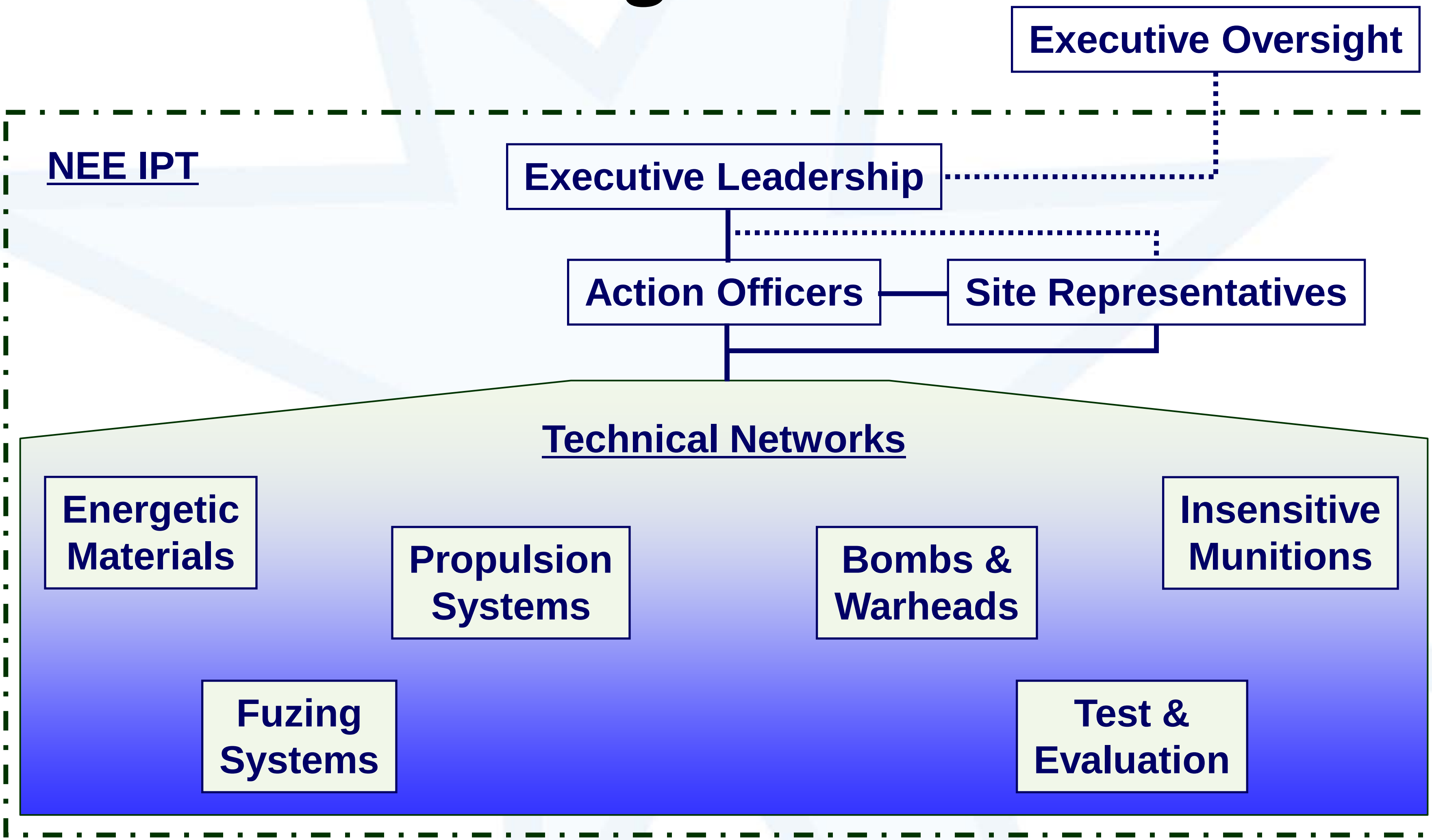
Navy Energetics Enterprise Vision

One Team

Dedicated to providing ordnance solutions to the Warfighters

NAVAIR China Lake & Point Mugu
NAVSEA Indian Head, Dahlgren & Crane

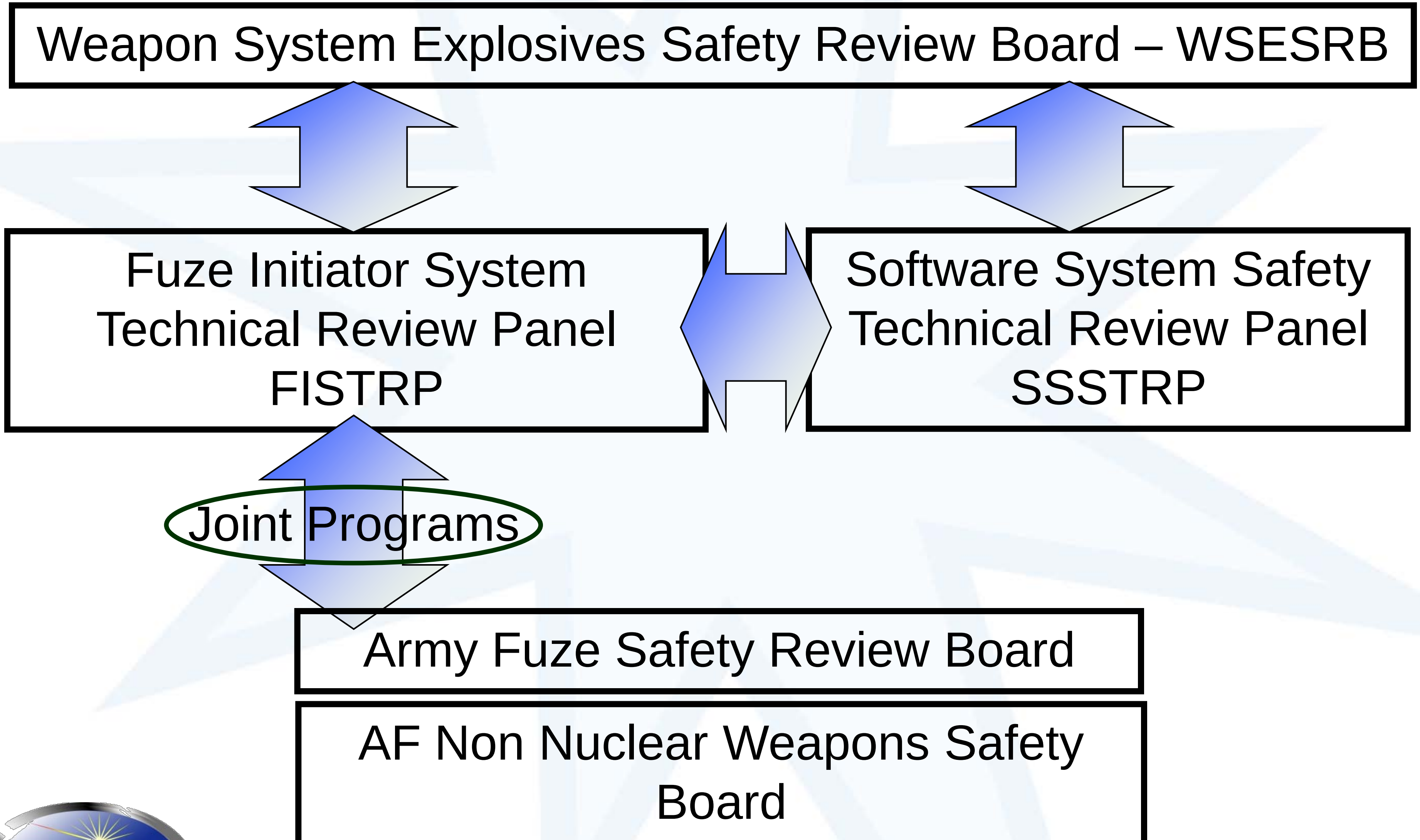
NEE Organization



NEE Goals

- Provide stewardship of unique Navy capabilities to ensure current and future Navy warfighting requirements are attainable and supportable
- Speak with a coordinated Navy voice
- Work together to improve efficiency and rationalize resources to provide responsive, safe and affordable ordnance solutions

Navy Fuze Safety Review Process



Fuze and Initiation Systems Technical Review Panel (FISTRP)

Panel Chair – Gabriel Soto

Panel Members –

Raymond Ash	**Ralph Balestieri**	**Brian Will**
Randy Cope	**Micheal Demmick**	**Bradley Hanna**
John Hendershot	**John Hughes**	**George Hennings**
John Kandell	**David Libbon**	**Eugene Marquis**
Scott Pomeroy	**Tinya Coles-Cieply**	
Melissa Milani		

Current Topics of Interest/Challenge

1978 Joint Fuze Management Board Policy on Safe Separation Analysis
Emerging FESWG Guidance on Charge-Based Memory

MIL-STD-1316 STANAG 4187
MIL-STD-1901 STANAG 4368
MIL-STD-1911 STANAG 4497

Navy Fuze Acquisition

FMU-164

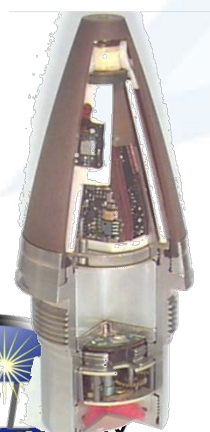
- Requirements
  - Improved reliability - 97% @ 90% confidence
  - Backward compatible to FMU-139 interfaces
  - Hard target penetration
    - FMU-143 specification
  - New arming & function delay times
    - Serial data interface programmability

- Schedule
  - RFP released on 22 December 2009
  - Source selection starting April 2010
  - Contract award scheduled 4th Qtr 2010
  - IOC scheduled in 2017

5”/54 Gun Fuzes

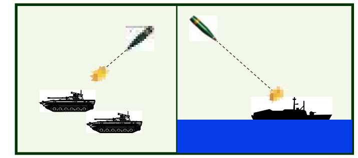
- MK 432 Electronic Time (ET)
  - First production 2002
  - ET only, no PD backup
  - KE-ET & HE-ET

- MK 437 Multi Option Fuze Navy (MOFN)
  - Design Initiated 2002
  - ET, PD, PD Delay & HOB
  - Lacks AAW capability
  - Land Attack & ASuW

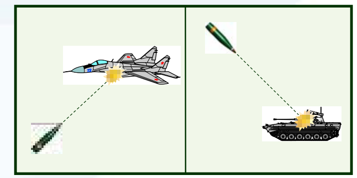


- MK419 Multi-Function Fuze (MFF)
  - Design Initiated 1995
  - USN Unique Fuze
  - ET, HOB, PD, AIR Prox, AUTO
  - Selectable HOB
  - Rain Reliability
  - Sea Clutter Filter – AIR
  - Land Attack, ASuW, & AAW

Electronic Time (ET)



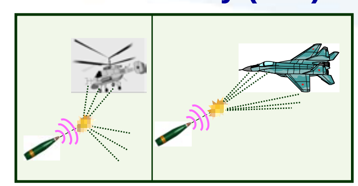
Point Detonating (PD)



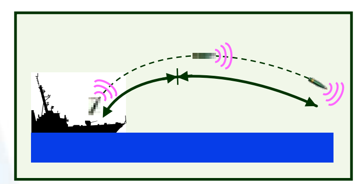
Surface Proximity (HOB)

PD Delay

Air Proximity (AIR)



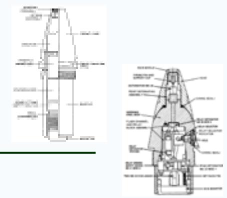
Autonomous (AUTO)



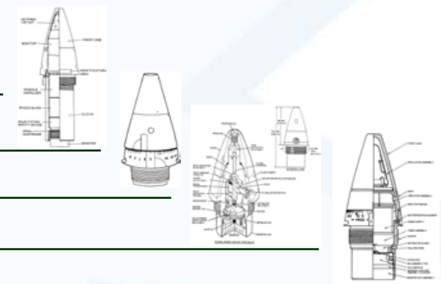
5”/54 Gun Fuze Roadmap

PAST | 2003 | CURRENT | FY15 | BYND FYDP

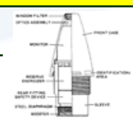
MK91 Mod 1: Infra-Red
MK399 Mod 0: Point Detonate



MK73 Mod 11/13: Variable Time
MK342 Mod 1: Mechanical Time/Point Detonate
MK407 Mod 1: Point Detonate/Delay
M732: Controlled Variable Time



MK404 Mod 1: Infra-Red



MK419 Mod 0: Multi-Function Fuze
MK432 Mod 0: Electronic Time

MK419 Mod 1: Multi-Function Fuze
MK437 Mod 0: Multi-Option Fuze Navy

OBSOLETE
OBSOLESCENT/SUSTAINMENT
ACTIVE/FUTURE

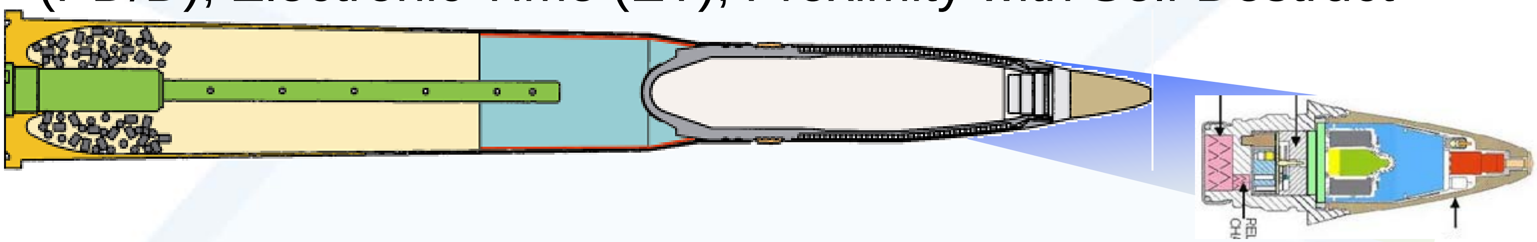
Navy Guided Projectiles

- 155mm Long Range Land Attack Projectile (LRLAP)
  - Gun-launched, rocket-assisted guided projectile
  - Currently in EMD phase as part of the Advanced Gun System on DDG-1000 Class destroyers
  - Qualification and guided flight testing underway, completion scheduled in 2012
  - LRIP to begin in FY13
  - Range > 63nmi
  - Electronic S&A and electro-mechanical ISD

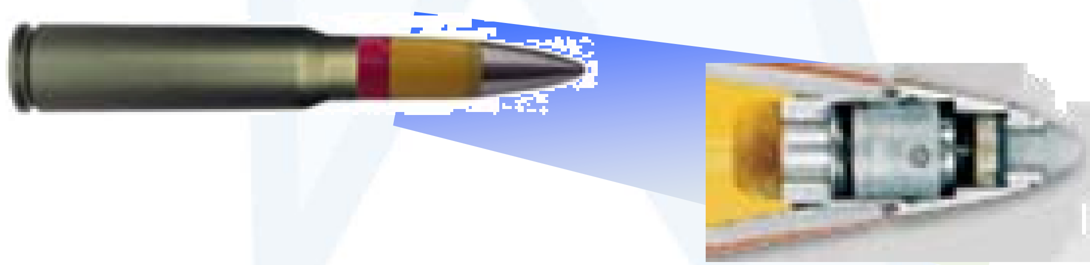
- 5” guided projectile development is not currently funded
  - Joint Fires AOA study pending

Additional Navy Gun Ammunition

- 57mm/L70 MK 295 Mod 0 – High Explosive – 3P Cartridge (HE-3P)
  - Pre-fragmented explosive projectile with programmable, proximity fuze
  - 6 Fuze Modes:
    - Time Gated Proximity (TGP), Time Gated Prox with Impact Priority (TGIP), Point Detonating (PD), Point Detonating Delay (PD/D), Electronic Time (ET), Proximity with Self Destruct



- 30mm X 173 MK266 Mod 1 – High Explosive Incendiary – Traced (HEI-T)
  - Super Quick FMU-151 Fuzed PBXN-5 projectile
  - High Order Blast/Fragmentation w/ Incendiary Effects



Navy Fuze Work Highlights

- **NAVAIR: Impact Switch Investigation**
- **NAVAIR: Dynamic Impact Simulation of "High G Hardened Fuzes"**
- **Joint JFTP / NAVSEA PMS495: MEMS Fuzing for High Reliability Systems**
- **Joint NAVSEA PMS495 / ONR: Versatile Explosive Train Integrated into a MEMS S&A Device**
- **ONR: MEMS Fuze for Marine Corp Flight Control Mortar**
- **JIMTP: Extremely Insensitive Detonating Substance (EIDS) Initiation System**
- **JFTP: MEMS Retard & Impact Sensors**

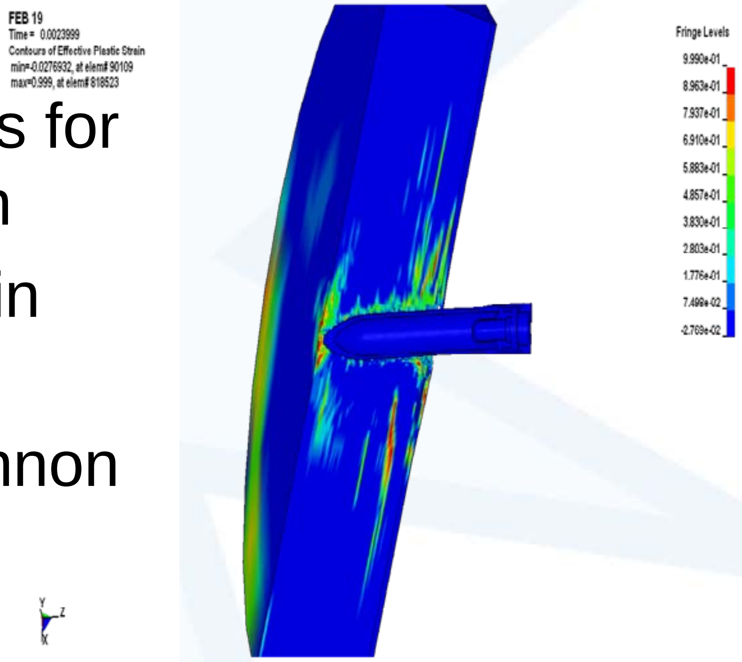
Impact Switch Investigation

- Investigation objective is to characterize switch vibration response
- FY09 start schedule for FY10 completion
- Switch becoming more sensitive to vibration as exposure is accumulated
- Switch characterization conducted using flight test vibration levels
- Reporting on preliminary results

Open Session VA Briefing provided by Mr. Sam Tuey

Dynamic Impact Simulation of "High G Hardened Fuzes"

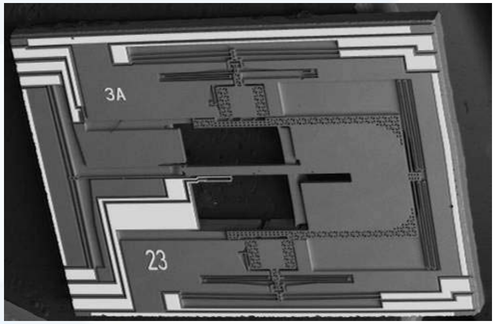
- Evaluation of latest LS-DYNA Impact Simulation Software
- Creating LS-DYNA input templates for hard target penetration application
- Impact deceleration, stress & strain calculated for penetrator Fuzes
- Results compared to NAVAIR cannon and sled test data

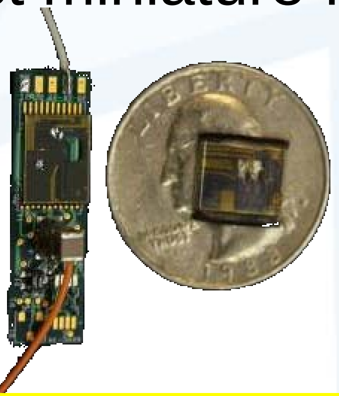


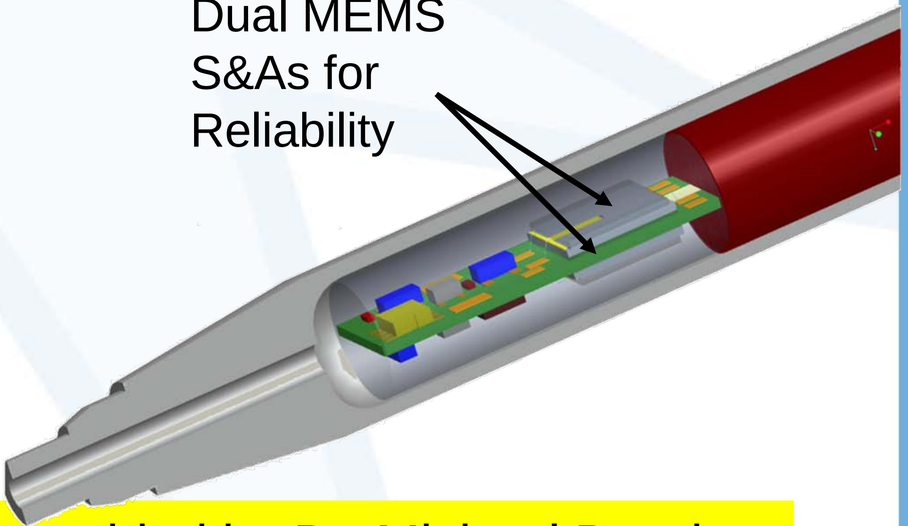
Open Session IIIA Briefing provided by Dr. Paul Glance

MEMS Fuzing for High Reliability Systems

- Development of G-hardened miniature Fuze component technology mine defeat penetrator application
  - Silicon on Insulator (SOI) MEMS S&A
  - Micro detonator
  - MEMS initiator
  - Low-cost miniature fire-set





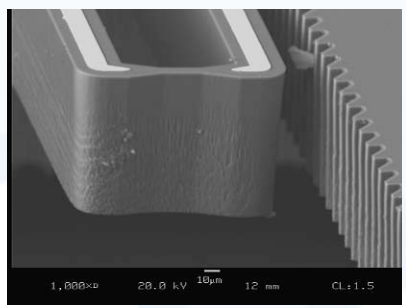


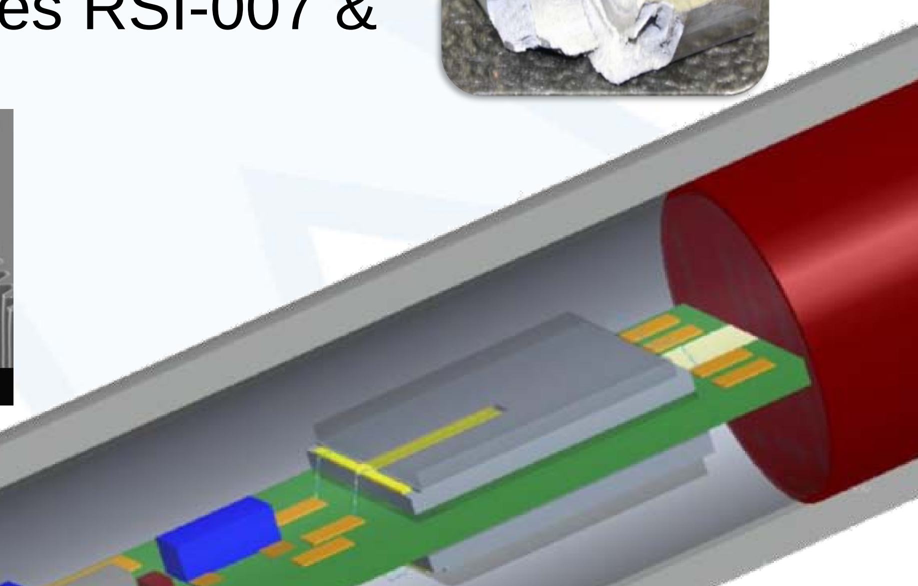
Closed Session IVB Briefing provided by Dr. Michael Deeds

A Versatile Explosive Train Integrated into a MEMS S&A Device

- Development of integrated initiation and explosive train component technology for MEMS based S&A application
- Developed for small volume applications turning tight corners
- Employs Cl-20 based explosives RSI-007 & EDF-11 ink

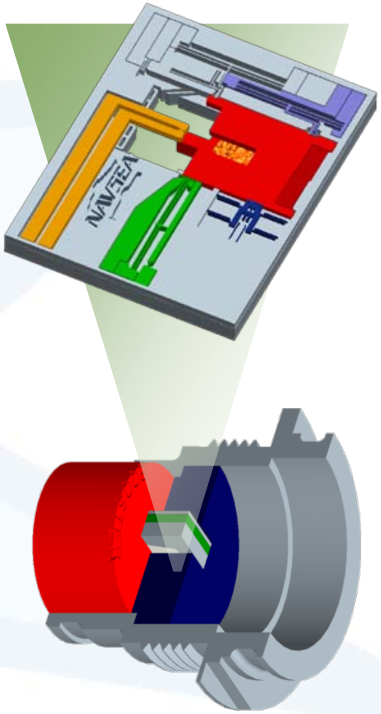
Vaporization of an IHDIV MEMS initiator

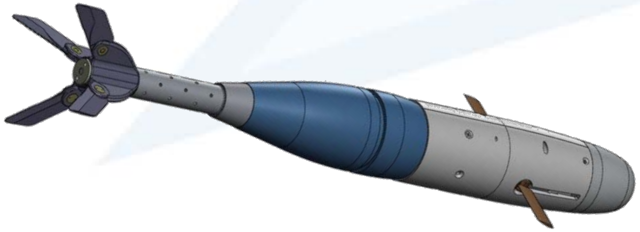


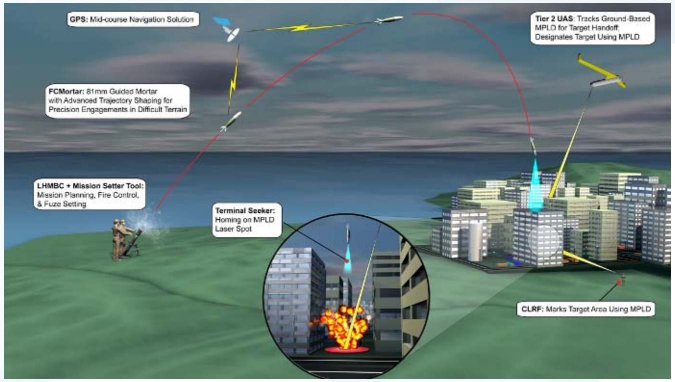


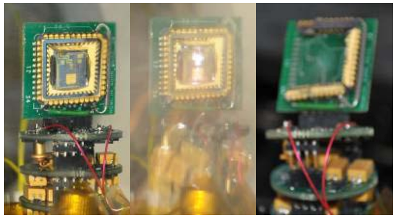
Navy MEMS Fuze
For Marine Corp Flight Control Mortar

- S&A for 81 mm Precision Urban Mortar Attack (**PUMA**) – Future Naval Capability (FNC)
  - Joint Navy / Army S&T system development
  - Supports Marine Corps Conventional Weapons (CW) Science & Technology Objectives
  - System demonstration in FY14
- MEMS based S&A





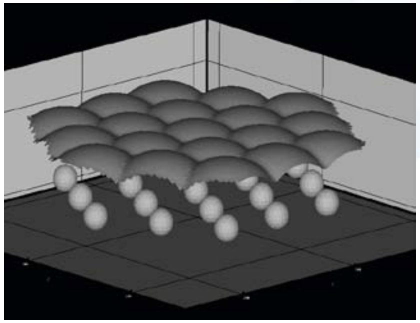


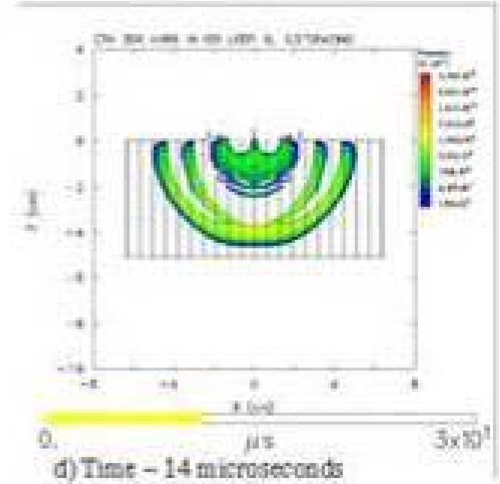


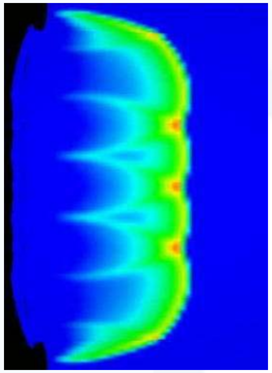
Closed Session IVB Briefing provided by Dr. Dan Jean

Extremely Insensitive Detonating Substance (EIDS) Initiation System

- An Initiation System that emulates large diameter boosters for use in initiating EIDS materials
- OSD funded through Joint Insensitive Munition Technology Program
- Joint Navy (NEE) led effort with Air Force, Army, & Los Alamos participation
- Improved IM performance through elimination of large, relatively sensitive booster
- System requires simultaneous initiation of multiple detonation points







Closed Session IIIB Briefing provided by Mr. Brad Hanna

MEMS Retard & Impact Sensors

- ***Objective: Obtain DoD retard and impact sensors with precision, reliability, producibility and cost effectiveness by exploiting existing MEMS micro-fabrication and packaging technologies***
- ***Traditional coil spring-mass technology:***
  - *Wide performance variability per mechanical spring tolerances*
  - *Difficult to precisely sense low G's with "macro world" springs*

- ***MEMS technology appears well-suited for making improved low-G sensors per DoD exploratory work to date:***
  - *NAWCWD: precision-electroplated G-sensors*
  - *NSWCIH: silicon G-sensors and packaging*
  - *ARDEC: metal G-sensors and packaging*

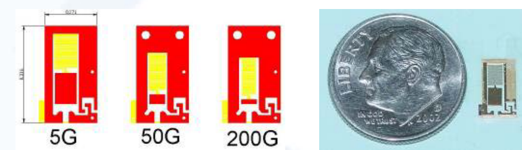


Illustration and Photograph Courtesy of NAWCWD

- ***FY10 Focus: low-G impact sensors (<100G) & very low-G retard sensors (<5G)***

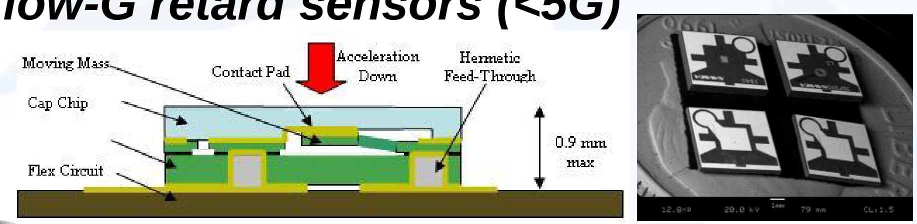


Illustration and Photograph Courtesy of NSWCIH

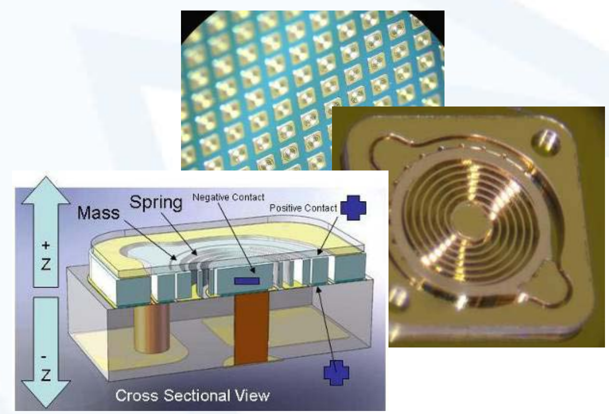


Illustration and Photographs Courtesy of ARDEC

Closed Session IVA Briefing provided by Mr. Walt Maurer

Summary

Today's Navy

- NEE - Leveraging the abilities of multiple installations
- FISTRP / FESWG / Joint Reviews - Safety conscious
- Cradle to grave support of the warfighter
  - Concept
  - Advanced Development
  - Research and Development
  - In-Service Support
  - Quality Assurance

RDECOM

Malcolm Baldrige National Quality Award 2007 Award Recipient

High Reliability Fuzing Architecture for Cluster Munitions

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

54th Fuze Conference

12 May 2010

Karen M. Amabile, US Army ARDEC

James Hartranft, US Army ARDEC

Outline

- Current Landscape
- Political Policy
- Artillery Submunitions
- Cluster Munition Study
- High Reliability Fuzing
- Approach
- Probabilistic Technology
- Summary

Current Landscape

- DPICM Munitions have come under increasing scrutiny for UXO left on the battlefield
- US cannon and rocket weapons carrying submunition payloads are classified as Cluster Munitions & required to meet a <1% UXO rate by 2018

- “Legacy” cannon fire Cluster Munitions in the inventory are all not compliant with existing policy
- Retrofit Self-Destruct Fuzing Technology has not been able to reach the goal of <1% UXO in current systems
- Impacts:
  - warfighter has lost the military utility of DPICM warheads
  - Less effective substitute munitions have been used in theatre

Cluster Munition (CM) Policies

DOD Policy (19 JUN 2008)

- CM defined as munitions composed of a non-reusable canister or delivery body containing multiple, conventional explosive submunitions
- After 2018, only employ CM containing submunitions that after expulsion, do not result in >1% UXO across range of intended operational environments
  - No waivers
  - SD/SDA can reduce hazards, but are factored in the 1% UXO
- Until 2018, use of CM requires approval by Combatant Commander

Oslo Process (30 MAY 2008)

- The Oslo Process bans all munitions with multiple explosive submunition payloads each weighing less than 44 lbs (20 kg)
- Exempts CM that adhere to the following criteria:
  - Each submunition must weigh more than 8.8 lbs. (4kg)
  - CM must contain less than 10 submunitions
  - Each submunition must detect and engage a single target
  - Must have an electronic self destruct and self deactivate capability.
- CM stocks must be destroyed within 8 years (can request up to 4 year extension)
- Prohibits use of existing stockpile of artillery US DPICM (referenced above)

The United States did not sign up to the Oslo Process

Artillery Submunitions

Background:

- Submunitions are fired from 105 mm and 155 mm artillery
- The Dual purpose Improved Conventional Munition (DPICM) submunitions used in these artillery applications have reliability issues
  - Several programs have tried to add backup self-destruct or self-neutralize features
  - Self-neutralize will not meet the requirements of the DoD policy
- DPICM target sets include armor and light targets/personnel
- The solution must provide compliance with existing DoD 1% Unexploded Ordnance (UXO) policy in all operational environments – given proper cargo expulsion.

Artillery Submunitions (contd)

DPICM Submunitions:

- M42/M46 DPICM use M223 fuze
  - Arming ribbon is critical element in reliability
  - Ribbon provides drag to unscrew arming mechanism and to orient submunition in flight
  - Single impact mechanism for detonation

Artillery Submunitions (contd)

US Full bore Submunition Efforts:

– Sense and Destroy Armor (SADARM) XM898
  - Medium to hard targets
  - No longer in production

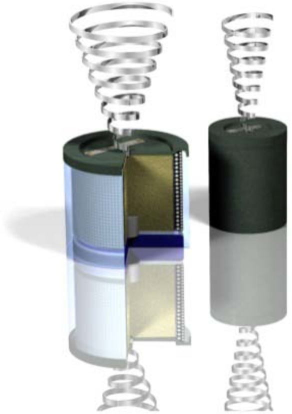
SADARM

– Common Smart Submunition
  - ARDEC S&T Program to demonstrate a low-cost anti-armor submunition
  - Currently in development

– Proximity Initiated Submunition (PRAXIS) concept
  - Tri-mode fuze that includes a proximity fuze, a time fuze and a point Detonating (PD) fuze in each submunition

Cluster Munition Study

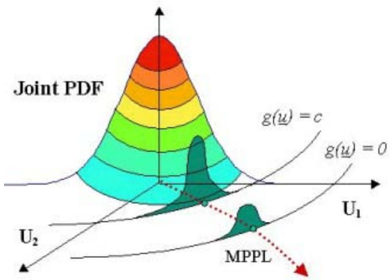
- Army conducted a study on the target sets & the potential solutions
- One of the conclusions was to pursue a PRAXIS-type of solution
- PRAXIS concept was the most effective and efficient against the desired target sets

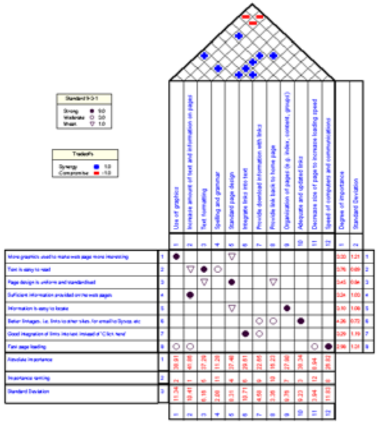


PRAXIS

High Reliability Fuzing

- Many fuze components affecting reliability
  - Target sensing
  - Arming signature sensing
  - Power supply
  - Safe and arm
  - Explosive train
  - Backup modes to function





- Reliability of systems vary dependant on firing / target conditions, manufacturing lots, etc.
- Expulsion / dispense environment is harsh
- Having redundancy within the fuzing architecture to increase functional reliability may require additional safeties in the system.
- Eliminate single point and common mode failures

Cluster Munitions Replacement Science & Technology Program

Purpose:

- Demonstrate an ultra reliable, lethal Cluster Munition (CM) Alternative which is compliant with signed DoD CM Policy and achieve <1 % UXO.

Products:

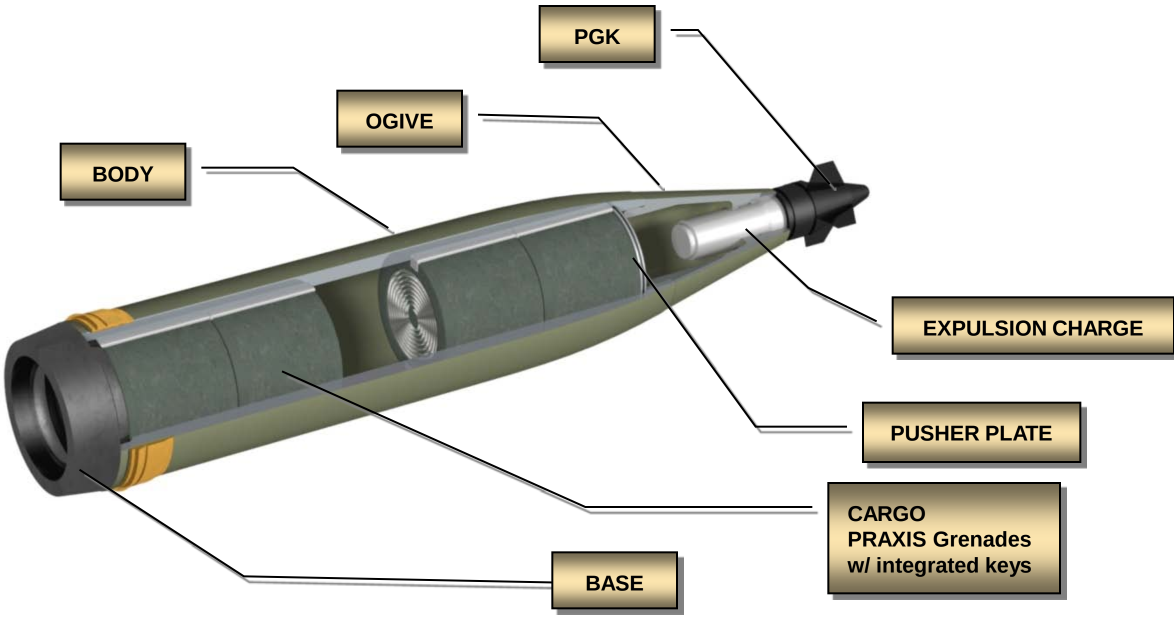
- 155mm cannon ballistic demonstration of integrated "full bore" sub-munition prototype
- Arena test and analysis demonstrating enhanced lethality blast fragmenting submunition & effective lethal area
- Application scalability analysis across multiple calibers and delivery systems

Payoff:

- Warfighter operational benefits
  - Enables continued use of critical lethality capability
- Benefits (ATO-D)
  - DoD CM Policy compliance (<1% UXO)
  - Lower costs via reuse of demilled 155mm metal parts

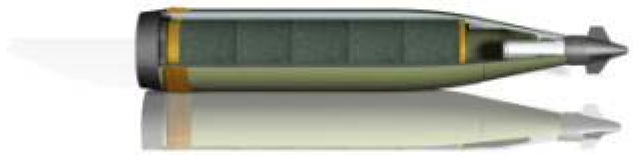
PRAXIS features

- Full bore submunition
- Extreme Reliability Tri-Mode Fuze
  - Proximity
  - Impact
  - Time
- ATO Goal- < 0.25% UXO
- Can be fired at MACS5
- Reuse existing M483A1 metal parts
- Adaptable
  - 155mm Artillery
  - 105mm Artillery
  - GMLRS Rocket Systems

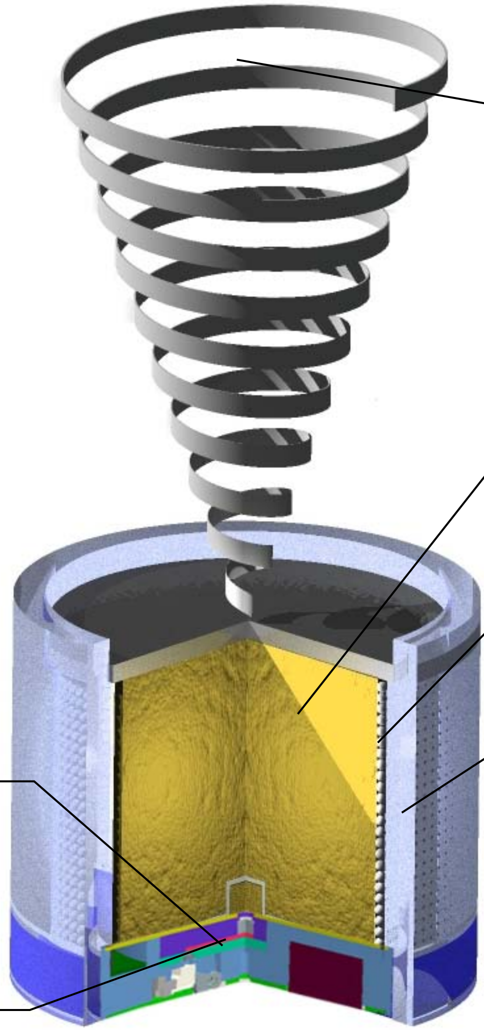


Approach

- The PRAXIS submunition is designed for:
  - Low Cost
    - Few moving parts
    - Conventional materials
    - Leverage proximity submunition fuze work done for Navy ERGM
  - High Reliability
    - Tri-Mode Fuze to provide extreme reliability
      - Proximity
      - Impact
      - Time
  - Enhanced Lethal Effects
    - Improved performance energetics
    - Bi-Modal Effects Warhead
      - Optimized Anti-Materiel Fragments from Submunition Casing
      - Optimally sized Tungsten Ball Matrix for Anti-Personnel Effects
      - Detonation at optimum height for Cannon Cluster Munition target sets

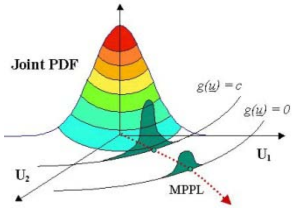


Approach (contd)



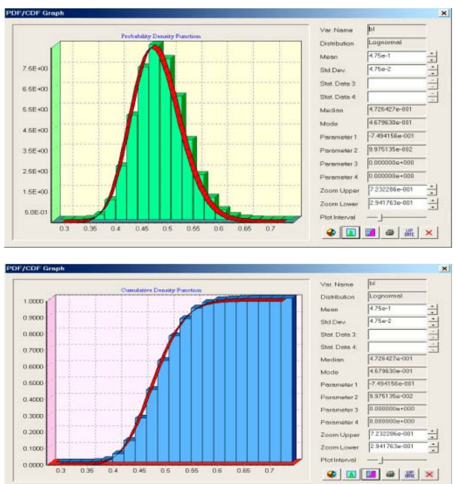
Approach (contd)

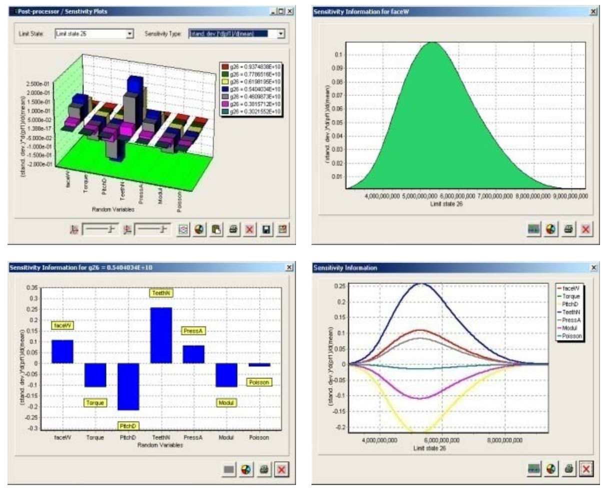
- Fuzing architecture with parallel features in terms of arming, target sensing, and power functions IS NECESSARY.
- Highly reliable arming scheme achieved with the following characteristics:
  - Redundant, independent methodologies
  - Elimination of common mode failures
- Require the expulsion system concept as part of the fuzing architecture
- Perform component trade study
- Perform component reliability analysis
- Perform modeling & simulation
- Identify high reliability fuze architectures
- Organize initial Quality Function Deployment (QFD) matrix

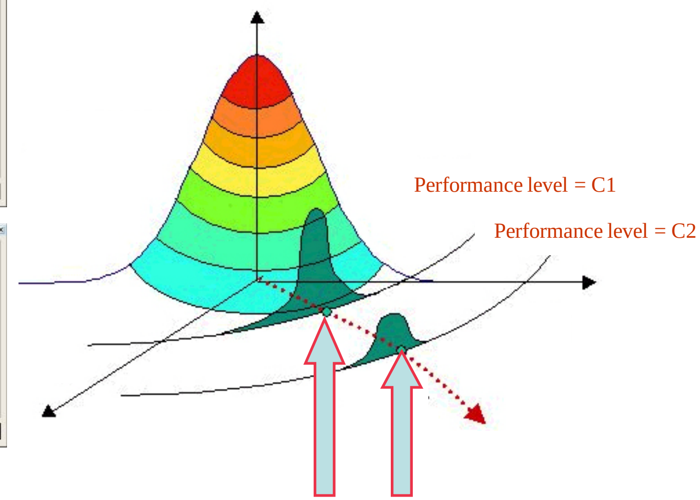


Probabilistic Technology Approach

- Probabilistic Technology provides 3 metrics to quantitatively evaluate process performance early in the decision process when no data is available







1. Probability Information
   - Reliability, risks, failure prob.
   - Critical failure modes ID
   - Performance range
   - Most-likely performance value
   - Safety-factor calibration
   - Many more

2. Process Sensitivity Measures
   - Key process variables & uncertainties
   - Guidelines to develop test plans
   - Guidelines for inspection & repair planning
   - Guidelines to develop improvement plans
   - Guidelines to develop control plans
   - Guidelines to develop monitoring plans
   - Many more

3. Most-Probable-Points (MPP)
   - Safety control systems
   - Certification tests
   - Reliability demonstration tests
   - Critical combination of parameters
   - Most likely failure points
   - Many more

Summary

- Investing in technology research to provide improved capability once afforded by Cannon Cluster Munition
- Domestic & foreign policy could impact future design requirements
- ARDEC is proactive in ICM technologies:
  - ✓ Providing core expertise to develop replacement technologies for CM
  - ✓ Process member in the effort
  - ✓ Addressing customer needs with stakeholders
- Developer must provide new munitions that:
  - ✓ Address the technical gap
  - ✓ Compliant with existing/emerging policy
  - ✓ Producible, Reliable & Cost competitive

Adaptive Imaging and Guided Fuse Technologies

Professor Ron Barrett

Director of the Adaptive Aerostructures Laboratory (AAL)
Aerospace Engineering Department
The University of Kansas, Lawrence, Kansas USA

AAL ...Backroom for the Innovation-Driven Aerospace Organizations of the world...

5th Annual NDIA Fuze Conference
Kansas City, Missouri 12 May 2010

Purpose:

Describe to the fuze community the state of the art in adaptive optics and flight control technologies

Outline:

I. Background & Brief Introduction to Adaptive Materials

II. History of Programs

III. New Classes of Adaptive Actuators

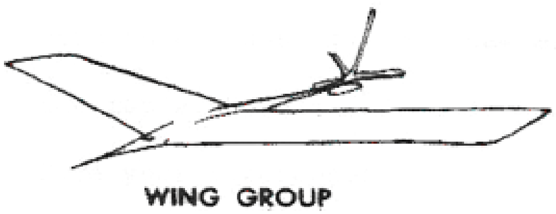
IV. Current & Future Programs Enabled

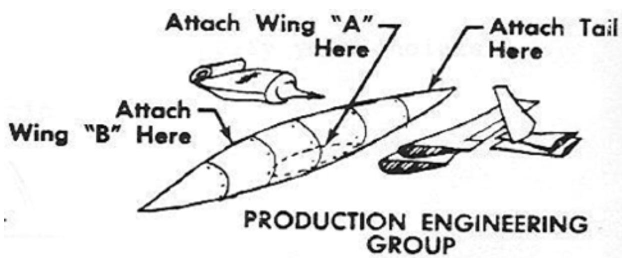
Adaptive Materials

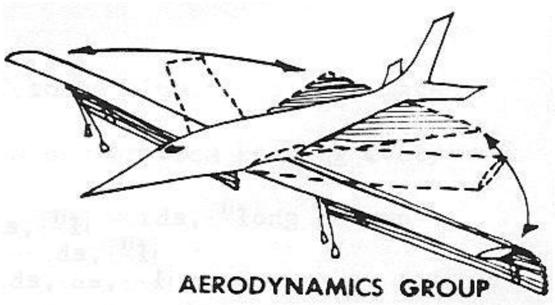
… A Paradigm Shift

Old Paradigm:

Structural deformations indicate that a given loading state is occurring and must therefore be accommodated.





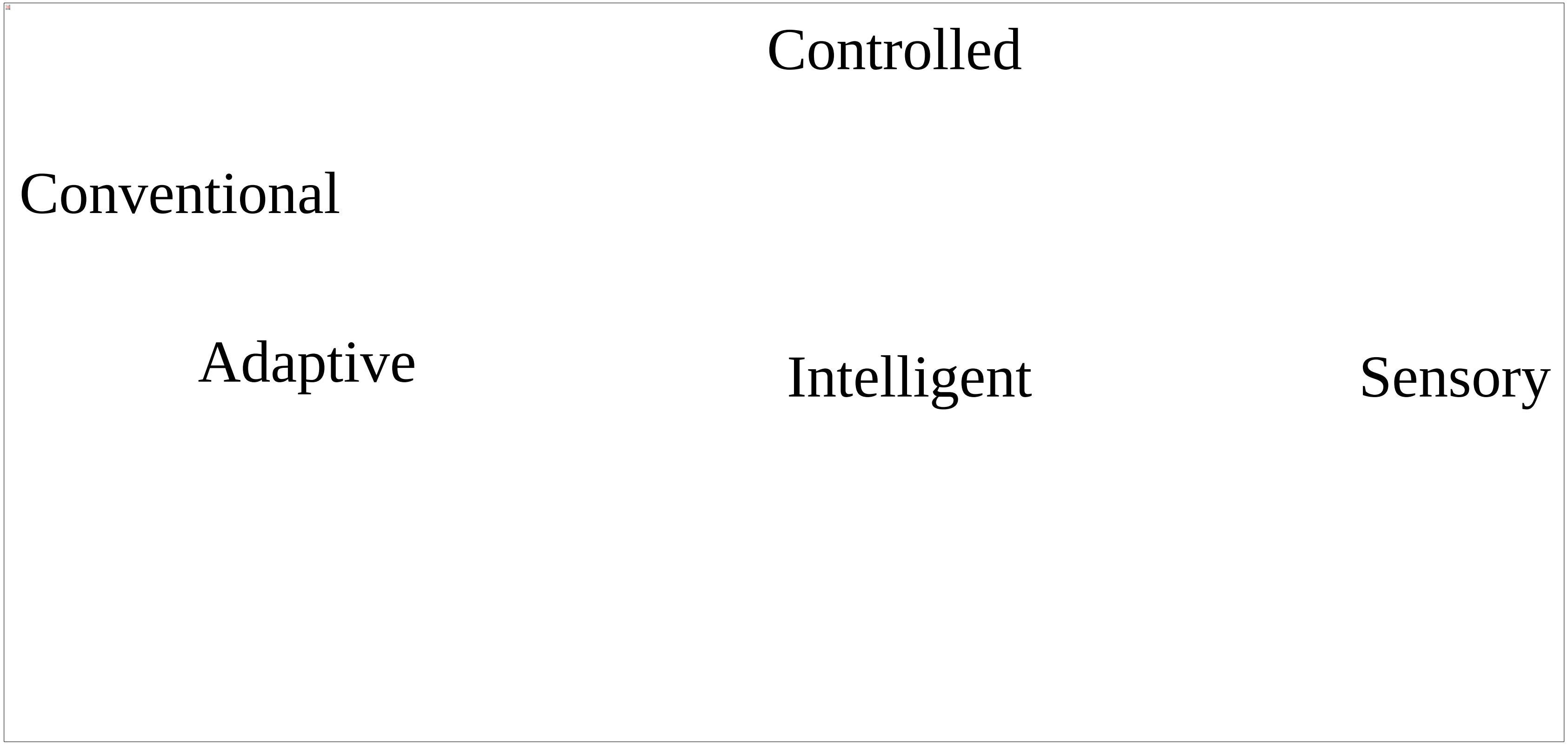


New Paradigm:

Structural deformations can be controlled and can therefore be used to enhance mission effectiveness.

Adaptive Materials:
A (Very) Brief Introduction

What are Adaptive Materials & Structures?



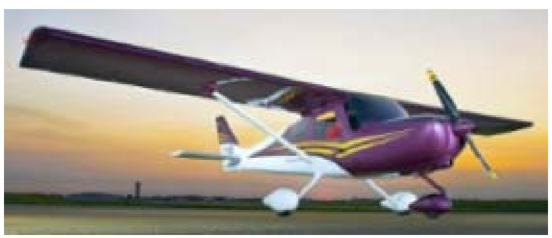
Adaptive Aerostructures: A (Very) Brief Introduction

- Most Useful Classes of Adaptive Materials:
  - Shape-Memory Alloy -
    High Deflection, Slow, Lots of Power
  - Variable Rheology Materials -
    Good for clutching and changing stiffness
  - Piezoceramics -
    Very Fast, Low Power
  - Optically Adaptive Materials -
    Newest class, controllable color, luminosity, reflectivity, opacity

R. M. Barrett 12 May 2010 Unclassified All information from public sources

Adaptive Flutter Test Surfaces

- *Solid State*
- *Order of magnitude less device weight*
- *Order of magnitude less installation weight*
- *Half the acquisition price of the conventional system*
- *Half the installation price and downtime of the conventional system*
- *Exacting Phase Control*
- *Flight Rated to Mach 3*
- *Half the flutter insurance rates*



US & International Patents pending

First 20 years of Programs with Lineage to Flying Adaptive UAVs

All information from public sources

Unclassified

12 May 2010

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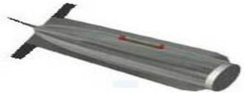
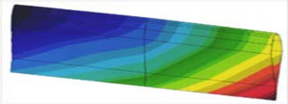
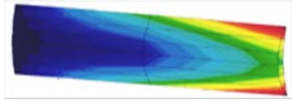
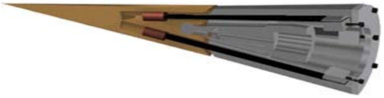
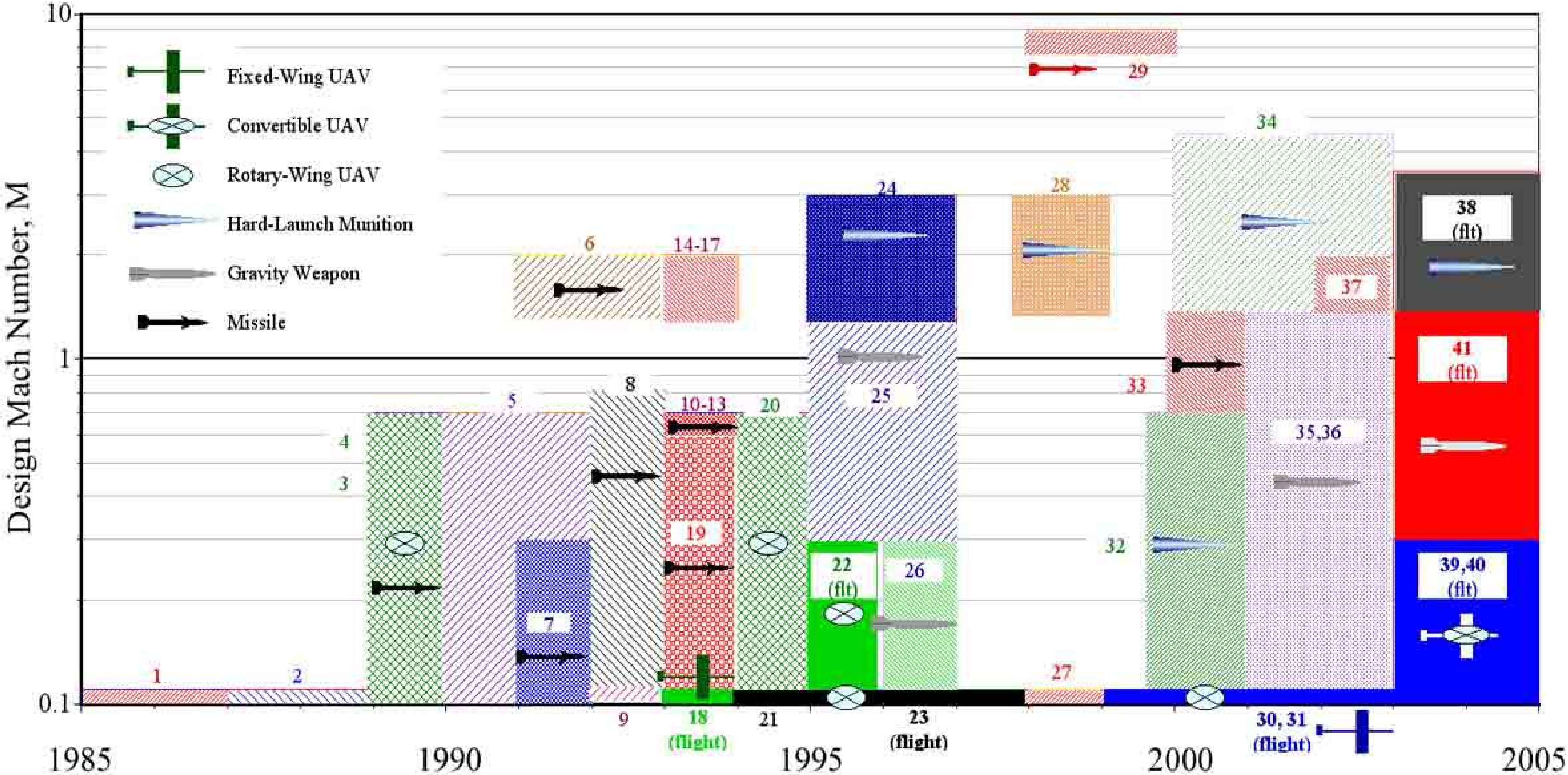








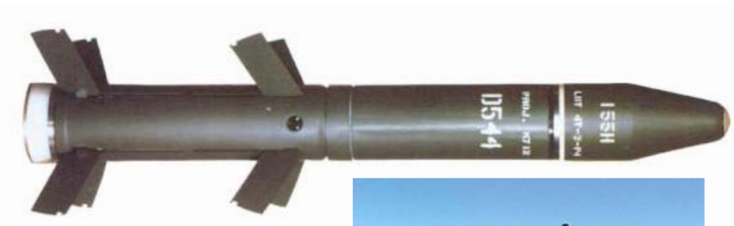
Overview of Programs with Lineage to Flying Adaptive UAVs



R. M. Ba

Brief Guided Round History

M712 Copperhead 1975



XM 982 Excalibur & ERGM

Guided Round History

Reducing the caliber...

M 247 Sergeant York 1977 - 1985

Guided Round History

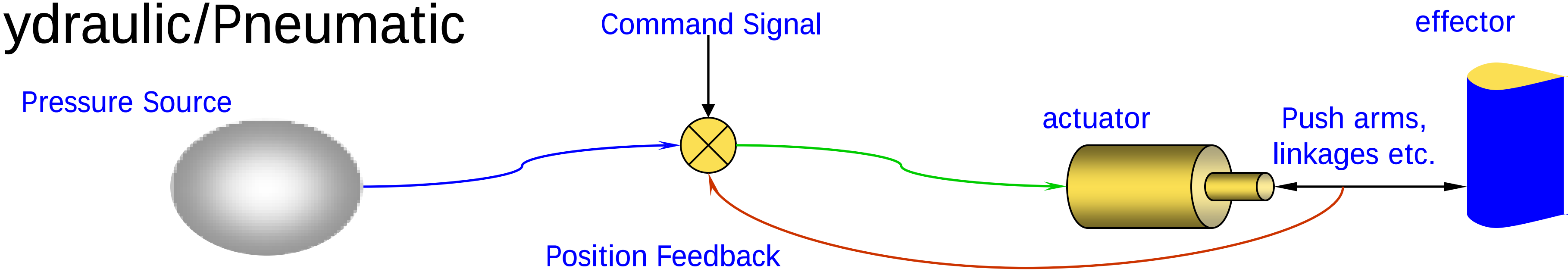
What's needed in a low caliber FCS actuator?

What is needed in such a flight control actuator???

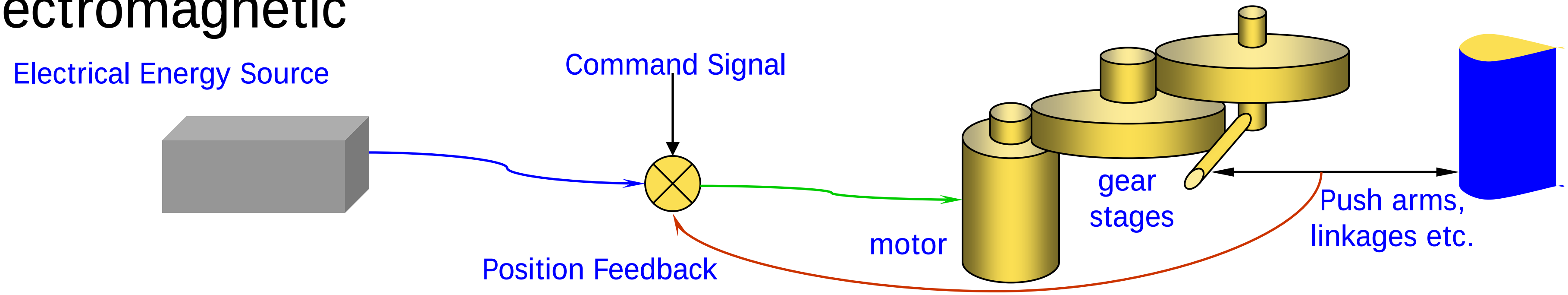
- Setback tolerance: 5,000 - 200,000g's
- Balloting, setforward, ringing impervious
- Compatible with supersonic control effectors
- Not affected by atmospherics (rain, dust, dirt, snow, etc.)
- High feedback command fidelity maintained during all flight phases
- 20 yr storage life
- -40 to +145°F
- Lightweight (<1g), Low Volume (<1cc), Low Power (10's of mW)
- High bandwidth (>200 Hz)
- Production shipset costs in single dollars... at most

Adaptive Materials Actuation… Different

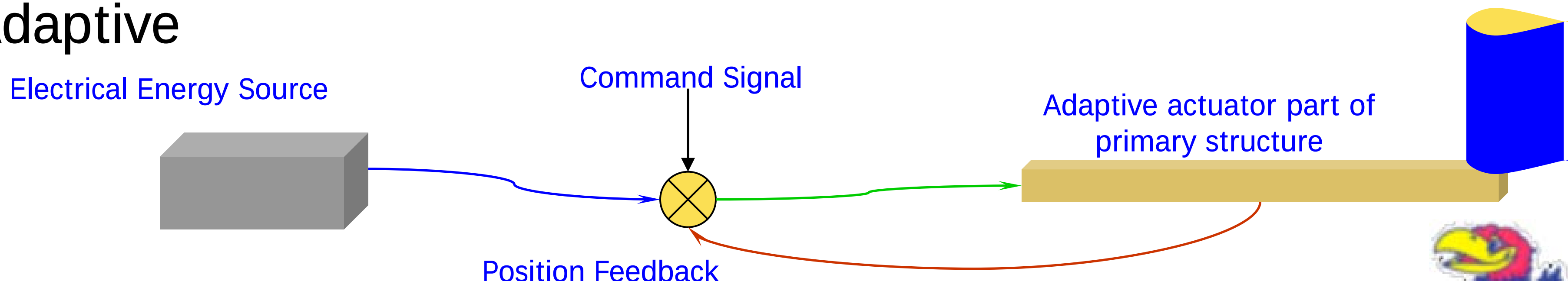
Hydraulic/Pneumatic



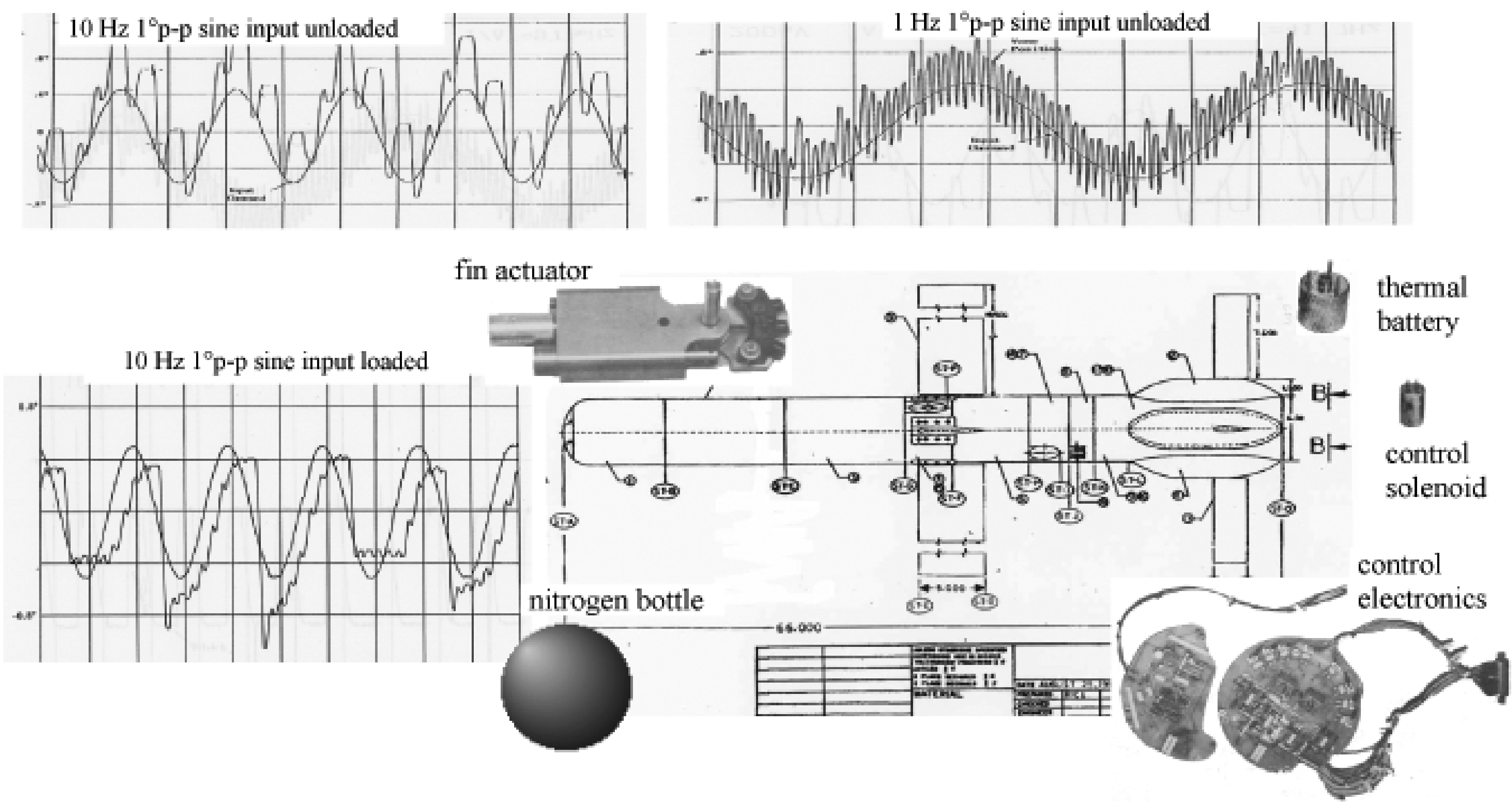
Electromagnetic



Adaptive



US Army FOG-M FCS…

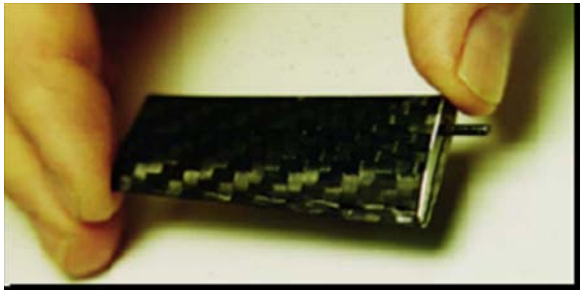


One possible solution... from the MAV world

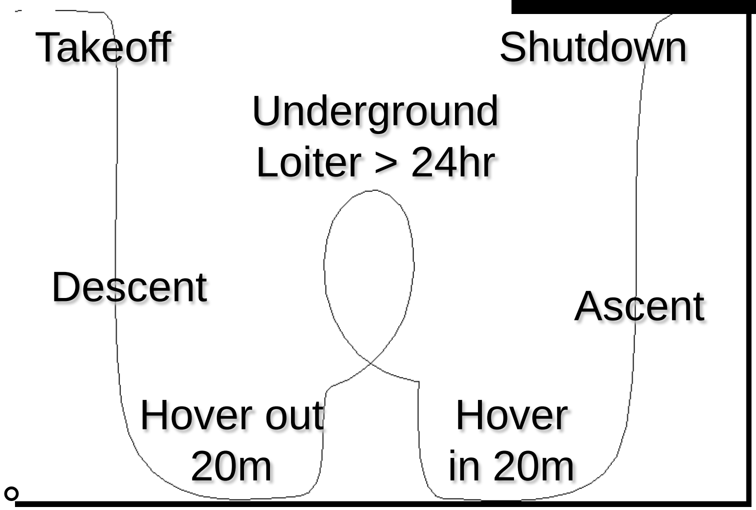
The 1st Micro Aerial Vehicle (MAV) -- by the DoD CounterDrug Technology Office 1994 - ‘98

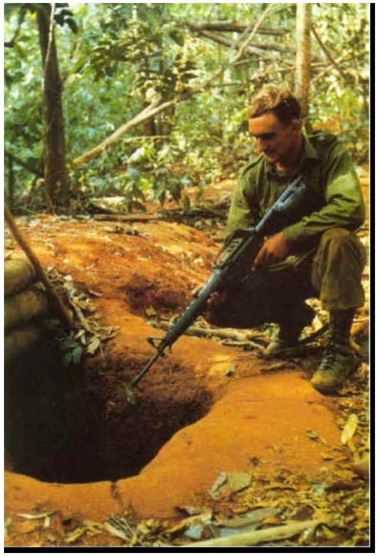
[redacted]

Enabled by Flexspar Piezoceramic Stabilators



Mission Profile:



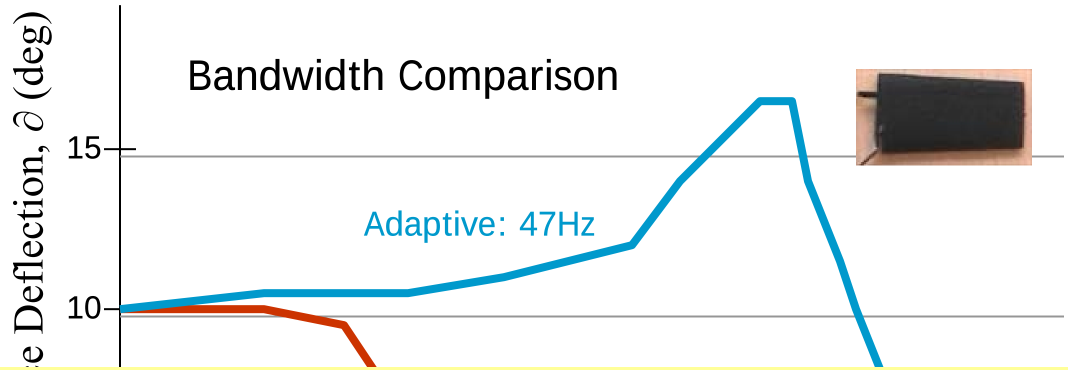


Stabilator Characteristics:

- total mass 5.2g
- actuator mass: 380 mg
- max. static deflections: ±11°
- max power consumption: 14 mW
- pitch corner frequency: 47 Hz
- first natural frequency in pitch: 23 Hz

Advanced UAVs:

Driving the need for Adaptive Actuators -- faster, lighter, stronger



Adaptive Surfaces vs. Conventional Servos

- 96% reduction in power consumption
- 16x increase in bandwidth
- 99.2% decrease in slop
- 12% OWE savings
- 8% MGWTO savings

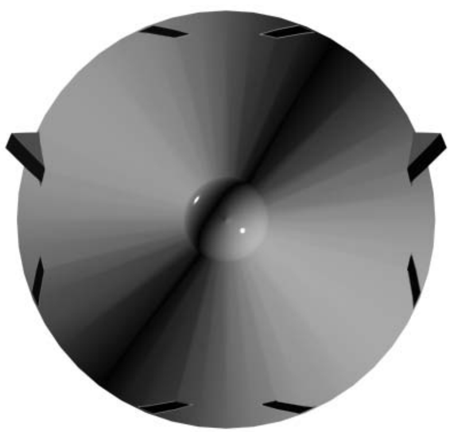
Operating Empty Weight Fraction

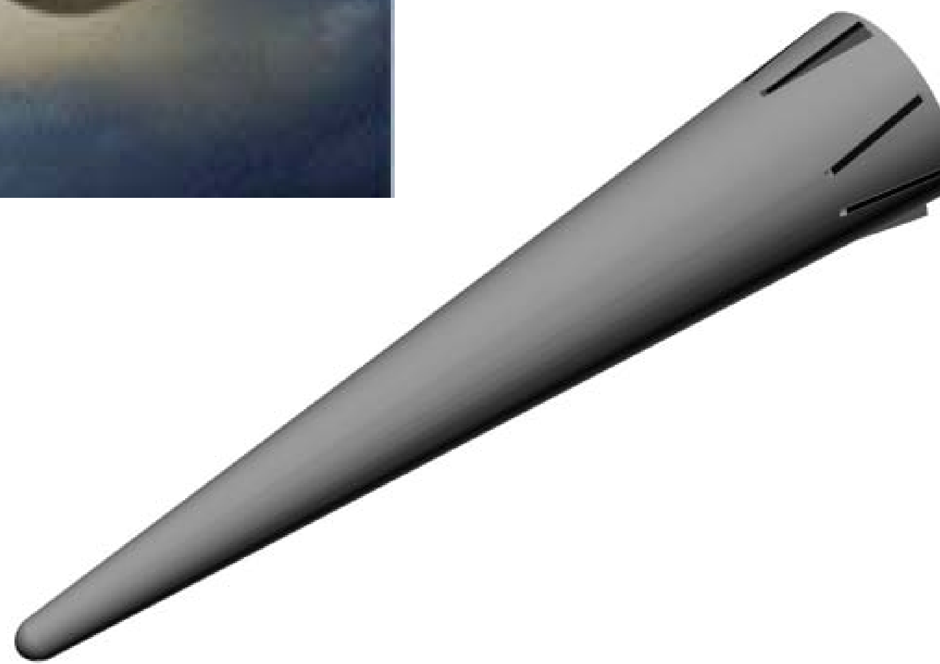
Gravity Weapons

Interceptors

SMDC HITT Program 1997 - 2000

Hypersonic
5ms Response
Pitch, Roll, Yaw control





Guiding Lower Caliber Rounds… More History

Barrel-Launched Adaptive Munition (BLAM) Program 1995 - '97

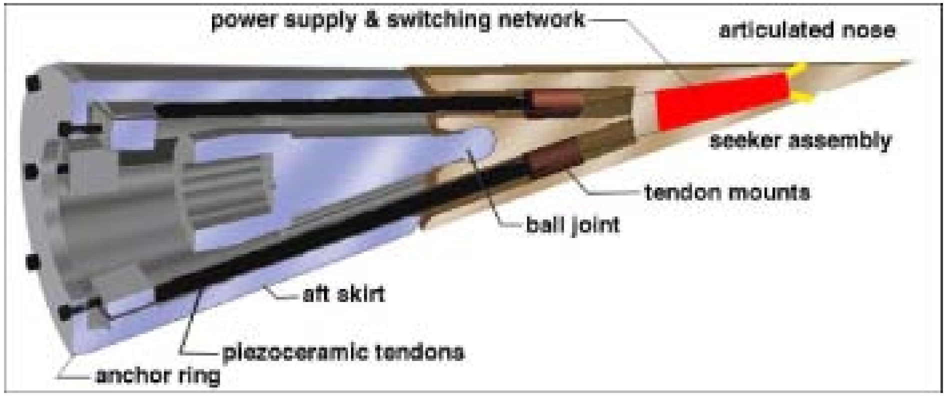
USAF/AFRL-MNAV

- Aerial Gunnery (20 - 105mm)
- Extend Range
- 2g maneuver

(Eglin AFB tests '97)

(Mach 3.3 tests '96-'97)

- Increase hit probability
- Increase probability of a kill given a hit
- Reduce total gun system weight fraction



Guiding Small Arms Rounds... More History

Range-Extended Adaptive Munition (REAM) Program 1998 - '99

TACOM-ARDEC (Picatinny-APG) Phase I SBIR

- Guide 50 cal sniper rounds against targets moving up to 100km/hr
- 10cm dispersion @2km under 99% winds, up to 10% grade

Guiding Small Arms Rounds... More History

Range-Extended Adaptive Munition (REAM) IRAD 1999 - 2001

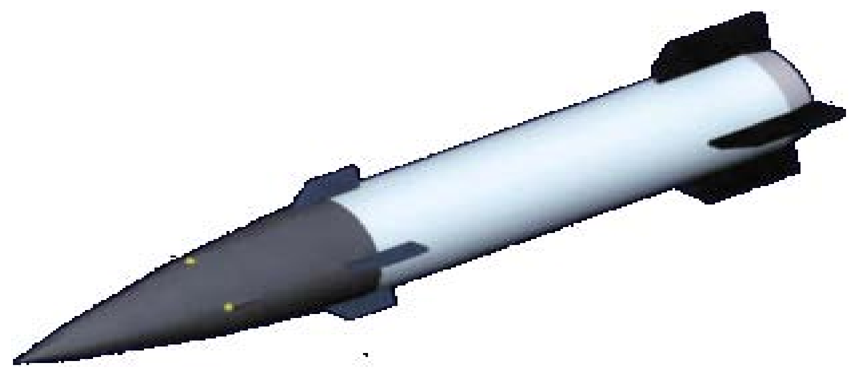
BAT-Lutronix Corp. developed supersonic piezoelectric FCS actuators

Guiding Small Arms Rounds… More History

Shipborne Countermeasure Range-Extended Adaptive Munition (SCREAM) Program 2001 - '03

DARPA-TACOM ARDEC SBIR Phase II

- Change from sniping to countering high jinking rate sea-skimming missiles
- Change from 0.50 caliber to 40mm
- Change from ~2g's of maneuver authority to many tens of g's
- Entire FCS passed 41,000g shock table testing



Guiding Small Arms Rounds... More History

Shipborne Countermeasure Range-Extended Adaptive Munition (SCREAM) Program 2001 - '03

DARPA-TACOM ARDEC SBIR Phase II

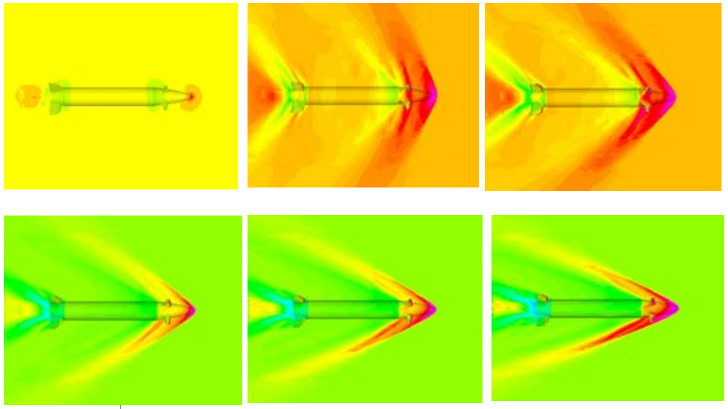
SCREAM Actuator Challenges:

- Long actuator bay length
- Difficulty pushing beyond 50,000g's
- Low deflection -- ~ok for sniper, not ok for SCREAM

Hmmm...

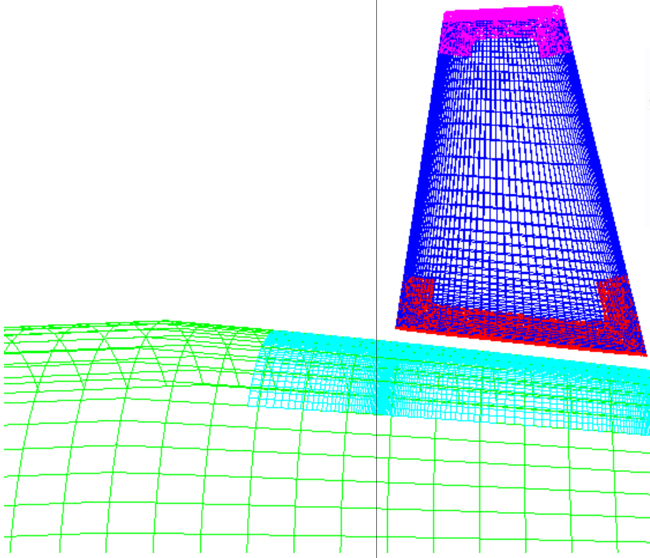
Other Adaptive FCS Efforts

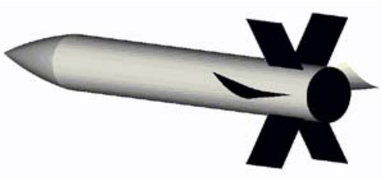
Rabinovitch & Vinson 2000 - present



again... low authority
can't survive balloting, setback unsteady aero...

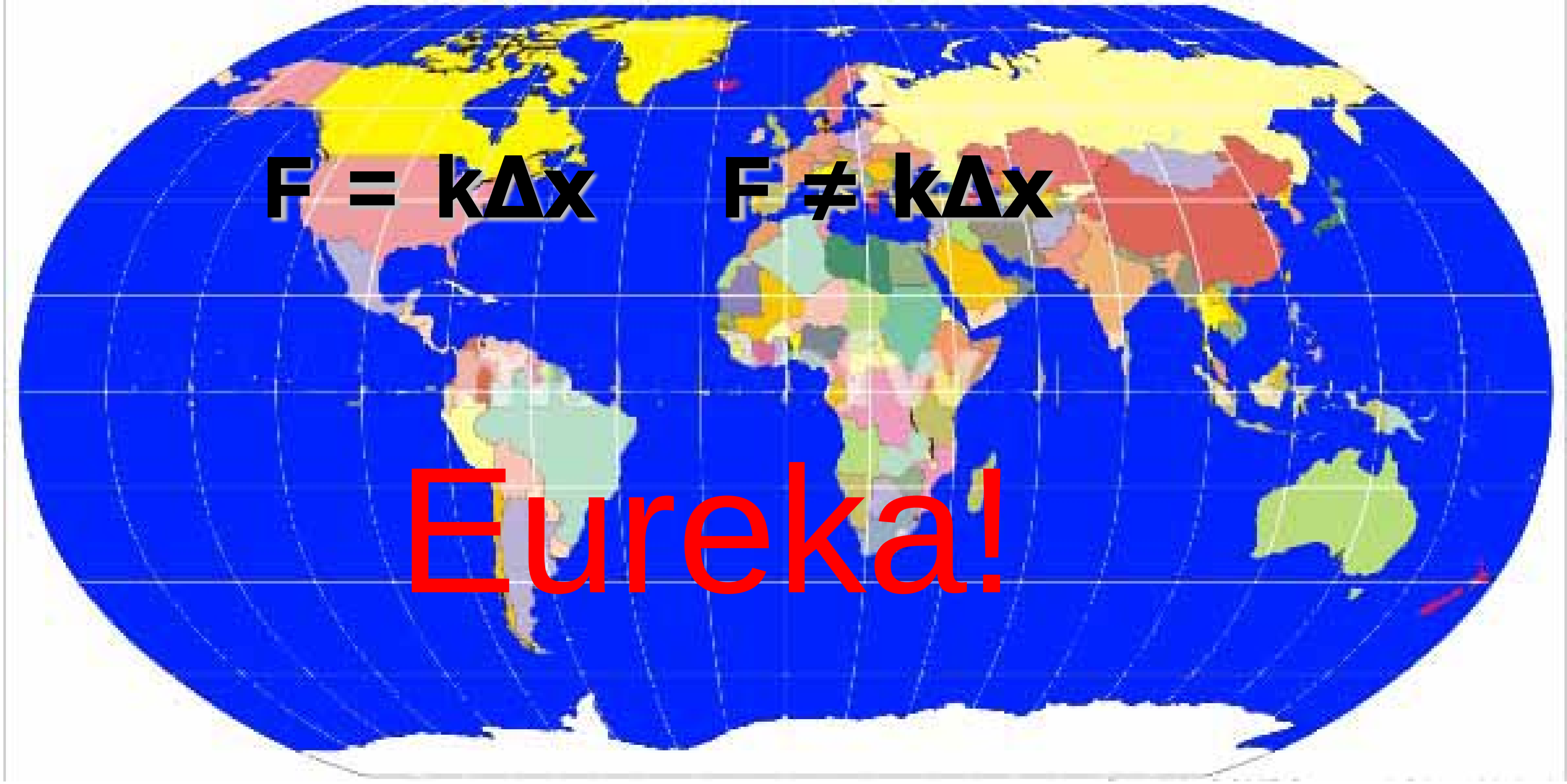
Now Where???





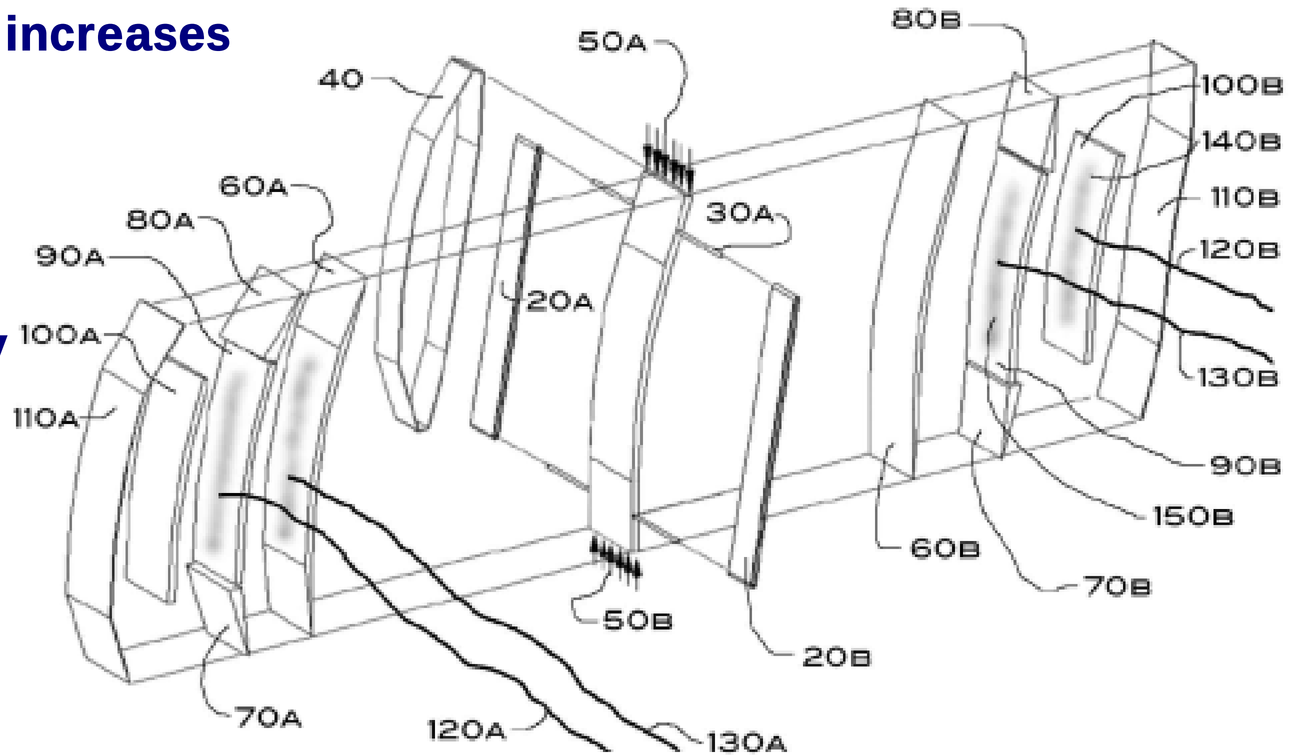
Guiding Small Arms Rounds… The Ephphany!

Discoveries from Europe… 2003 - 2004



PBP Actuators: Real Performance!

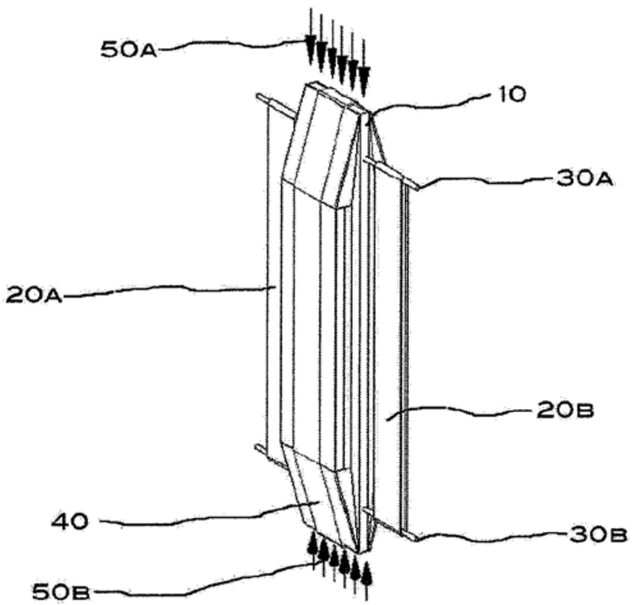
- Fraction of the weight, size & power consumption of US Actuators
  (i.e. much smaller actuator bays)
- 300+% deflection increases
- Higher bandwidth
- Lower cost
- Lower g-sensitivity

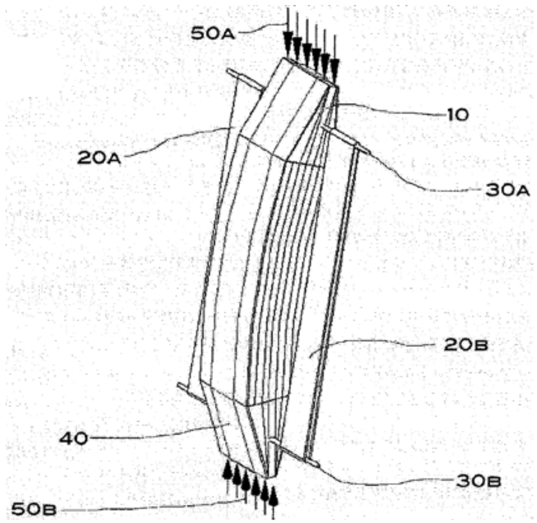


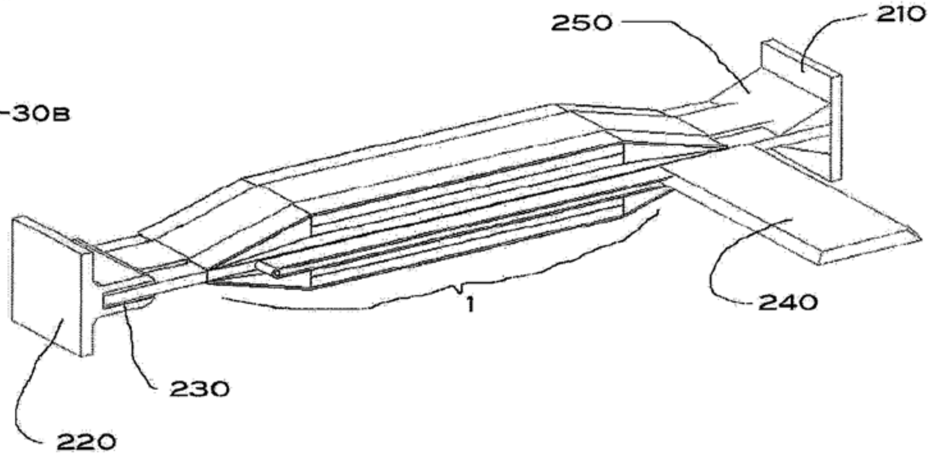
Worldwide patent application: 18 Jan. 2005

PBP Actuators: Real Performance!

Assembled, functioning actuator:

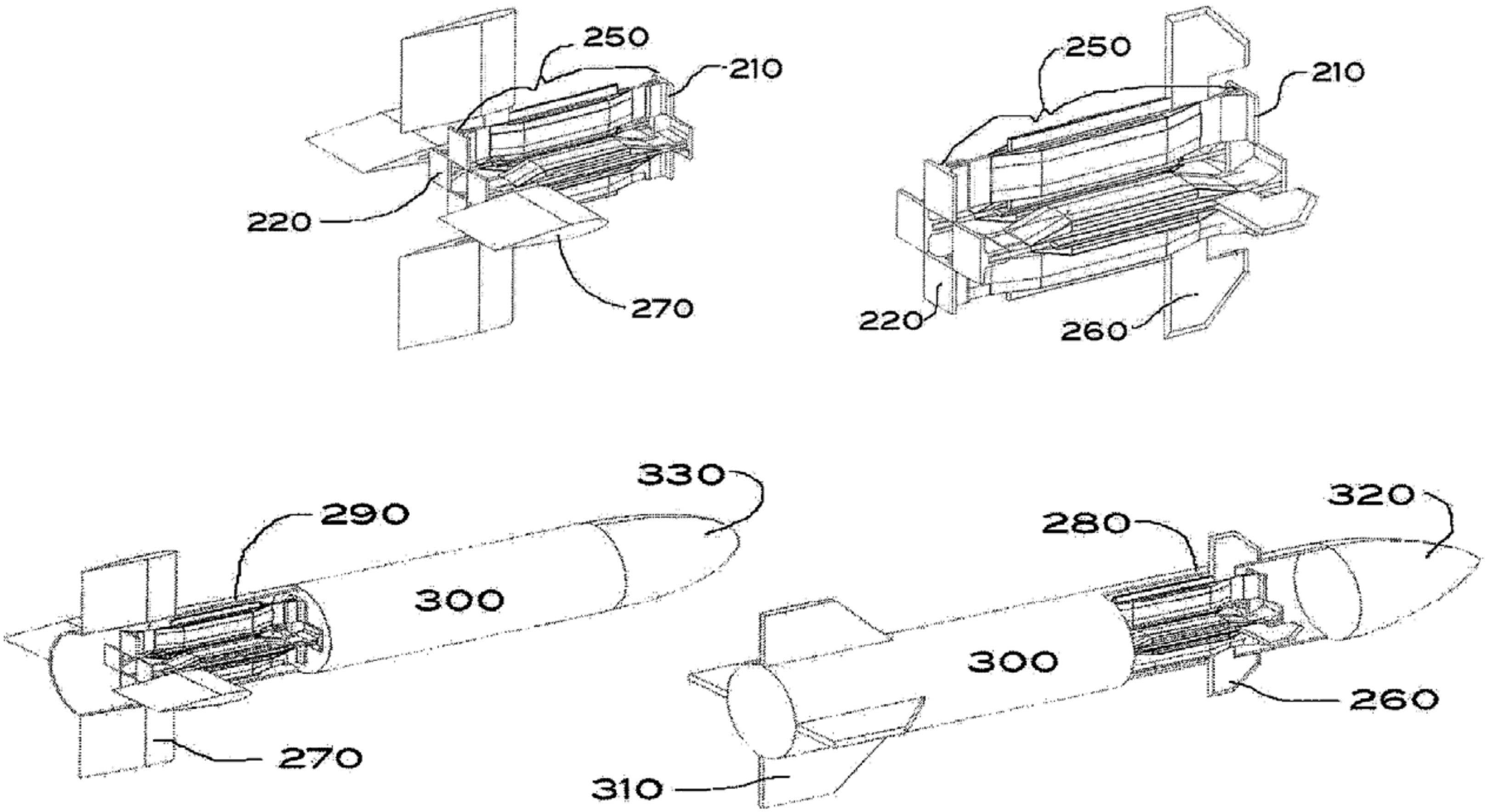






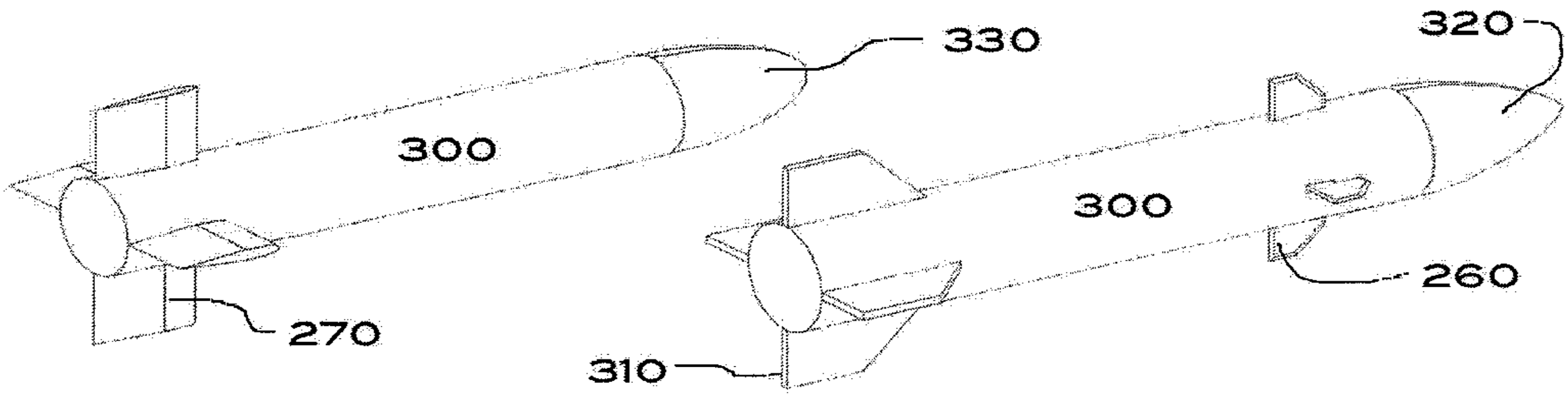
PBP Actuators: Real Performance!

Assembled Hard-Launch Capable Actuator FCS Units:



PBP Actuators: Real Performance!

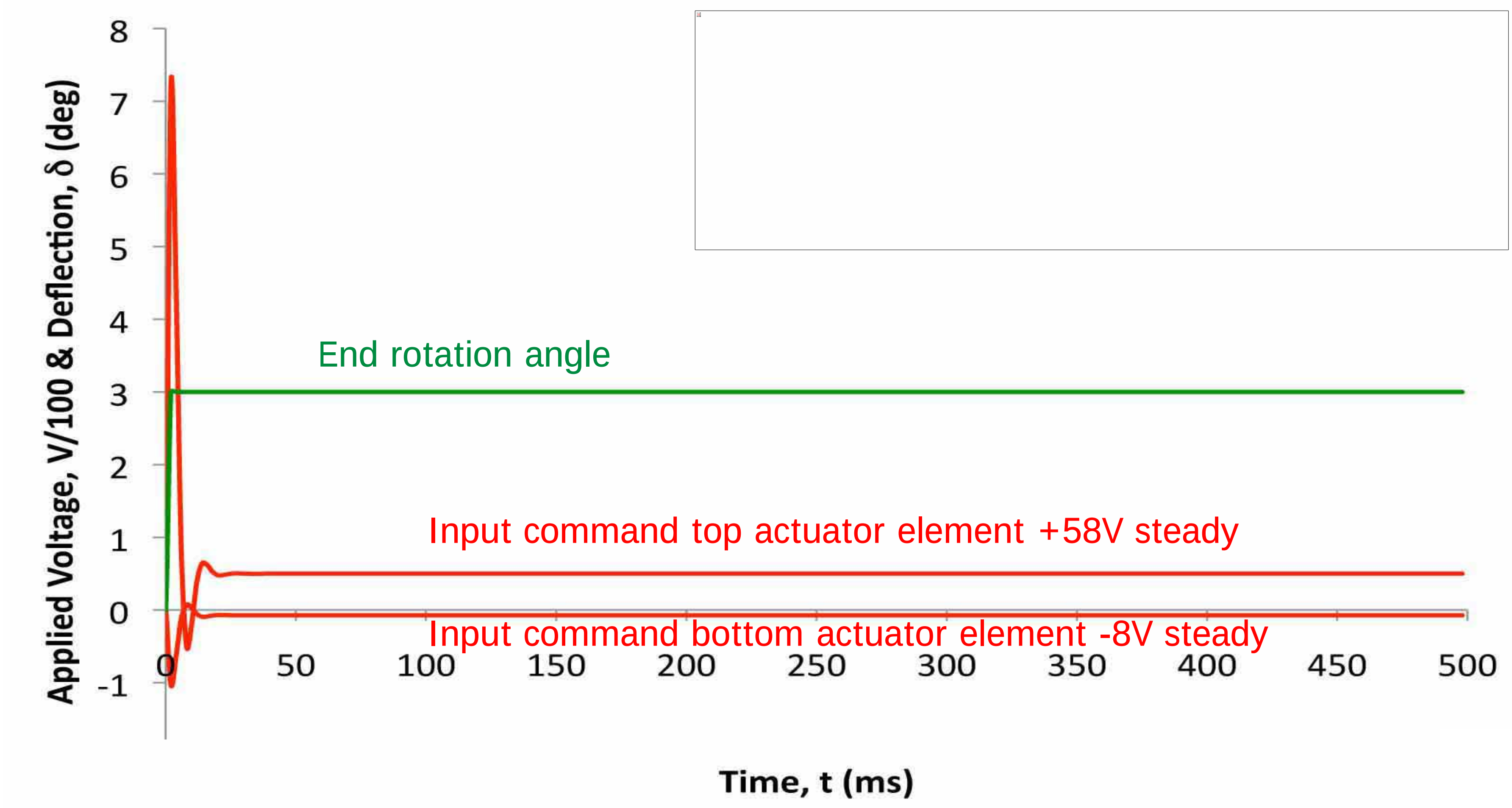
Assembled Hard-Launch Capable Actuator FCS Units:



PBP Actuators: Fastest around…

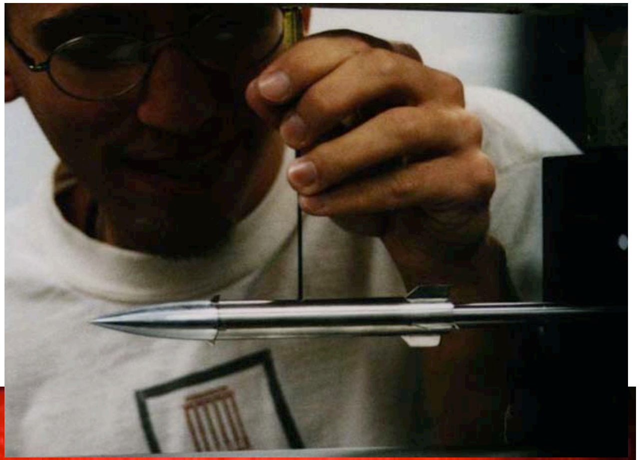
Best performance in the adaptive structures industry:

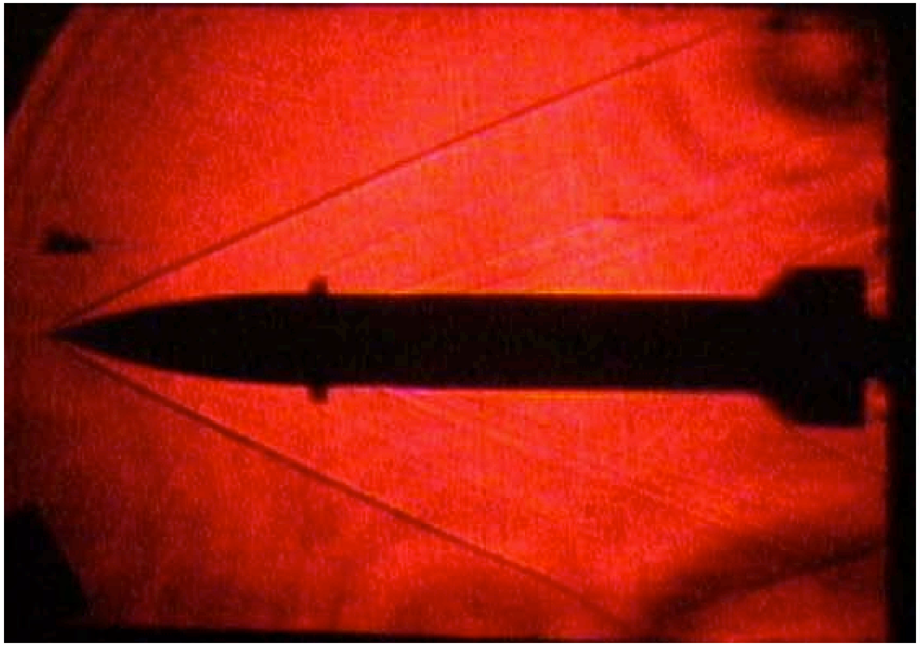
- **1kHz equivalent bandwidth**
- **Driving 0.40 / .50 cal Mach 4.5 canards**



PBP Actuators: Real Performance!

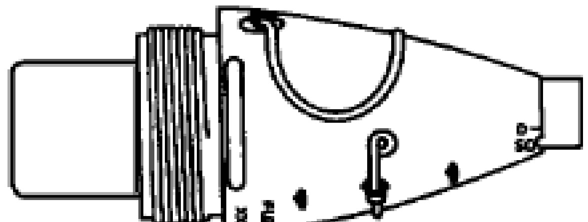
Mach 3 Testing – FCS works well!





PBP Actuators: Moving up in caliber – Easy!

Mortar Fuses

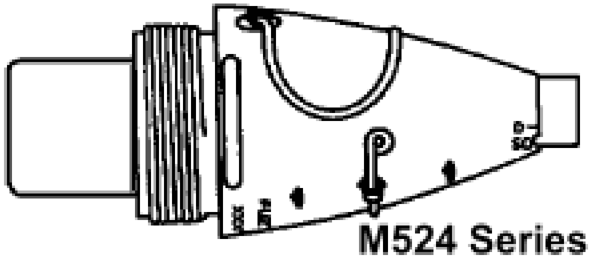


M524 Series

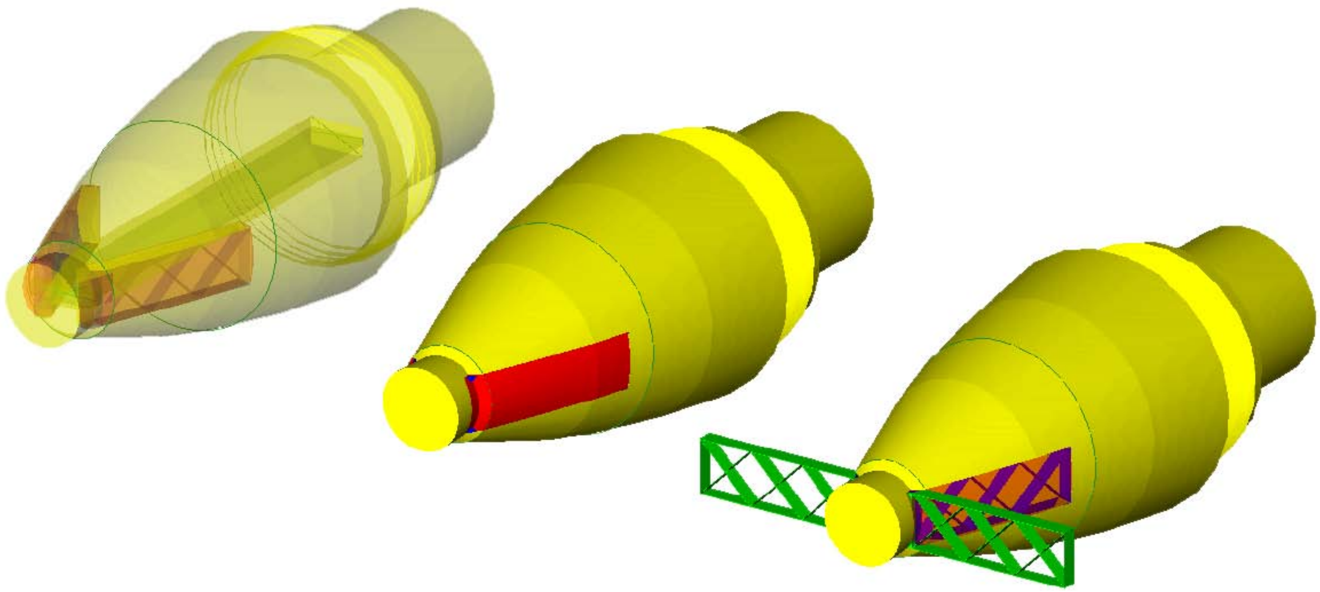
Howitzer Fuses

PBP Actuators: Moving up in caliber – Easy!

Fuse PBP FCS Designs



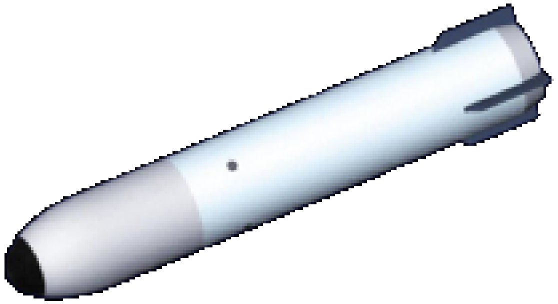
Designs to drive both blade and grid-fin control surfaces full pitch, roll & yaw from apogee for ~8cc volume, through 100 Hz, <1W



Families of Steered Piezoelectric Enhanced Adaptive Rounds (SPEARs)

- Roll Stabilized Recon. SPEAR

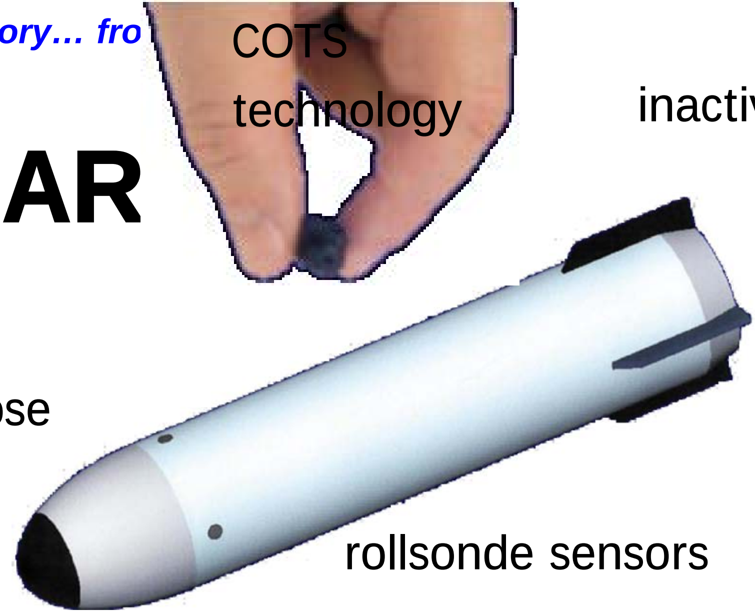
- Full Control Recon. SPEAR



Roll Stabilized SPEAR

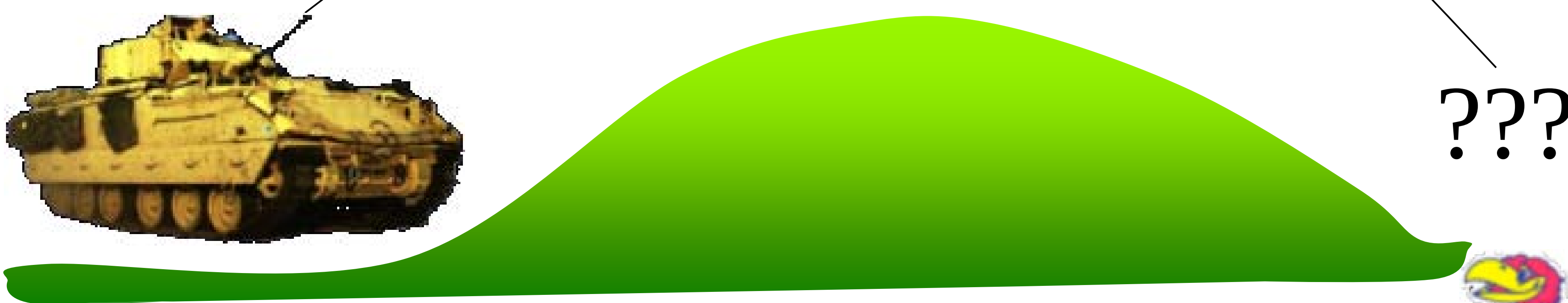
“Look Over the Hill”

Supersonic MAV mission



Tactical Benefits:

- Fastest way to get local reconnaissance images
- Totally impervious to weather/gusts
- ~ $20/round



Roll Stabilized Recon. SPEAR

Necessity of Roll Stabilization

Smooth bore/obturating band launch 20mm:

roll rate > 8rps

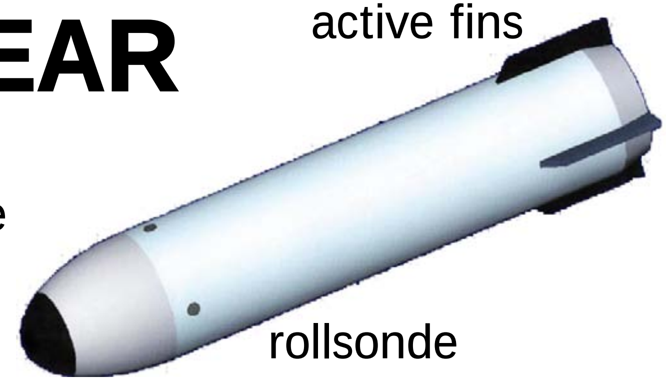
flare

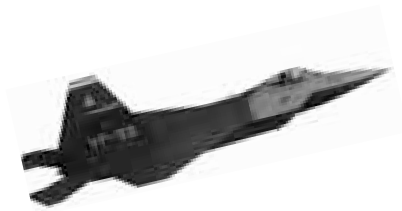
12Ga

Full Control Recon. SPEAR

Full Battlefield

Reconnaissance





40,000 ft (12km)

20mm (16mm) saboted SPEAR

Mach 0.8, 15° launch

Friendly Fire reduction / elimination

Micro Optics Steering w/piezo

±2° through 1kHz

fully proportional

sizable down to 20mm rounds

hardened through 10,000g's

solid state

20+yr life

Questions?

… and a few interesting facts about Kansas…

Hilly, wooded Lawrence, home of the University of Kansas
45 min. West of Kansas City

A very blue dot in a very red state: Lawrence ~ Kansas as Austin ~ Texas

Transportation Hub, Flight Test
Light Aircraft Manufacturing

Avionics

R&D, Flight Test, Aircraft Design
Missiles, Munitions, UAVs

Airline Aircraft Maintenance
Insurance
Spares
Interiors
Avionics
Salvage
Airframe Design, Development, Production

THALES

Modeling the Interaction of a Laser Target Detection Device with the Sea

Gary Buzzard, Thales Missile Electronics
Proximity Fuze Product Technical Manager

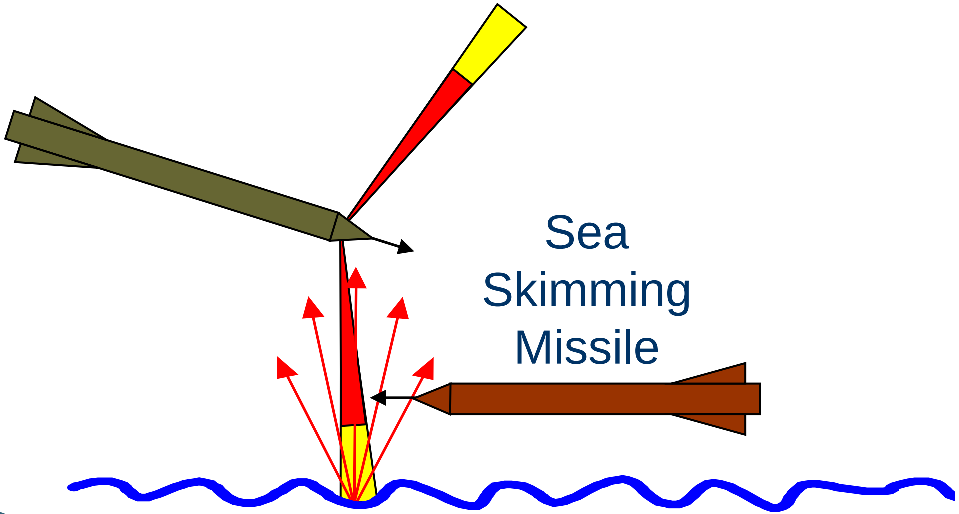
Land Defence

Content

- Low Level & Embedded Threats
- TDD Sensor Options
- Multiple Fan Beam Laser Sensor TDD
- Laser Sensor Interaction with the Sea
- Modelling the Sea Surface
- Modelling Sensor Response to the Sea
- Model Validation
- Model Applications
- Recent ‘AFIAC’ Sea Data Gathering Trial
- Summary

Low Level & Embedded Threats

- Threat proximity to sea surface a challenge for the TDD
  - Sea skimming missiles close to sea clutter
  - Fast Inshore Attack Craft (FIACs) embedded in sea clutter
- Clutter reflections difficult to differentiate from target
  - Can be similar range and amplitude
- Analysis of TDD performance requires representative models of sensor interaction with the sea surface



Boston Whaler with rocket launcher

THALES

TDD Sensor Options for Low Level Threats

- TDDs for low level applications have historically employed Radar and/or Passive IR sensor technologies
  - Mature and validated models have been developed for simulation of the interaction of these sensors with the sea surface
- Active IR (laser) sensors offer an attractive alternative for reasons of detection precision and cost
  - Semiconductor laser sources in near IR
  - To date have not been employed in low level roles due to the uncertainty of their response to the sea surface
  - Absence of validated models with which to quantify the interaction

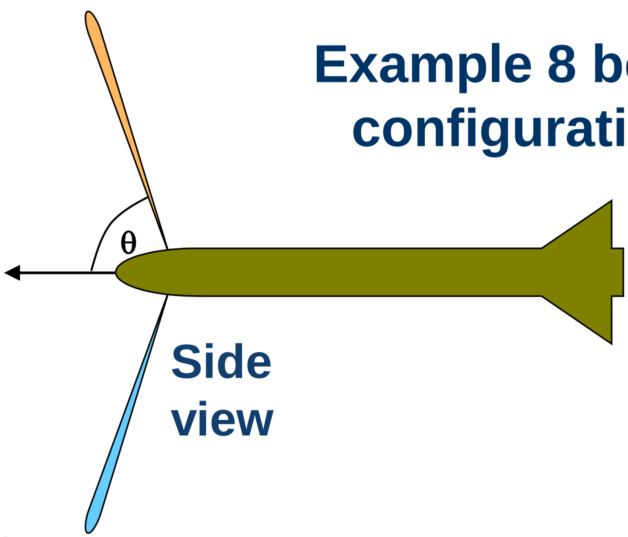
Dual Mode Radar and Passive IR Fuze

THALES

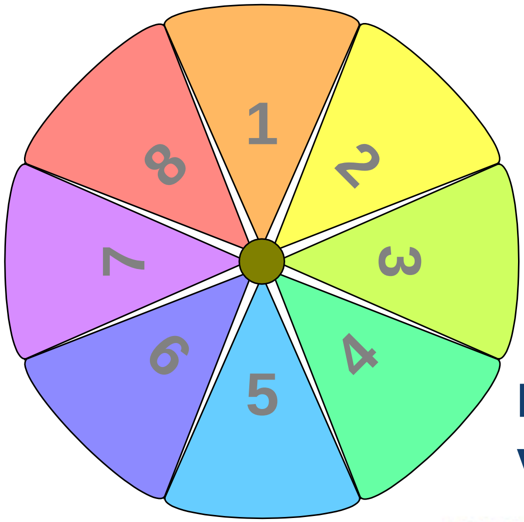
Multiple Fan Beam Laser Sensor TDD

- Multiple fan beams provide full azimuth coverage
  - Beam geometry approximates to a hollow cone
    - Forward looking with a semi angle to ~60°
    - Good match fragmenting warhead dynamics
  - Each fan a miniature Lidar able to measure range (time of flight)
    - Based on near IR pulsed semiconductor laser emitter technology and silicon pin diode receivers
  - Emphasis on use of low cost COTS opto-electronic components

Example 8 beam configuration



Side view

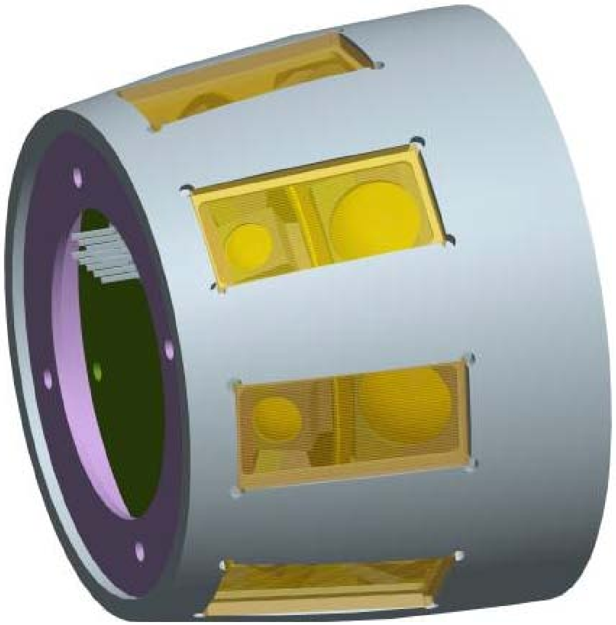


Nose on view

THALES

Multiple Fan Beam Laser Sensor TDD

- Part of the Thales ‘Modular Vision for Future Target Detection Device Technology’ briefed last year
  - Re-use of common signal processor and other key components
- TRL5/6 hardware demonstration of fan beam laser TDD
  - Subject of UK research over past 5 years



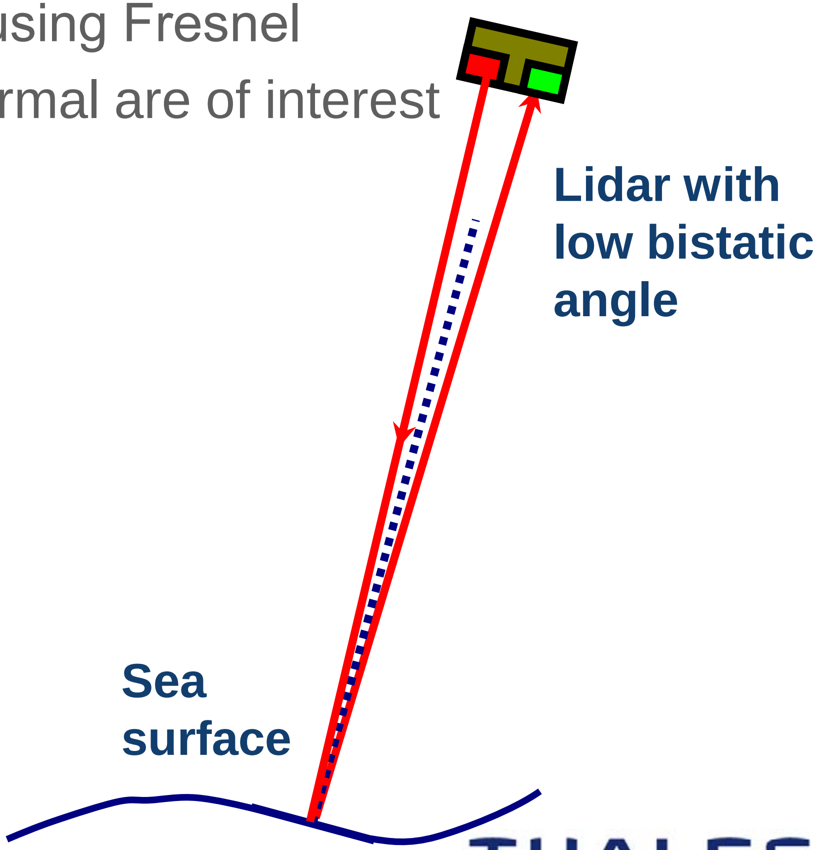
8 Beam packaging Concept

- Product now in full development
  - Body mounted configuration (ϕ<80mm)
  - Designed for volume manufacture
  - Extensive use of low cost moulded optical elements and mechanical parts
  - Light weight
  - Fully re-programmable
  - Development and qualification planned to complete by end 2010

Laser Sensor Interaction with the Sea

- Operating at near IR wavelength (λ~0.9μm)
  - Imaginary component of refractivity (k) very small
  - Bulk absorption high hence volume backscatter can be ignored
  - Real component of refractivity (n) ~1.33 can be used to estimate surface reflectivity (ρ) using Fresnel
  - Only incident angles close to normal are of interest
    - Small sensor bistatic angle
    - Fresnel equations simplify
    - Reflectivity ~2%

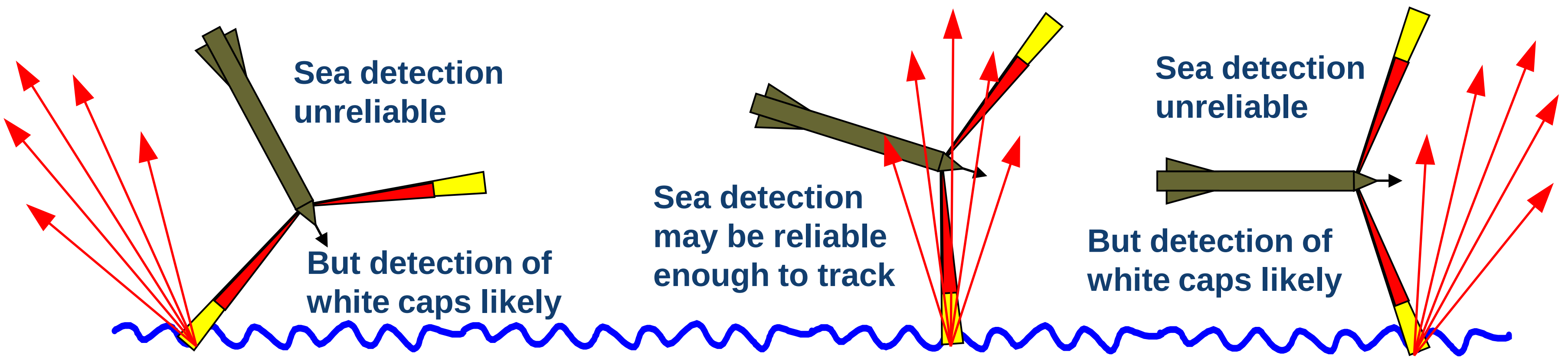
$$\rho = \left(\frac{(n-1)}{(n+1)} \right)^2 \approx 0.02$$



THALES

Laser Sensor Interaction with the Sea

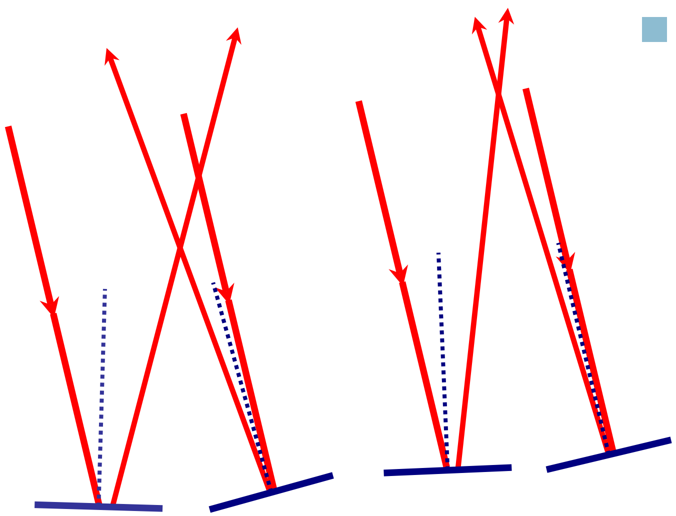
- Active IR (laser) sensor response to sea ‘intermittent’
  - Sea surface behaves like a rippled mirror with a 2% reflectivity
    - Strong reflection if surface elements intersect beam near normal
    - Very low response if illuminated surface not close to normal
    - Response depends upon complex geometry of beam and rippled shape of sea surface
  - White caps can present a diffusely scattered signature
    - Detected over a broad range of illumination angles



THALES

Modelling the Sea Surface

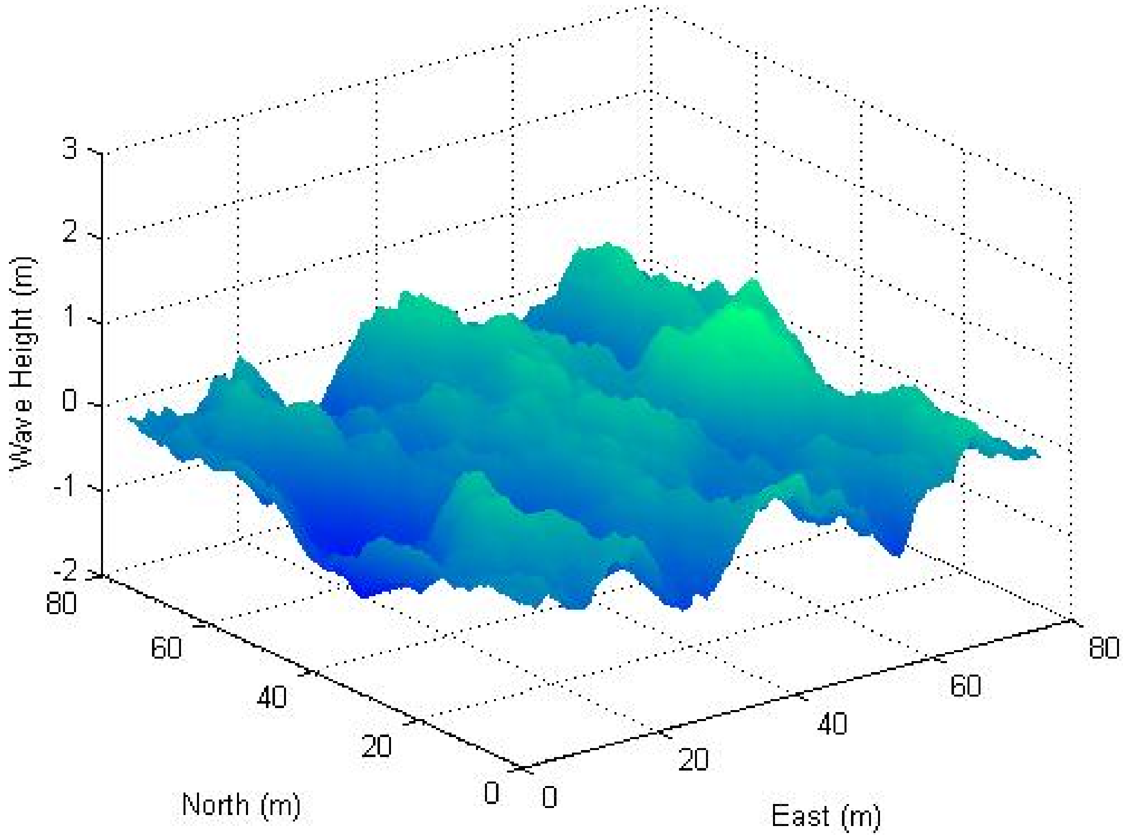
- Sea surface modelled as an array of small 2% reflectors
  - Contiguous surface comprising non planar facets
    - 5mm x 5mm (or smaller)
  - Arranged to represent 3D geometry of sea surface
  - Model shares origins with existing radar TDD interaction model
    - Smaller facets due to much shorter wavelength (~1μm versus ~10cm)
    - 64bit PC with large memory capacity used to run analyses (slowly)



- TDD sensor interaction model
  - Multiple fan beam geometry modelled
  - Defined engagement trajectories
  - Intersection of beams with 3D sea model
  - ‘Pulse by pulse’ response modelled
  - Summation of reflected pulse components from multiple facets computed

Modelling the Sea Surface

- Model uses wave spectrum proposed by Elfouhaily
  - Both gravity & surface capillary waves modelled
  - Capillary waves (e.g. λ<25mm) significant at laser wavelengths

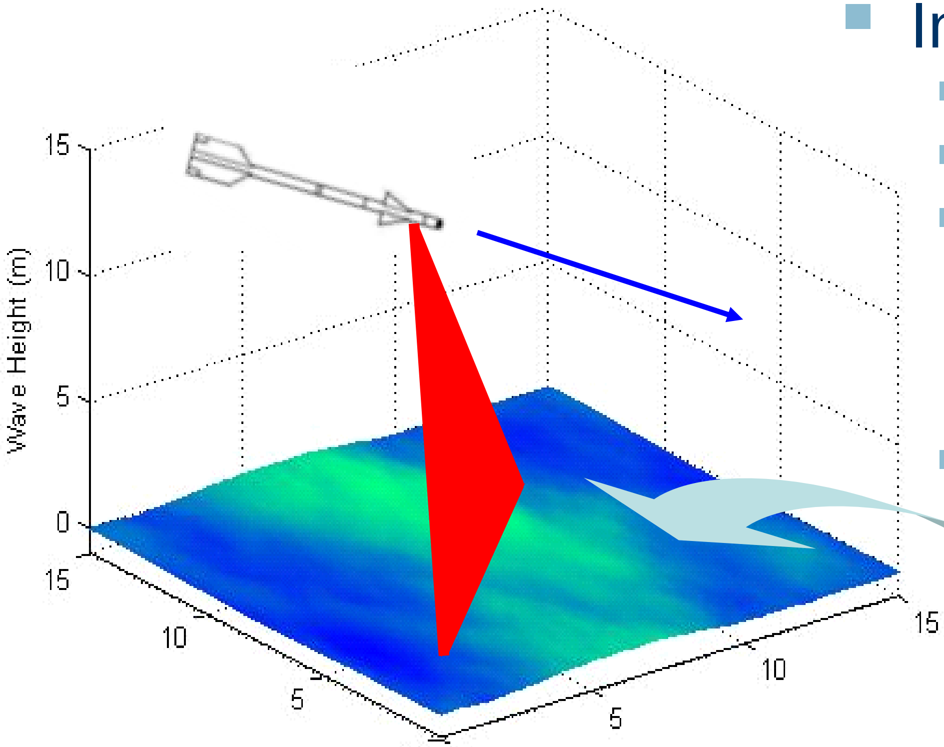


- Parameters adjusted to vary sea conditions
  - Fetch
  - Wind speed & Direction
  - Resolution (e.g. 5mm)
  - Patch Size
- Wide variety of sea conditions modelled
  - Case shown a 80m by 80m patch, 12m/s wind, 500km fetch

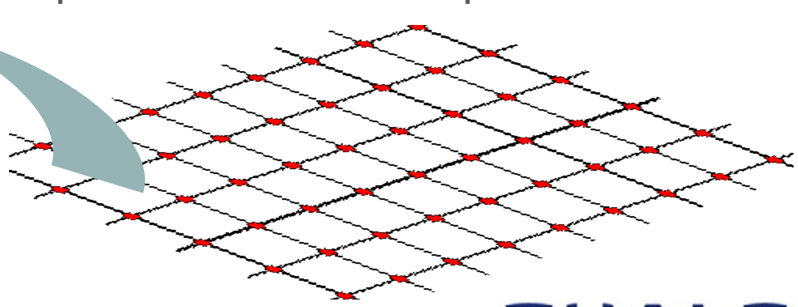
THALES

Modelling Sensor Response to the Sea

- Sea surface modelled as a regular grid of heights
  - Height at each vertex derived using the Elfouhaily spectrum
  - Characteristics of each element calculated from adjacent vertices
    - Normal vector of each element
    - Radii of curvature in two orthogonal axes



- Intersection of beams with grid
  - Shot lines calculated to each element
  - Occurrences of surface normals found
  - Incremental contributions to pulse responses determined from;
    - Sensor parameters (e.g. power, etc)
    - Element radii of curvature
  - Repeated at Pulse Repetition Rate



Model Validation – Sea Data Gathering

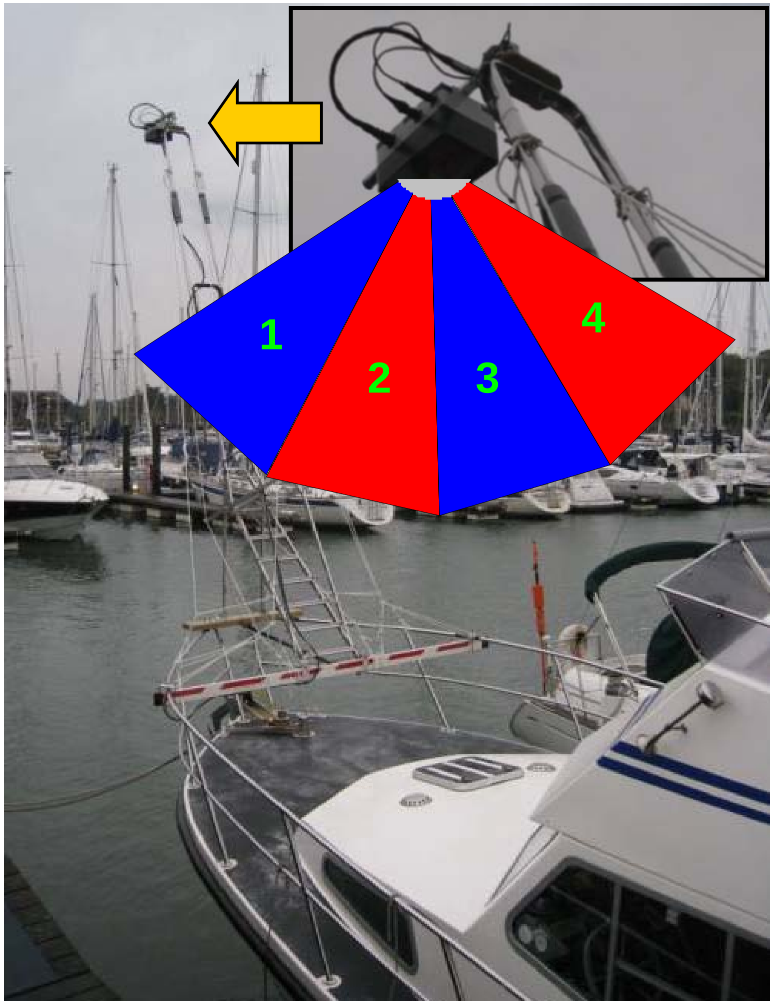
Initial Pencil Beam Laser Sensor Trials

Metric	Trials Value	Model Value	Comment
Detection rate %	~30%	~34%	~ 6kt wind

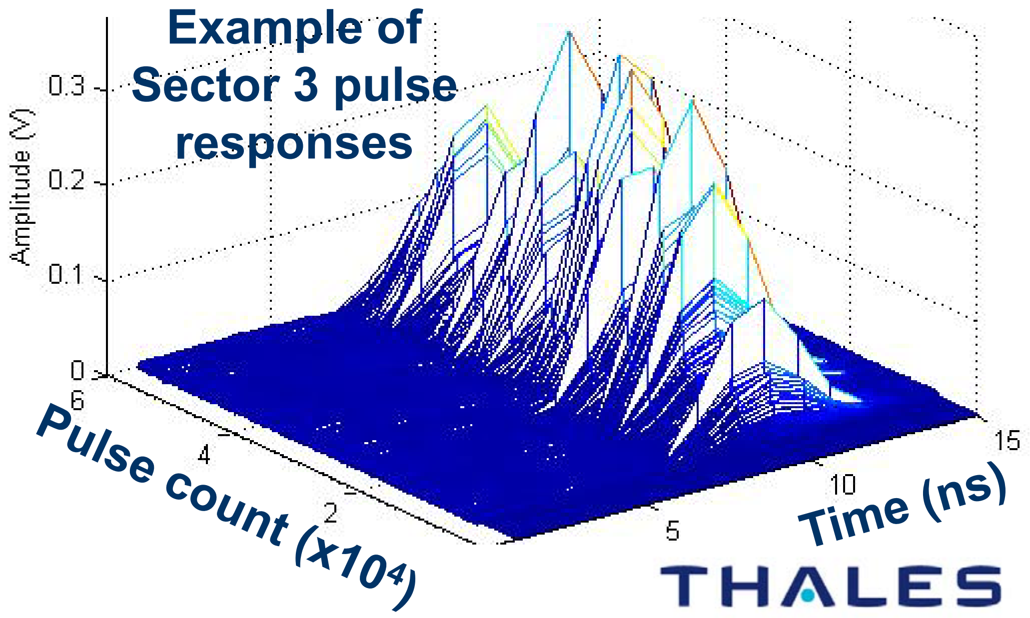
- Pulsed laser sensor
  - Narrow beam width <1°
  - Sensitivity calibrated
- Mounted on bows of vessel
  - Beam viewing sea surface ahead of wake
  - Adjustable pitch & roll angles
  - Adjustable height
  - Vessel speed ~13 knots
  - Wind speed/bearing recorded
- Threshold crossings recorded
  - Fair correlation with model
  - Provided initial validation

THALES

Multiple Fan Beam Laser Sensor Trials



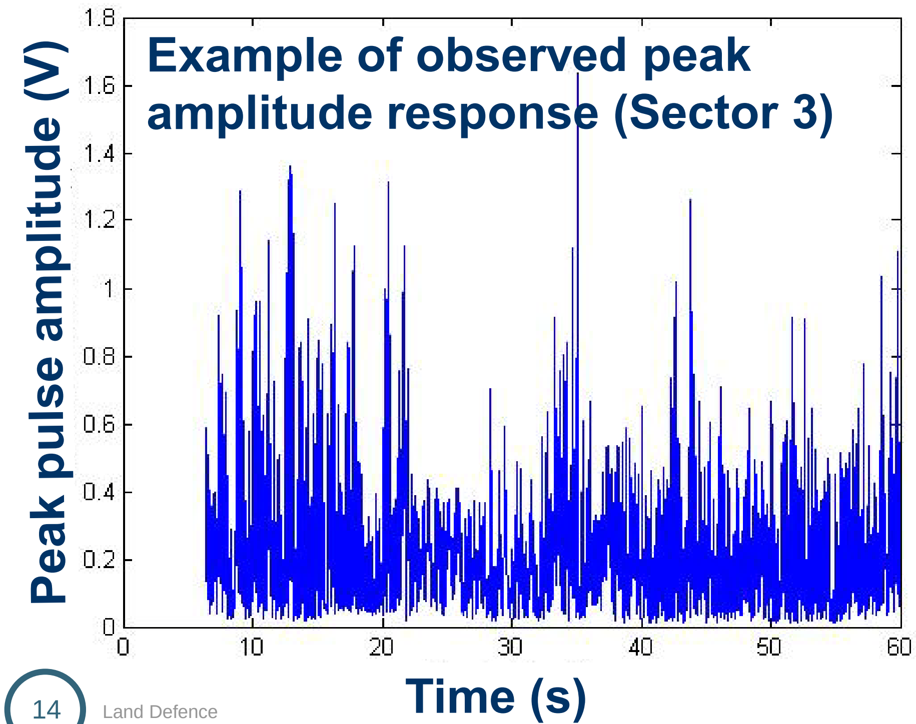
- Experimental form of future TDD
  - Four 30° contiguous fan beams
  - Partial azimuth coverage (only downward beams see reflections)
  - Received pulse waveforms digitised
  - Data recorded for various sensor orientations and sea conditions



THALES

Detection rate (%) Averaged over Multiple Cases

Sensor Height	Fan Beam Angle from Vertical (°)					
	0°		10°		20°	
	Trial	Model	Trial	Model	Trial	Model
3.4 m	89	93	86	56	36	13
5 m	80	91	83	39	9	8

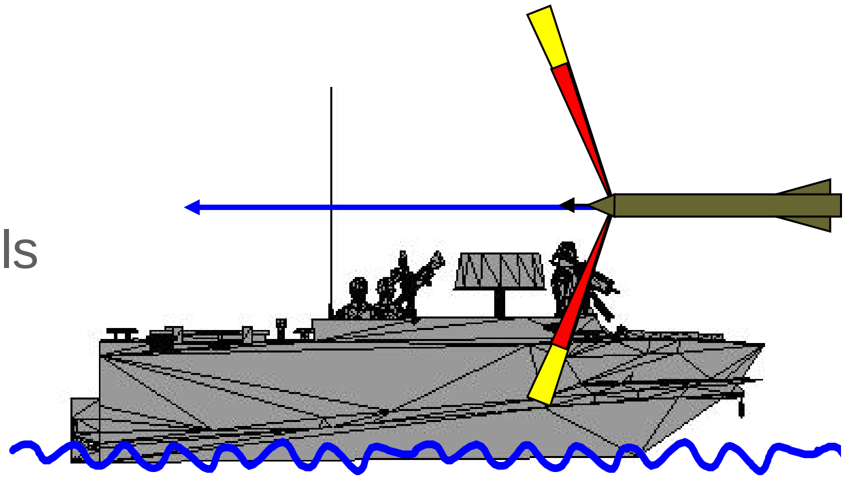


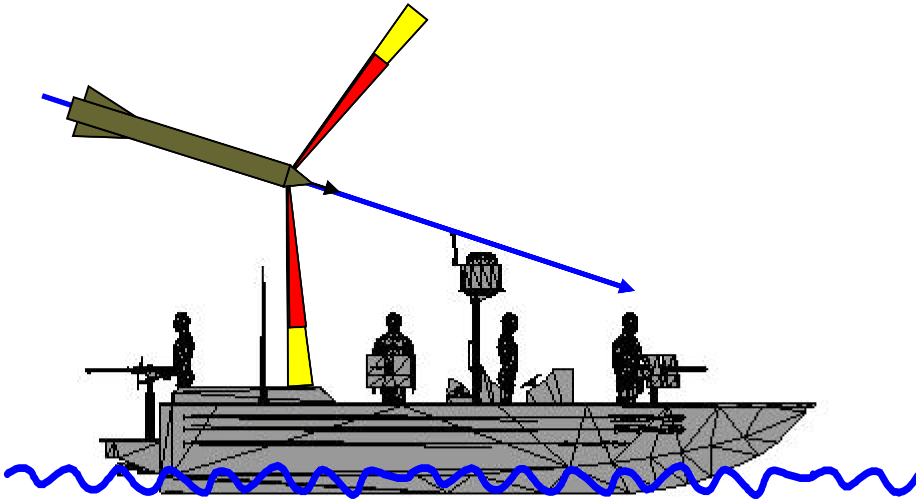
- Fair agreement between Model and practise
  - Good comparison between modelled and observed detection rates
  - Fair comparison between predicted and observed pulse amplitude distributions

THALES

Model Applications – Anti FIAC Algorithms

- FIAC targets modelled
  - 3D facet models
    - Diffuse Lambertian reflectors
  - Embedded in sea clutter models
  - Various dive angles modelled
  - Combined response to target and clutter modelled



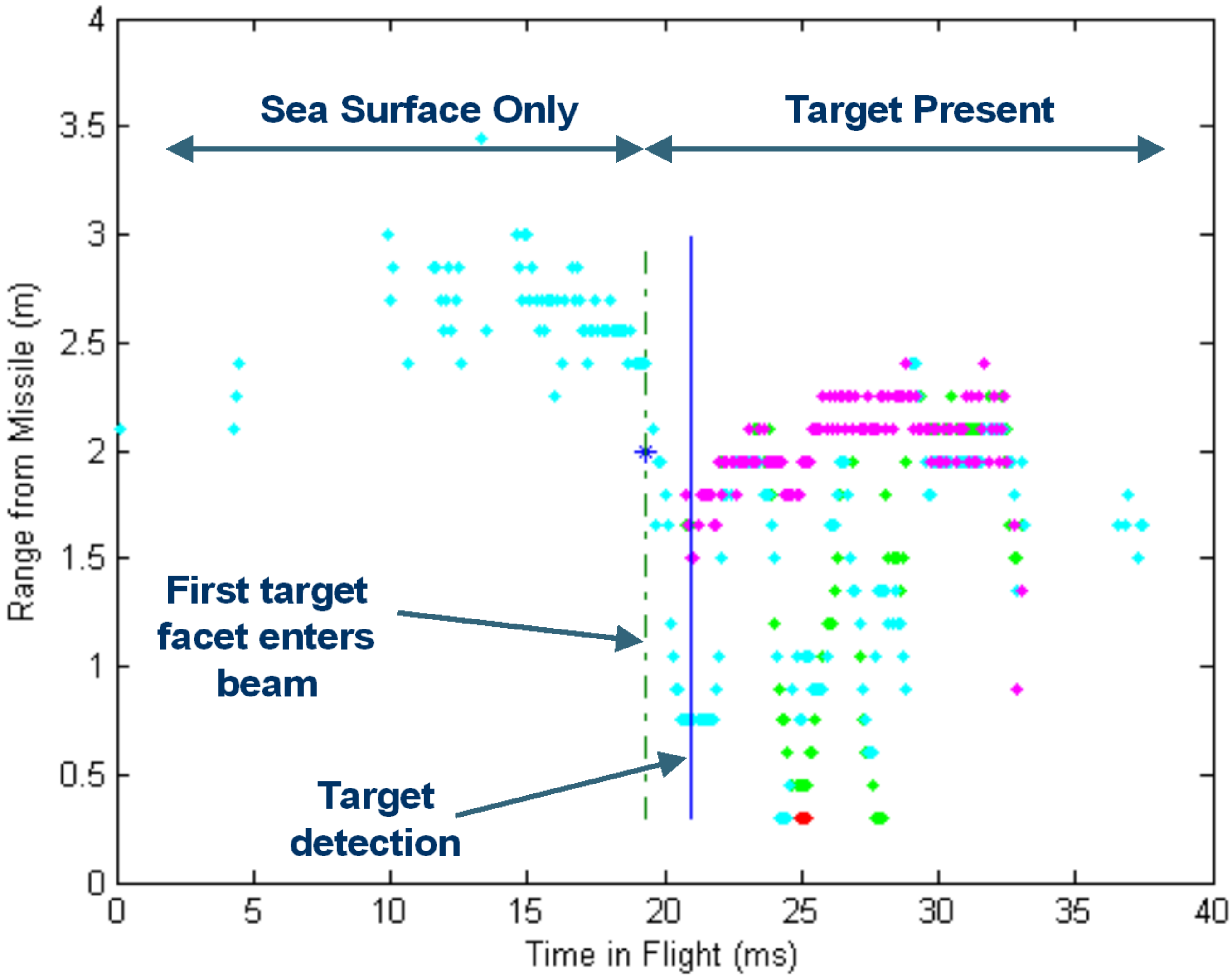


- Algorithm development
  - Sea clutter rejection
  - Reliable target detection
  - Initial algorithms constructed and tested
  - Initial results encouraging
  - Validation in progress

THALES

Model Applications – Anti FIAC Algorithms

Example Model Output – Case of Horizontal Trajectory



Sector 1 - Red

Sector 2 – Green

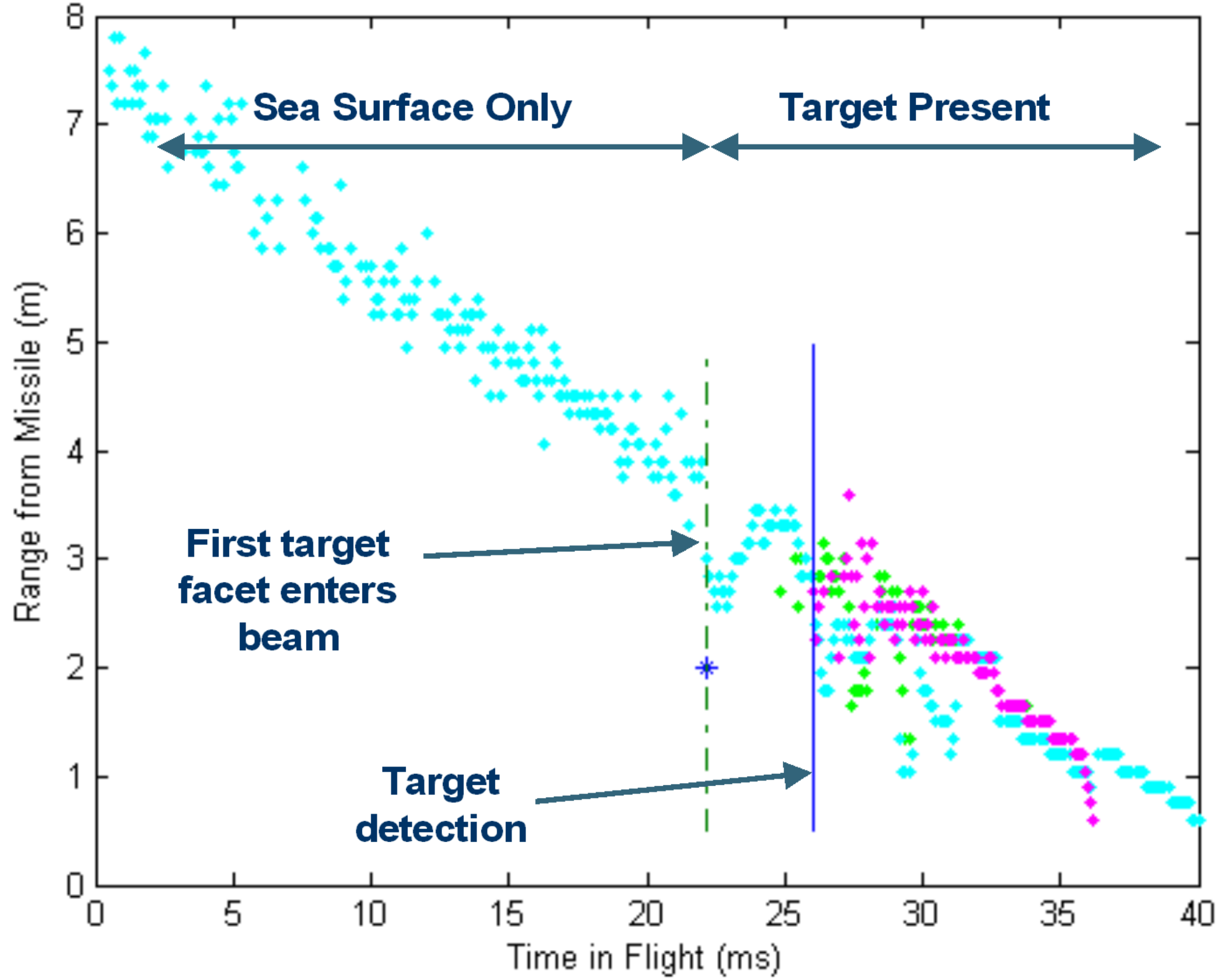
Sector 3 – Cyan

Sector 4 – Mager

Sector 4 – Black

THALES

Example Model Output – Case of Diving Trajectory



Sector 1 - Red

Sector 2 – Green

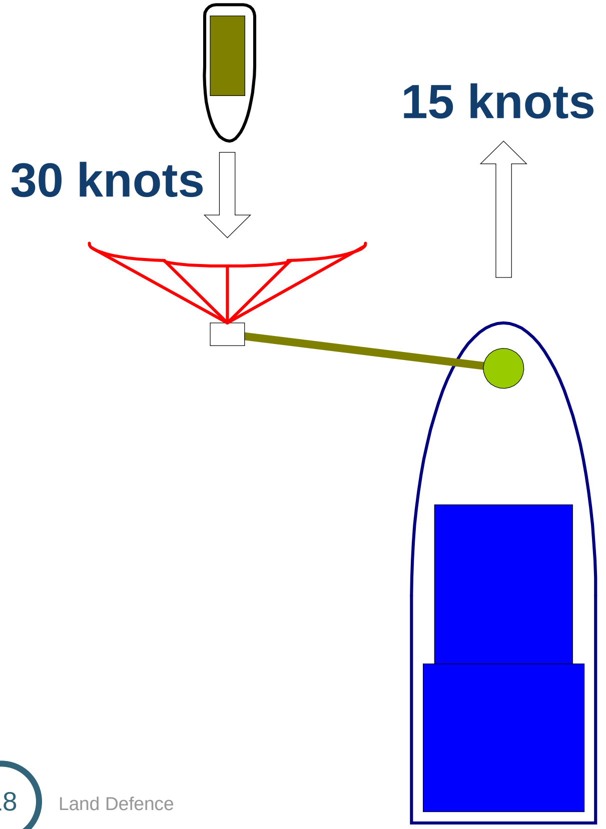
Sector 3 – Cyan

Sector 4 – Magenta

Sector 4 – Black

Recent 'AFIAC' Sea Data Gathering Trial

- Sensor deployed on boom to one side of vessel
- Rib 'target' travelling at speed under / to one side of sensor
  - Provides representative wake data
  - Data to be used for validating models and developing algorithms



THALES

Recent 'AFIAC' Sea Data Gathering Trial

THALES

Recent 'AFIAC' Sea Data Gathering Trial

Summary

- A model for the response of a multiple fan beam laser TDD to the sea surface has been developed
- Initial data gathering and model validation performed
  - Received signal levels estimated by the model compare favourably with those of the trials data
  - The predicted variability of the signal returns from the sea appears to be confirmed by the trials
- Facility to embed targets in scene
  - e.g. FIACs and sea skimming missiles
  - Supports the development of a lidar sensor TDD for Anti FIAC and anti Sea Skimmer missile applications

Any Questions ?

NDIA Fuze Conference

Kansas City, Missouri

May 11-13, 2010

RDECOM

Malcolm Baldrige National Quality Award 2007 Award Recipient

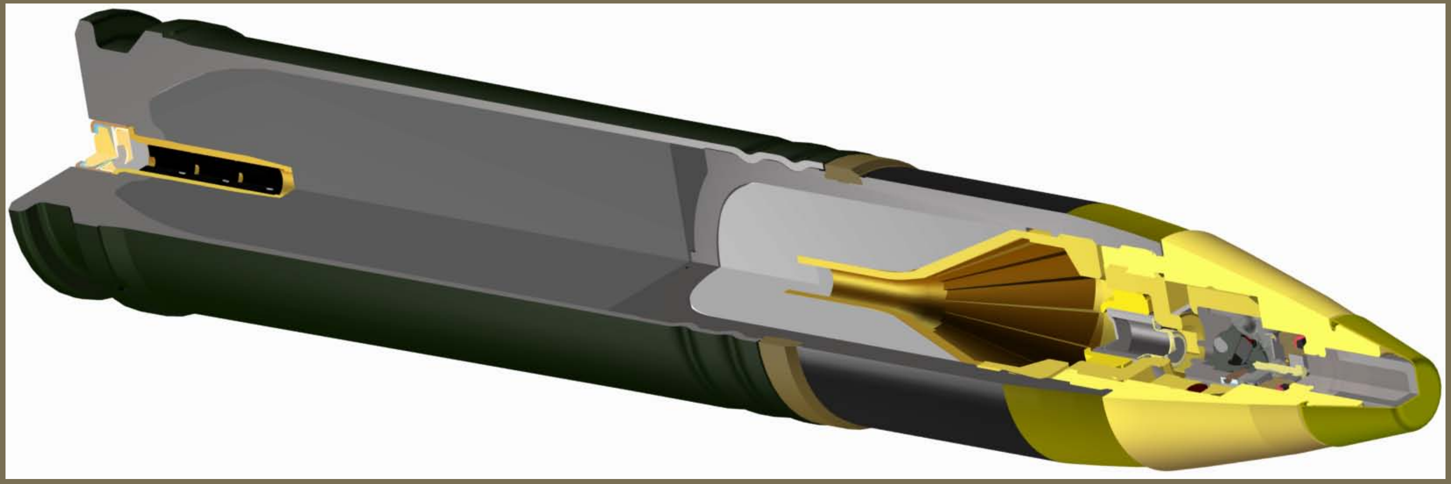
Fuze Technology Integration (FTI) Improved 30 mm

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

John T. Geaney
Advanced Fuzing Concepts Team
Fuze & Precision Armaments Technology Directorate
ARDEC

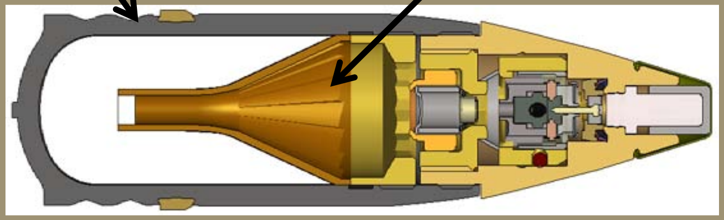
M759 Fuze

- The M759 is a Point Detonating Dual Function Fuze
  - Functional modes are impact and inertial
- The M759 Fuze is used on the M789 High Explosive Dual Purpose cartridge



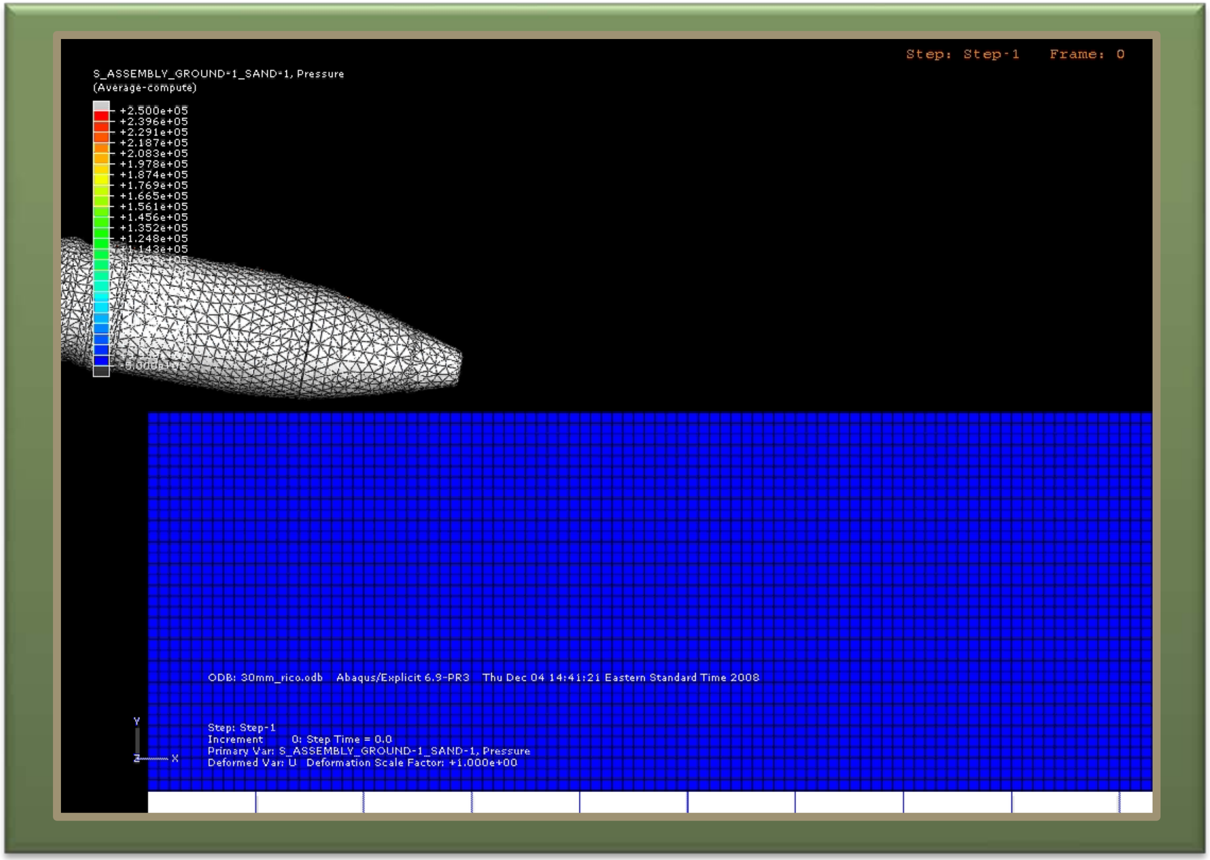
M789 Cartridge

- The M789 HEDP Cartridge is designed for use against light armor and anti-personnel targets
- The M789 is fired from the M230 Chain Gun on the Apache AH-64 helicopter



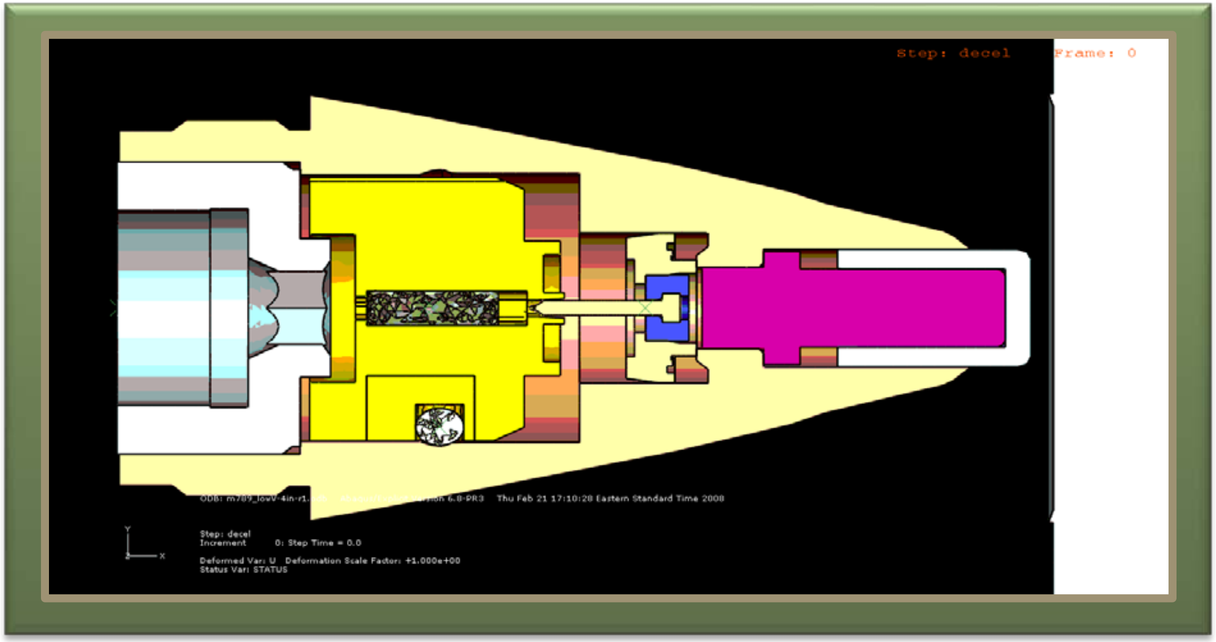
Problem

- When fired at soft targets such as sand or soil, at long range, the M789 will penetrate the target medium to a depth that minimizes the blast and fragmentation effect.
- A Fuze Technology Integration (FTI) Project was initiated to increase the soft target sensitivity of the M759 fuze



Insensitivity Investigation

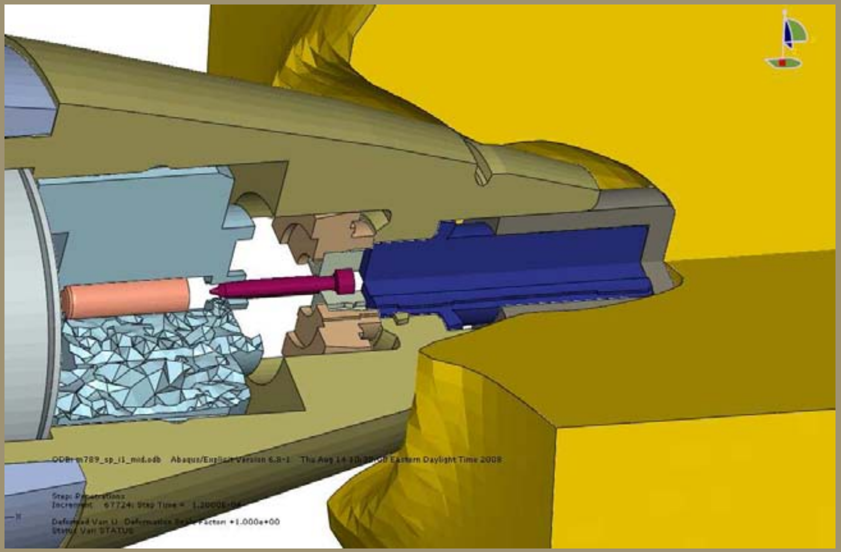
- User reports do not indicate any change in performance when the M789 cartridge is fired at hard targets
- No indication that cartridges were not detonating after impact with soft targets
- In an effort to understand the response of the current M759 configuration, modeling and simulation analysis was conducted

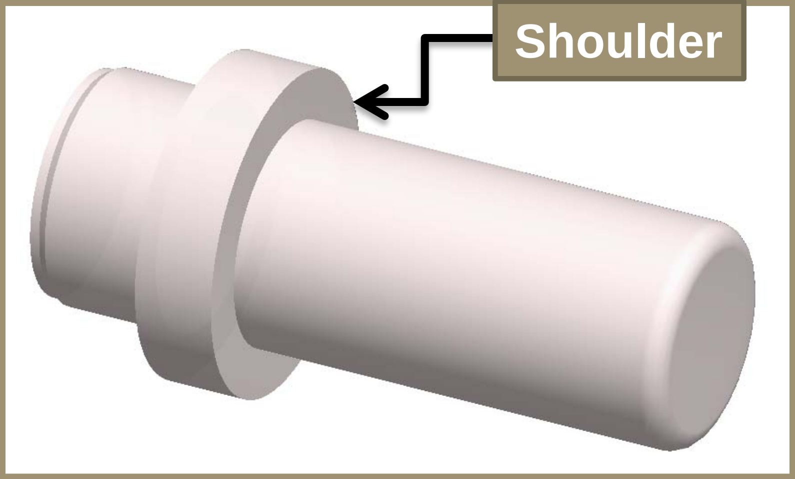


Results of M&S analysis show the projectile burying into soft target materials.

Probe Investigation

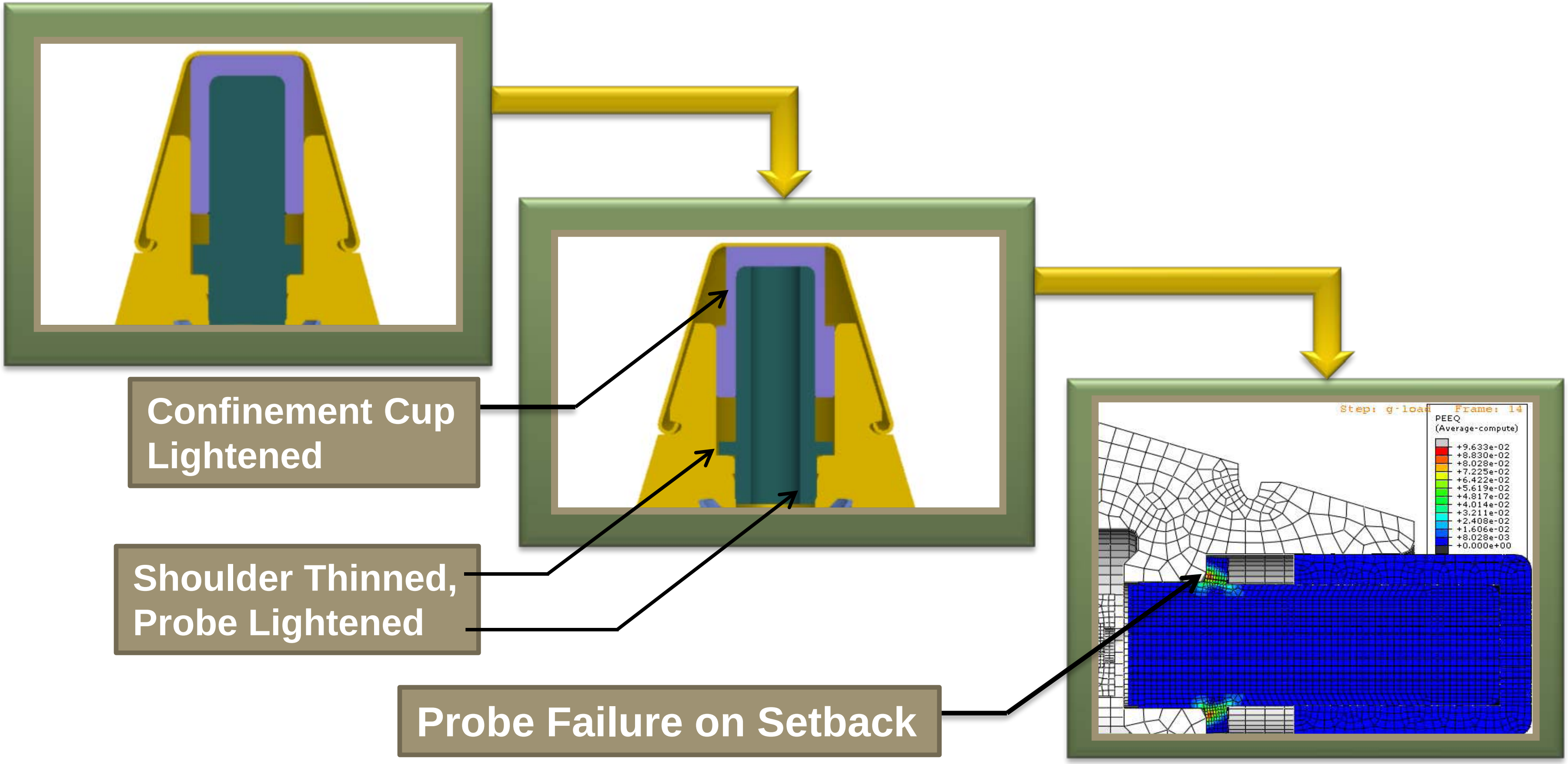
- On impact with a hard target, a shoulder feature on the glass-filled nylon probe shears, allowing it to impact the firing pin
- In addition to shearing the shoulder, the probe must overcome an interference fit in the o-give before it can slide into the firing pin
- Analysis shows that the shoulder does not shear on soft target impacts.





Probe Investigation

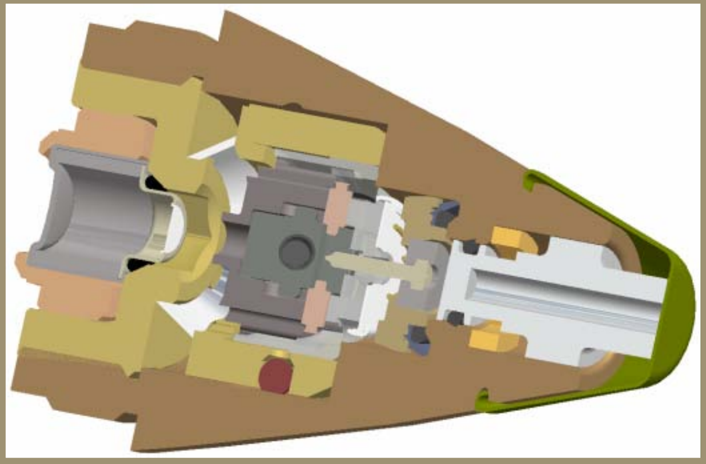
- Efforts to optimize the probe, shoulder, and probe confinement cup did not yield a design that would survive the inertial loading during setback and shear on soft target impacts



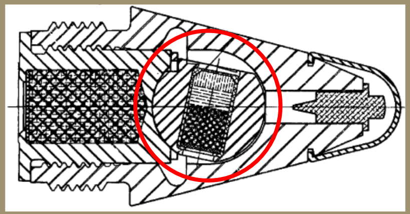
Spin Clip Design

- As an alternative to the probe shoulder feature, a spin clip solution was investigated
- The spin clip constrains the probe during setback and releases at the tactical spin environment
- A similar design approach is used in the M505A3 fuze
  - A spin clip provided anti-rotation to an unbalanced rotor

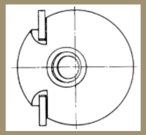
M789 with Spin Clip



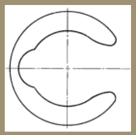
M505A3 Fuze Assembly



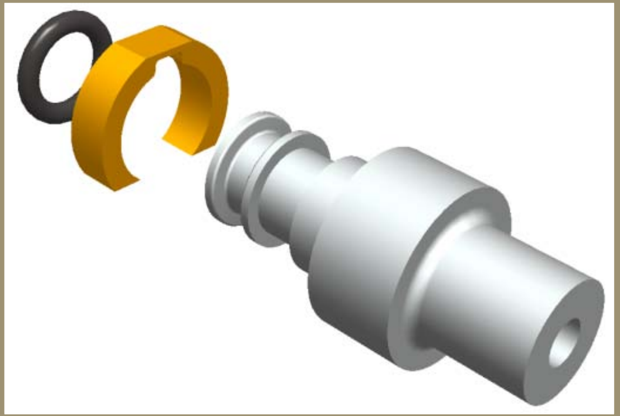
Rotor Assembly



Rotor Detent Spring



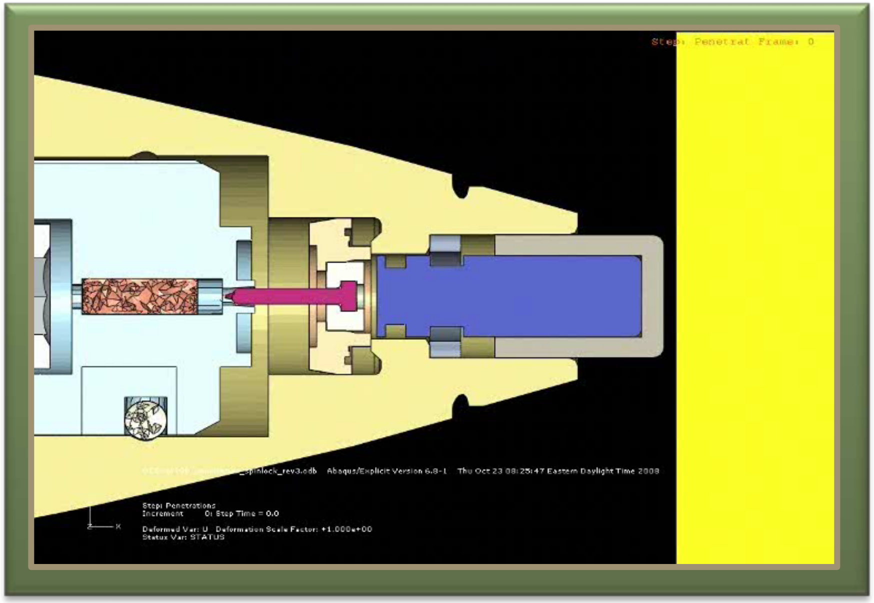
Modified Probe & Spin Clip



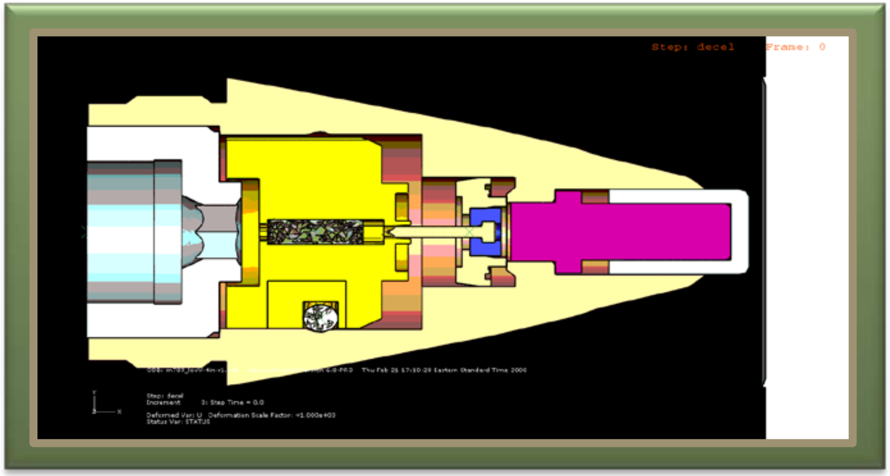
Spin Clip Design

- Baseline M759 model used to simulate spin clip performance
- Spin clip simulation illustrated increased sensitivity compared to baseline simulation on soft target impacts
- Long range (Low Speed) conditions were modeled in the simulation to illustrate the worst case sensitivity scenario

Spin Clip Configuration



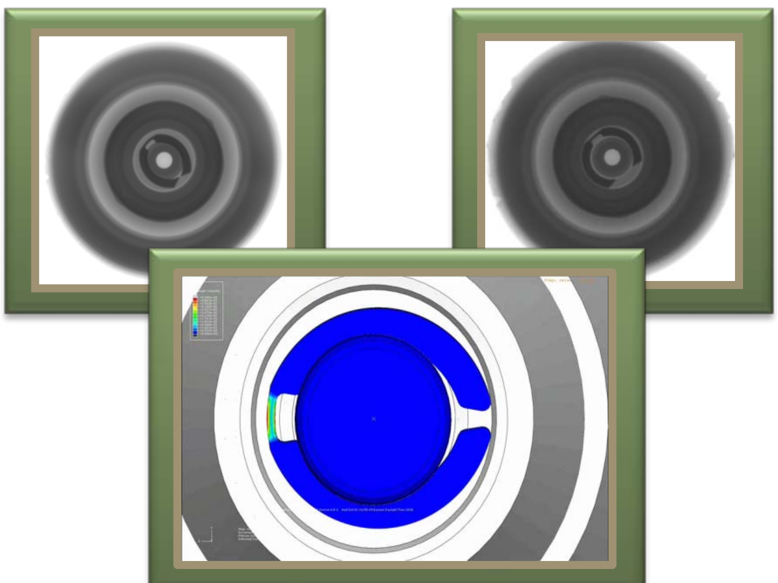
Production Configuration



Spin Clip Testing

- Small lot of spin clips and modified probes manufactured at the Fuze Development Center, ARDEC
- Airgun tests and high speed spin tests conducted to verify results of modeling and simulation
- Results of bench testing provided confidence to build prototype fuzes

High Speed Spin Testing to 60,000 RPM



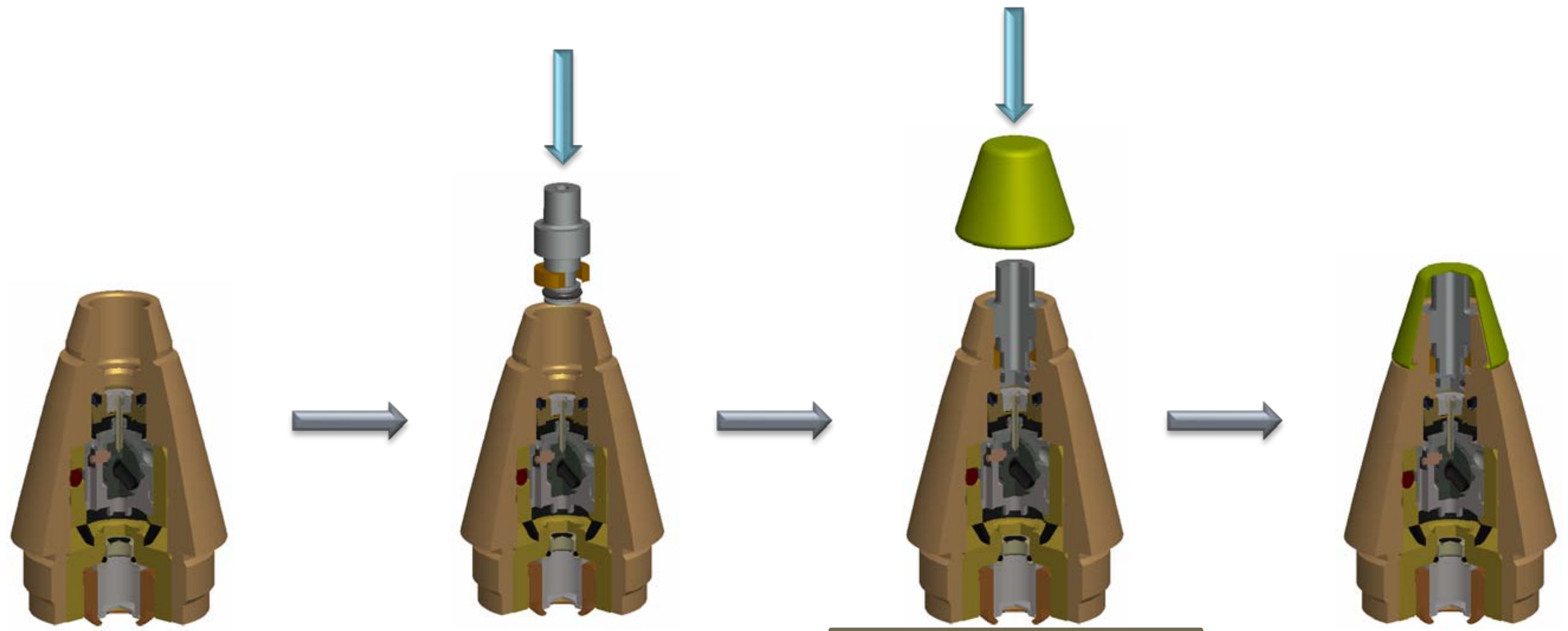
Airgun Testing To 125,000g's

Post Airgun

Post Spin

Prototype M759

- April 2009, 110 prototype fuzes assembled at Allegheny Ballistics Laboratory (ABL), Rocket Center WV
- Fuzes were assembled on the assembly line, and removed at the probe installation step to be hand assembled



Fuzes removed from assembly line at probe installation.

Probe assemblies installed by hand.

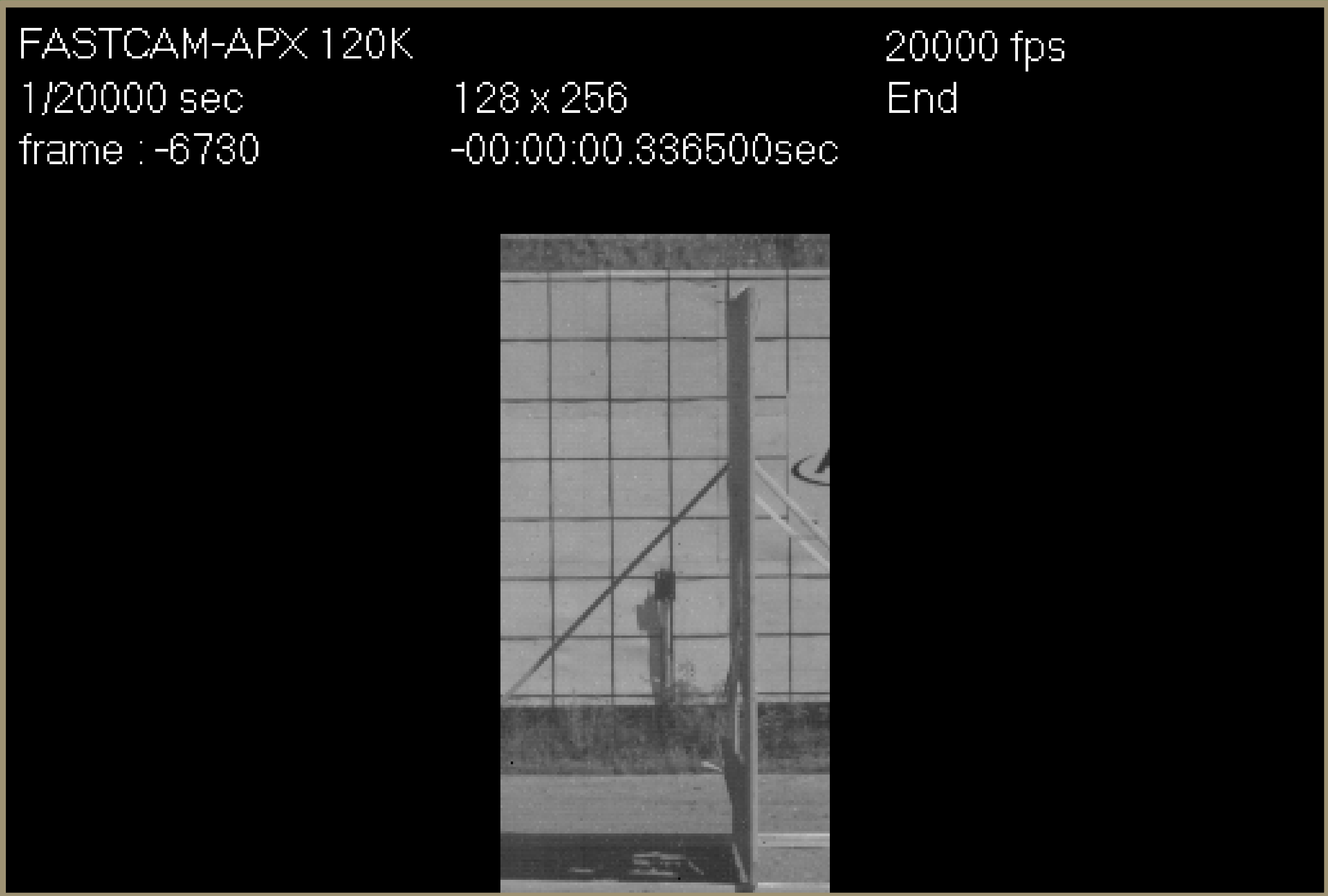
Fuzes returned to assembly line for assembly completion.

Prototype M789 Testing

- June 2009, soft target sensitivity testing was conducted at Alliant Technologies Proving Ground (ATPG), Elk River MN
- Prototype and production configuration M789 projectiles fired at ¼" plywood targets at a range of 1000m
- 45 prototype configuration projectiles detonated on impact with target, all prototype projectiles functioned on target
- 21 production configuration projectiles passed through plywood targets and detonated on impact with smash plate behind target, all production projectiles passed through target without functioning

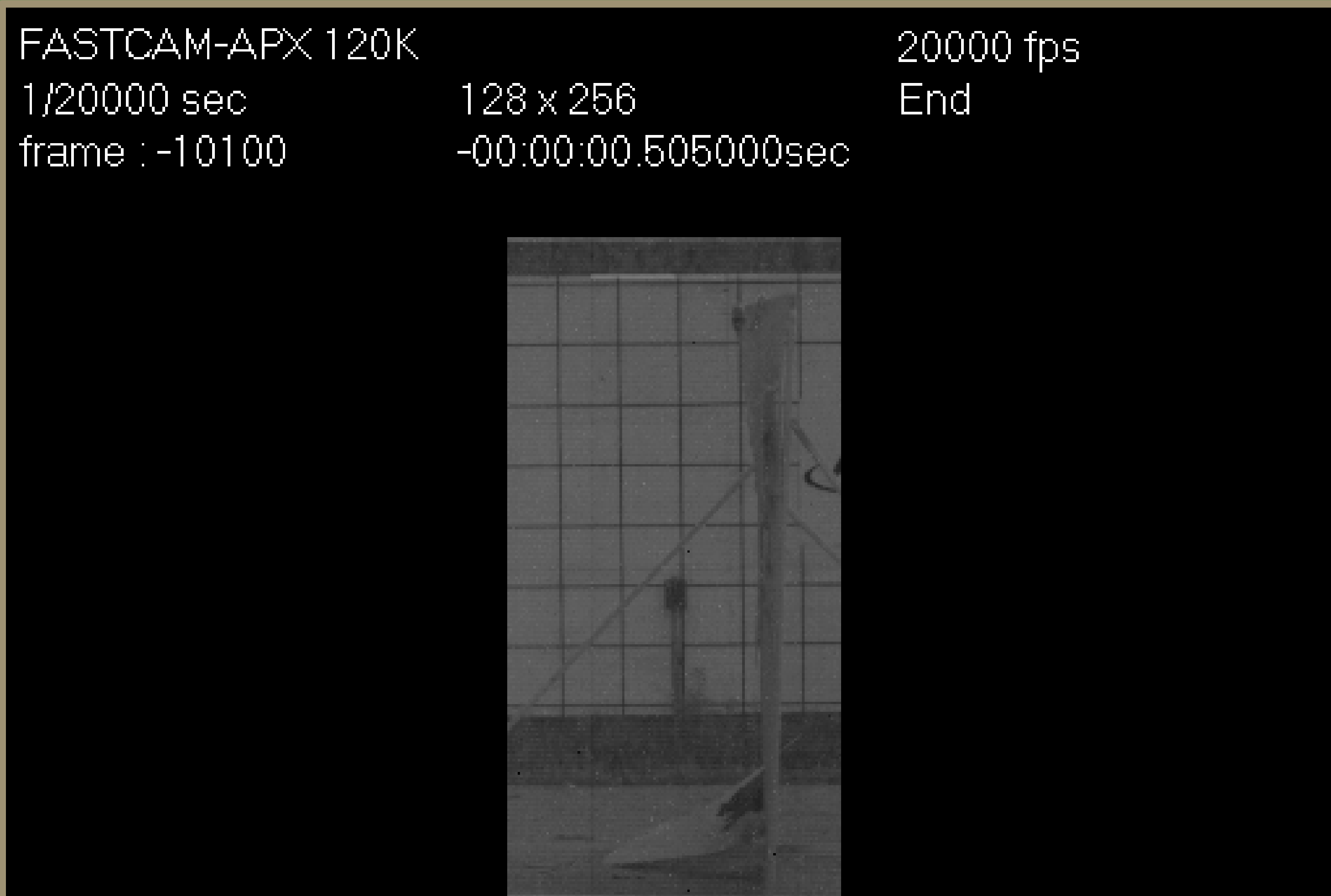
Prototype M789 Testing

Production Configuration M789, ¼” Plywood Target, 1000m



Prototype M789 Testing

Prototype Configuration M789, ¼” Plywood Target, 1000m



Prototype M789 Testing

- December 2009, sand target testing conducted at Yuma Proving Ground (YPG), Yuma AZ
- Prototype and production configuration M789 projectiles fired at a groomed sand pad at a 2000m range
- Complications with video coverage and projectile accuracy yielded few usable data points
- Delay can be seen in production configuration as projectile scrapes across the sand prior to detonating, no such delay seen in prototype configuration

Prototype M789 Testing

Production Configuration M789, Sand Pad, 2000m

Prototype M789 Testing

Prototype Configuration M789, Sand Pad, 2000m

Future Work

- Conduct assembly of additional 750 prototype cartridges
- Conduct Pre-First Article Acceptance Testing to verify performance
  - Arming, Non-Arming, TV-T, Target Reliability, Armor Plate Sensitivity
- Conduct Sand Berm Sensitivity Testing
  - Collect additional sand response data
- Conduct Brush Sensitivity Testing
  - ¼” Plywood, 1/16” Chipboard, ½” Celotex, ¼” Ø Wood Dowel Array
- Conduct fragmentation testing to quantify sensitivity affect on lethality

Questions?

UNCLASSIFED

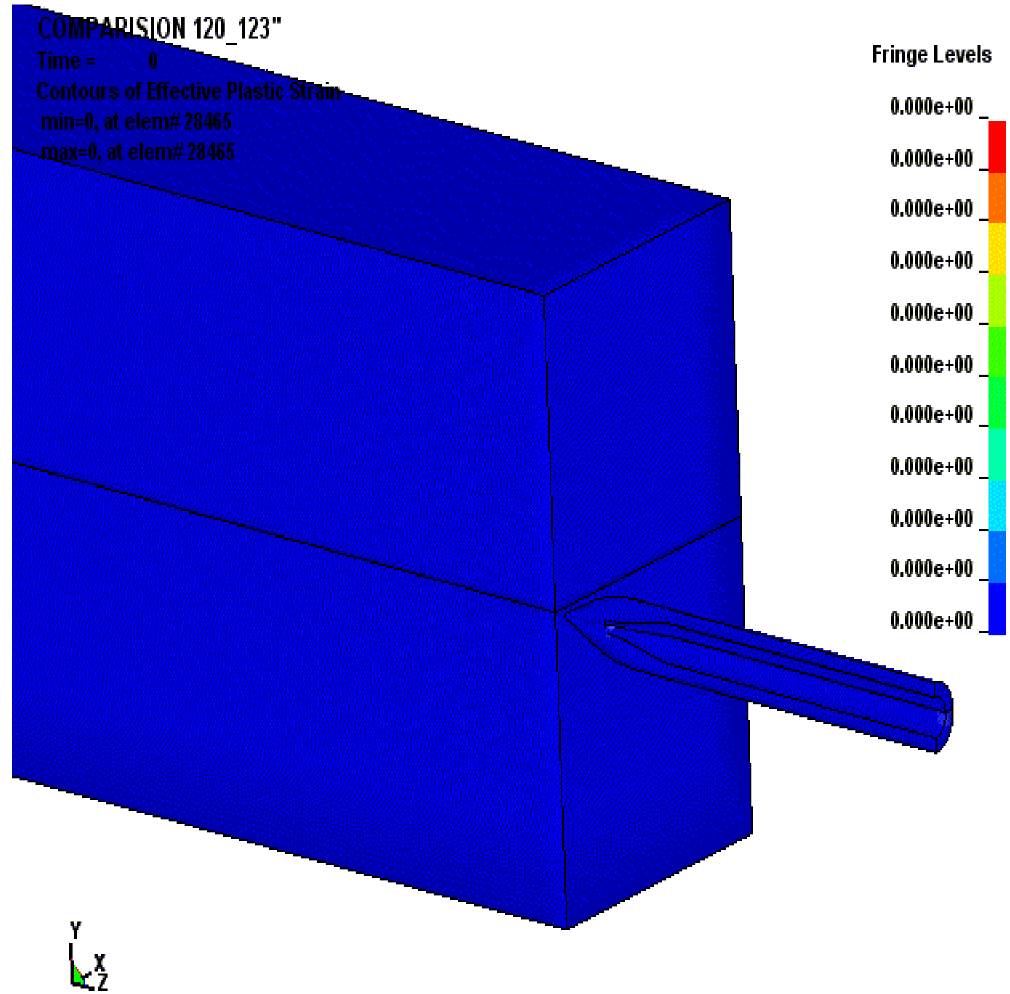
54th Annual NDIA Fuze Conference; May 12, 2010

TITLE

Dynamic impact simulation of “high *g* hardened fuzes”.

AUTHOR

Paul Glance, PhD
ME US NAVY
CHINA LAKE



Purpose and goal

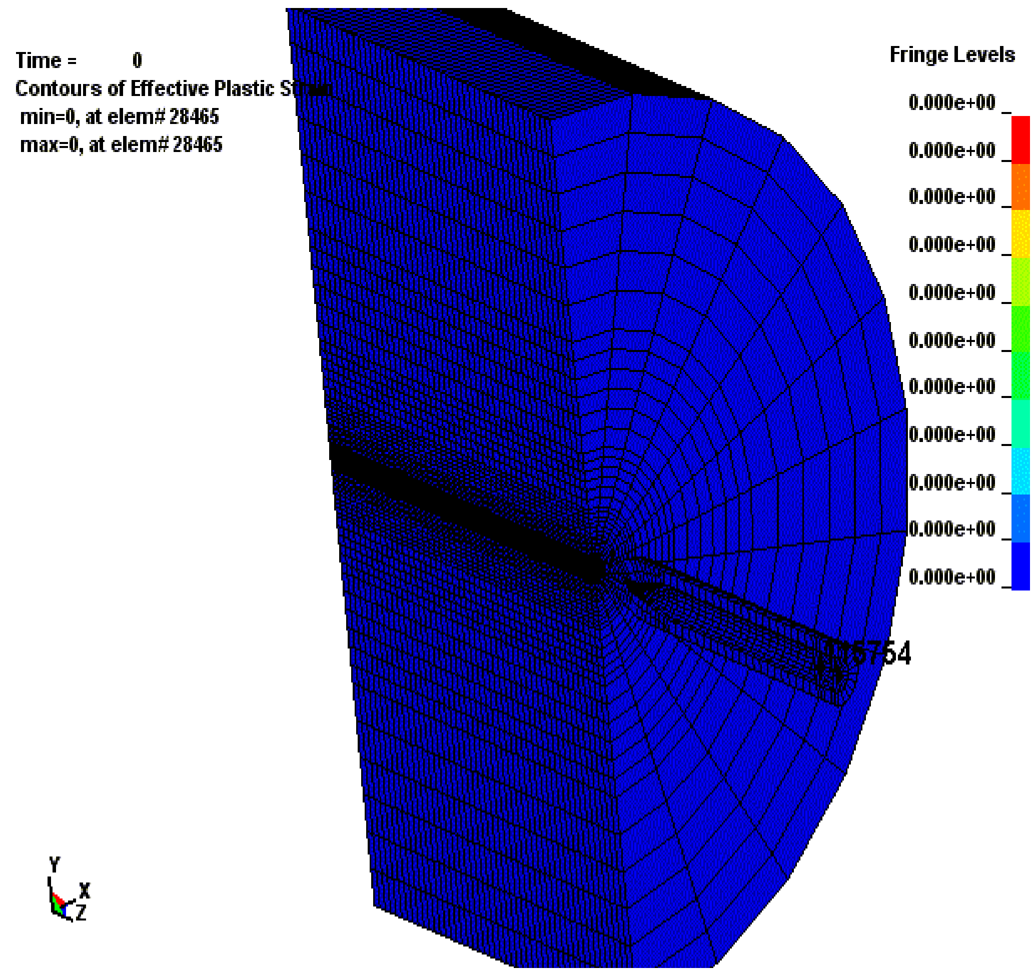
- The purpose of this paper is to document the development of a new simulation tool which is being employed to simulate deceleration, stress, and strain imposed on penetrators and fuzes during typical cannon and sled tests.
- The secondary goal is to create standard "LS-DYNA input templates" which can be employed by the "non-expert user" to simulate cannon and sled tests.

New Simulation method

Concrete model
*MAT_159
Failure damage
User friendly
Fast / Robust

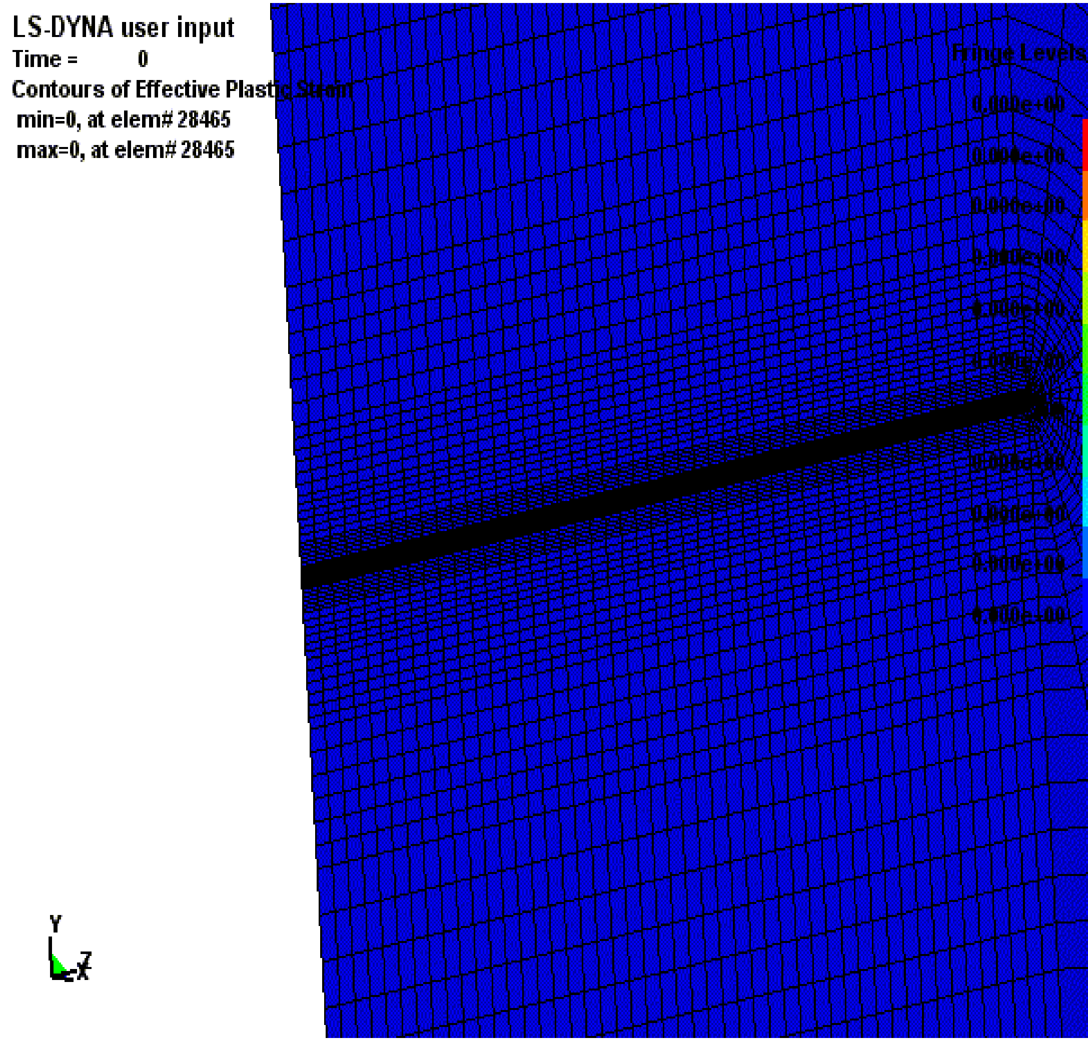
Lower stiffness material dominates performance
e.g. concrete
10 times lower mod
10 times lower yield

Concrete model is critical
Penetrator is secondary



Down load written paper

- UNCLASSIFIED LS_DYNA input template can be down loaded DTIC website
- UNCLASSIFIED written paper version of presentation may be down loaded DTIC website
- paul.glance@navy.mil
- 760-939-7358



BACKGROUND

- Cannon tests and rocket propelled sled tests are the standard test methods employed to “proof test” the successful operation of hardened fuzes.
- The new LS-DYNA concrete material model (*MAT 159) and eroding contact option allows rapid simulation of impact penetration and by-passes the need for excessive computer run times often required for Arbitrary Largrangian Eulerian (ALE) LS-DYNA models and equation of state (EOS) material models.
- This paper describes a simple, fast running LS-DYNA application for simulating cannon and sled tests which runs on a “Dell workstation employing one Intel processor” in a few hours of equation-solver time and accurately predicts; depth of penetration, exit velocity, deceleration, and the typical “conical” entrance and exit fracture patterns in a concrete target.

Three types of impacts

Three impact cases are investigated and the results compared to test data. The three cases are:

- Case-1, typical calibration impact case of a known penetrator impacting, arrested, and captured by a large concrete block. Compare to open literature.
- Case-2, typical cannon test with concrete target blocks. Compare to on-board data recorder.
- Case-3, typical sled test with a sequential target set consisting of concrete blocks, air voids, and back stop. Compare to prior tests.

Post-test photographs of the impact face of the 1.83, 1.37, and 0.91-m diameter targets.

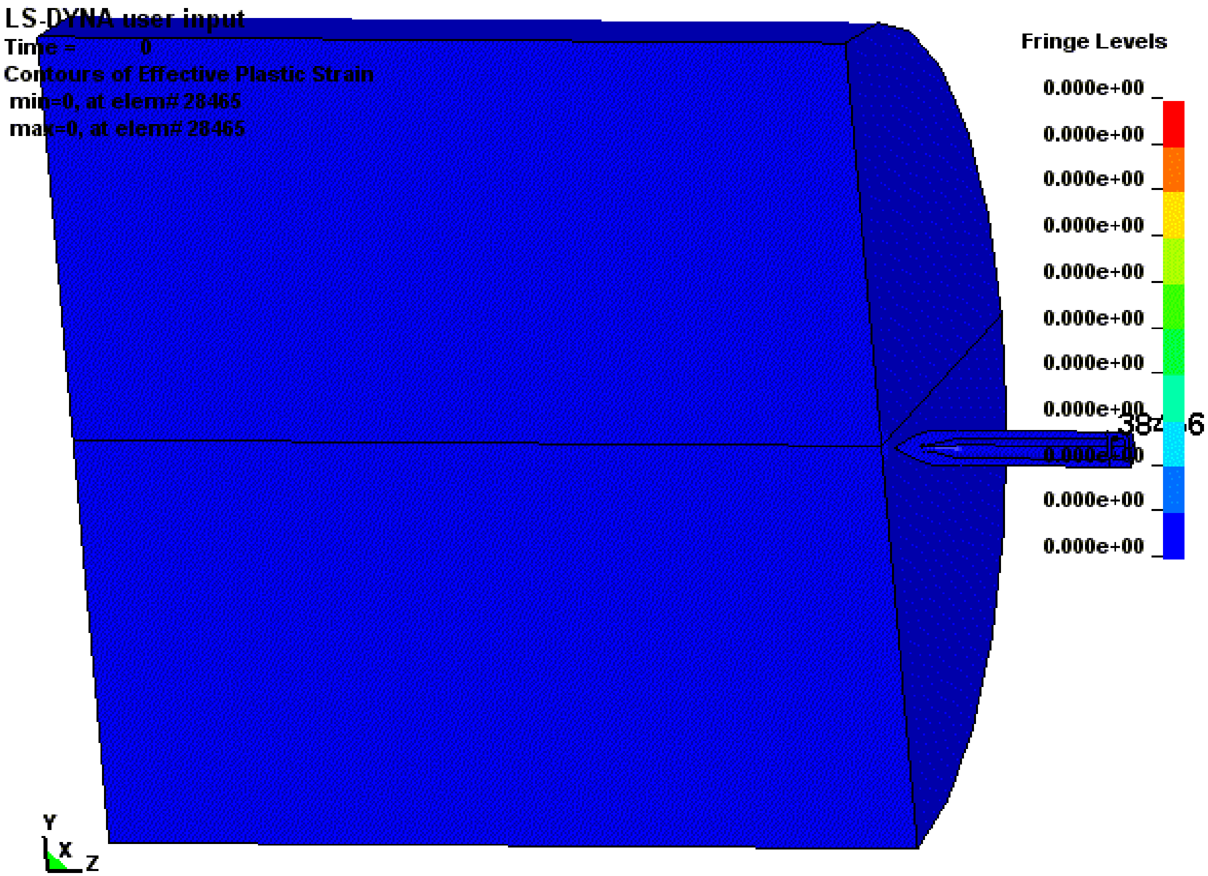
D/d = 24
V_s = 335 m/s

D/d = 18
Vs = 332 m/s

D/d = 12
Vs = 337 m/s

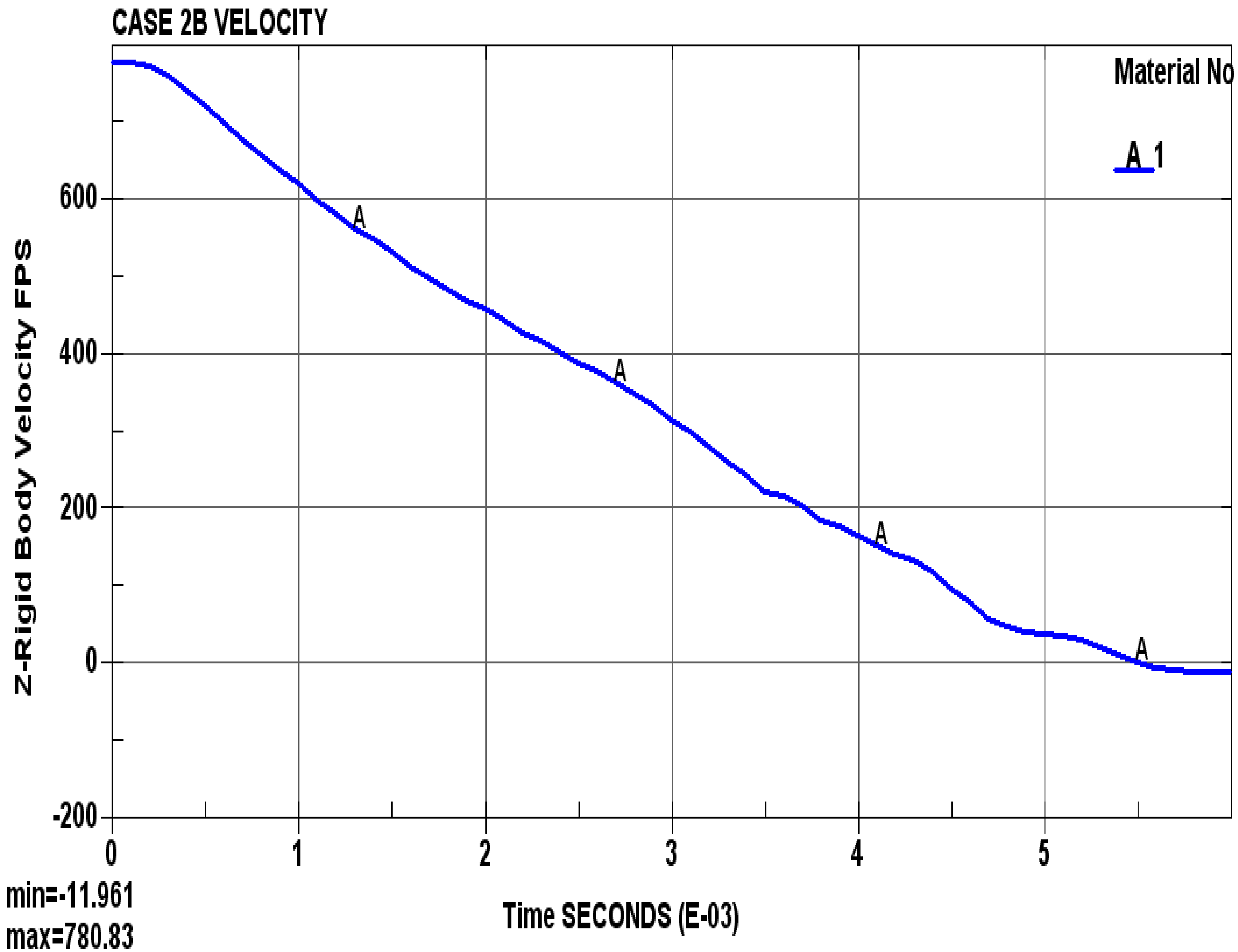
Case 1b, no exit, large target, correct damage pattern, penetration and rigid body deceleration

1/3 to 1/2 dia damage



Case 1b Velocity

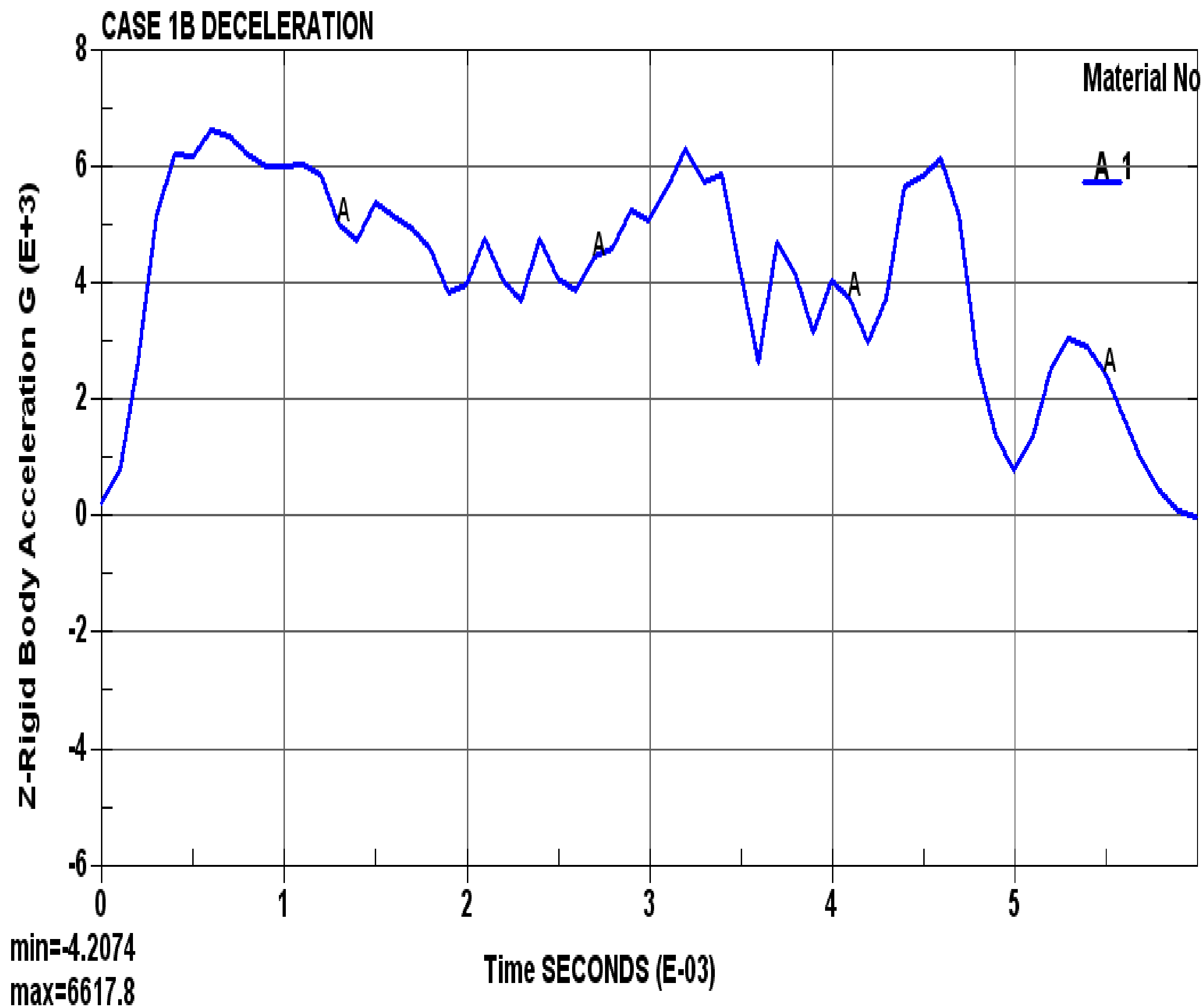
Approx
Linear negative
slope



Case 1b Deceleration

Square wave
Deceleration pulse
For case1 only

Concrete acts as
Energy absorber
Applications
Back stop

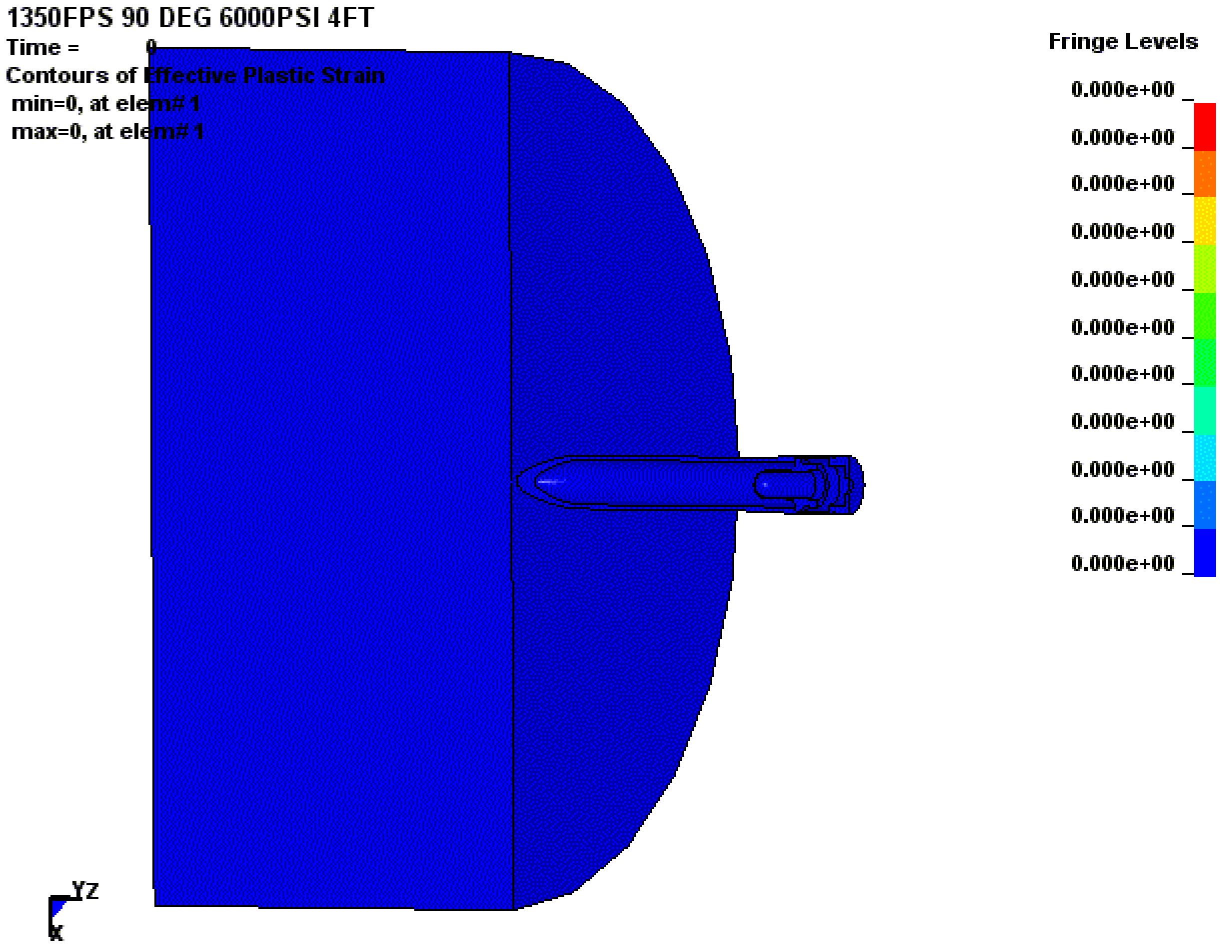


Case 2 Eglin Air Force Cannon test

Case 2 Eglin Cannon test exit face

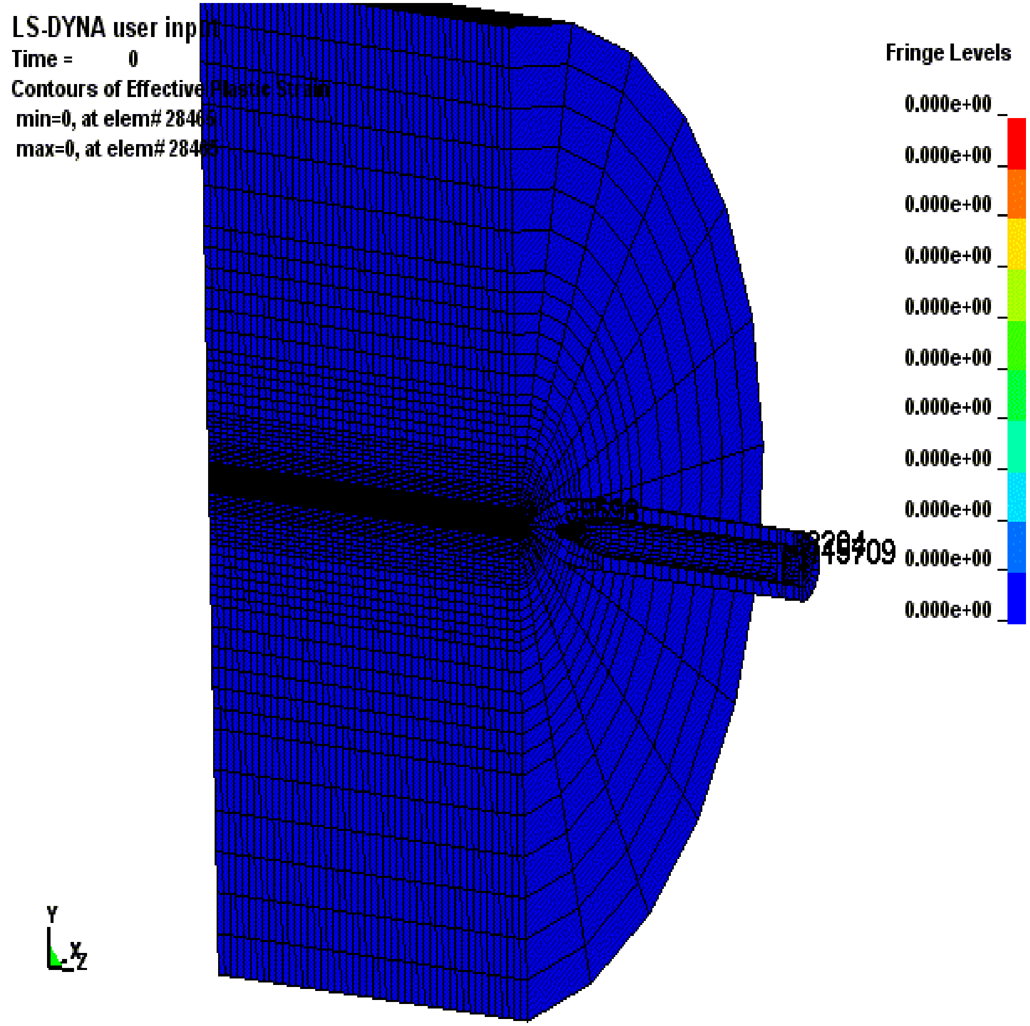
Note exit face 100% fracture

Case 2, cannon, 4 feet concrete correct exit velocity and deceleration

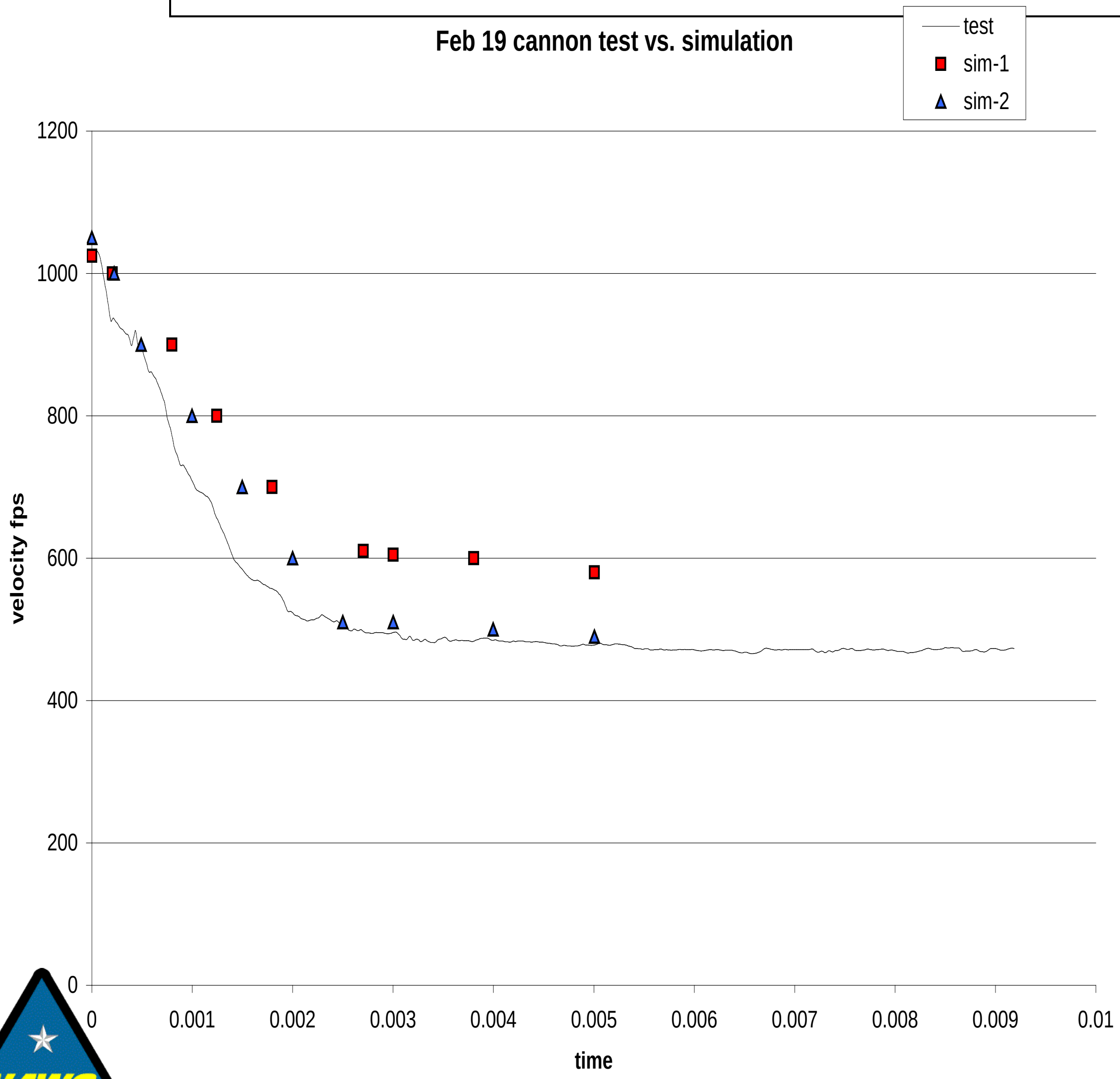


Approx fracture pattern

The concrete fracture region (erosion region) and spall pattern of the present methodology also agrees in general appearance with high speed test film but varies from test to test due to the nearly random crack propagation of concrete. The high speed film of the test shows that the concrete continues to fracture after the penetrator has exited the target.



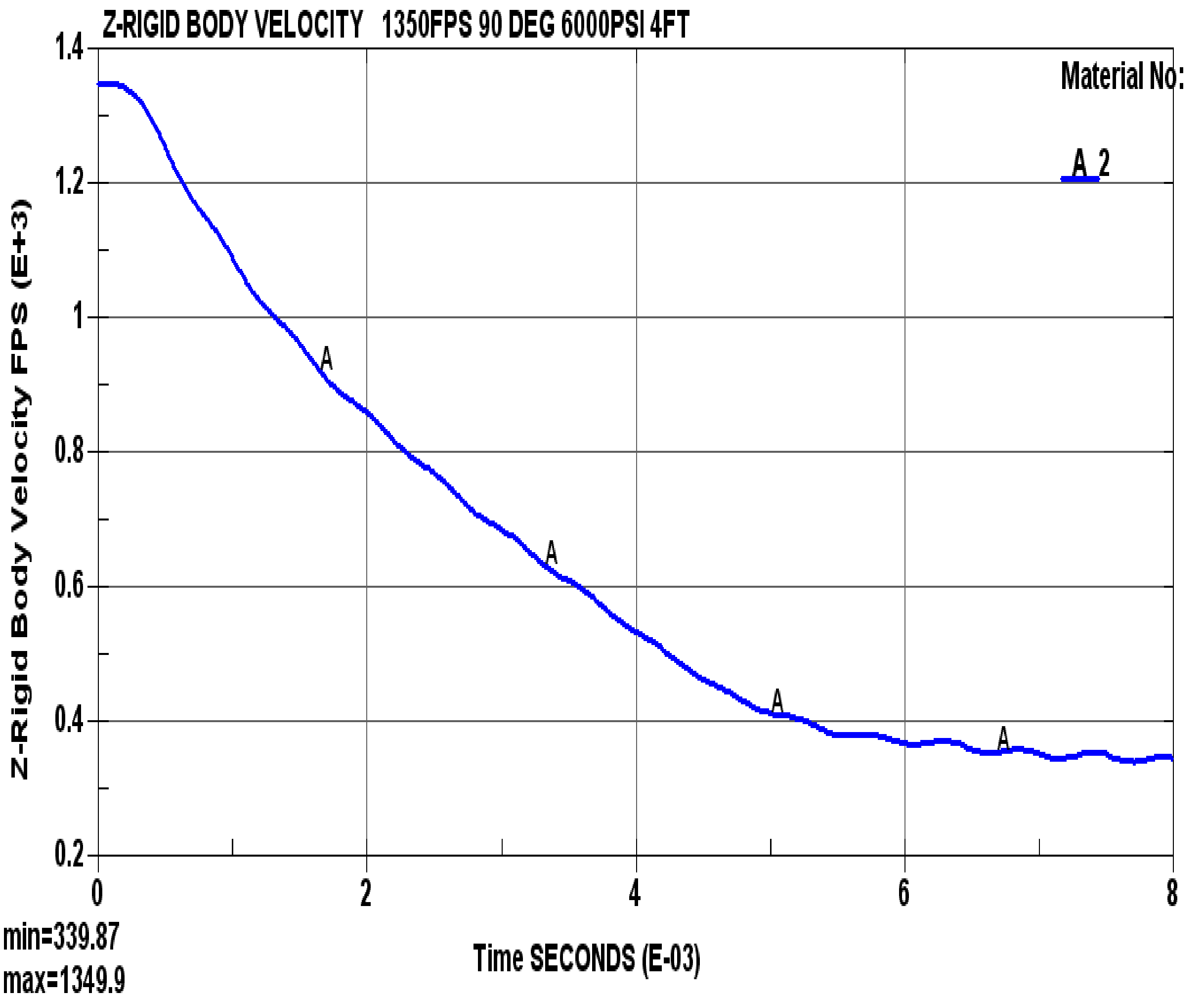
Comparison test vs. simulation; velocity vs. time



Second iteration
Approx matches
Test data

Concave curve
Entrance max negative slope
Break exit face
Sliding friction

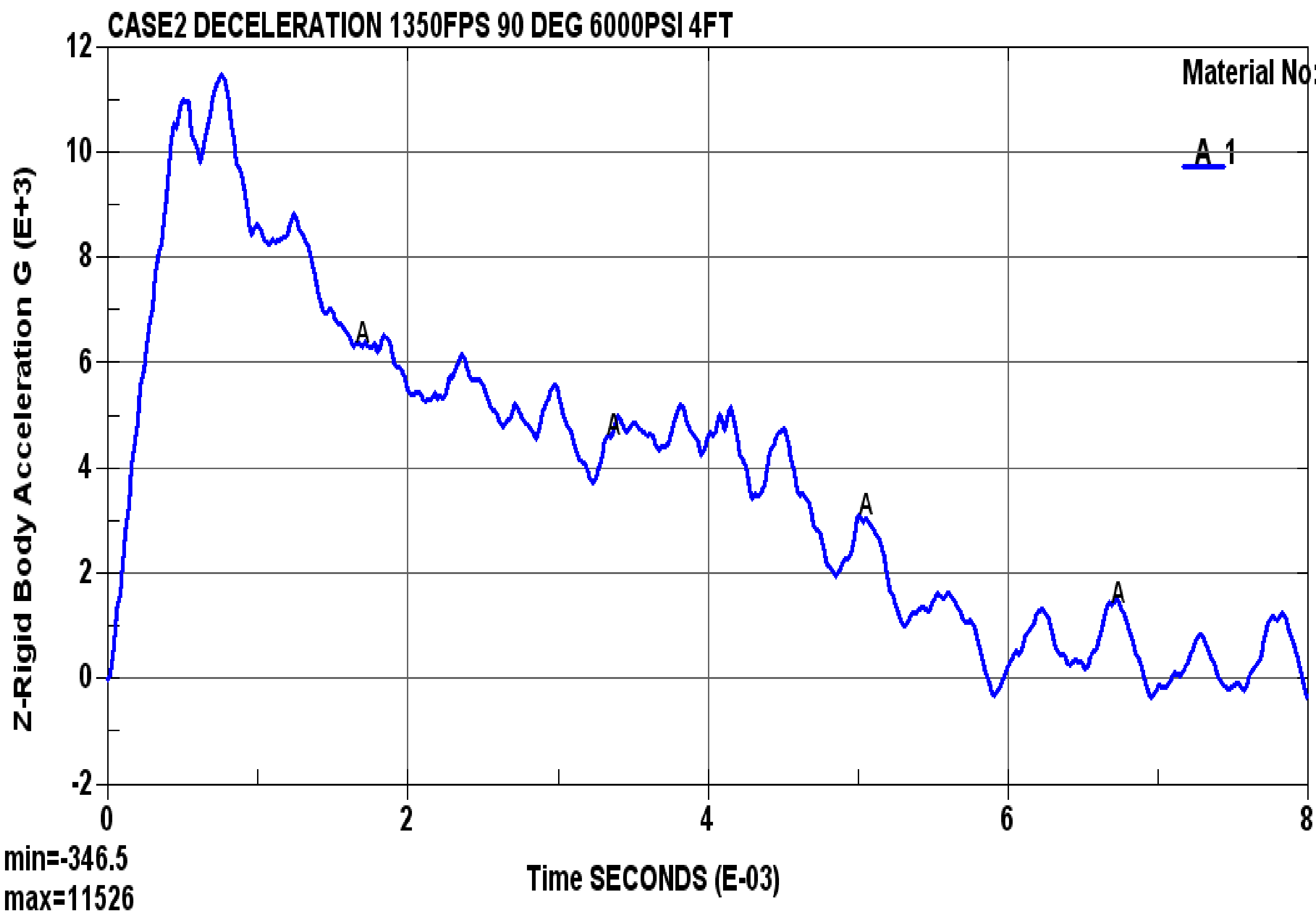
Rigid body velocity exit 340 vs. 358



Concave curve
Break exit face
Sliding friction

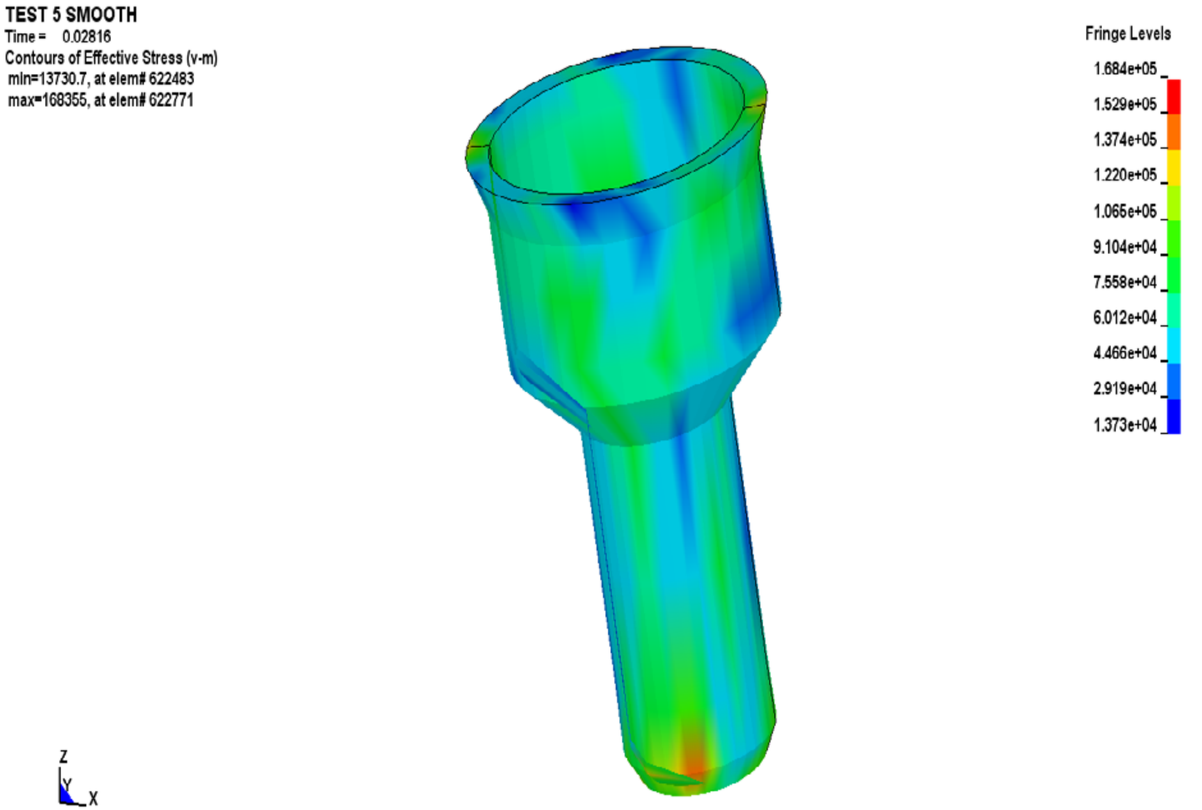
Rigid body deceleration

Peak G reported depends on
Filter
Location
Type accelerometer
Sampling rate



Max stress during impact for generic fuze well

Max strain and stress
For each part at each time step
Determine failure

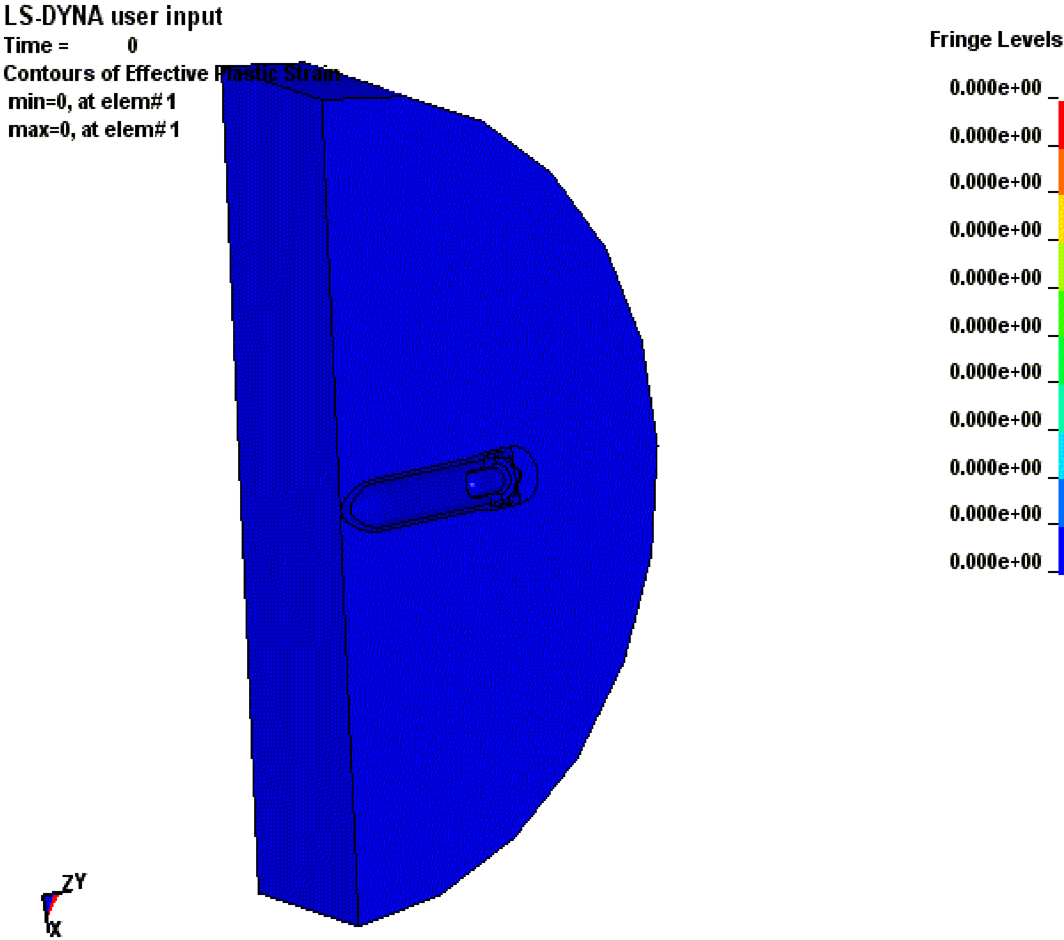


Case 2b, 15 degree, 2 feet concrete

Same Input parameters for;

6 target sets
Large and small penetrators
Large and small diameter targets
Range of impact velocities
Range of angles of impact
Half and quarter models
Course and fine mesh

All compare well with test data

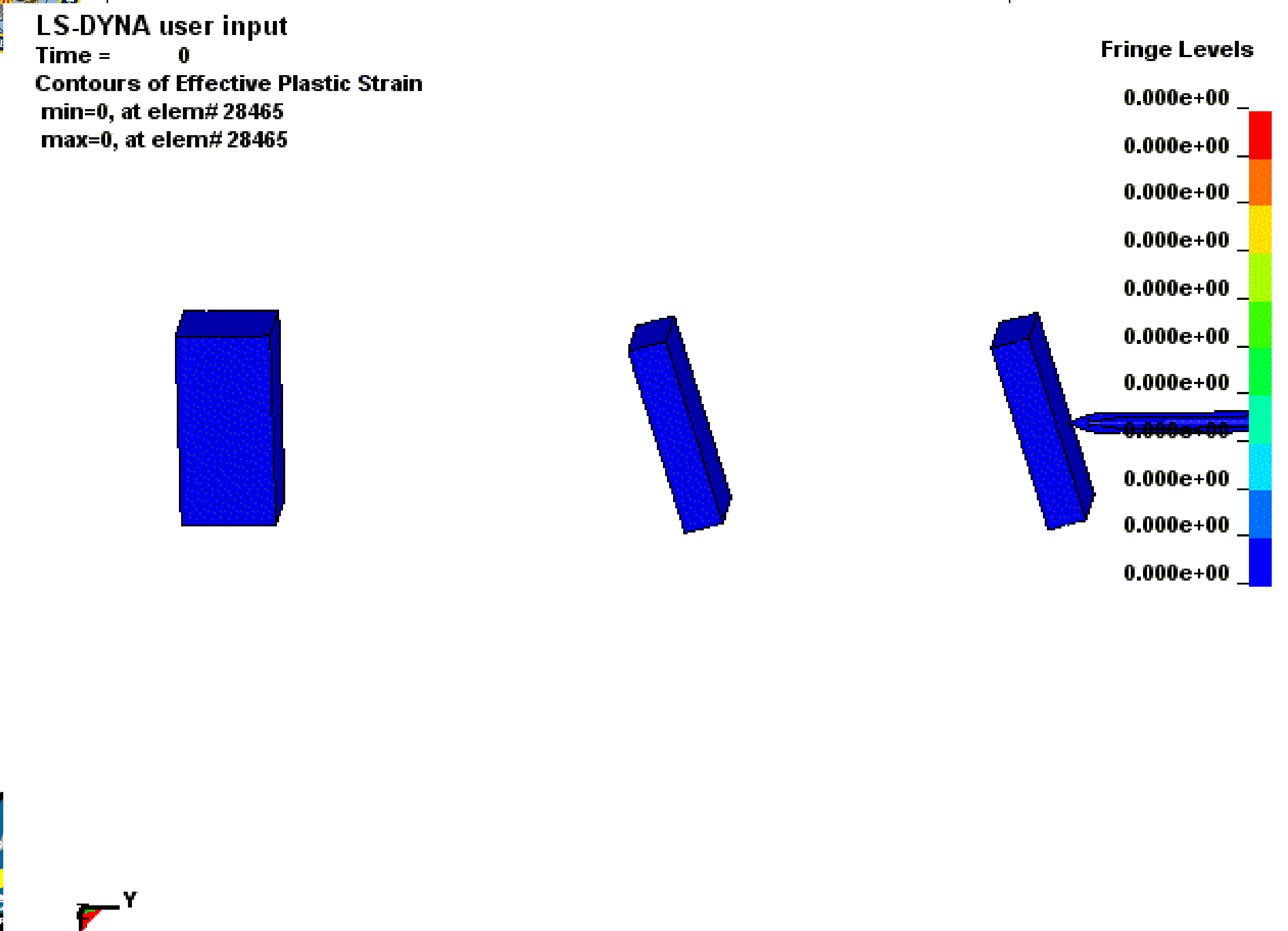


Case 3 SNORT Rocket sled track test

Full scale China Lake test

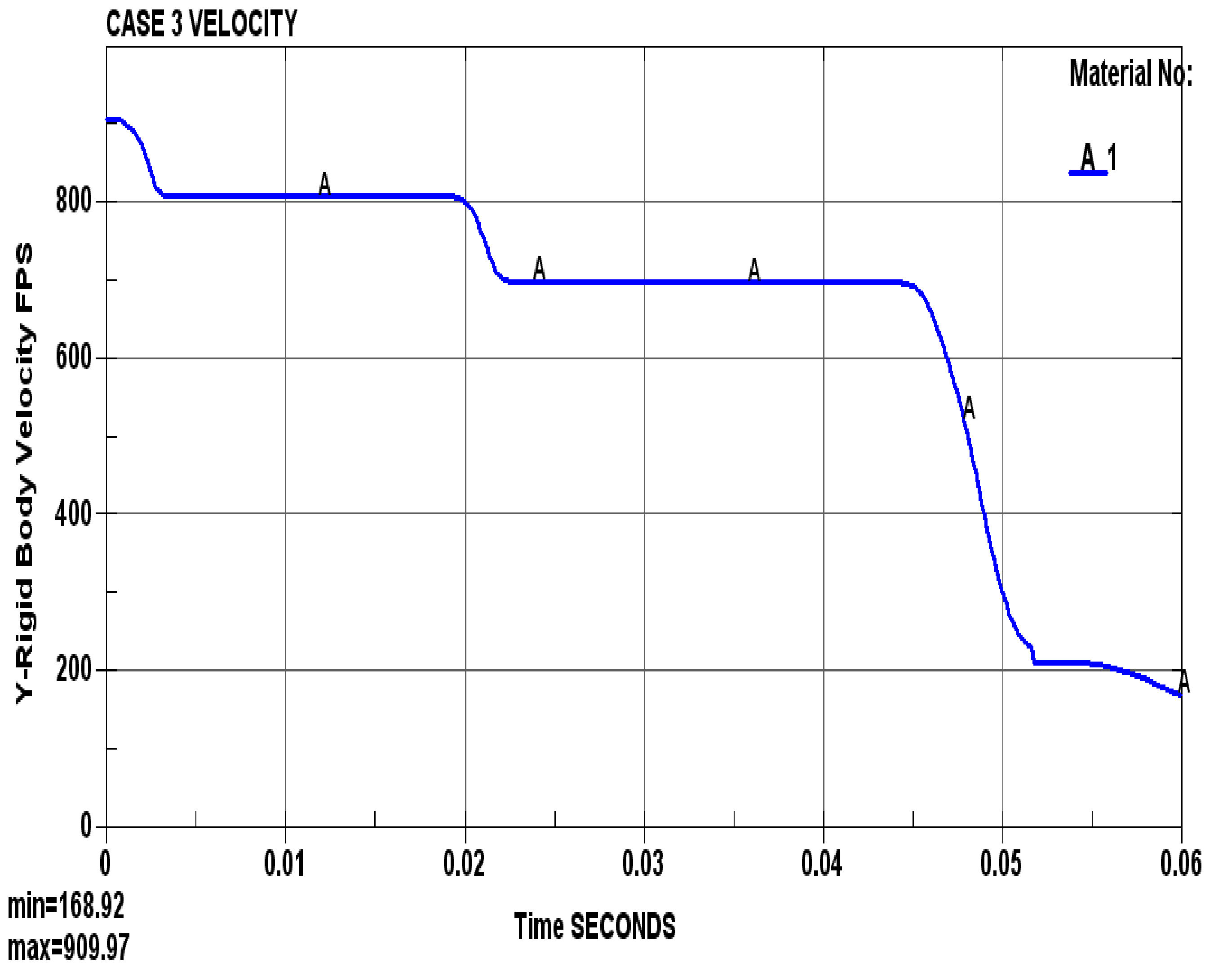
AOA for SNORT tests is random 1-3 deg

Case 3 SNORT test



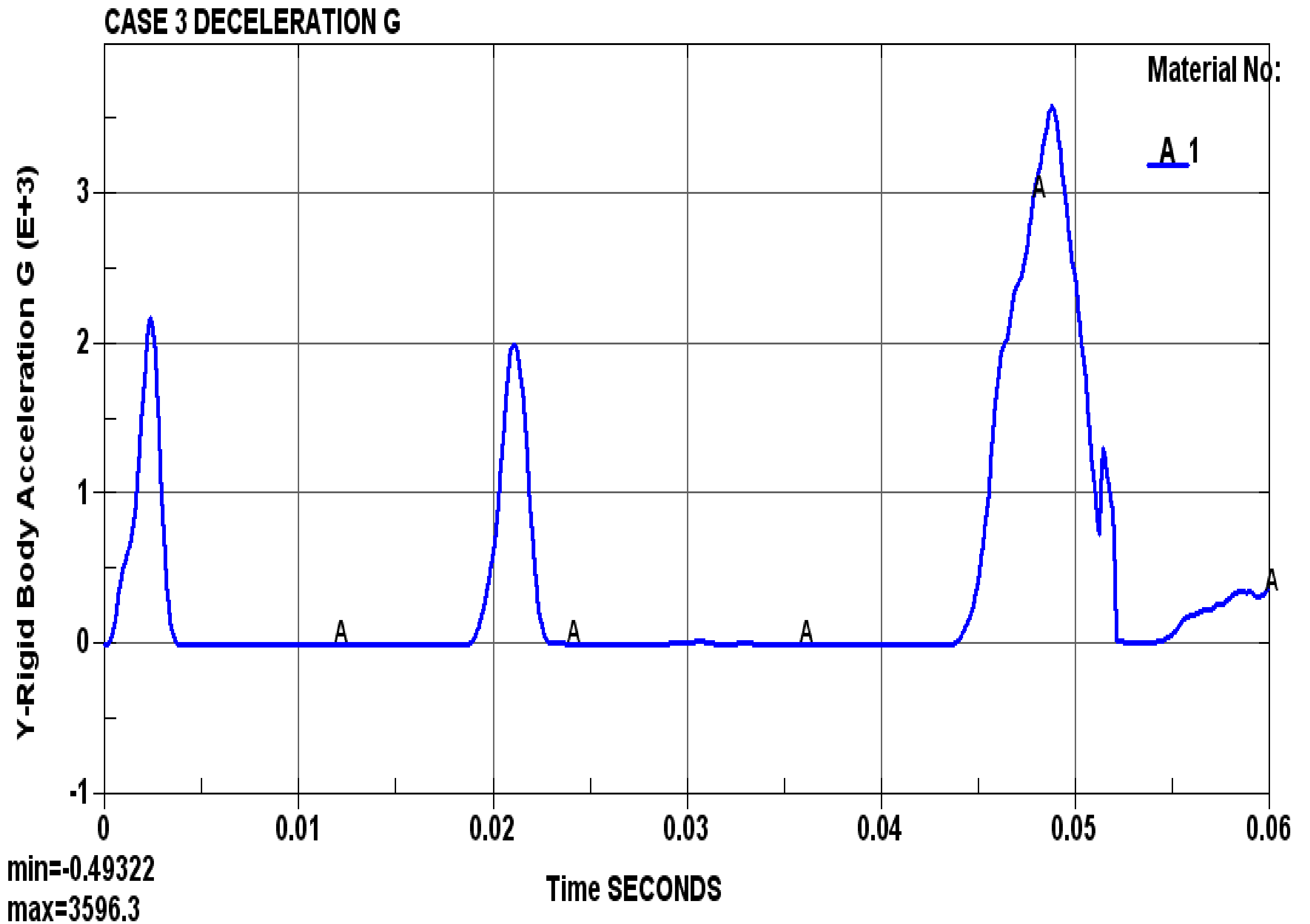
Case 3 velocity vs. time

Smooth well
Behaved curve
Fuze can Sense
velocity



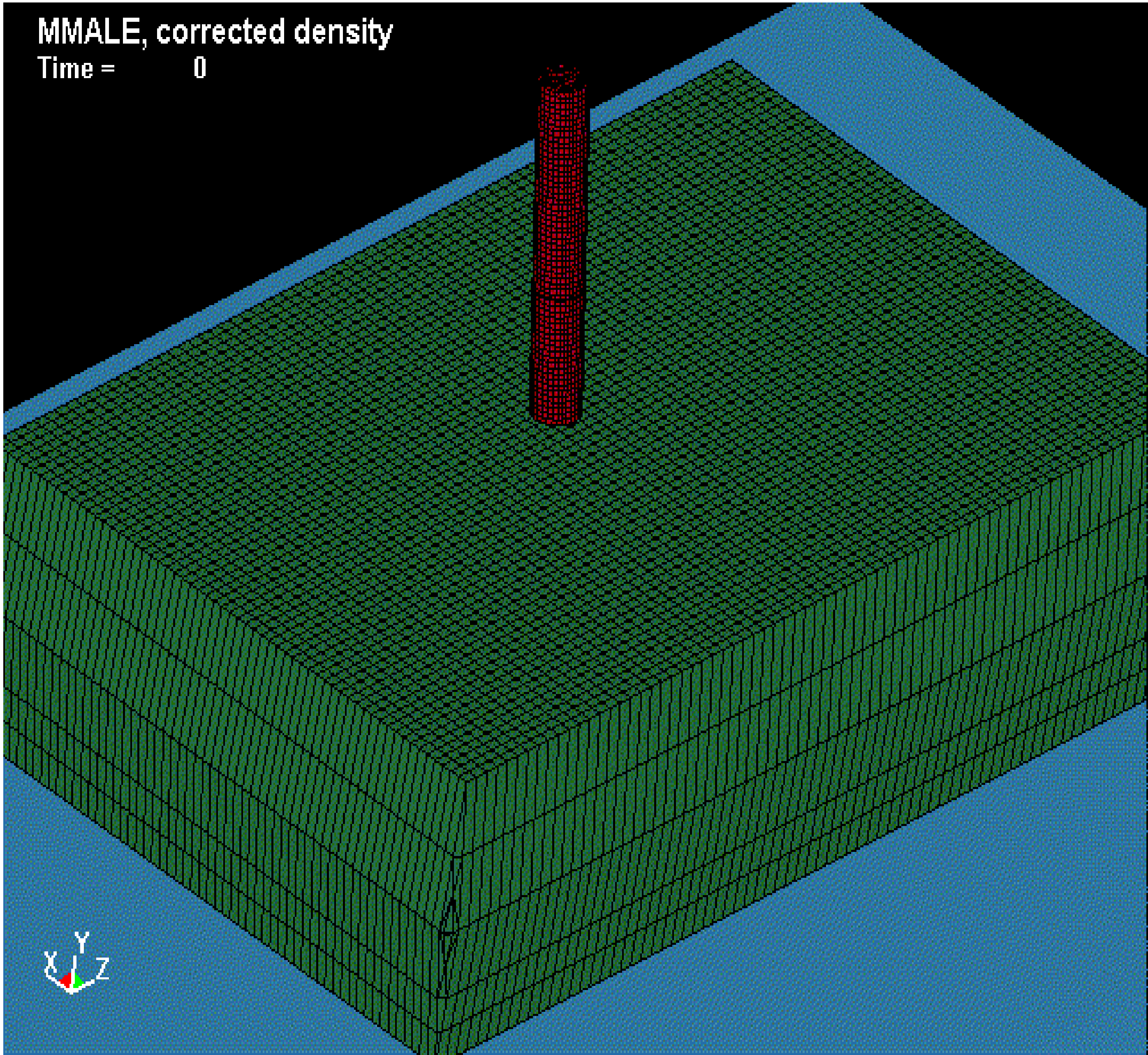
Case 3 Deceleration, g

Short
Deceleration
Pulses
May approach
High frequency
noise



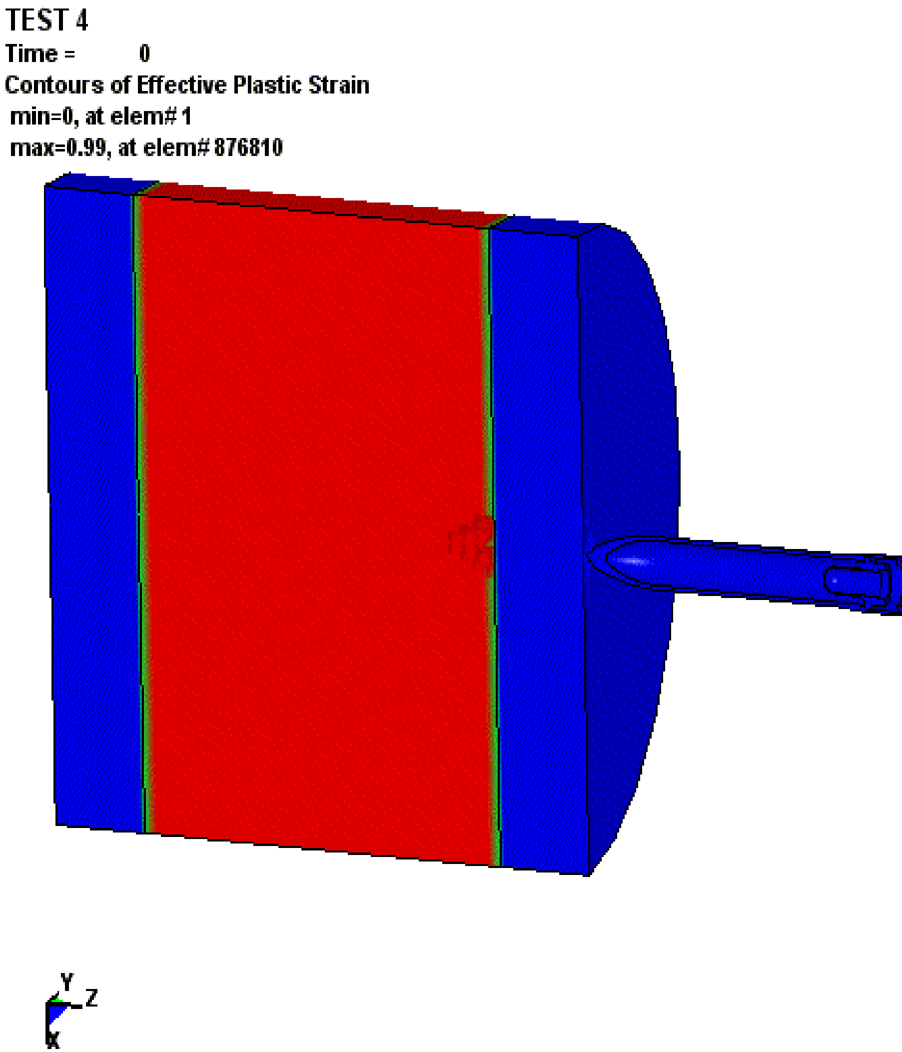
FLUID example requiring full ALE method with fluid interaction

low velocity impact into air bag floating on “China Lake”



Recommendations

- TEST---Better concrete and soil target specification; density, compression mod, no aggregate, consistent mix
- Peak deceleration----better specification of filter, location, standard method
- Fuze--- velocity sensor
- Simulation---Standard template for each test

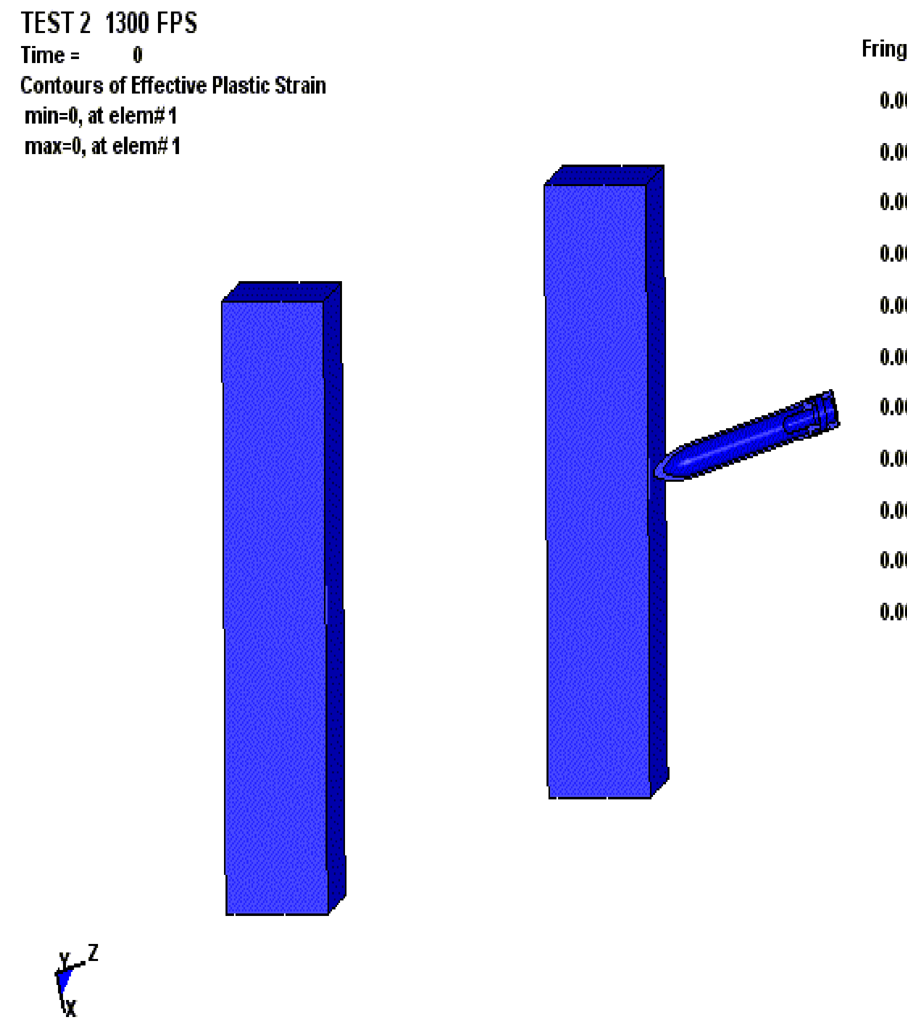


Conclusion

- A new application of LS-DYNA has been developed by the Safe-Arm Development Branch, NAWCWD to determine stress and strain loadings on fuzes during cannon and sled tests. The simulation results are in good agreement with test data. The new simulation tool will find application as a standard method of specifying fuze performance requirements and allows calculation of stress and strain, under a wide range of impact conditions and targets.

Thank You

- Please download the written paper and direct questions to
- Paul Glance
- Paul.glance@navy.mil
- 760-939-7358



Challenges in Hard Target Fuze Design
and Critical Technology Development

Chad R. Hettler

Hard Target Systems
Sandia National Laboratories
Albuquerque, NM 87185-0661
crhettl@sandia.gov
(505) 284-9459

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Unclassified Unlimited Release

Presented at the 54th NDIA Fuze Conference,
May 2010, Kansas City, MO

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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The Challenge of Hard Target Fuze Design

harsh environment

- **Stuff breaks in harsh environments**
- Need reliability in future fuze development
  - Reliability, survivability, performance
- Too many failure modes for fly-fix-fly approach

Our Approach

A big problem needs a systematic approach….

1. Discover immature technologies
   - efficiently and effectively guide our development resources
   - system, subsystem, and component levels
2. Characterize and develop models
   - Target impact environments
   - Performance of fuze subsystems and components in target environments
3. Use models to design for reliable performance
   - impact environment models to determine requirements
   - Performance models as tools to design for reliability through the given target environment

Model Based Design Method

<u>Have requirements and ability to design to meet them</u>

- Understand the target environment
  - Mechanical and Electrical
    - e.g. Fuze subsystem must operate through….

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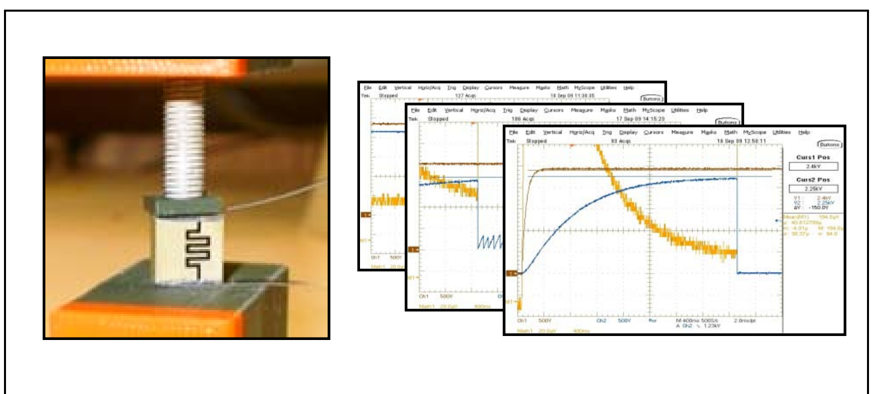
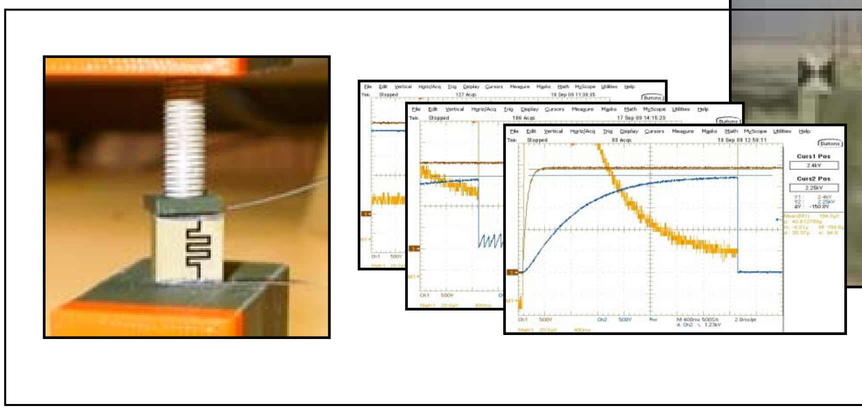
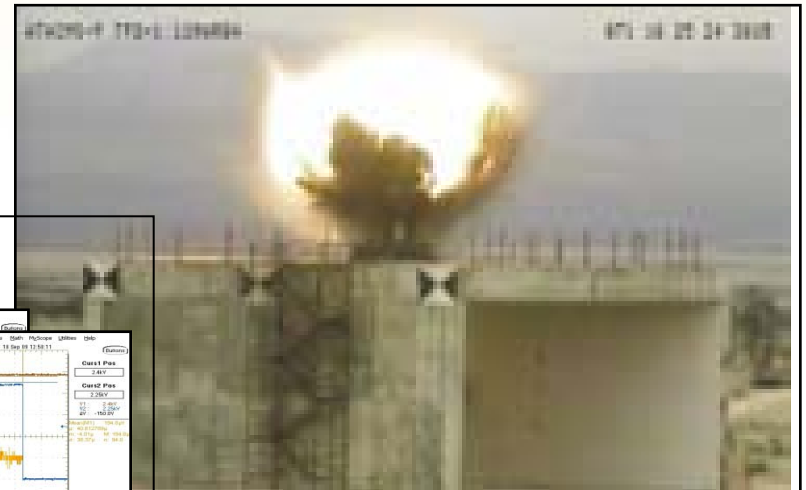
- Understand subsystem and component performance variation through stress and electrical disturbances
    - e.g. Given this stress, the current leakage will vary by….



Model Based Design Method

Have requirements and ability to design to meet them





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- Use performance models to design fuze electronics with margin for reliable operation through target environments

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Too complex for an Edisonian approach

- Can't rely on full-scale tests to uncover all failure modes
- Full scale high-g testing is high dollar
- Development dollars are limited
  - If we're not learning,
    we're wasting resources

http://search.janes.com/janesdata/binder/jalw/images/p0130675.jpg

- Need to know what are we learning from our failures
  - If it didn't work….how do we fix it?
  - Finding 10,000 ways it doesn't work….doesn't work for us

"If I find 10,000 ways something won't work, I haven't failed…. because every wrong attempt discarded is another step forward."

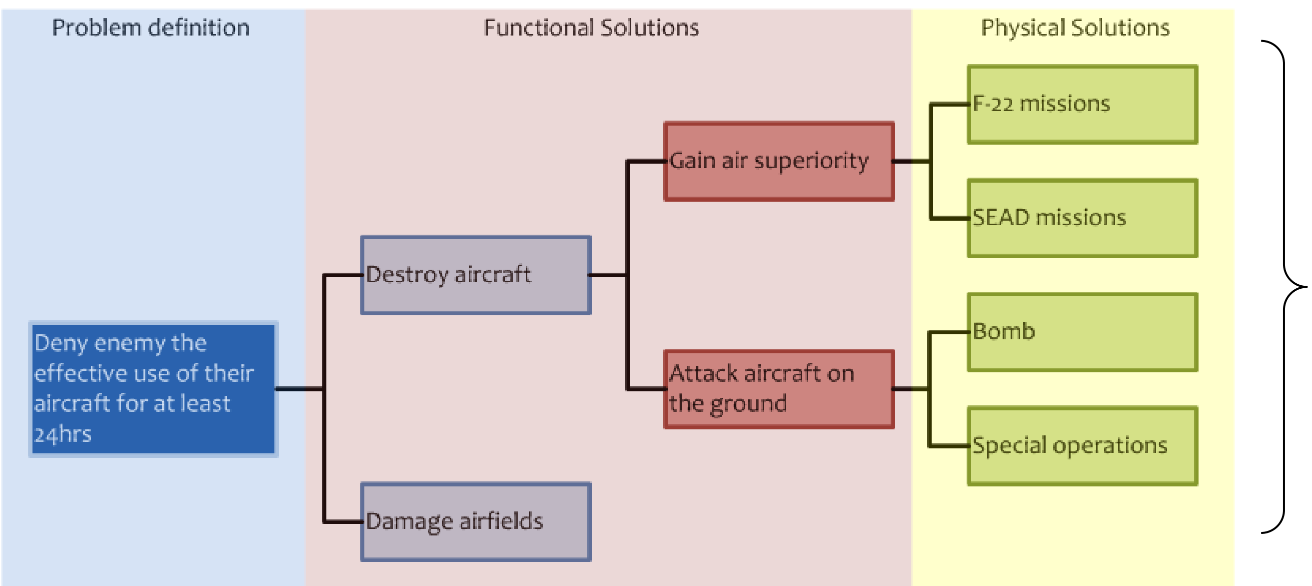
- Thomas Alva Edison, *US inventor (1847 - 1931), Encyclopedia Britannica*

Systematic approach to development

- Assess capabilities to focus development
  - First step is to assess maturity of available technologies
  - At system, subsystem, component levels
  - Can't develop a reliable system without reliable components

Capabilities Assessment

- **Determine Gaps in Technologies**
  - System, subsystem, component levels
  - Multi-physics; Mechanical, Electrical, Explosive….
  - Help roadmap our long term goals and challenges
  - Efficiently and effectively guide our development resources

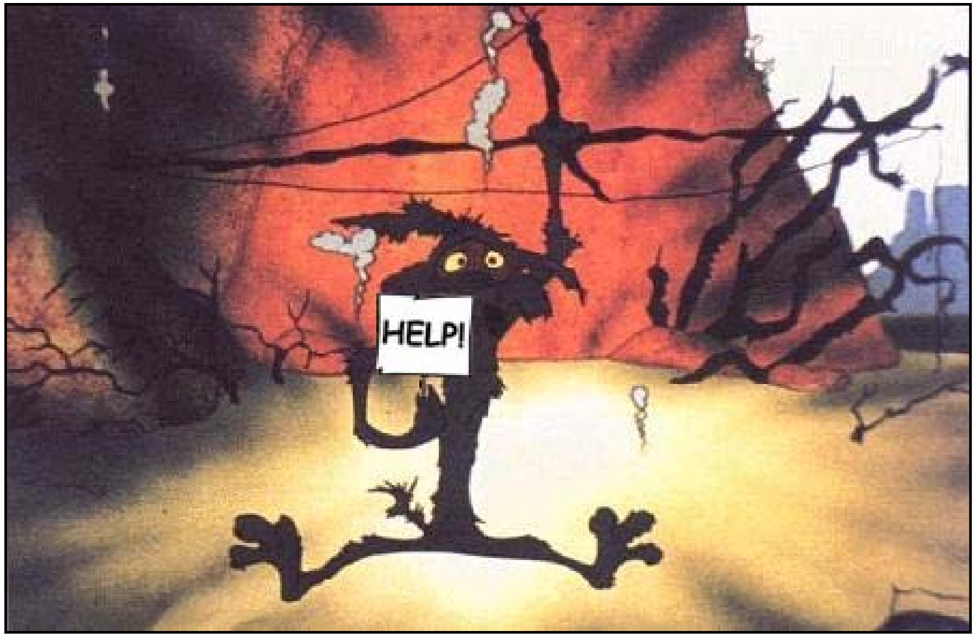


Research technology options and associated maturity levels (TRL)

Define immature technologies…. before it's too late

- Fuzes have one good outcome: Initiation when intended
- They have two glaring incorrect outcomes
  - Initiation before or after intended
  - Failure to initiate
- Perform failure analysis before failing expensive tests

If we don't understand failure modes….this is heavy risk



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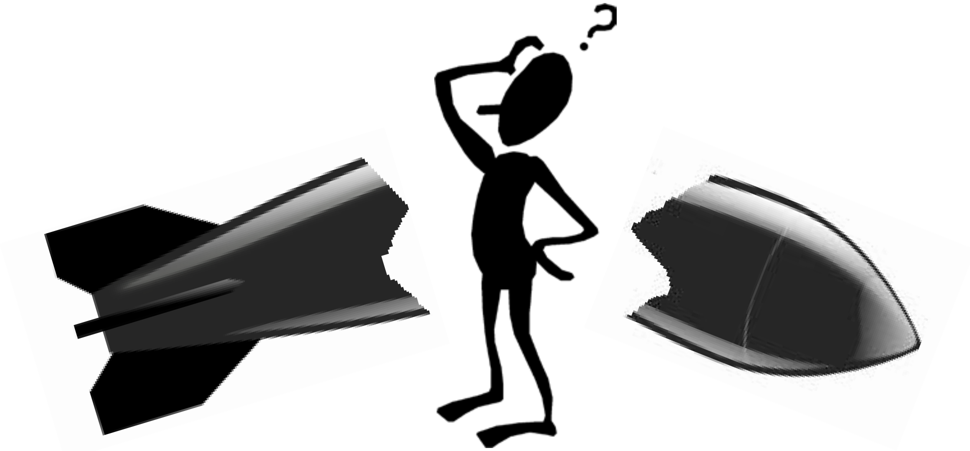
Focus Tests on Understanding Performance

Go / No-Go testing gives limited information

- **If we simply increase g-levels until something breaks….**

  ….did we learn how to make it work the next time?



Engineer tests to understand performance success

- **If it did work….do we know why?**
  - Want enough understanding for reliable transition to other programs, applications, form factors, industry

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Need Capabilities to Understand:

- **What is the target environment?**
  - Mechanical and Electrical
  - Requirement for weapon performance

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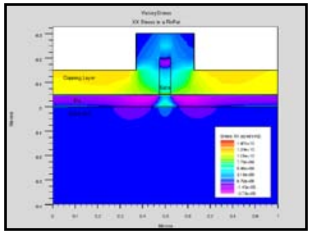
- **How does the fuze perform?**
  - Characterize subsystems and components to develop models for performance variations and failure modes in the target environment



http://www.silvaco.com/tech_lib_TCAD/simulationstandard/2009/oct_nov_dec/a1/a1.html

- **What can we do to prevent failures?**
  - Have tools in place to define requirements and design to satisfy them
  - Need systematic approach to development

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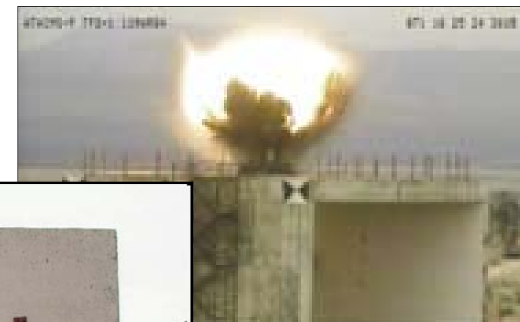
What is the target environment?

- **May survive in sub-scale, then fail in full scale**
- **Fundamental failure modes associated with full-scale environments are not understood**
  - Uncharacterized target environments
  - Uncharacterized system performance



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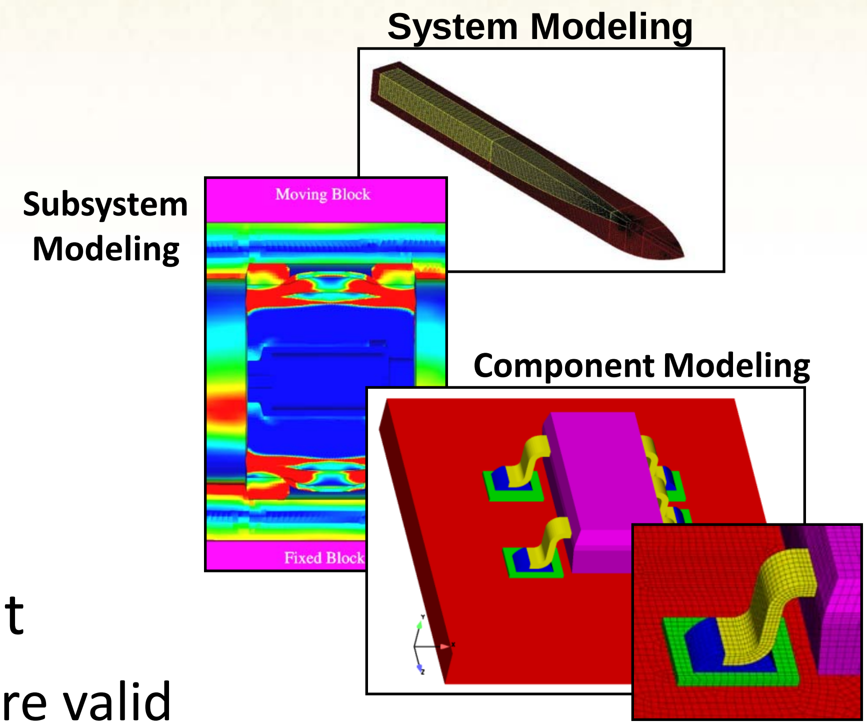
Characterize Target Environment

- Stresses seen on
  - Weapon body
  - Fuze subsystem
  - Fuze components



http://www.dtic.mil/ndia/2009fuze/2009fuze.html

- Induced electrical environment
  - Lot of theories….which ones are valid and what are the effects?
    - What types of energies and how are they coupled
      - Plasma from reentry body
      - Charged weapon body
      - System ground loops

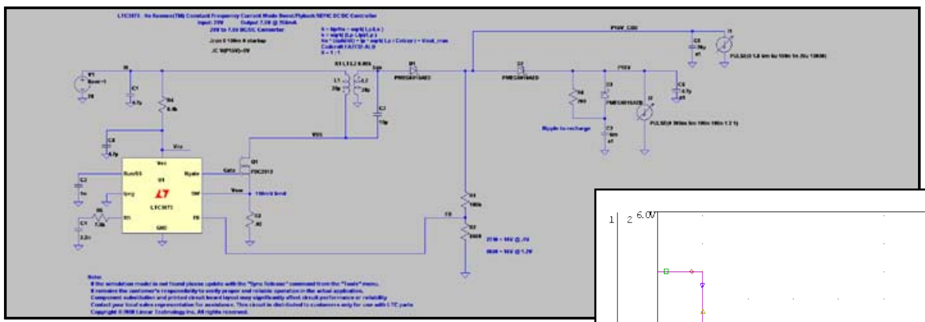
Understand our designs
Understand the electrical environment

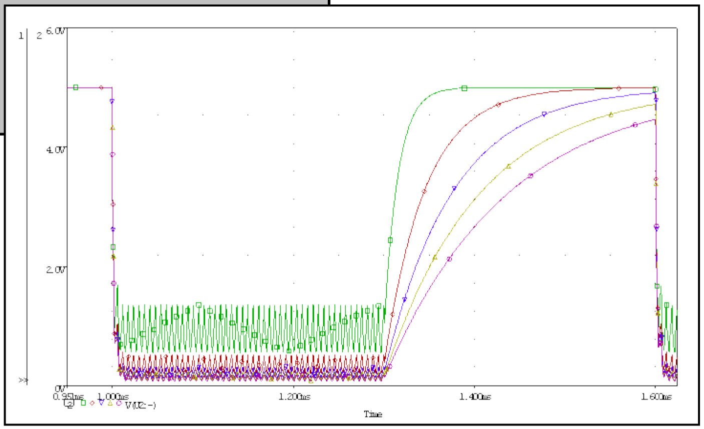
- If we don’t know what it ***must*** perform through

  ….We should at least know what it ***can*** perform through

  – Design for mitigation and understand our performance margins

    e.g. How much susceptibility to EMI, capacitive coupling….





Electrical Parametric Performance Modeling

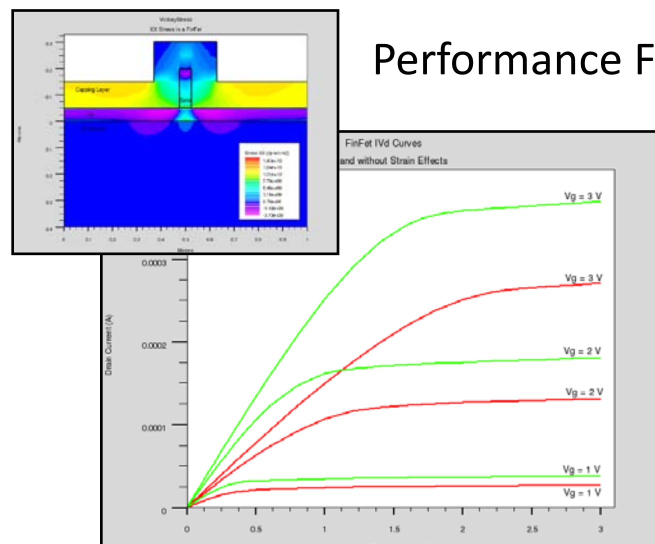
How does the fuze perform?

Knowing the target environment is only useful if we can do something about it

- We need performance models to design for reliability
- What causes failure

....mechanical damage or electrical performance?

Physical Failure

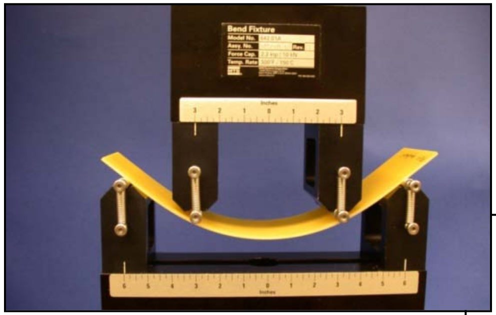


Performance Failure

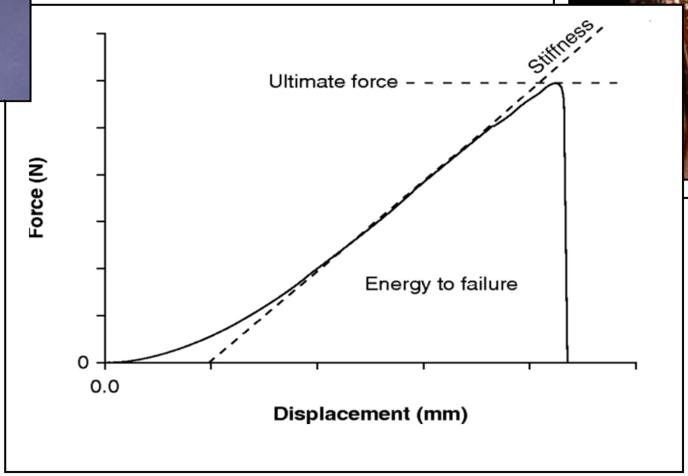
http://www.silvaco.com/tech_lib_TCAD/simulationstandard/2009/oct_nov_dec/a1/a1.html

Mechanical Failure

- Model the breaking point of hard target components
  - Where does the part physically fail….?



4-point bend test



http://ajs.sagepub.com/content/34/7/1094/F3.large.jpg

Force vs. Displacement

Physical Failure

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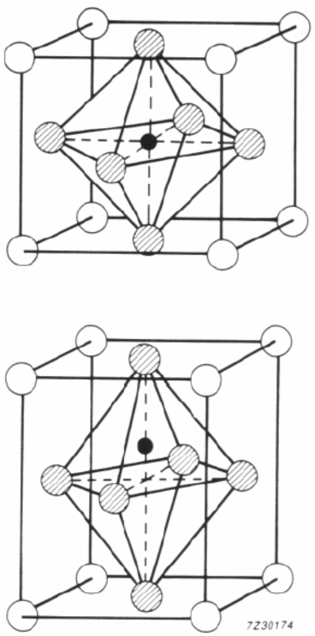
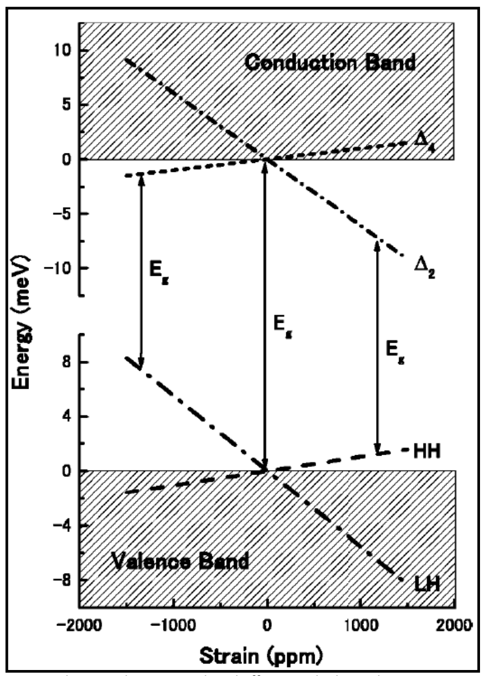
Electrical Component Performance

If it survives mechanical impact….will it perform electrically?

- e.g. Stress can effect crystalline structures, effecting intrinsic properties of semiconductors and dielectrics
  - band-gap energy, dielectric constants , current-voltage relationships

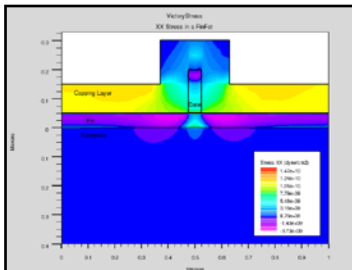


Lattice Deformation



K. Matsuda, Y Kanda, Stress-induced effects on depletion-layer capacitance of metal-oxide-semiconductor capacitors, Apllied Physics Letters, vol. 83, n 12, Nov. 24 2003.

E_g vs Strain



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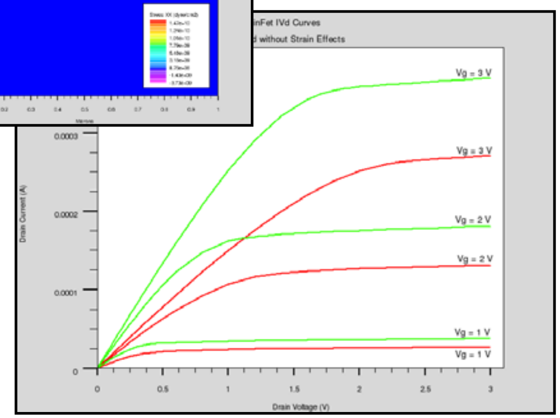

Drain Current vs. Strain

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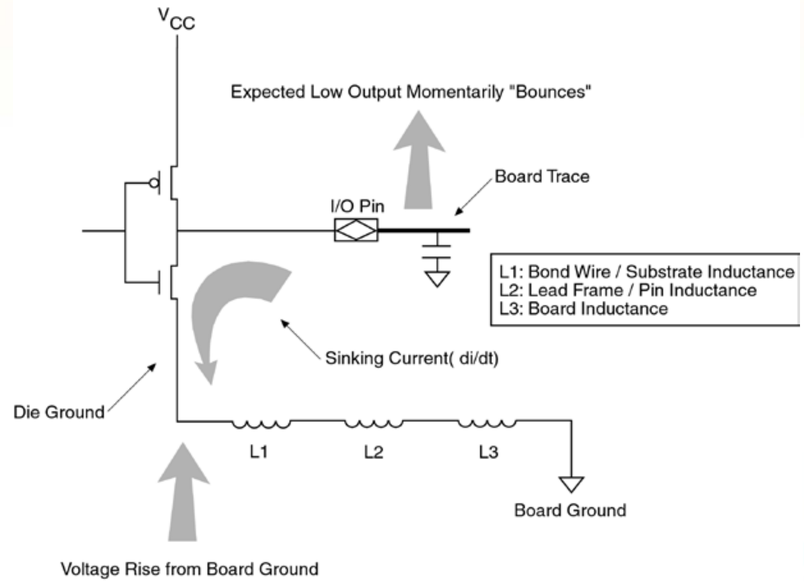
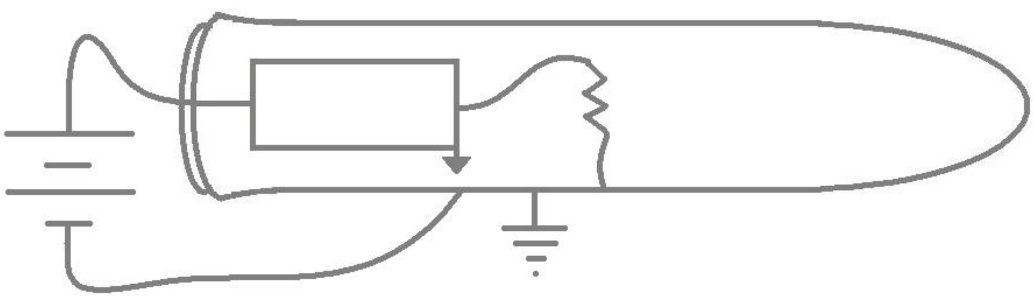
Electrical System Performance

- **At the fuze subsystem level**
  - Piezoelectric effects
  - EMI
  - Voltage level shifts
  - Ground bounce
- **At the weapon system level**
  - Coupled Energy
  - Ground loops



Altera Coporation, Minimizing Ground Bounce & V_{CC} Sag,
www.altera.com/literature/wp/wp_grndbnce.pdf



What can we do to prevent failures?

- Stuff breaks in hard target environments
- Big problem needs a systematic approach
  - At system, subsystem, and component levels
  - Identify critical technologies
- Focus resources to efficiently and effectively develop our gaps and immature technologies
- Model based engineering to design for reliable performance

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Collaborations

- The Defense Threat Reduction Agency funds work to investigate the effects of stress on the electrical performance of components

- Air Force Research Labs is aiding in this effort

- Army RDECOM is modeling the mechanical effects of stress

Questions / Comments ?

BACKUP SLIDES

What does it all Mean?

- **By failing to address the high-g fuzing problem holistically, the cost is high:**
  - **Poor collaboration**
  - **Duplicated effort**
  - **Poor understanding of high-g science**
  - **Poor integration of test results and analysis**
  - **Unclear understanding of the truly necessary areas of research (focus is lost)**
  - **No/little documented design guidelines for high-g**
    - **And no framework for getting there, either**

It is natural for a problem too big for one group to get to this state. However, when it is realized that the techniques/tools exist to correct the problem, they should be taken advantage of.

Systems Engineering: Systematic Innovation for Hard Target Fuzing

Patrick O'Malley

Department 2627: Hard Target Systems

Sandia National Labs

Albuquerque, NM

SAND2010-2883 C

Unclassified Unlimited Release

Presented to the 54th NDIA Fuze Conference, May 2010, Kansas City, MO

Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Objective

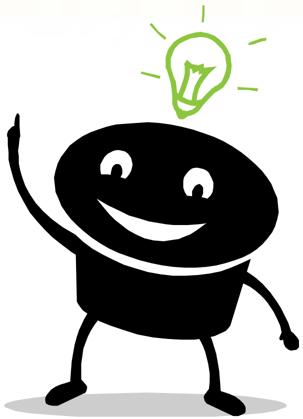
To do effective product development, a systematic and rigorous approach to innovation is necessary. Standard models of system engineering provide that approach.

> *The popular picture of innovators – half pop-psychology, half Hollywood – makes them look like a cross between Superman and the Knights of the Round Table. Alas, most of them in real life are unromantic figures …*
>
> — Peter Drucker, *The Essential Drucker*, Principles of Innovation

Two Views of Innovation

Flash of Genius

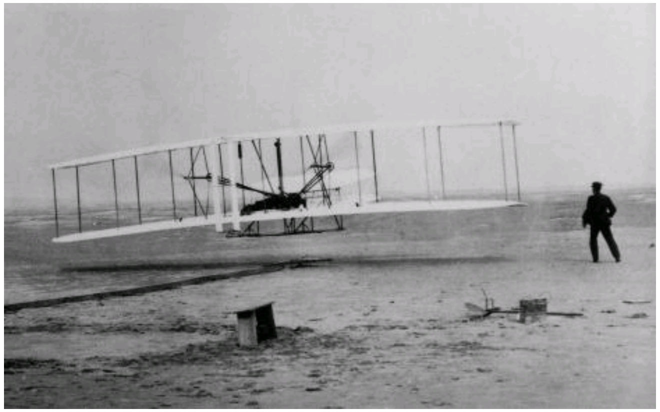
Innovation is an unexpected, brilliant idea



- ***Cannot*** be taught
- ***Cannot*** be reproduced
- ***Cannot*** be scaled to
- Typically unknown risk

Hard Work

Innovation is systematic exploitation of opportunities through analysis



- ***Can*** be taught
- ***Can*** be reproduced
- ***Can*** become a culture
- Typically ***risk aware***

Which view would you base a business or project on?

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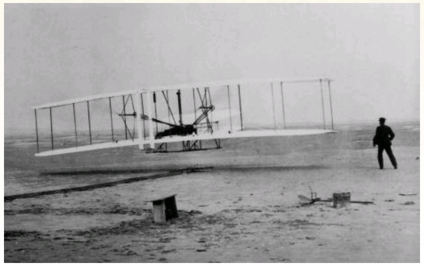
Innovations vs Great Ideas

Great Ideas

- Undefined impact
- No immediate utility; perhaps in the future
- Complex
- Not necessarily aligned with a specific need or outcome



Innovations

- Economic and social impact
- Has utility immediately
- Simple, focused
- Applied to a specific, clear and defined application

… the innovation that creates new uses and new markets should be directed toward a ***specific****,* ***clear****,* ***designed application****. It should be focused on a specific need that it satisfies, on a specific end result that it produces*.

— Peter Drucker, *The Essential Drucker*

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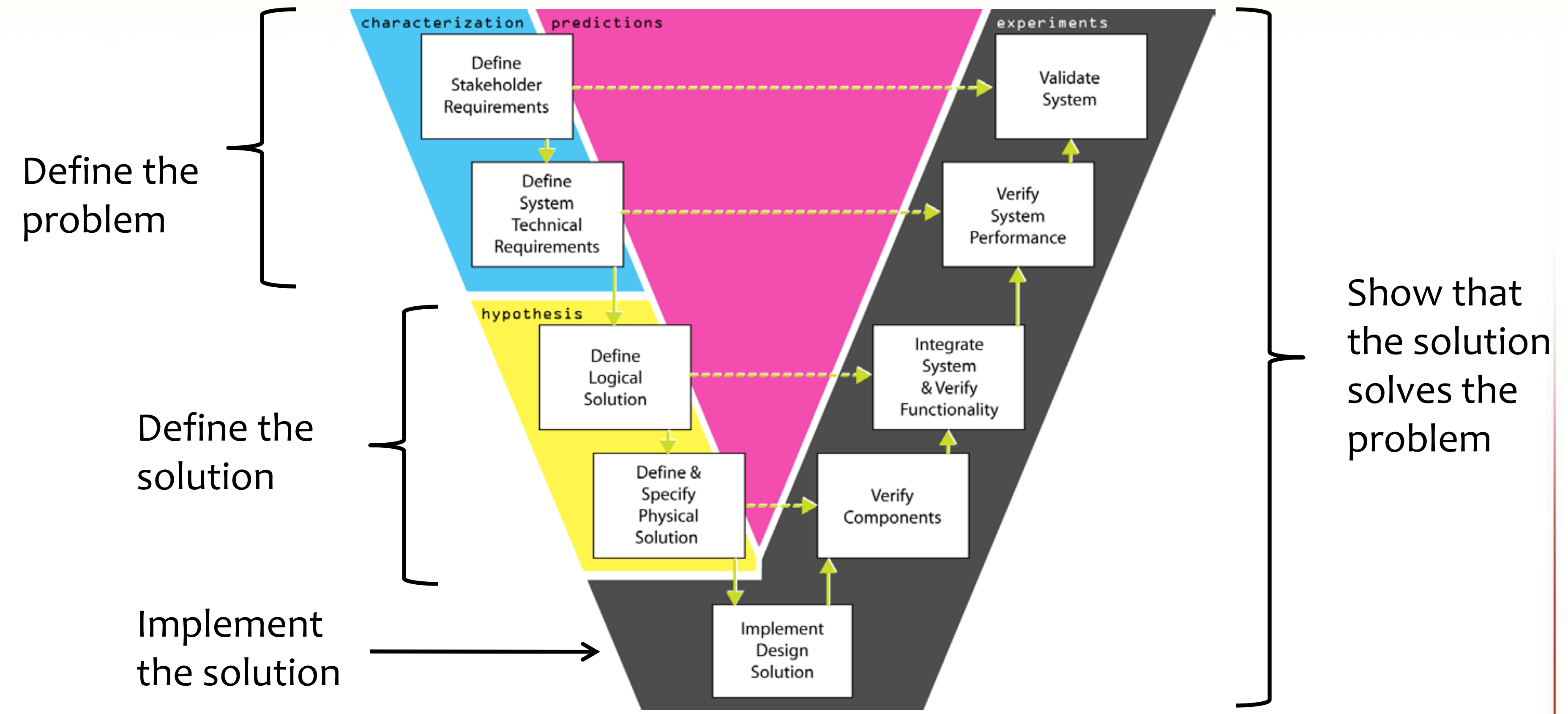
One Slide Introduction to the System Engineering Process

The V-model is the predominant model of the system engineering process:

This V-model is based on EIA-632, *Processes for Engineering a System*



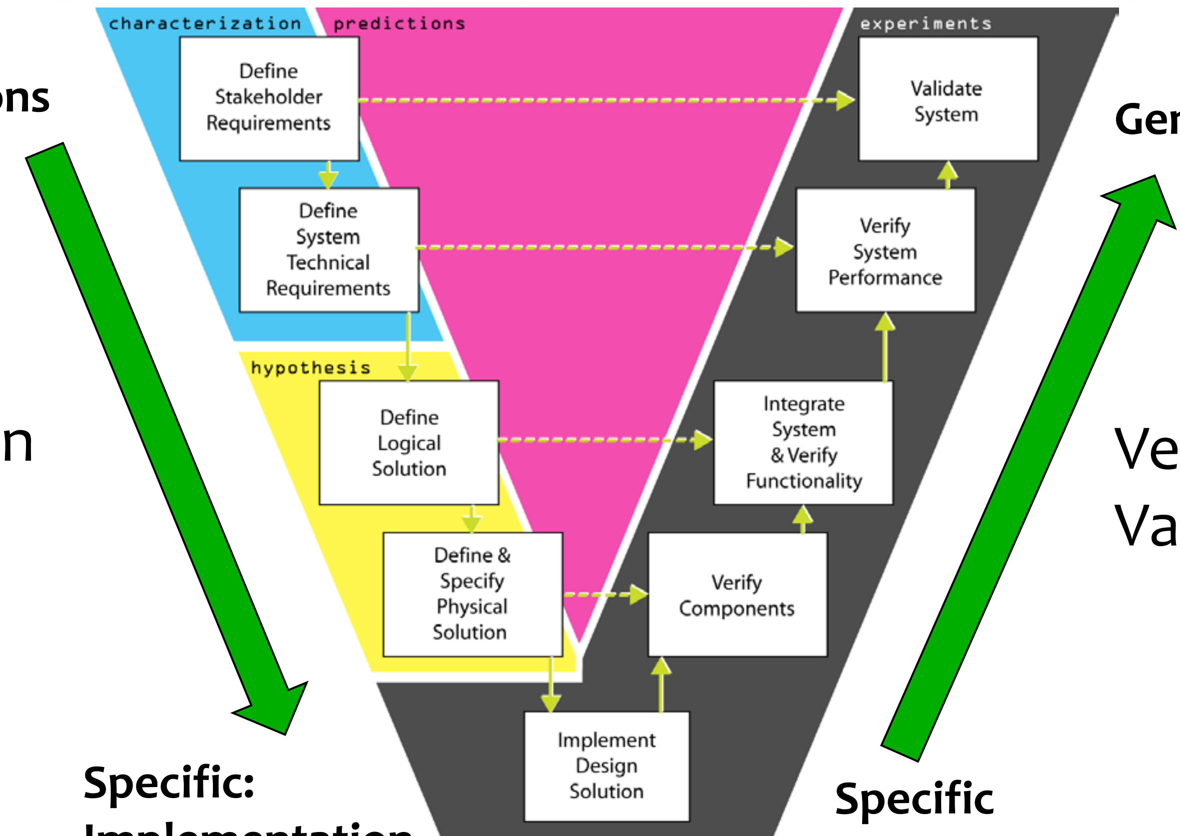
A typical implementation of SE will include multiple V's

The V-Model and Innovation

- The key to the V-model is in progression from general concepts to a specific solution
- This allows for ***systematic*** exploration of the solution space

General:
Goals, missions

Design



Specific:
Implementation, components

General

Verification & Validation

Specific

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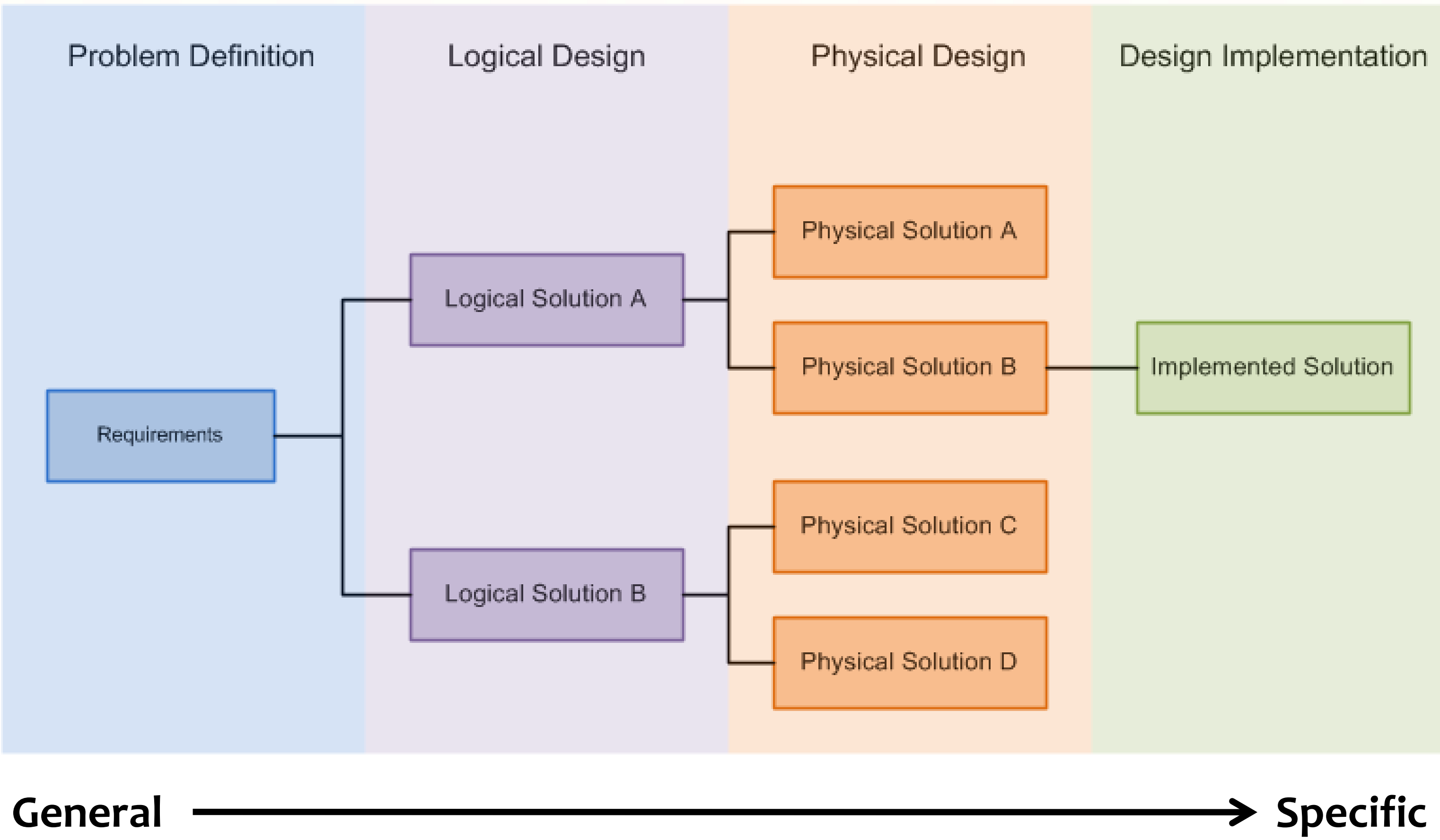
The V-Model in Action

The V-model of development leaves the solution space open, allowing for innovations in the form of solutions.



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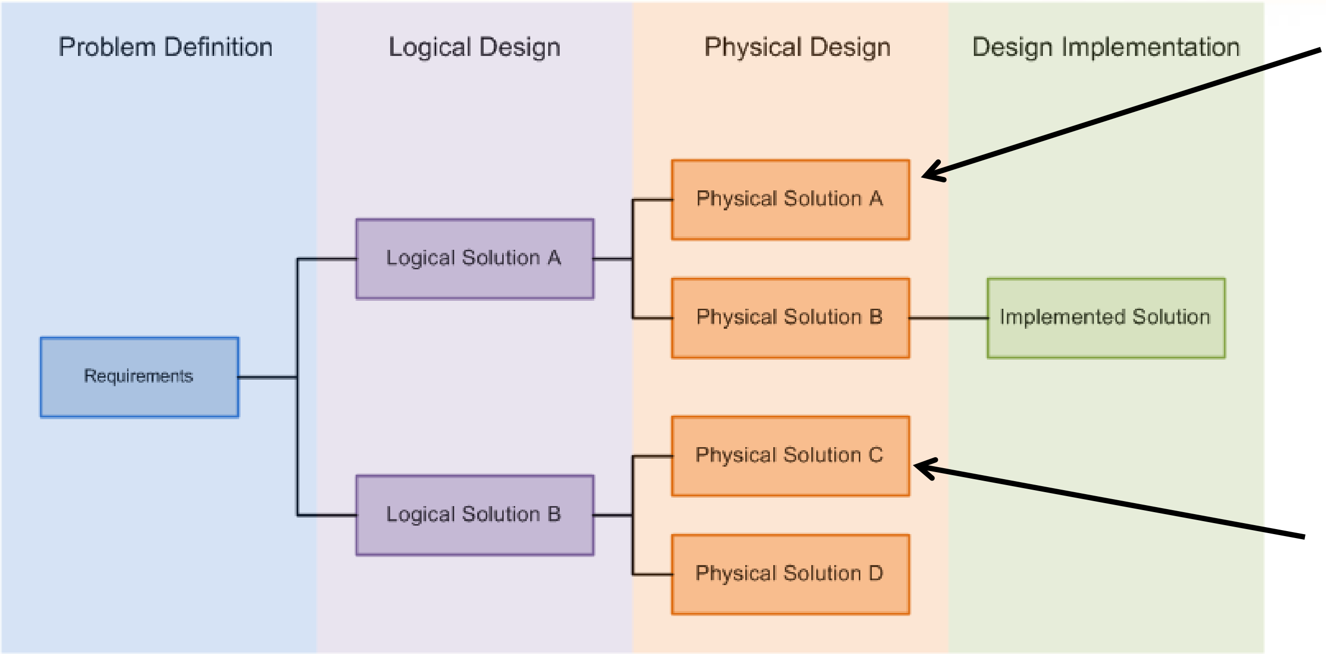
Risk and Opportunity Awareness

The systems engineering process identifies innovations that could improve the utility of a solution …



Solution A may have a higher utility than Solution B if a technological leap were made

Solution C may have higher economic risk but significantly higher performance payout

… because you don’t want to waste resources on solutions that won’t help your business

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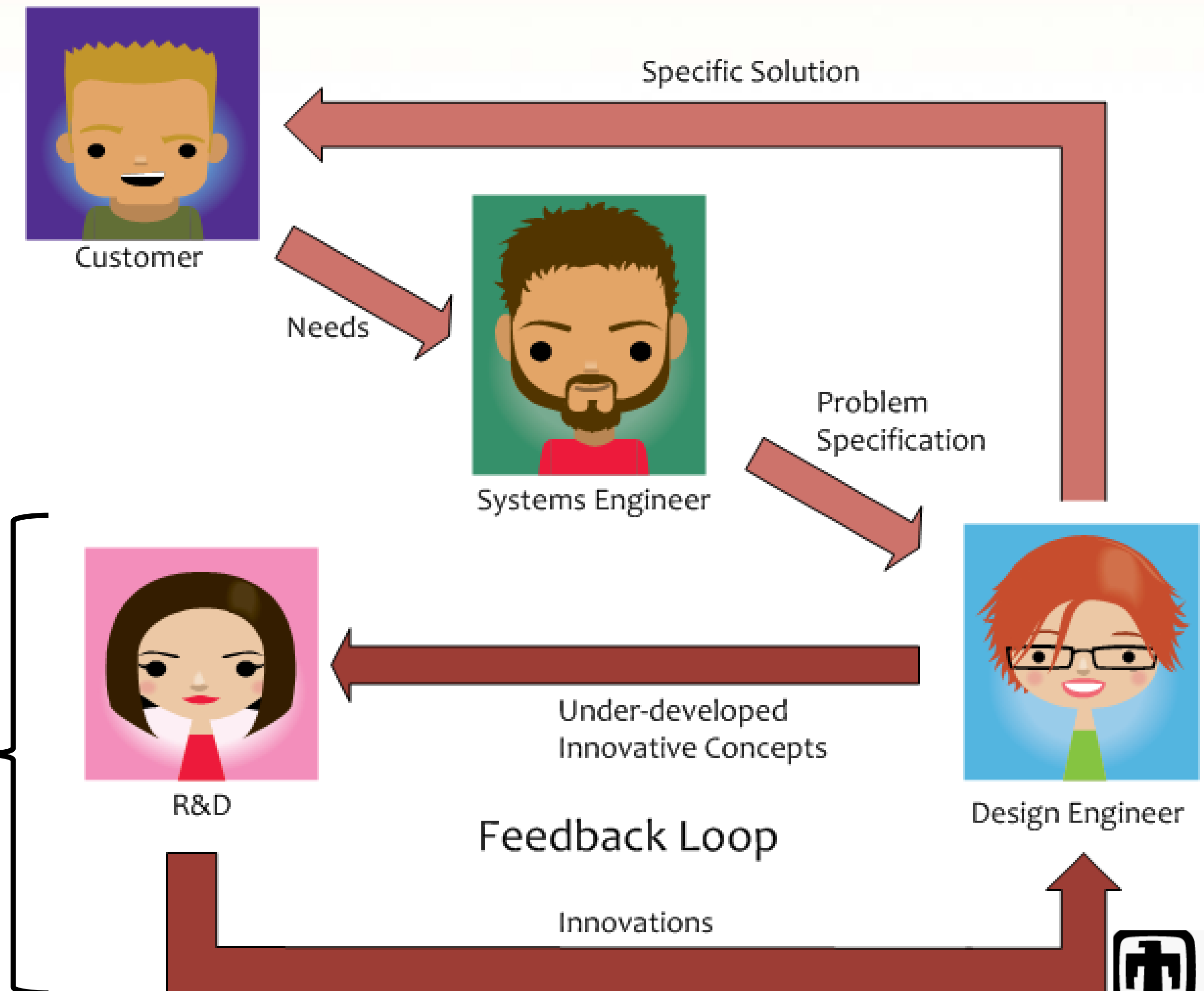
Enabling Focused Innovation

The systems engineering ***process*** enables a business structure that identifies , develops and uses innovations



The feedback loop exists because SE focuses innovations on specific applications

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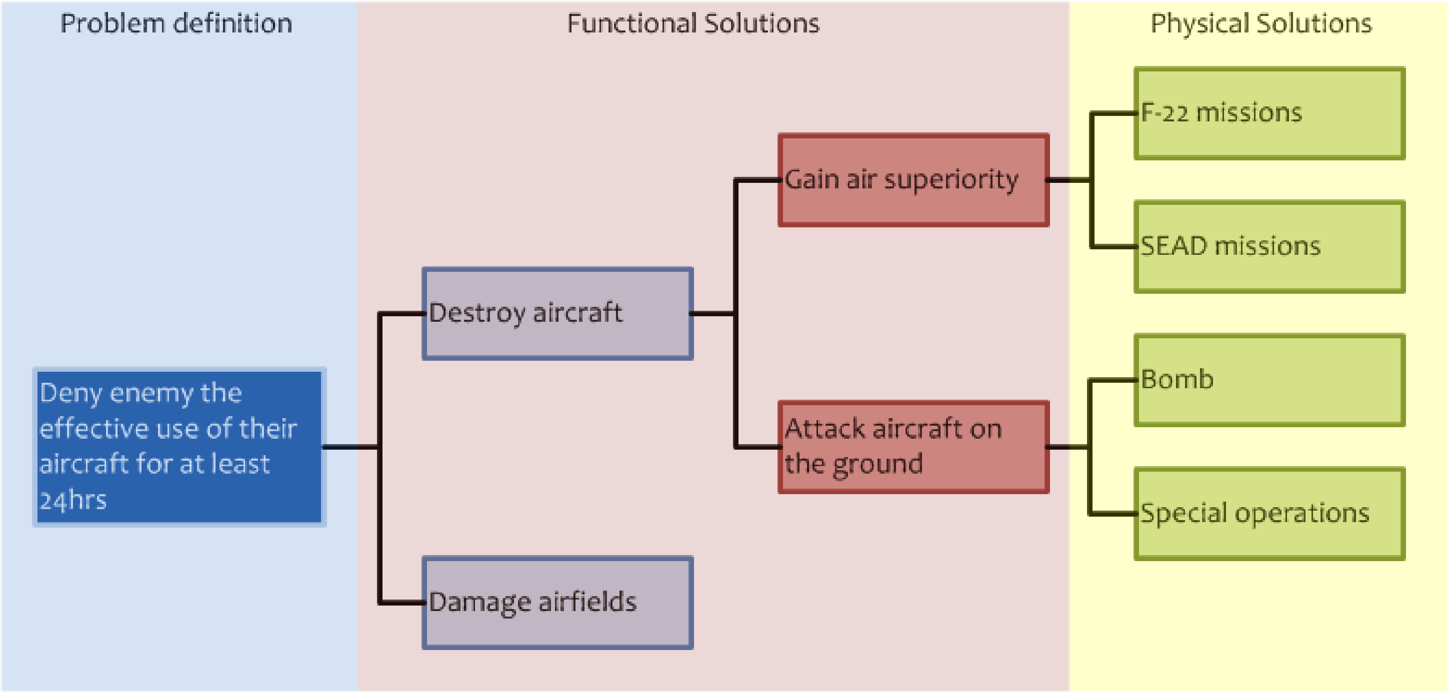
Roadmapping

Not all innovation stems from problem solving during product development …

Finding areas of innovation at a high level operates the same way using the Vee model



Commonly called "Capabilities-Based Assessment"
See "Capabilities Based Assessment User Guide" from https://dap.dau.mil/Pages/Default.aspx

Final Words

- This has been a very brief introduction to using system engineering to develop new innovations
- Note that a lot of detail has been neglected
  - Specifically: The “how” of implementing system engineering and achieving assured designs

QUESTIONS?

US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

Malcolm Baldrige National Quality Award 2007 Award Recipient

Integrating Manufacturability into Fuze Design

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Fuze Development Center

US Army RDECOM ARDEC Fuze Division
Picatinny Arsenal, NJ

Stephen Redington, PE
973-724-2127

May 12, 2010

NDIA 54rd Fuze Conference – Kansas City

How to blow the competition away

(above results not typical, individual results may vary)

- INTRODUCTION
  - The Fuze Development Center
- Common pitfalls in development
- Two design approaches
- Integrating manufacturability
  - Key concepts
- Infrastructure examples
- Summary

US ARMY RDECOM

The Fuze Development Center
Picatinny NJ, Building 1530

Fuze Development Center Mission:
Accelerate New technology to the Field

Malcolm Baldrige National Quality Award 2007 Award Recipient

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

- You know your project is in trouble when:
  - Cost, schedule and performance are equally weighted.
  - The plan to meet the schedule requirement assumes none of the planned risk factors are ever encountered.
  - Requirements change but cost and schedule do not.
  - Your successful concept demonstration leads management to believe they have a product.
  - The formula (2 x Manpower = ½ Schedule) is applied.

- Common pitfalls that impact schedule & cost
  - Using concept development for product development
    - Misleading results
    - Schedule and cost overruns
    - Dead end projects
  - Insufficient documentation during development
    - Results cannot be reproduced
    - Lost progress / wasted money
  - Uncontrolled materials used in development
    - Results cannot be reproduced
    - Misleading results

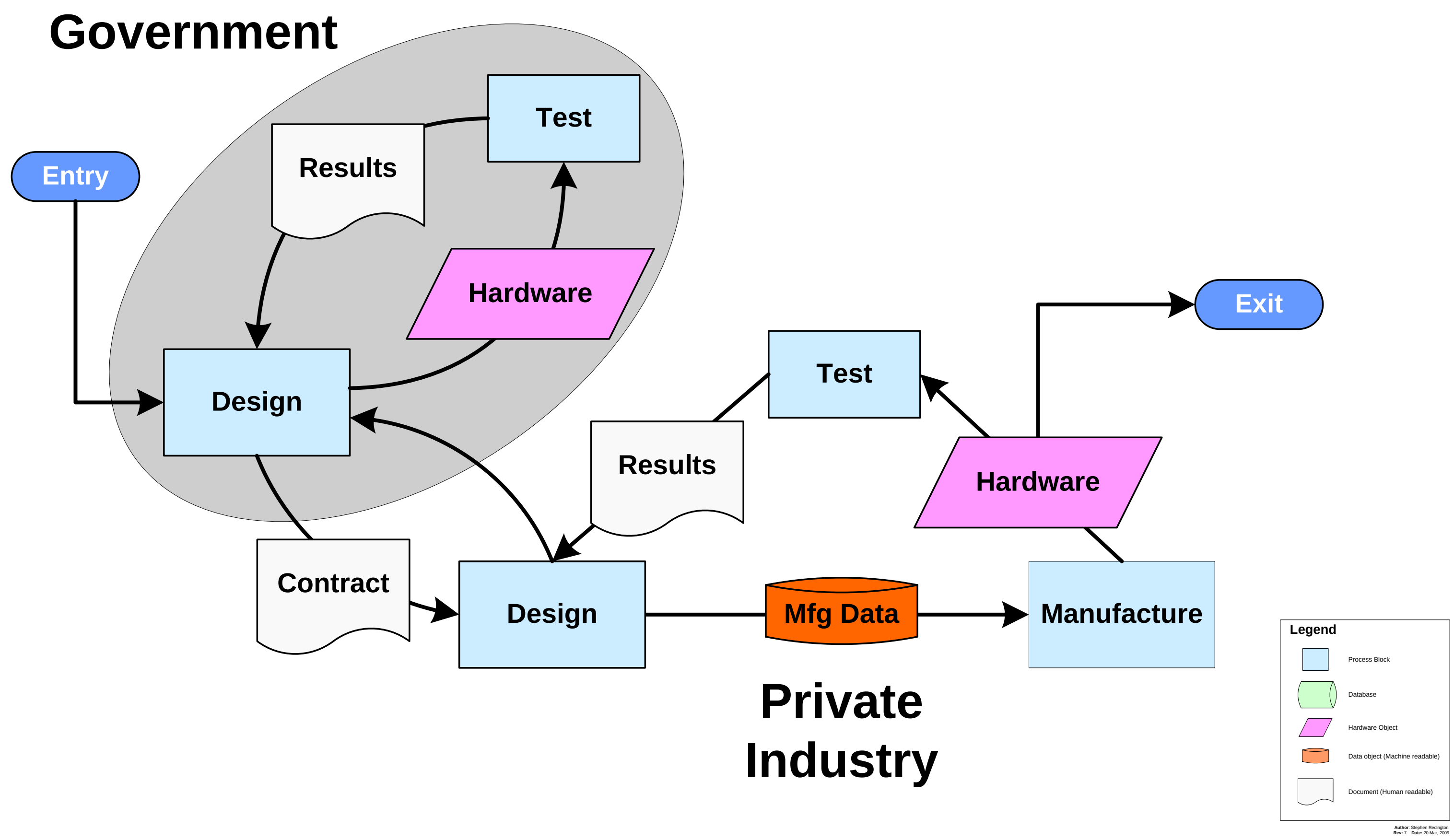
Integrating Manufacturability Common Pitfalls

- Uncontrolled development processes/methodology
  - Diminishes teamwork
  - Duplication of effort
  - Lack of focus
- Lack of teamwork
  - Results cannot be reproduced independently
  - Duplication of effort
  - Schedule delays
- Absence of configuration controls during development
  - Results cannot be reproduced
  - Schedule delays
  - Cost overruns (Rework)

- Lets get something straight !!!
  - Experimentation (A few of a kind)
    - Focus on answering questions (is it useful?, how does it work?)
    - Ideal for exploring new or unknown technology
    - Documentation nonexistent or incorrect due to uncontrolled changes
    - Limited or no direct product transition (product potential only)
    - Foundation for a new competency
    - Often mislabeled as prototyping
  - Prototype (The first of many)
    - Focus on fielding a new capability
    - Results reproducible by an independent party
    - Easily transitions to production
    - Foundation for spiral development / product improvement

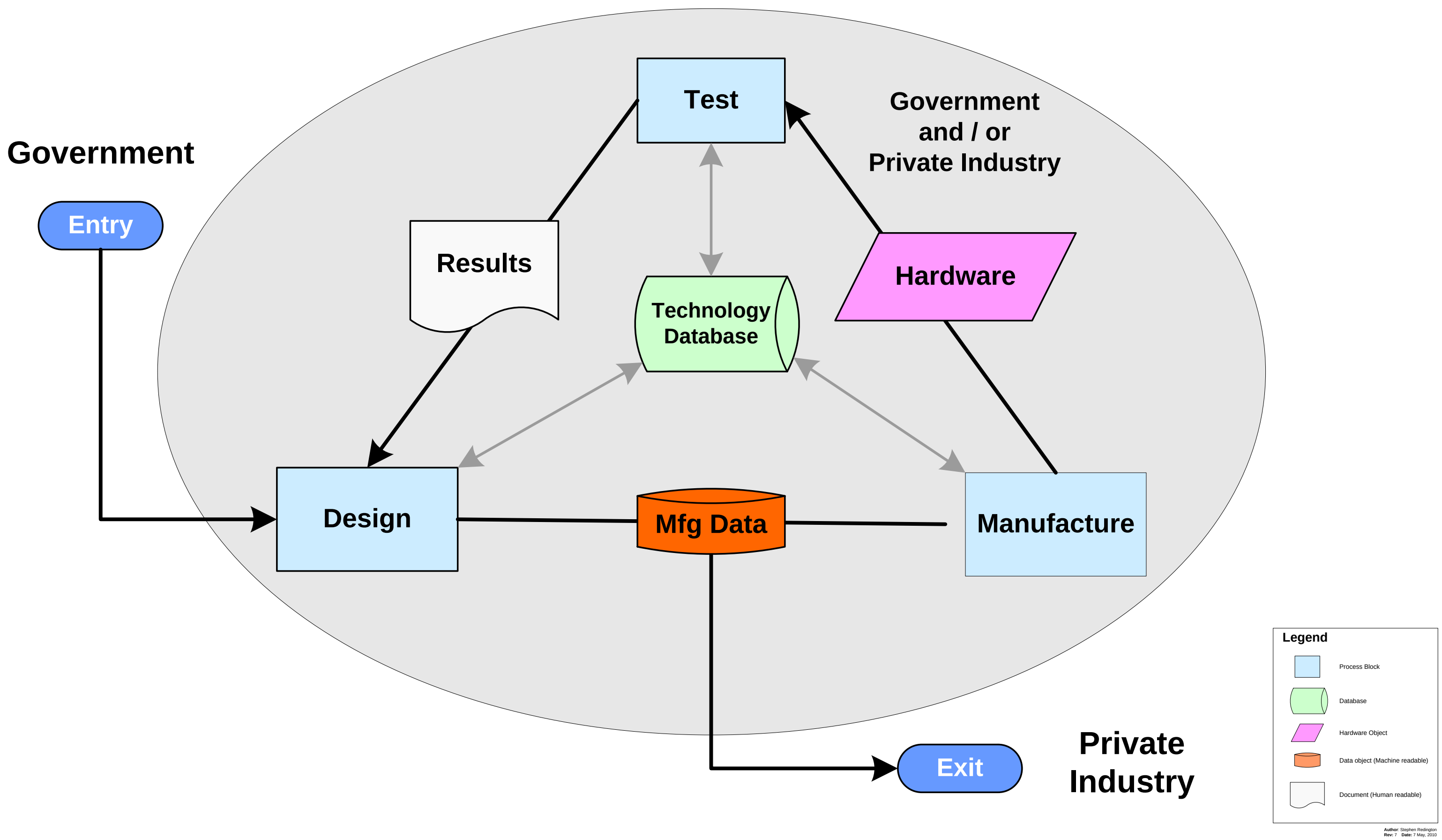
Concept Prototyping

A model for experimentation and development



Integrated Producibility

An integrated model for experimentation and product development



- Integrating manufacturability in development
  - Focus on the product more than the part
    - Products can be delivered, parts cannot
  - Focus on documentation up front
    - Assume nothing, specify everything
    - Is there enough detail for someone else to fabricate the design
  - Stay under control
    - Follow a design process
    - Enforce a mechanism for identifying prototype configurations
  - Promote teamwork
    - Minimize schedule delays
    - Share and incorporate specialized knowledge

- This is extra work. Why Bother?
  - Benefits
    - Less rework down the road
    - Shorter time to field
    - Lower overall cost
    - Improved uniformity / consistency of performance
  - Key concepts for success
    - Information Identification
    - A Self Documenting Design Process
    - A Self Explanatory Design Process
    - Feedback Controls
    - Design for Reuse / Prevent rework
    - Manufacturing Awareness

- Information Identity is Key to Producibility
  - Identify information first, then create it
    - Enables product level documentation up front
    - Don't create information, then identify it (indicates lack of planning)
  - Promotes teamwork / Enables information sharing
  - Mechanism depends on enterprise philosophy
    - Stupid numbers
      - Imply no information about the item / No classification errors
      - Simple rule to create / No exceptions to deal with
      - Requires an IT system to be useful
    - Smart numbers
      - Embed information about the item / Subject to human error
      - Must follow rules to create / Exceptions create problems
      - May or may not require an IT system to be useful

- Self Documenting Design Process
  - Shared common templates are key
    - Establish drawing format pages for all CAD tools
    - Establish common fabrication notes for all applicable technologies
    - Use your ID system to manage
  - Integrate the design process with your ID system
    - Make getting an ID number the first step in design
    - Promote configuration control up front
  - Leverage IT to make it work
    - Avoid human factor road blocks
      - Generate your ID numbers automatically
    - Automate repetitive tasks

- Self Explanatory Design Process
  - Consider human factors to minimize error
    - Minimize misinterpretation of design information where possible
    - Eliminate superfluous / irrelevant information
    - Accurate schematic representation of all elements in assembly
    - Physical location on schematic implies physical grouping on a PCB although no rules exist in reality
  - Group all appropriate information together
    - One archive per item to be fabricated
    - Natural enforcement of configuration
  - Review designs like your seeing them for the first time
    - Is it clear and easy to understand
    - Is it complete

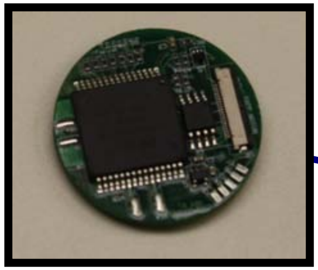
- Enable feedback control in development
  - Capture and retain cost information where possible
    - Enable design to cost
    - Use as a metric (not actual cost) due to volatile nature
    - Use to quickly focus attention to "big ticket" items driving cost
  - Inventory information
    - Avoid designing in new parts / maximize reuse
    - Reduce schedule and cost at development time
  - Tracking and monitoring
    - Manage product development by managing its physical (tangible) parts rather than work breakdown on the project schedule
    - Track metrics that are easily quantifiable (tangible)
    - Avoid metrics that involve time (process over schedule)

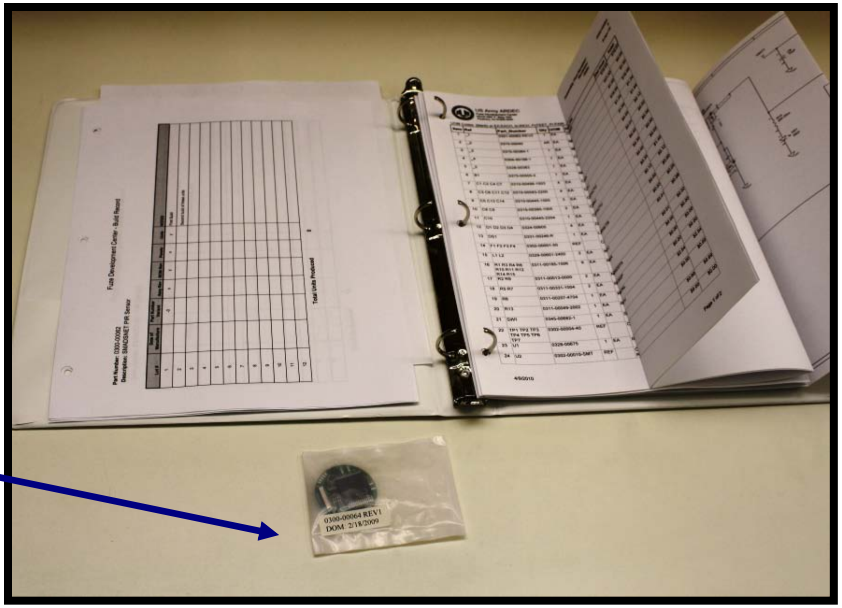
- Design for reuse / Prevent rework
  - Design history is the core competency of the enterprise
    - Provide a foundation for repeat work
    - Provide a foundation for new work
    - Success or failure is irrelevant, either result builds knowledge
  - Centrally locate Information
    - CAD tools share common libraries
    - CAD information is the foundation for the next iteration
    - Make historical data accessible
  - Correct erroneous information immediately
    - Think of the next design error you will be preventing

- Increase Manufacturing Awareness
  - What can be made verses what can be drawn
    - What can done by machine / What needs to be done by hand
    - When are tooling holes needed and how are they used
    - What is a reference datum
      - How are they used
      - Where should they be located
  - What kind of machines are applicable / available
    - How do the machines work
    - Where do they get their reference
    - What kind of tolerances are they capable of
  - What kind of tools are applicable / available
    - How are the tools used

Infrastructure

How to go from here……





To here

- A universal ID numbering system
  - Select the best compromise of number intelligence

O C S S - E E E E E - V V V V V

Organization (1 digit)	Class (1 digit)	Subclass (2 digits)	Entity (5 digits)	Variant-(Optional) (0 to 5 characters)

Note:

Only 6 classes cover everything

CLASS
- 1 – Public Information
- 2 – Code
- 3 – Component
- 4 – Assets
- 5 – Products
- 6 - Documents

3 SUBCLASS
- 00 – Custom CCA
- 01 – Custom PCB
- 02 – Custom Footprint
- 03 – Custom ASIC
- 04 – Custom Hardware
- 05 – Custom Energetic
- xx – COTS

6 SUBCLASS
- 00 – Technical
- 01 – Memoranda
- 02 – Presentations
- :
- 10 – Circuit Card Assembly
- 20 – Hardware
- 30 – Product

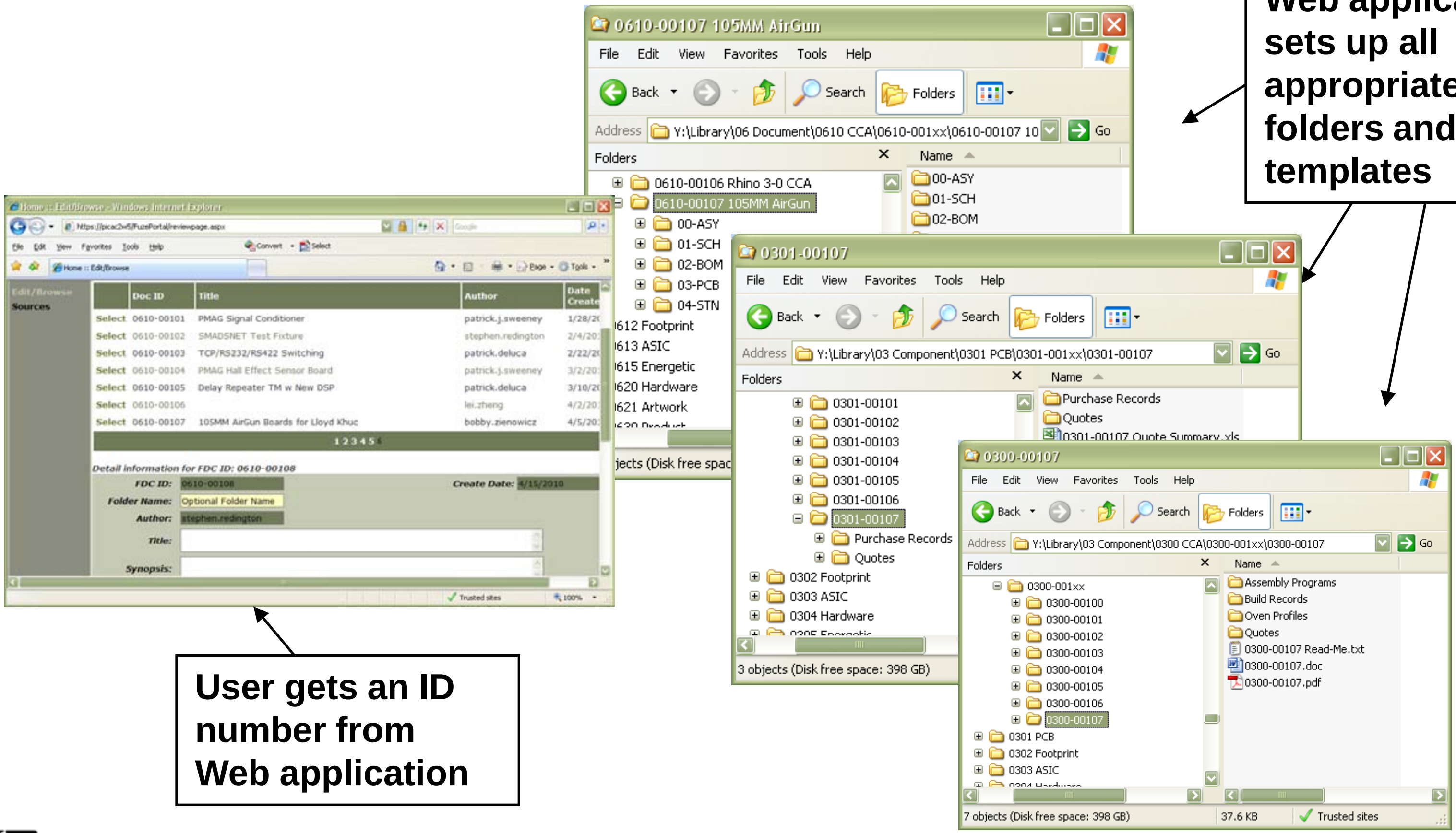
This presentation is

FDC # 0602-00013

Example of an Information identification scheme used by the FDC

- Self Documenting Process

Web application sets up all appropriate file folders and CAD templates

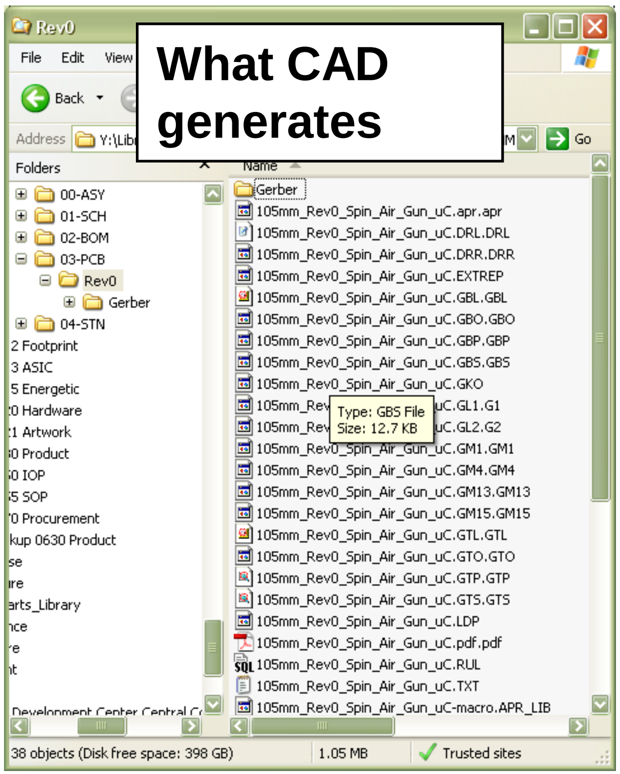


User gets an ID number from Web application

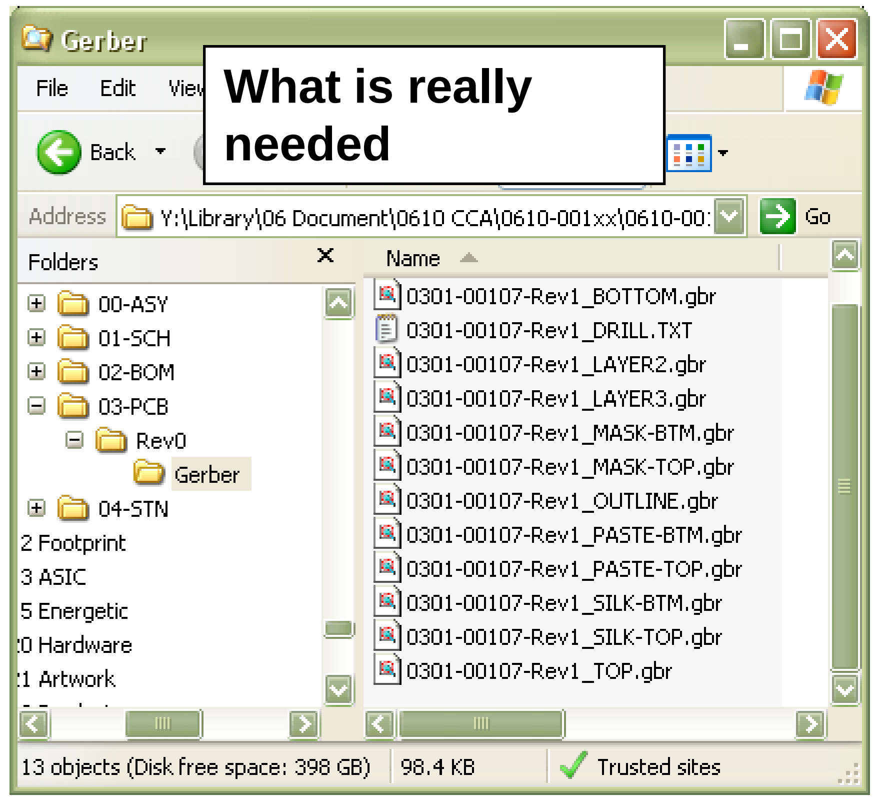
- Self Explanatory Process

Look from the recipient point of view

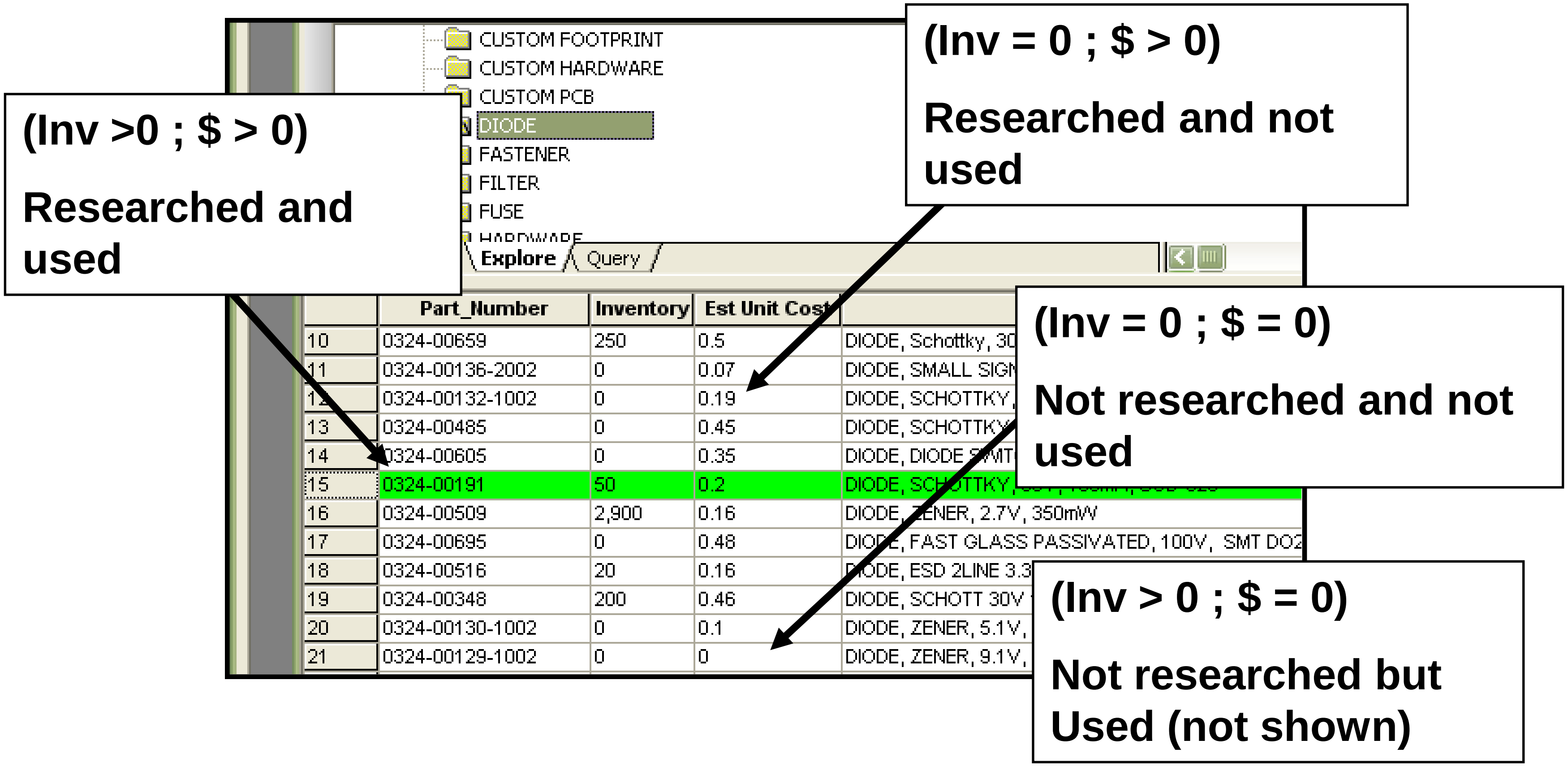
What CAD generates



What is really needed



- Feedback control example (cost & inventory)



Integrating Manufacturability
In closing…

- Pay as much attention to little problems as you would the big problems
  - Unlike experimentation, one unsolved little problem will kill a product just the same as one big problem.
  - Solving little problems early can help you solve big problems latter.
- Its easier said than done
  - Everyone agrees that integrating manufacturability up front is a good thing. How many actually do it?
    - Expect resistance on both sides: engineering and management
  - Infrastructure and Management support are essential.

Questions

Fuze Development Center

US Army RDECOM ARDEC Fuze Division
Picatinny Arsenal, NJ

Stephen Redington, PE
973-724-2127

OPTICAL SYSTEM TO CONTROL TERMINATION OF SMALL- AND MEDIUM-CALIBER MUNITIONS

Sergey Sandomirsky*, Alexander Naumov*, Naibing Ma*, Paul Shnitser*, and George G. Gibbs**

*Physical Optics Corporation, ssandomirsky@poc.com
**MARCORSYSCOM, george.gibbs@usmc.mil

Presentation

For NDIA 54th Annual Fuze Conference

Kansas City, MO
May 12, 2010

Needs

- Proximity fuzes (PFs) are widely used in large-caliber (>50 mm) artillery shells, aviation bombs, and missile warheads.

- PF initiates ordnance explosive detonation at a given distance from the target.

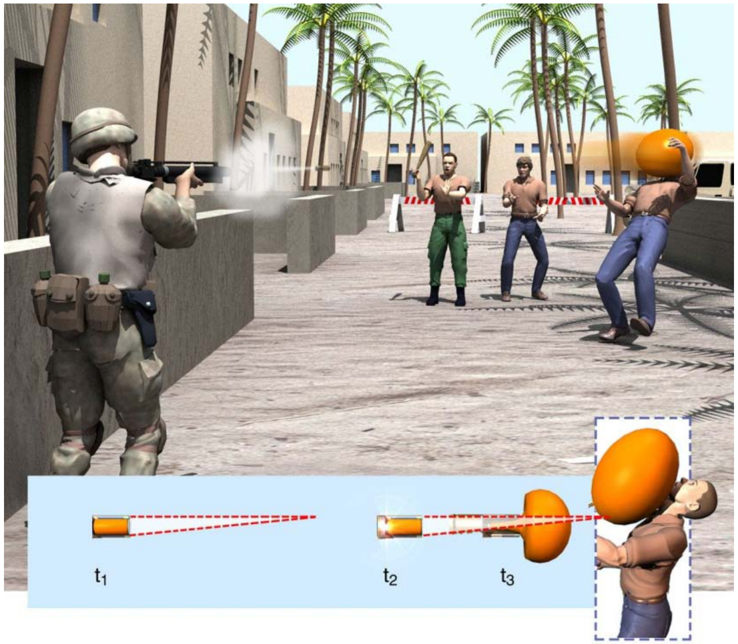
- Similar control of termination is needed for small- (12-gauge) and medium-caliber (40-mm) munitions in long-range nonlethal applications and in high-lethality airburst applications.

POC Solution

- The best suited fuze is an optical fuze based on a laser triangulation proximity sensor mounted inside a round.
- The laser proximity sensors (LPSs) being developed at POC can respond to a target emerging in front of a flying round at a distance from 0 to 2-3 m with a response time in tens of microseconds.
- Munitions assembled with LPS, does not require weapon modification.
- POC has developed prototypes for 12-gauge (Optical Proximity Sensor - OPS) and 40-mm (Smart Optical Proximity Fuze - SOProF) calibers.

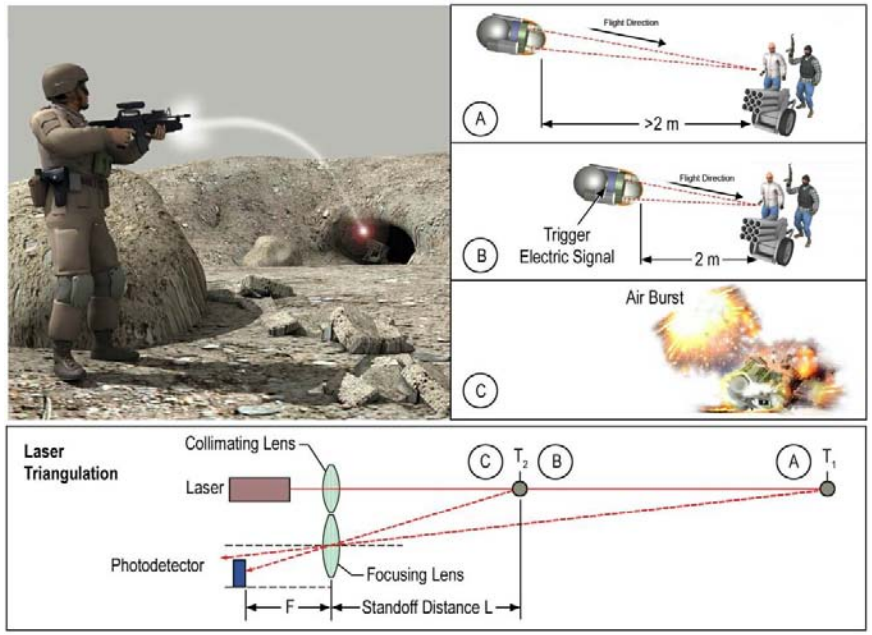
Application Scenarios

Nonlethal



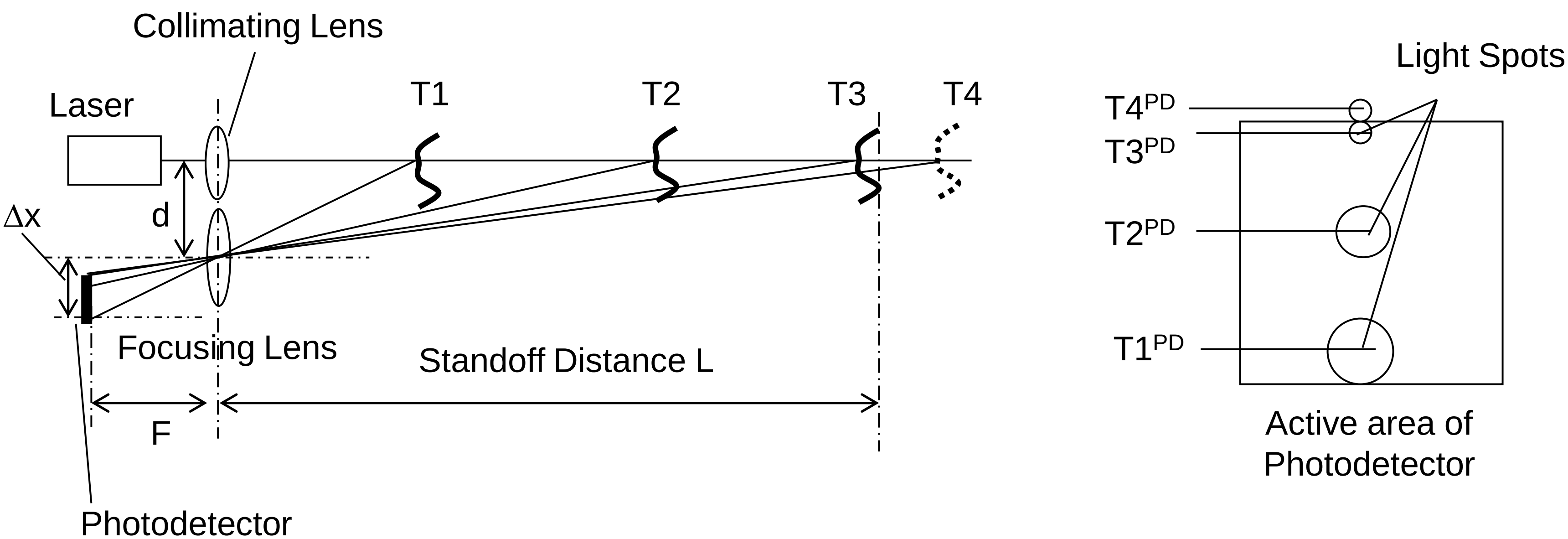
Application of the LPS (OPS) with variable-range kinetic energy munition with inflating bag.

High-Lethality Airburst



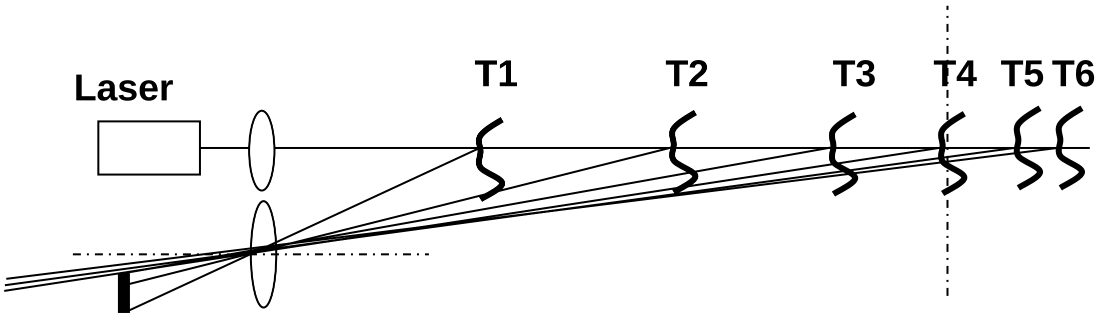
LPS (SOProF) installed on a high explosive 40-mm round; detects a target 0 m to 2 m from a projectile and activates electric initiator for airburst.

Laser Triangulation Principle

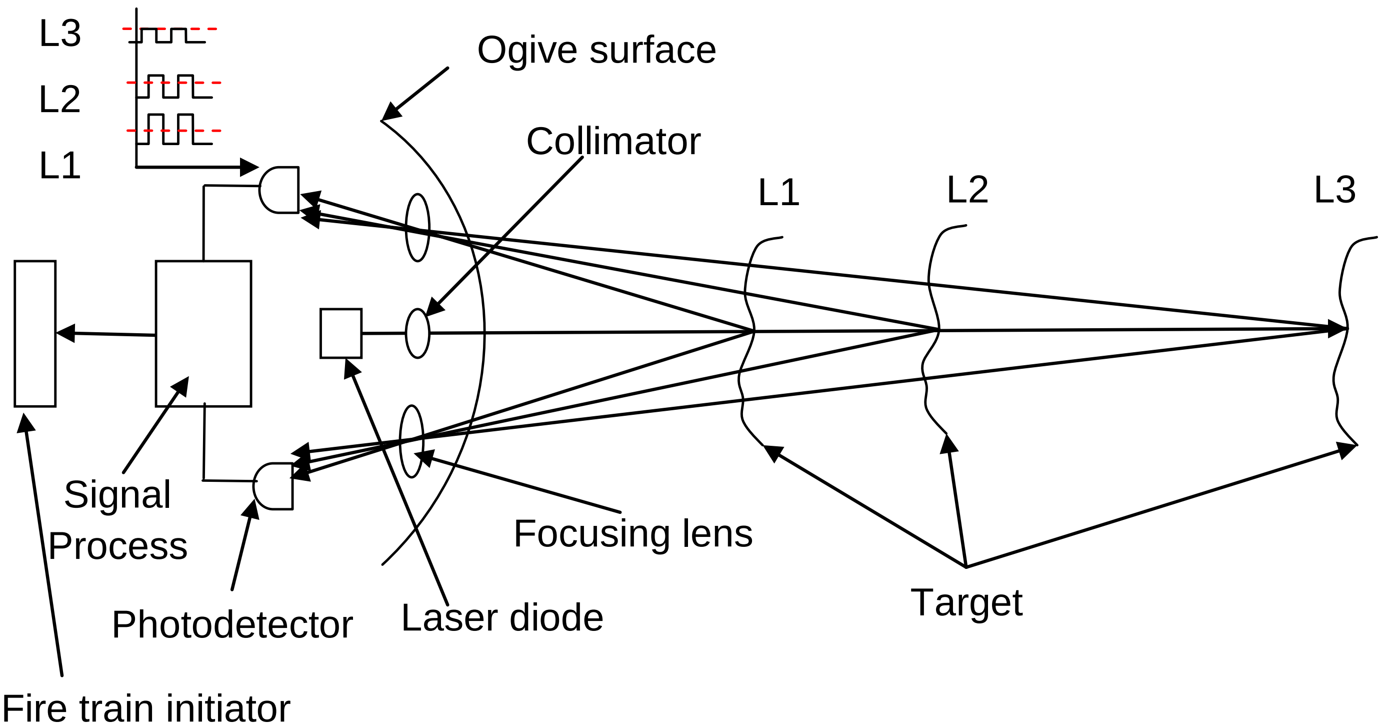


The transmitted laser beam reflecting from a target located at distances from T1 to T4 causes displacement of the beam image across the active area of the photodetector from position T1PD to T4PD. The beam image reflected from a target in position T4 does not reach the active area of the photodetector.

Laser Triangulation Principle (Cont.)



Laser Triangulation in an Axially Symmetric Configuration

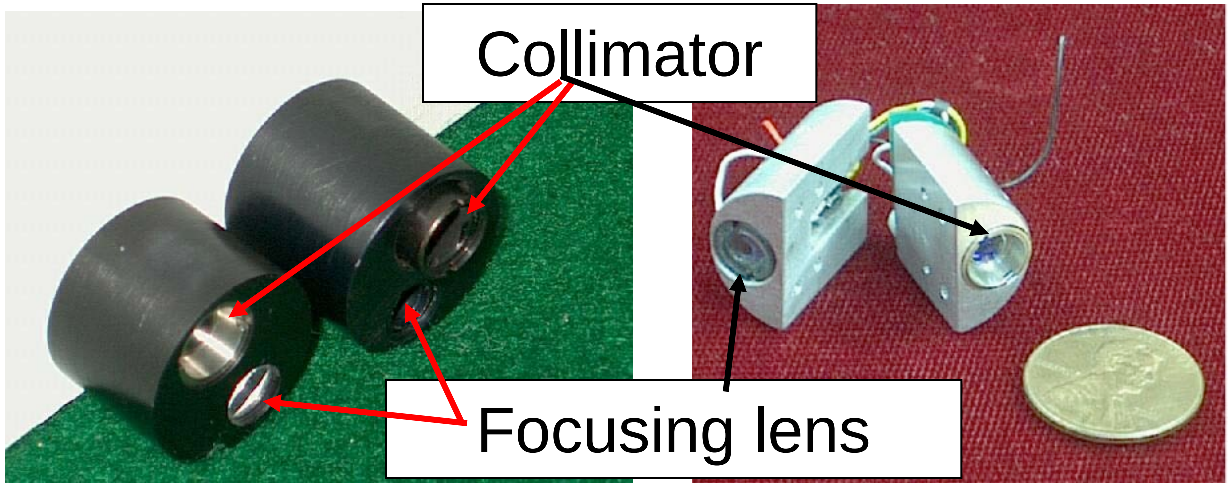


Advantages of axial symmetric arrangement of multiple apertures and photodetectors:

- Better ballistics due to center of gravity being located on the longitudinal axis of a round.
- Higher SNR due to averaging of multiple output signals

POC's LPS Prototypes

Three generations of OPS prototypes for 12-gauge caliber



Outside diameter, mm	17.8
Length including PC board, mm	19.0
Weight (without battery), g	10.2
Distance range, m	3-5
Light source: Laser diode @ 808 nm	200 mW

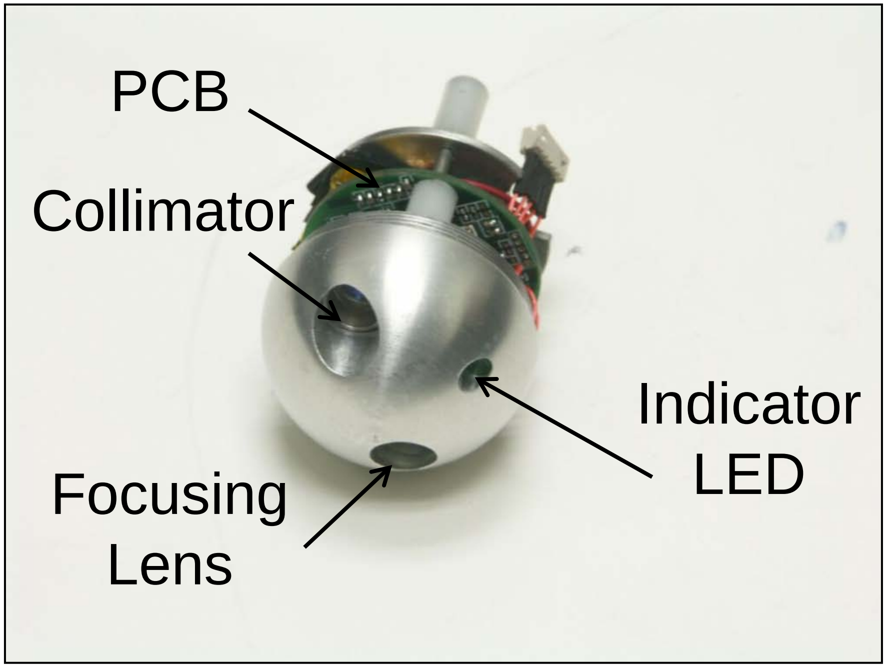
Splitting OPS for nonlethal applications.

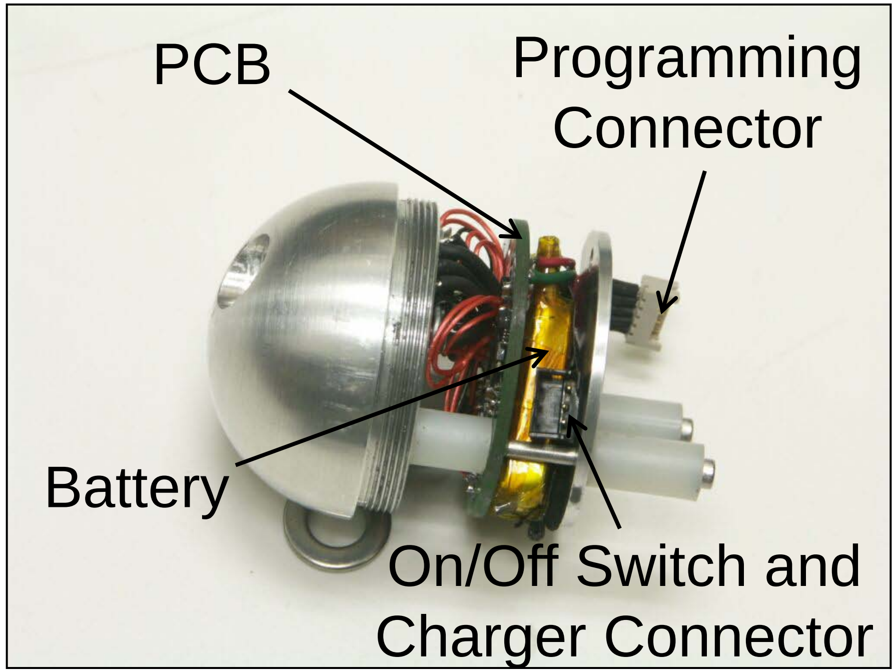
Power: 6 V Li/MnO_2 battery

LPS Prototypes (Cont.)

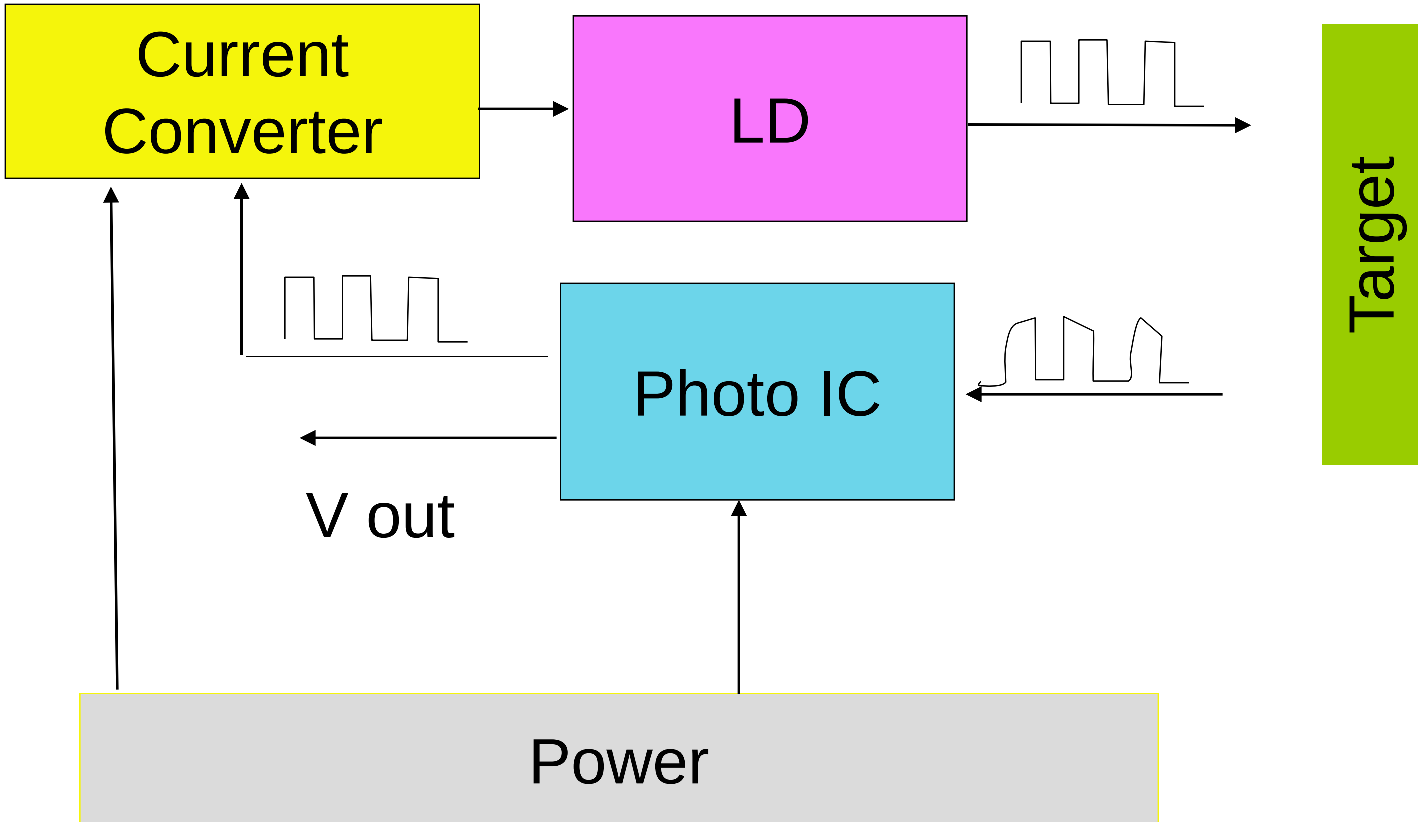
LPS (SOProF) assembled in M433 40-mm round model.

Power: 3.7 V Li-ion rechargeable battery



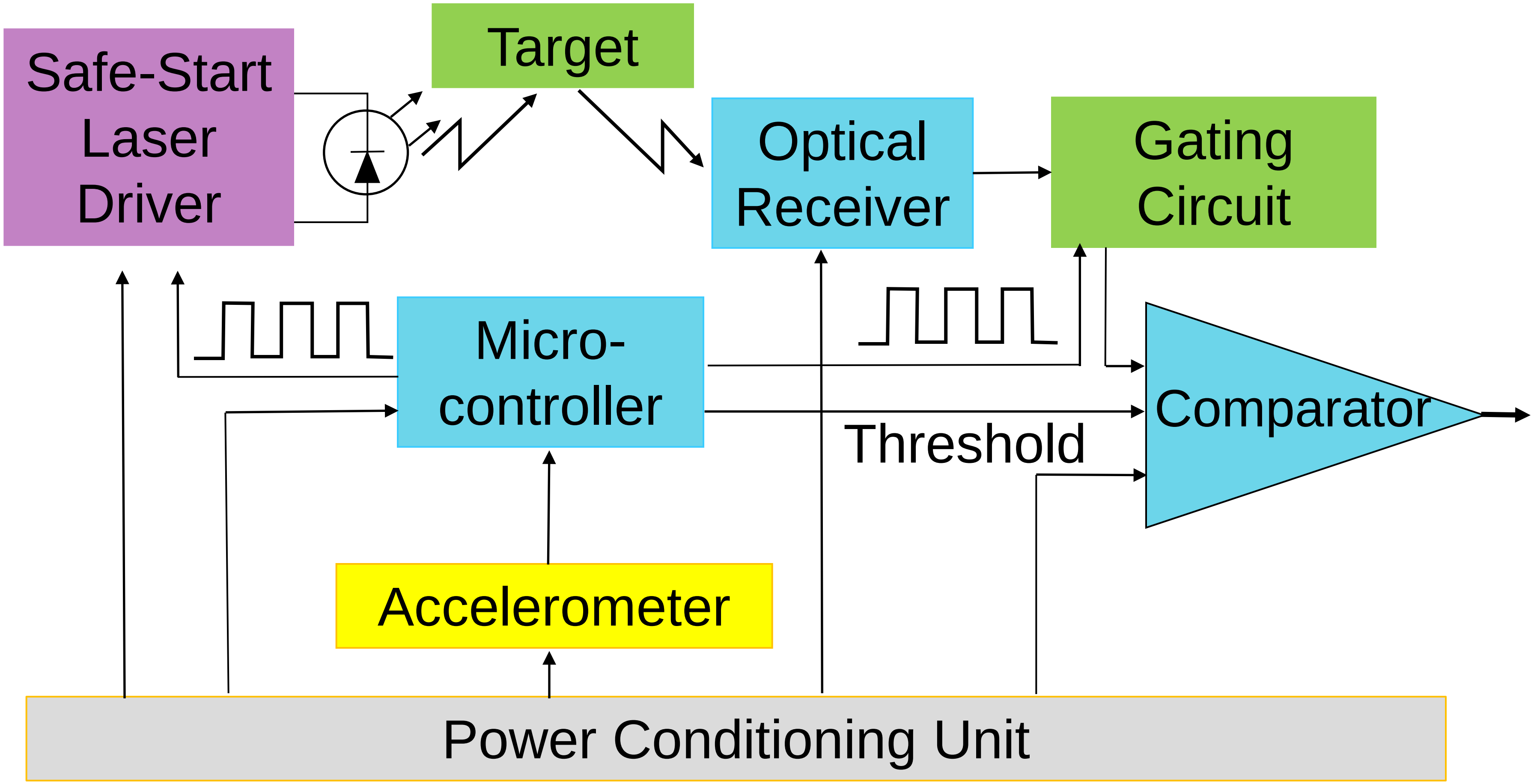


LPS Electronics



Block diagram of LPS prototype electronic circuitry for 12-gauge round. Light-modulating photo IC provides synchronous light detection, improving SNR and miniaturizing LPS package.

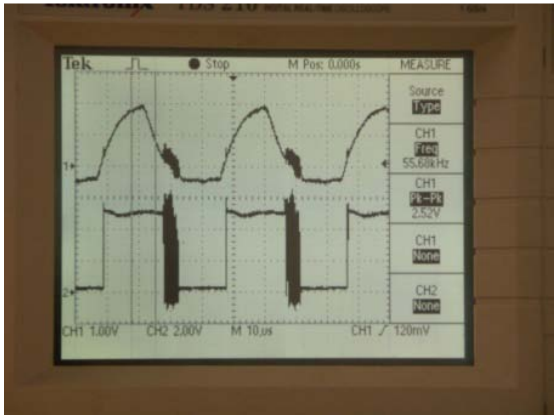
LPS Electronics (Cont.)



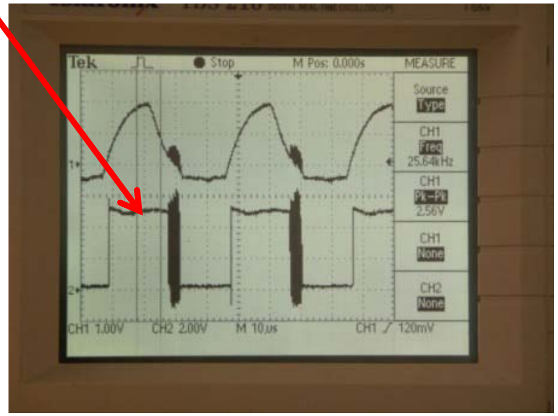
Block diagram of LPS prototype electronic circuitry for 40-mm round. Accelerometer functions as a power switch. Light modulation minimizes power consumption.

LPS Performance

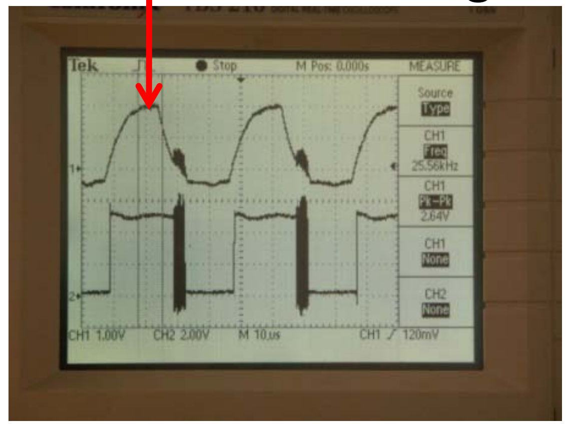
Output signals from the photodetector (top curve) and comparator (bottom curve) for different distances to the target.



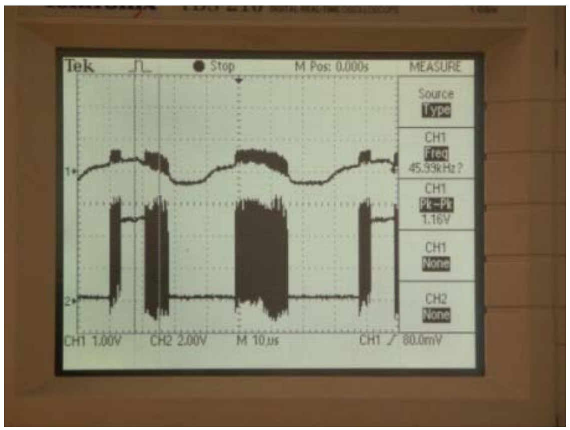
3 in.



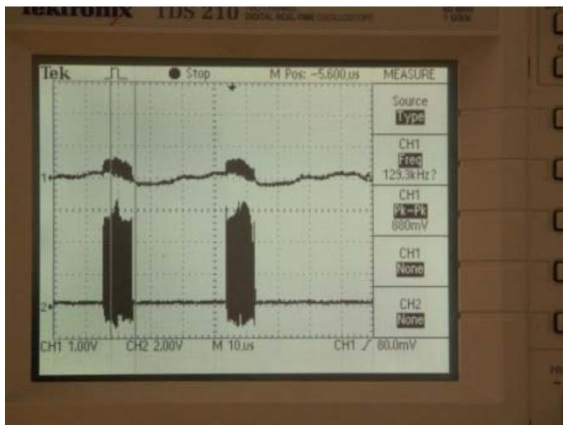
10 in.



12 in.

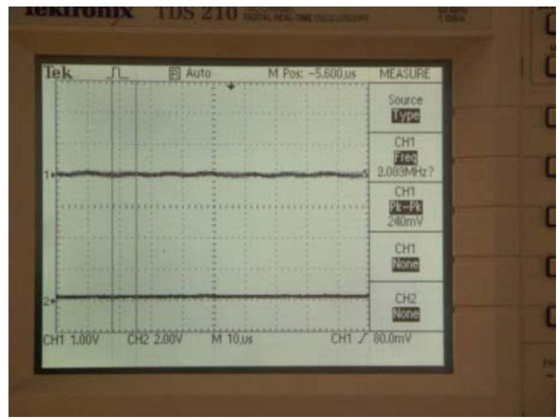


36 in.



72 in.

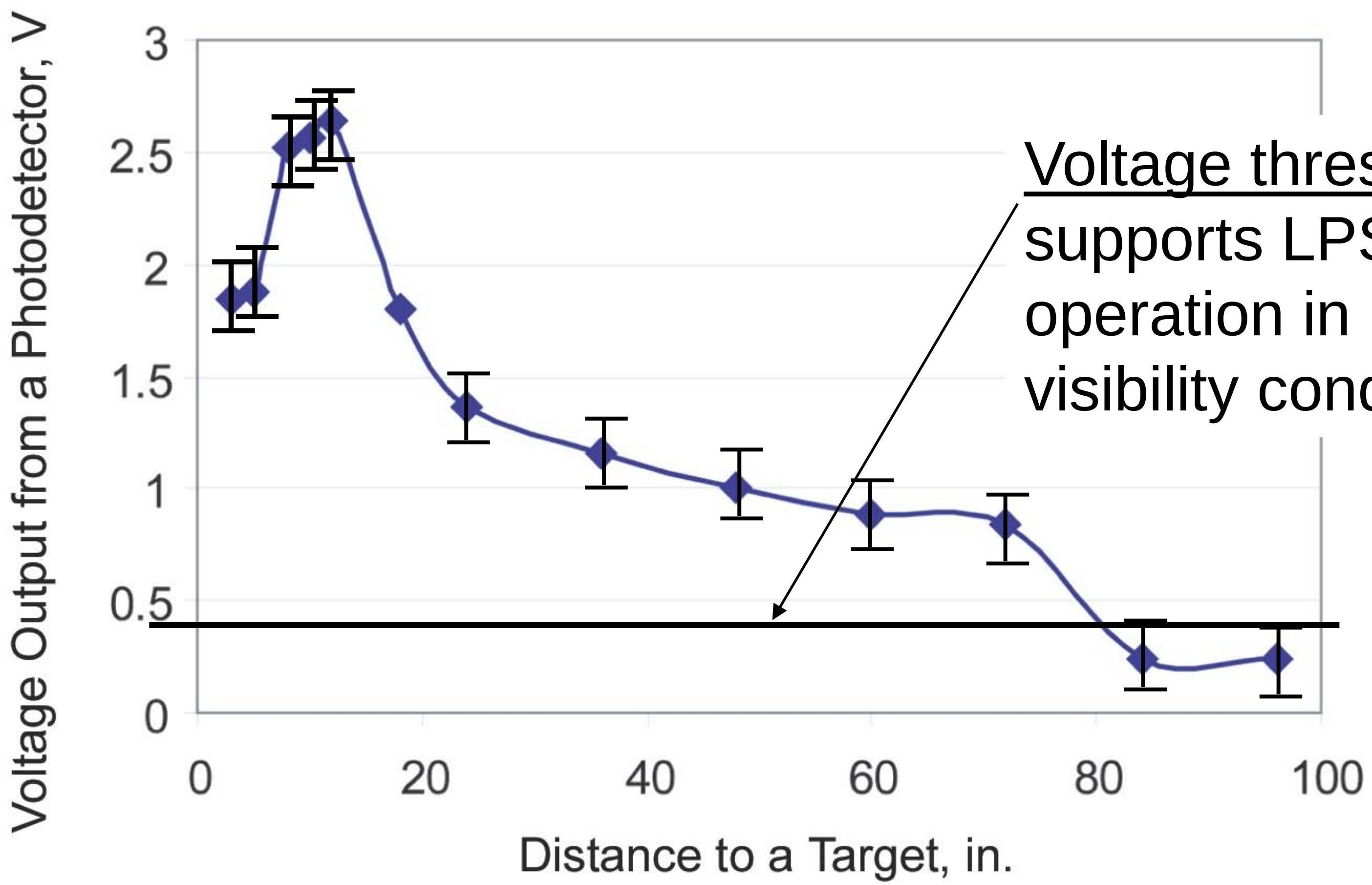
No response



96 in.

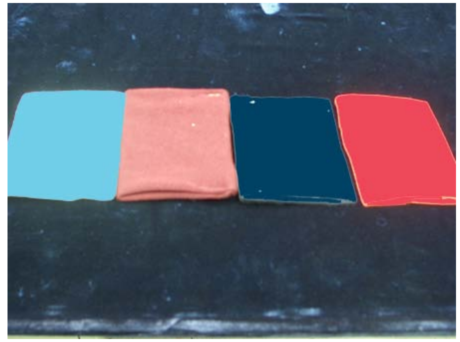
LPS Performance (Cont.)

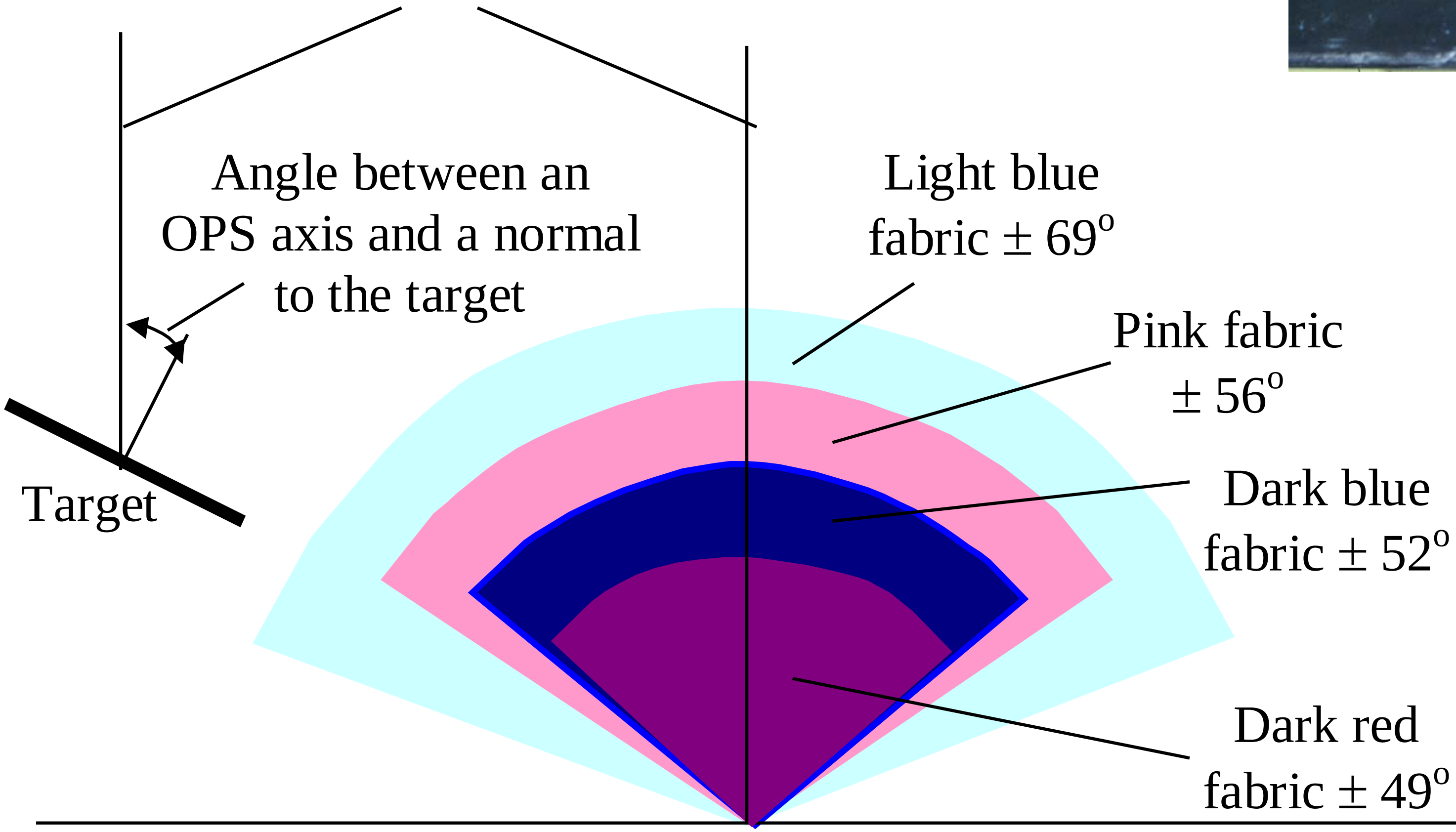
Output signals from the photodetector (top curve) and comparator (bottom curve) for different distances to the target.



LPS Performance

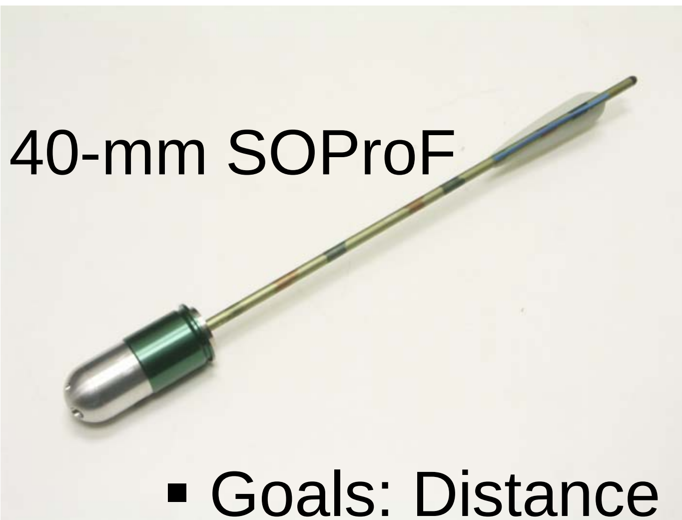
Angular diagrams of target detection at a distance of 3 m for four fabrics differing in color and texture, covering the target surface.



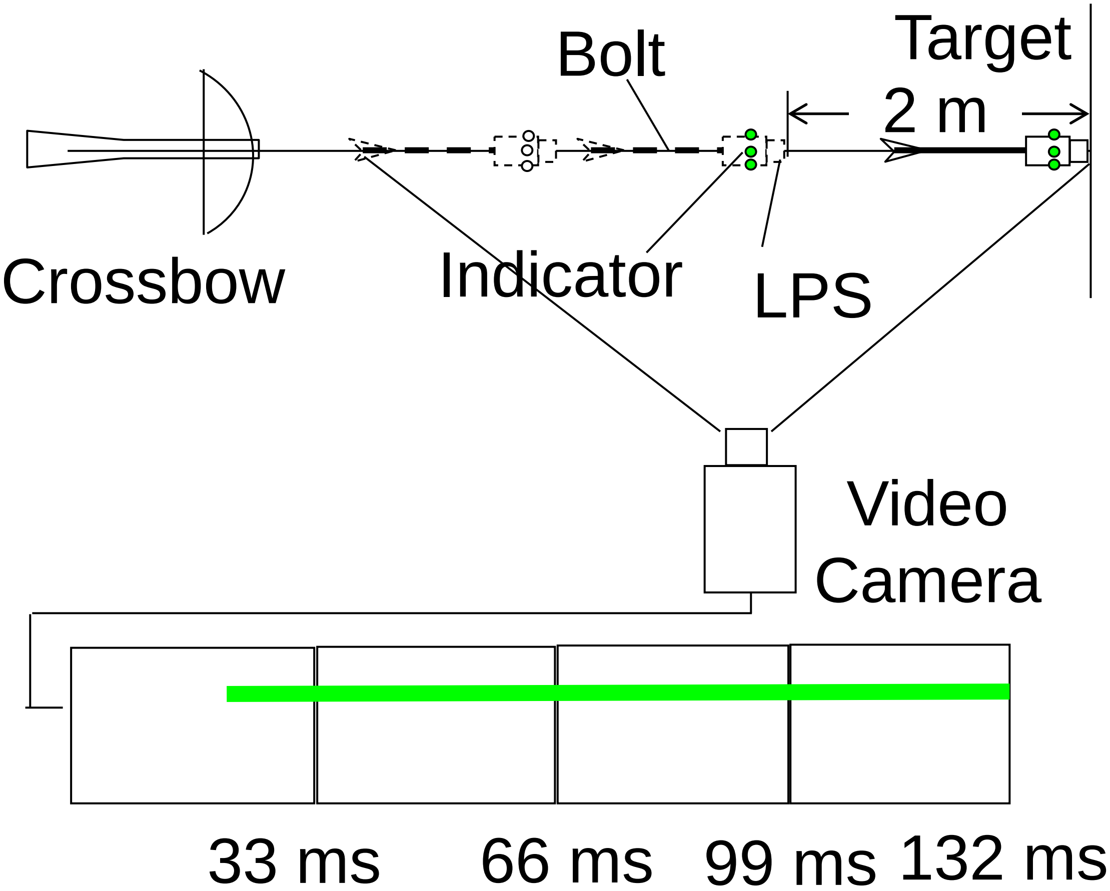


LPS Performance Demonstration

12-Gauge OPS



40-mm SOProF



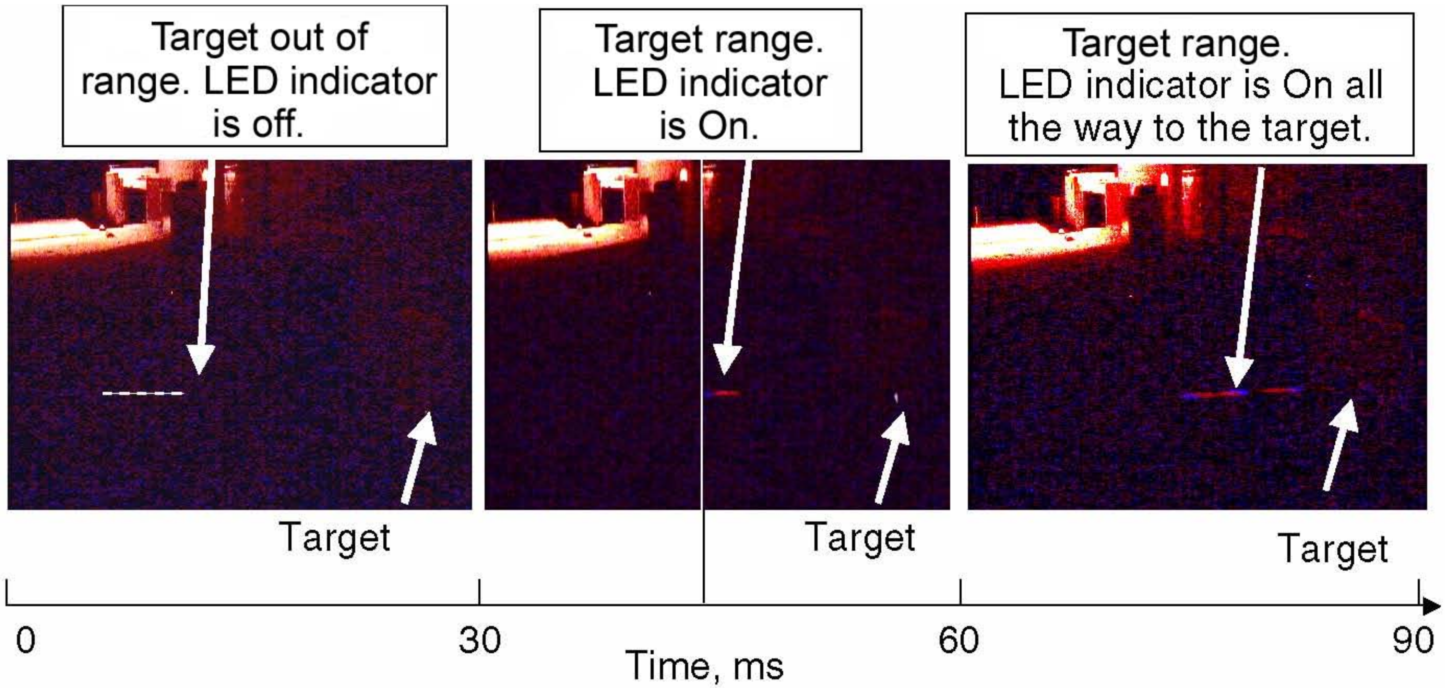
Frames

- Goals: Distance Range Verification; Shock Survivability

LPS Performance Demonstration (Cont.)

12-gauge OPS

40-mm SOPrOF

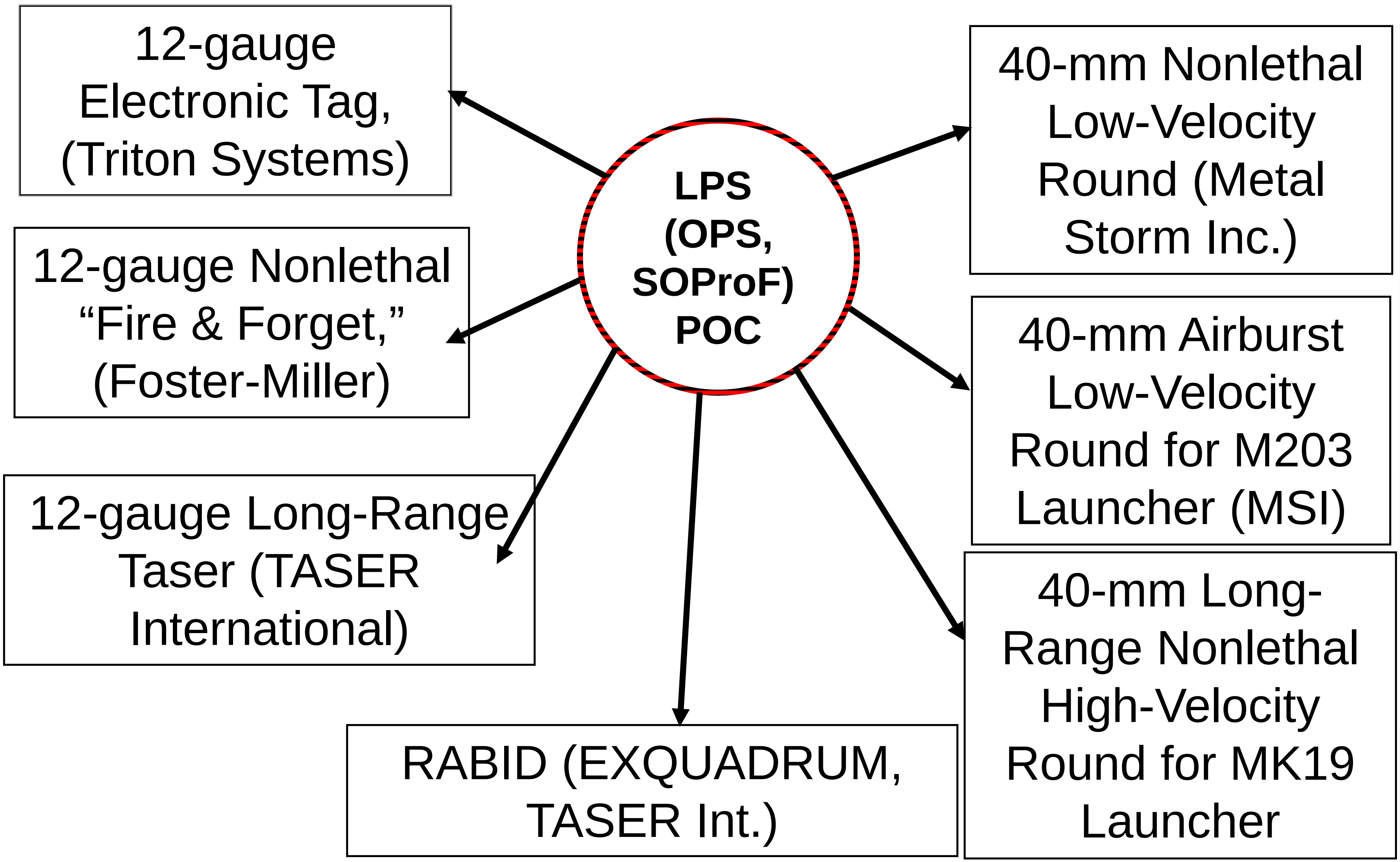


Summary of LPS Performance Demonstration

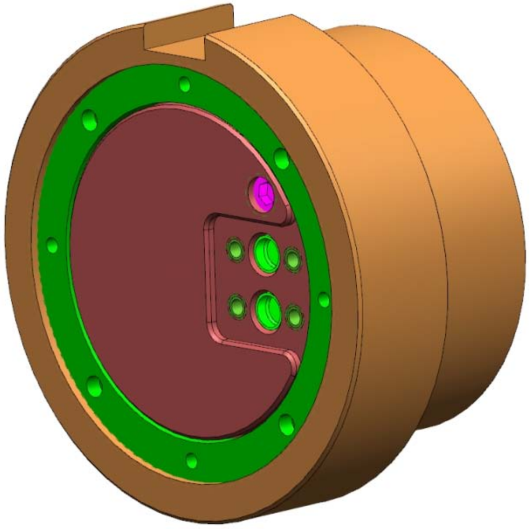
Parameter	Value
Bolt path during 1 frame Bolt speed with OPS assembly (estimated from light track) Bolt deceleration while hitting the target (5 cm penetration to full stop)	125 cm 47 m/s ≈2300 g

Parameter	Value
Bolt speed with M433/SOProF assembly (estimated)	45 m/s
Bolt deceleration while hitting the target (5 cm penetration to full stop)	≈2025 g

Potential LPS Applications



NavFire Guidance System – Integrated GPS and Mission Computer for Future Navigation Systems



Walter Trach, Jr.

Session IIIA
12 May 2010

Rockwell Collins

NavFire Guidance System Outline

- Precision-Guided Artillery
- NavFire Guidance System (NFGS) Design
  - Features
  - Subassemblies
- Core Functionality
- Integration
- Summary

Precision-Guided Artillery Purpose

- Increase Ground Force Effectiveness
  - Accurately hit specified target
  - Reduce (or eliminate) repeated adjustments

- Minimize collateral damage

Artillery Environment

- High velocities
- Launch shock
  - Set-back shock
  - Set-forward shock
- Canard/Fin/Wing deployment
- Rocket Boost
- Spinning Round
  - Variable depending on platform up to 350 Hz

Artillery Program Challenges

- Space limitation
  - Due to artillery round ogive
  - Smart weapons ogive contains fuze and guidance system
- Hostile Environment
- Shorter time to fielded system
  - Less time for design, implementation, integration, etc.
- Cost to win

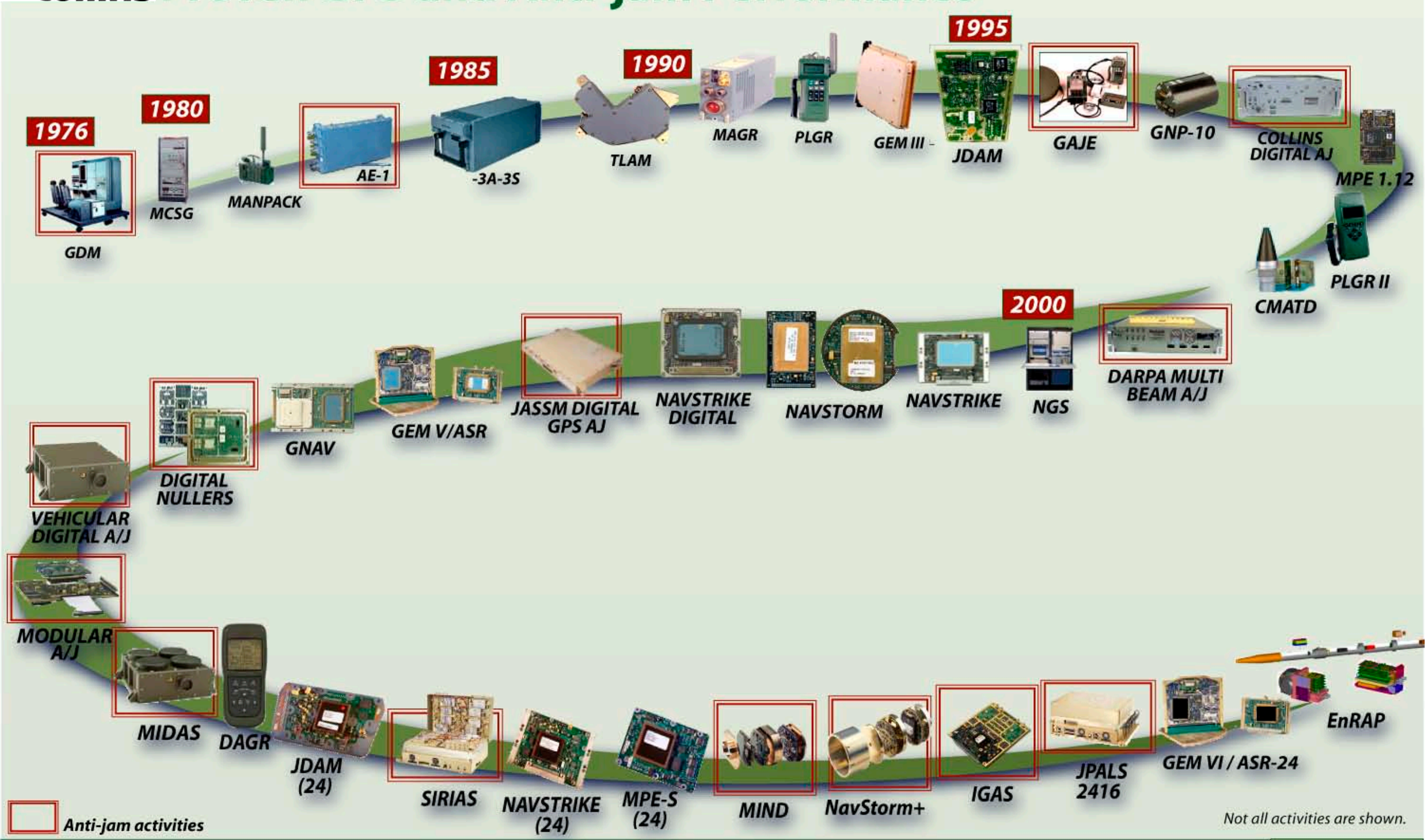
NavFire Guidance System (NFGS)

- NFGS Scope
  - Support artillery programs
  - Integrated guidance and navigation package
    - Reduce number of parts
    - More efficient design
  - Reduce user integration time

NFGS Features

- Small Form Factor
  - 45 mm outer diameter by 40 mm height
  - 150 grams
- Low Power
  - ≤ 5 Watts, nominal operation
- Performance
  - ≤ 6.0 second Guidance Solution availability (from Power On)
  - ≤ 5.0 meters CEP (standalone GPS)
  - ≤ 2.0 m/s velocity accuracy
- Gun Hard to 20,000 G
- Integrated 2-channel Anti-Jam
- Up-finding
  - ≤ 5 accuracy
- Software configurable
- Can host user algorithms

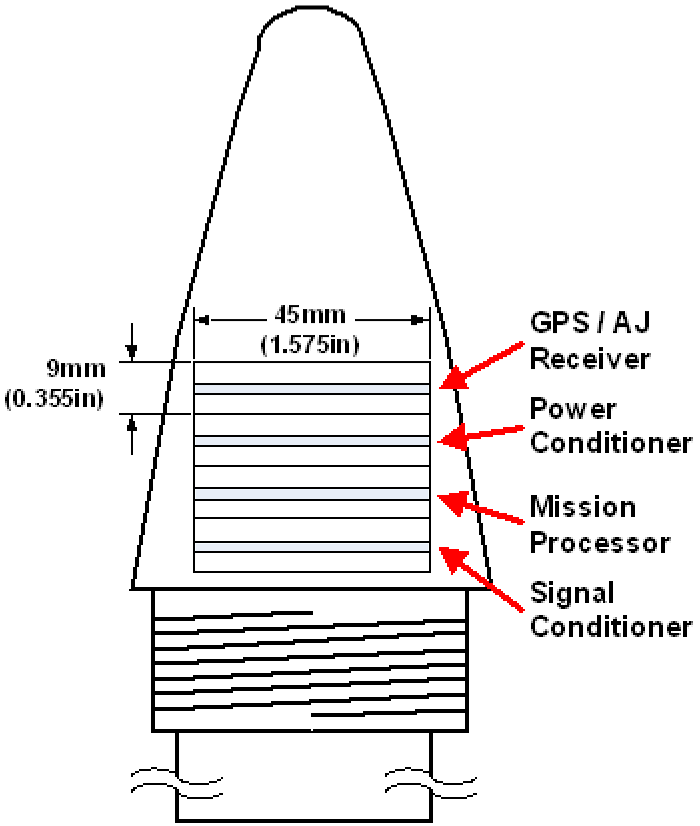
Proven GPS and Anti-jam Performance



SDB-RCAJ_001B.AI

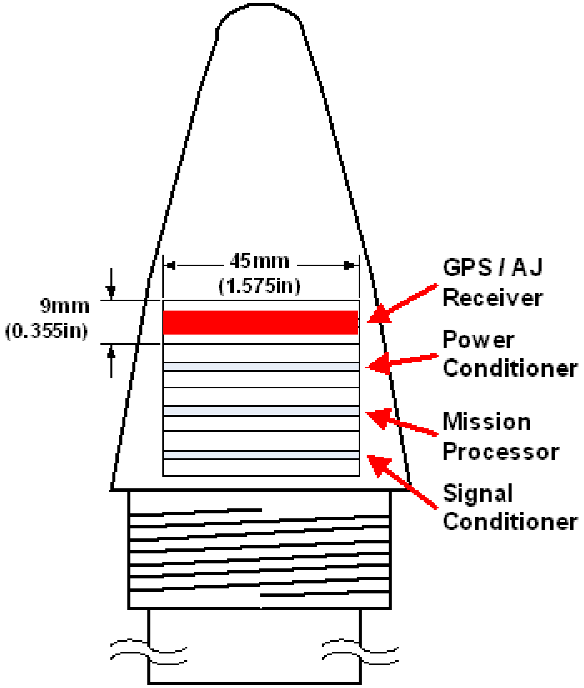
NFGS Subassemblies

- GPS Receiver
- Power Conditioning
- Mission Processor
- Signal Conditioning



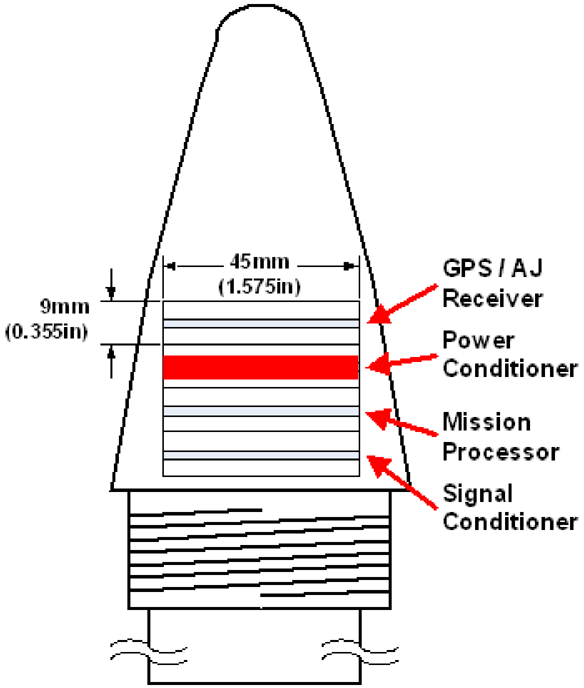
NFGS Subassembly - GPS Receiver

- NavFire GPS-AJ Receiver
  - Baselined on NavStorm™+ GPSR
    - Proven artillery GPSR
  - 2 RF Channels
    - L1 or L2 capable
    - Expandable to 4 channels
  - SAASM 3.7
    - Over 9000 correlators
    - 50% increase over previous SAASM
    - 36 acquisition, 48 tracking
  - KDP4
    - Integrated into SAASM 3.7
    - No longer separate hardware



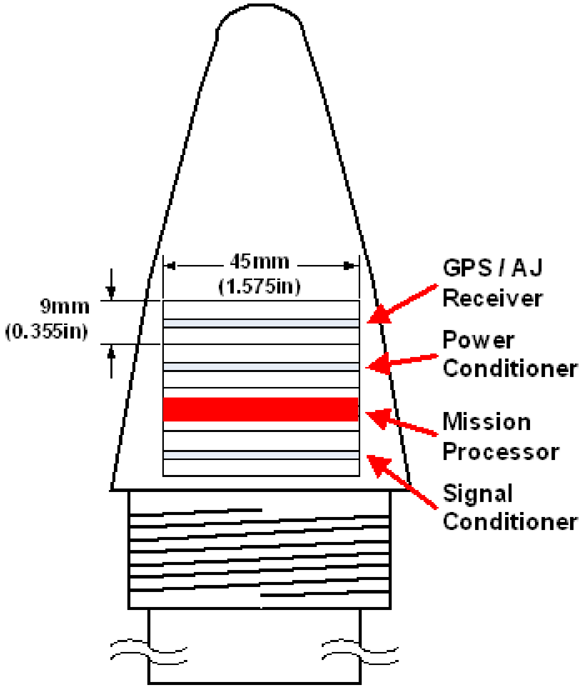
NFGS Subassembly - Power Conditioning

- User provided power
  - 4.75 VDC – 12.0 VDC
- Condition power for NFGS
- Primary power to auxiliary power switching
  - Supports Data Hold phase
- Charging circuit
  - Supports charging a super-capacitor
    - Used for Data Hold phase

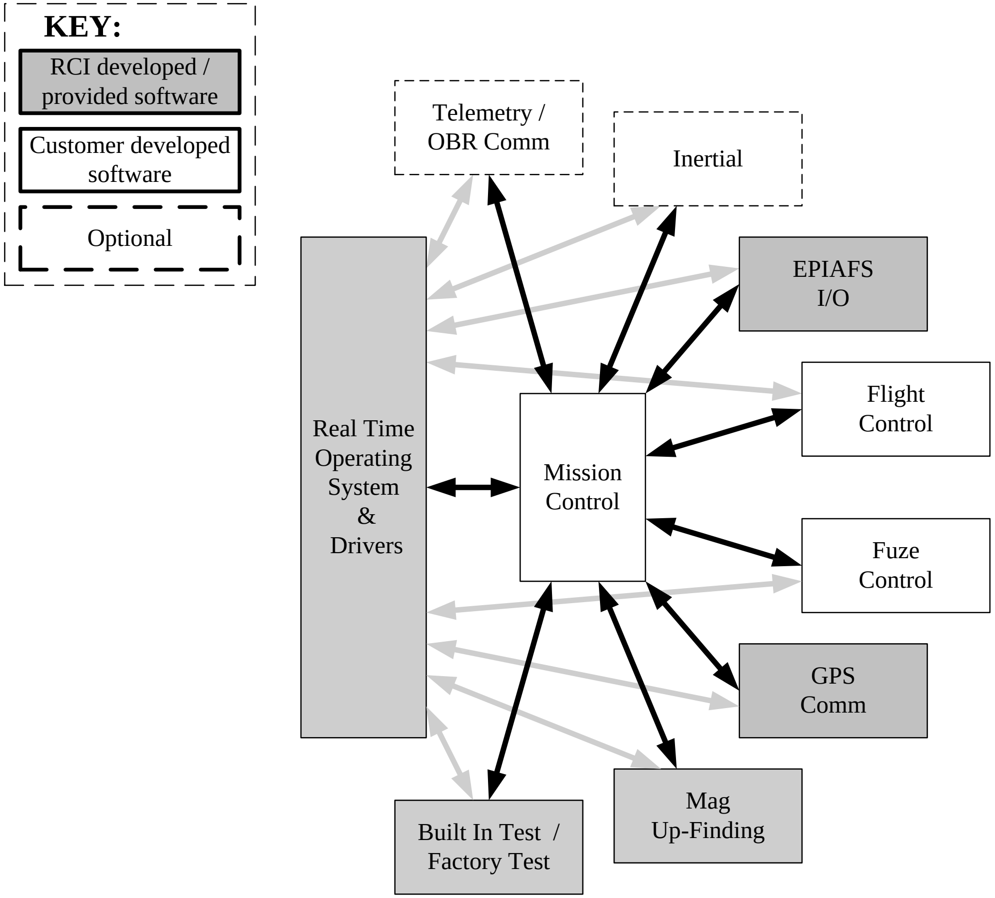


NFGS Subassembly - Mission Processor

- Driven by GPSR oscillator
  - Common time reference
- Microprocessor
  - Supports PoP Memory
- Real Time Operating System
  - VxWorks
  - POSIX-compliant
  - Portable to other RTOS
- Interfaces to guidance sensors
- Provides Status and Control

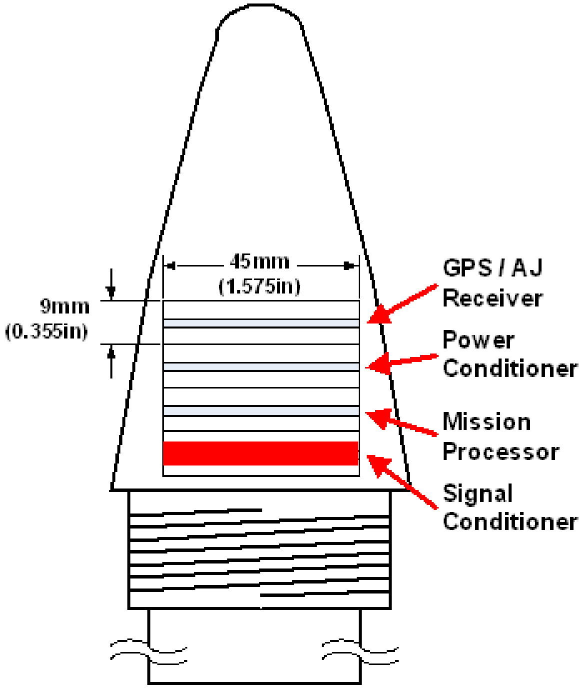


NFGS Subassembly - Mission Processor Software



NFGS Subassembly - Signal Conditioning

- Provides all interfaces for the NFGS
  - Configurable for unique interfaces
- Common interfaces supports
  - RS-422/485
  - USB
  - DS-101
  - 1PPS/TimeMark
  - Pulse Width Modulated (PWM)
- Artillery specific interfaces
  - FUZE
  - Enhanced Portable Inductive Fuze Setter (EPIAFS)



EPIAFS

- Inductive Interface
  - Provides Power and Data
  - Eliminates need for external interface connection

- Data interleaved with power pulses

Core Functionality

- Built-In Test
  - Performs BIT and provides results for all available sensors

- Provides Up-finding

- Provides GPS solution
  - Pseudorange and Delta range (PR/DR)
  - Position, Velocity, Time (PVT)

- GPS Interface
  - Provides GPS data in user-friendly format
    - Handles GPS message format and protocol
  - Handles GPS cryptokey data

Core Functionality (cont.)

- Interfaces with EPIAFS
- Interfaces with additional navigation sensors
- Flexible message protocol
  - User defined messages
  - NFGS and user application share memory
    - Common, defined memory locations for all internal data
  - NFGS defined messages
    - GPS data, BIT results, NFGS status, etc.
    - All data in NFGS defined messages available to user
- Supports user guidance algorithms
  - Hosted on NFGS Mission Processor

NFGS Up-Finding

- Required for precise guidance
- Determine roll angle and roll rate
- Magnetometer
  - Determines up based on Earth's magnetic vector
- Advanced Spinning Vehicle Navigation (ASVN)
  - Developed and patented by Rockwell Collins
  - Determines when antenna system is facing the sky
  - Applicable for very high rotation rates
  - Successful field tests

NFGS Integration - EPIAFS

- NFGS interfaces with EPIAFS
  - Routes power to super-capacitor charging circuit
  - Routes data to Mission Processor

- NFGS performs all EPIAFS communication
  - Handshaking, status, etc.

- Mission Processor parses EPIAFS-provided data
  - Places parsed data in common memory location
  - Data in IEEE format

Rockwell Collins

NFGS Integration

- Reduces user integration time
  - Combines GPSR, Mission Processor, signal and power conditioning
  - Handles GPSR I/O interface
    - Provides GPS data to user via memory location
    - User does not need to interact with the GPSR message protocol
  - Handles EPIAFS inductive interface
    - Charges super-capacitor
    - Parses and routes data
  - Handles I/O to guidance sensors

- User defined messages

- User's integration focus
  - Guidance, Navigation, and Control (GNC)
  - Fuzing

Summary

- NFGS developed as an integrated GPS and Mission Processor
- NFGS designed for precision artillery market
  - Small form factor
  - Gun hard
- Reduces user integration time
  - Users focus on GNC and fuzing
  - NFGS handles I/O to/from sensors
  - Up-finding built in

Questions?

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT, & ENGINEERING CENTER (ARDEC)

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

ARDEC Overview - 54th Annual NDIA Fuze Conference

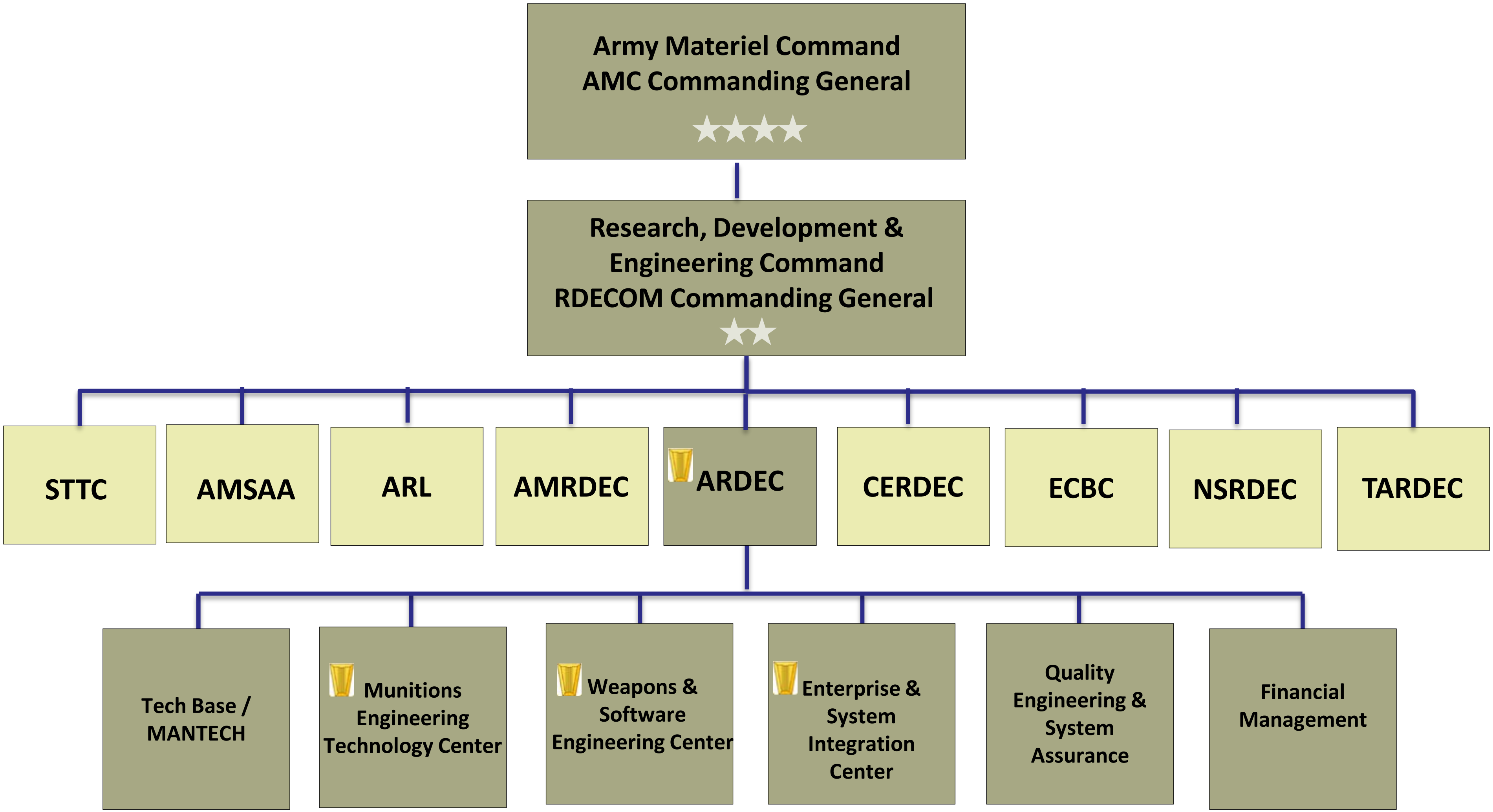
12 May 2010

Dr. Joseph A. Lannon

Director, ARDEC

US ARMY RDECOM

ARDEC Organization - Chain of Command



Malcolm Baldrige National Quality Award 2007 Award Recipient

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

US ARMY RDECOM

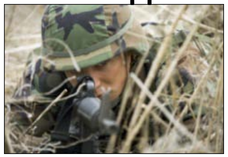
Armament Research, Development & Engineering Center

Research

Development

Production

Field Support



Demilitarization

Vision:

Innovative Armaments Solutions for Today and Tomorrow

Mission:

To develop and maintain a customer focused, world-class workforce that will execute, manage and continuously improve integrated life cycle engineering processes required for the research, development, production, field support and demilitarization of munitions, weapons, fire control and associated items.

Advanced Weapons – line of sight/beyond line of sight fire; non line of sight fire; scalable effects; non-lethal; directed energy; autonomous weapons

Ammunition – small, medium, large caliber; propellants; explosives; pyrotechnics; warheads; insensitive munitions; logistics; packaging; fuzes; environmental technologies and explosive ordnance disposal

Fire Control – battlefield digitization; embedded system software; aero ballistics and telemetry

ARDEC provides the Technology for Over 90% of the Army's lethality; Significant support to other services' lethality

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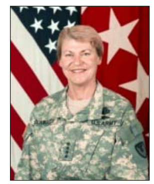
US ARMY RDECOM

ARDEC Supports Two LCMCs

Assigned/Direct Support	———
Coordination	- - - -

Headquarters, Department of the Army

Army Materiel Command, AMC
Gen. Ann E. Dunwoody



Joint Munitions & Lethality LCMC
BG Larry Wyche

PEO Ammo
BG Jonathan A. Maddux

- Project Manager Close Combat Systems (PM CCS)
- Project Manager Combat Ammunition Systems (PM CAS)
- Project Manager Maneuver Ammunition Systems (PM MAS)
- Project Manager for Joint Services (PM Joint Services)

Research, Development and Engineering Command, RDECOM
MG Nickolas G. Justice

Armament Research, Development and Engineering Center, ARDEC
Dr. Joseph A. Lannon

TACOM LCMC
MG Kurt J. Stein

- Program Executive Office Combat Support and Combat Service Support
- Program Executive Office Ground Combat Systems
- Program Executive Office Soldier

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ARDEC at a Glance

- Established "Center of Mass" for Armament Systems and Munitions for Joint Services
- ARDEC is the largest tenant at Picatinny Arsenal
  - Over 500 Buildings/64 Laboratories
- Proven track-record supporting transition of technologies to the field;

14 Materiel Releases (MR) in FY 08	18 MR in FY 09	2 MR in FY10
13 Urgent Materiel Releases (UMR) FY 08	22 UMR in FY09	2 UMR in FY10

- A total of 186 New Weapons and Equipment fielded since 9/11
- ARDEC Gov't Personnel* ~ 3570; 1340 new hires since FY99
  - Picatinny Site = 3095 Benet (Watervliet Arsenal) = 258
  - Rock Island Arsenal = 157 Adelphi & APG = 59
- >$200M invested in "World Class" experimental R&D facilities since mid-90's; Additional $75M planned
- Strong partnerships with Industry, Academia, and other Government agencies - Growth and Success through Cooperative Research and Development Agreements (CRADAs) = 118
- Intellectual Property*:
  - Invention Disclosures – 85
  - Patent Applications – 183
  - Patents Issued – 9
- Patent License Agreements = 16
- In-house rapid prototyping initiatives demonstrating new desired capabilities, supporting production prove-out and initial fielding demands
- > $100M Tech Base portfolio addressing Joint needs (Core Tech Base/ManTech only; does not include SBIR or Congressional Plus-ups)
  - $160M in Congressional in FY10




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* = as of 31 March 2010

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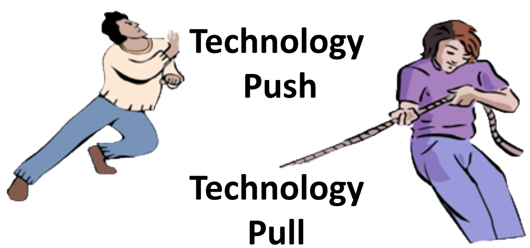
ARDEC Organizational Concept

Director/Deputy Director

- Tech Base/ MANTECH
  - Technology Innovation & Competency Development
- Munitions Engineering Technology Center
- Weapons & Software Engineering Center
- Enterprise & Systems Integration Center
  - Cost, Schedule, & Performance Adherence, Systems Engineering, Knowledge Management, Strategic Planning & Business Development
- Quality Engineering & System Assurance
  - Product Verification & Validation
- Financial Management Office
  - Financial Support



Empowered Teams Support Customer Needs throughout the Lifecycle

Collaboration Drives Success

US ARMY RDECOM

ARDEC Core Competencies

Collaboration Mechanisms

- ATOs/Tech Base
- Defense Ordnance Technology Consortium
- National Small Arms Consortium
- International Agreements
- Test & service Agreements
- CRADAs
- Rapid Prototyping

Advanced Weapon Systems

- Direct Fire weapons
- Indirect Fire weapons
- Scalable lethal Effects
- Non-Lethal Systems
- Small/Medium/Large Caliber Ammunition
- Directed Energy
- Remote Armaments
- Insensitive Munitions
- Fuzes
- Telemetry
- Precision Armaments
- Grenades
- Maneuver Support Munitions
- Demolitions
- Weapons & Munitions Manufacturing technology
- Detonators
- Explosive ordnance devices

Emerging Technologies

- Networked Lethality
- Defense Against Unmanned Systems
- Counter Terrorism Technologies
- Homeland Defense Technologies
- Advanced Materials / Nanotechnologies
- Novel Power & Energy Systems for weapons and munitions
- Armaments Manufacturing Science Technologies
- Reliability & Predictability Technology
- Modeling & Simulation of Armament systems
- System Engineering

Fire Control

- Battlefield Digitization
  - Software Applications
- Embedded Systems Software
- Firing Tables
  - Aeroballistics
  - Automated Test Systems
- Optics for Fire Control
- Smart Sight
- Projectile Tracking and Control
- Vehicle Health Management System
- Software Acquisition Support
- Software Engineering Processes
- Fire Control Technologies

Logistics

- Ammunition Logistics RDTE
- Battlefield Tools and Equipment
- Packaging

Advanced Energetics and Warheads

- Propellants
- Explosives
- Pyrotechnics
- Warheads
  - Kinetic Energy
  - Chemical Energy
  - Shaped Charges
  - EFPs
  - Fragmentation
  - Thermo baric
  - Multi purpose & Scalable
  - Non lethal
- Environmental Technologies
- Demil technologies

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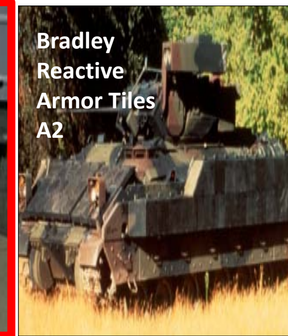
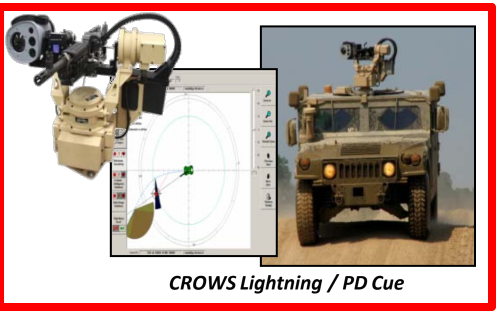
Weapons and Ammunition Fielded Since 9/11

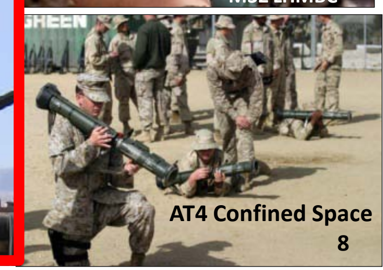




186 successful fieldings since 09/11/2001*

* = as of 15th March 2010

Army's Greatest Inventions 21 of 70 Soldier Choice Awards



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* = unique systems approved for fielding (e.g. MR) since 9/11/01

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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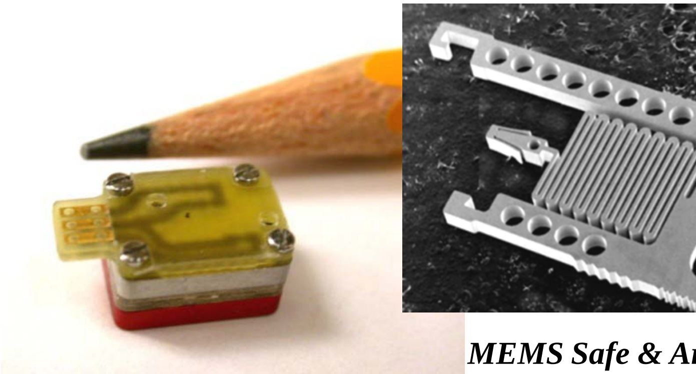
Significant Fuze Technical Accomplishments

Advance Fuze Technologies



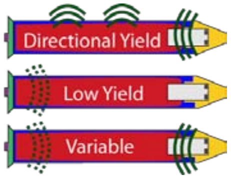
MEMS Safe & Arm (S&A)

Excalibur XM 982

EPIAFS

Affordable Precision Munitions

- *Scalable Technology for Adaptive Response (STAR)*
- *Affordable Precision Technologies*



Force Protection

Kinetic Energy Active Protection System

Non-Lethal Munitions

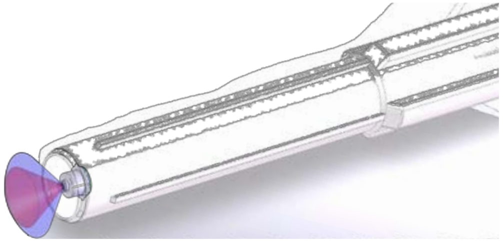
40mm LV Airburst Non-Lethal Munitions

Innovation

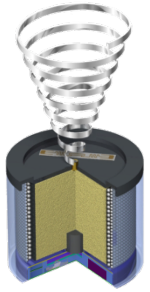
Lethal UAV

ARDEC Fuzing Technology Initiatives

- Scalable Technology for Adaptive Response (STAR) ATO
  - 250 mm GMLRS, 105 mm Precision, 30 mm Airburst
- Kinetic Energy-Active Protection System Target Detection Device (KE-APS TDD) ATO
- Cluster Munitions Replacement ATO
- DoD Joint Fuze Technology Program
- Affordable Precision Components ATO



KE-Active Protection System Interceptor



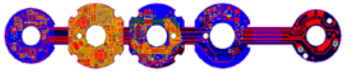
Practice Concept Cluster Munitions Replacement

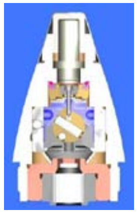
Fuze Technology Integration

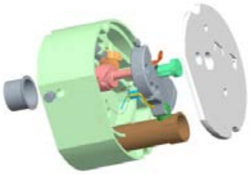

Reserve Battery

- Technology Insertion To Current Munition Items
- Addresses Industrial Base Single Point Failure Issues
    - Risk Mitigation:
        - Battery Aging
        - M734A1 Digital Signal Processor (Alternative Design)
    - Block Upgrades:
        - Standardization of Hand Grenade Fuzes
        - 30mm Increased sensitivity M759 Fuze
        - Mortar S&A enhancements
- PEO Ammunition / User Payoff:
    - Insert Current Technology Into Today's Munitions
    - Preclude Obsolescence By Incorporating Component Technology
    - Provide Safer, More Reliable and More Lethal Munitions


Hand Grenade Fuze


M734A1 Digital Signal Processor


30mm Increased Sensitivity M759 Fuze


Mortar S&A

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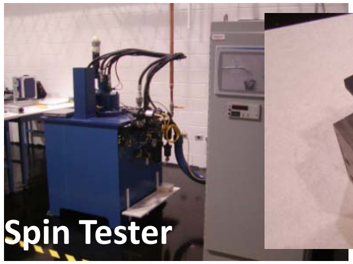
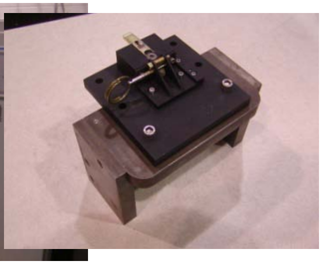
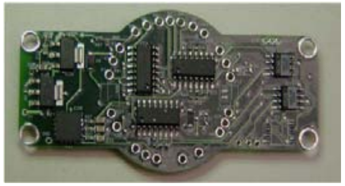
ARDEC In-House Fuzing Capabilities
Fuze Development Center





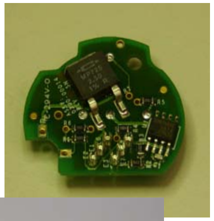


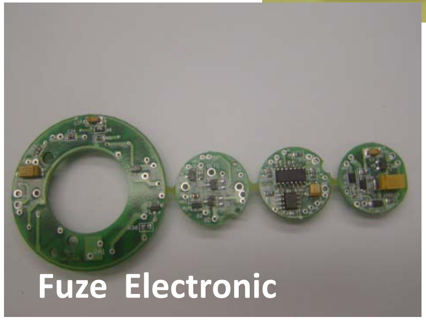
Capabilities for Rapid Prototyping:

Custom Circuit Card Design and Fabrication
Automated Surface Mount Assembly
Optical Strain and Stress Measurement
Environmental Test
Real-Time X-Ray Inspection
Stereo lithography
High Speed Spin Stand
Machine Shop

Current Projects Supported:

PGM Simulator
SMADSNET
EPIAFS GNC Trainer
Artillery Training Kit
M228 Support
M762 Training Fuzes
Anti-Tamper Fuze





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Mission: To Accelerate New Technology To The Field

Fuze Engineering Complex – Army BRAC

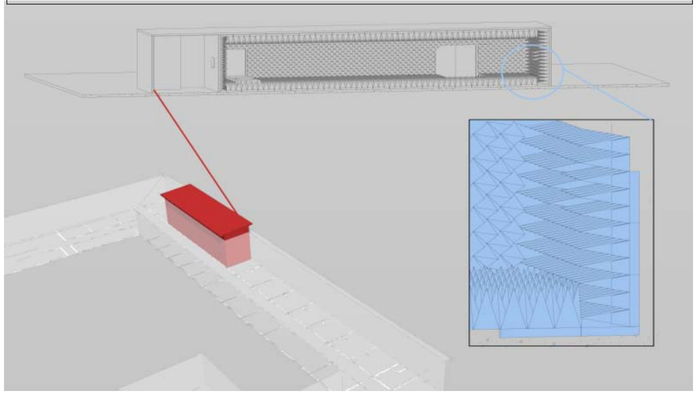
General Info

- *Fuze function currently located at Adelphi, MD (already part of ARDEC)*
- *Provides focus on fuze science and technology efforts and early development*
- *42 KSF: Admin space; Laboratory/Test areas; ammunition magazines*
- *Multiple sites around Picatinny Arsenal; renovations and new construction*

Army Fuze Engineering Complex

Fuze Energetic Research Laboratory

State of the Art Anechoic Chamber



Fuze Electromagnetic Research Laboratory

US ARMY RDECOM

Army Fuze Safety Review Board (AFSRB) Support 2009 - 2010

- **Initial/Interim Fuze Safety Certification (Test/TC)**
  - XM1156 Precision Guidance Kit (PGK) - 4 February 2009
  - Multi-role Anti-armor Anti-personnel Weapon System (MAAWS) 84mm Anti-Structure Munition (ASM) 509 **-** 4 March 2009
  - M762/M762A1 Electronic Time (ET) Fuze Used on 155mm XM1066 Infrared (IR) Illuminating Projectile – 8 April 2009
  - Selectable Lightweight Attack Munition (SLAM) M4E1 and M320E1 SLAM Improved Functional Trainer (SIFT) – 10 August 2009
- **Final Safety Certifications (MR):**
  - M153 Time Delay - Sympathetic Detonator (TD-SYDET) and M316 Trainer - 4 February 2009
  - Dual Safe Fuze for the AT4CS-RS 84mm HEAT Weapon - 18 March 2009
  - M156 Magneto-Inductive Remote Activation Munition System (MI-RAMS) with M39 Receiver (also know as "Type A Receiver") - 9 April 2009
  - M783 PD/Dly Fuze Used with 81mm M889A2 HE Mortar Cartridge and M734A1 Multi-Option Fuze for Mortar (MOFM) Used with 81mm M821A2 HE Mortar Cartridge – 30 June 2009
  - Smoke, Visual, Restricted Terrain, XM106 (formerly known as XM106 Screening Obscuration Device-Visual Restricted (SOD-Vr)) with M201A1 Mod 3 Fuze - 27 July 2009
  - F555 Electronic Time (ET) Fuze Used on 84mm 545C Illuminating Round - 25 September 2009
  - **XM7 Spider (SW control of Safety Critical Functions) – June 2009**
- **UMR & Approval Letters**
  - AFSRB, Navy Fuze & Initiation Systems Technical Review Panel (FISTRP), and Air Force Nonnuclear Munitions Safety Board (NNMSB) Executive Secretary on Anti-Structural Munition (ASM) Hand Grenade, MK14 - Mod 25 February 2009
  - 2.75 Inch (70mm) XM282 Multi-Purpose Penetrator (MPP) Warhead Rocket - 28 April 2009
  - M762/M762A1 Electronic Time (ET) Fuze Used on 155mm XM1066 Infrared (IR) Illuminating Projectile - 14 May 2009
  - Viper Strike Munition (VSM) Used on the Hunter Unmanned Aerial Vehicle (UAV) (Impact Mechanism change and added timeout detonation feature) - 3 September 2009

ARDEC FOCUS:
Smaller, Smarter, Safer Fuzing for the Warfighter

US ARMY RDECOM

Summary

- Global Leader In Armaments Technology Solutions
- Provide Exceptional Customer Satisfaction
  - We work with soldiers:
    - Develop new armaments systems
    - Improve fielded systems
    - Quickly solve field problems
- State of the Art Fuzing Capabilities
  - In-House Facilities
  - S&T Technical Expertise

Flexible, Agile, Innovative and Responsive

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40mm Infantry Grenade Fuzes

54th Annual Fuze Conference
«The Fuzing Evolution – Smaller, Smarter and Safer»
Kansas City, MO - May 11-13, 2010

Michael BUTZ
Product Management
JUNGHANS Microtec

A Diehl and Thales Company

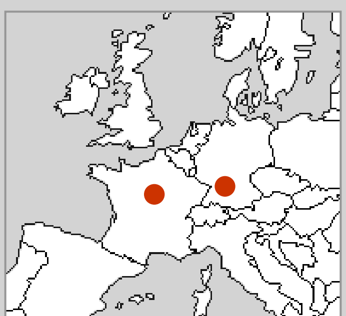
Outline

- Company Presentation
- Program Background, Application
- Requirements for DM431A1
- Overview of JUNGHANS 40mm Products
- Overview of the Cartridges and Fuzes
- DM431A1 IG HV fuze family
- DM431A1 - Fuze Design
- Fuze Functioning Modes
- Arming Criteria
- Safety and Reliability
- Trial Results
- Conclusion

Company Presentation

JUNGHANS microtec

- **A global leader in the field of ammunition fuzes and S&A devices**
- **Full range of products**
- **Key competencies in**
  - Fuzing technologies
  - Micro-technologies
  - Ammunition electronics



Program Background, Application

- Increasing intensive military action in urban terrain and a move to asymmetric combat situations triggered demand for other types of guns and ammunition for those situations
- German Army required a 40mm IG HV fuze with SD mode
- Selection of US M549 design as basis
- Improvement of the M549 PD fuze into DM431A1 PDSD fuze
- September 2002: First serial production contract
- Following the successful completion of the development phase the DM431A1 fuze was already presented at the Fuze Conference in 2003

Program Background, Application

- The DM431A1 fuze is in serial production since 2003
- Both DM441 and DM451 fuze are now entering the international markets

- DM431A1 Customer: Diehl BGT Defence – End users: GER, NOR, ITA, IRE, LV, NL, PL
- DM441 Customer: Hellenic Defence – End users: GRE, FRA, QATAR
- DM451 Customer: Diehl BGT Defence – End user: GER

Program Background, Application

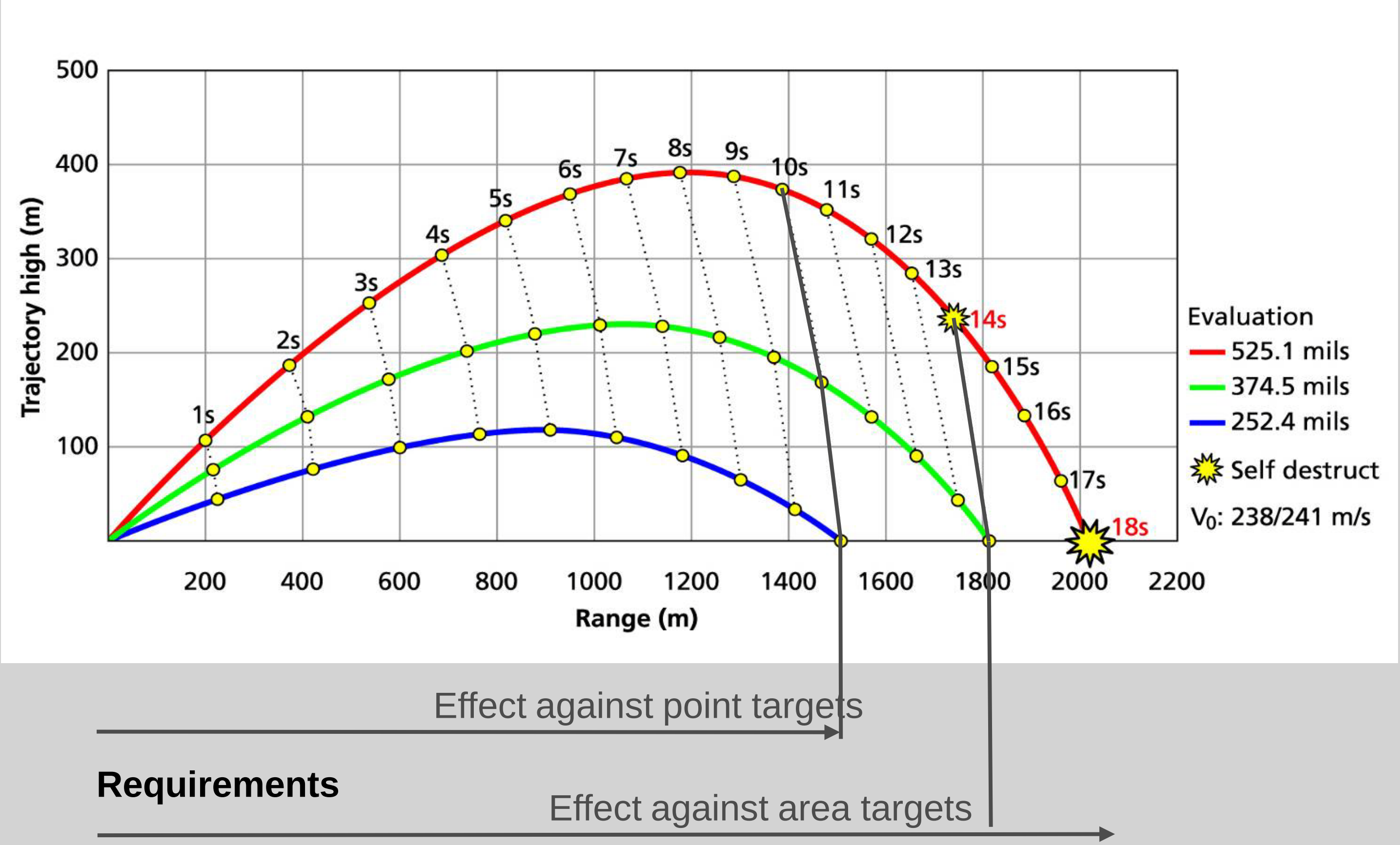
- AGL 40mm from Heckler & Koch

- H&K AGL mounted on German Vehicle FENNEK

Program Background, Application

JUNGHANS microtec
40mm Fuzes

- Maximum range with integrated SD mode is 1.800m
- The German Army requirement is between 100m and 1.500m combat distance



A Diehl and Thales Company

Requirements for DM431A1

- STANAG 4157; STANAG 4187
- MIL-STD-331B; MIL-STD-1316B; MIL-STD-810E
- Overall functional Reliability ≥ 97%
- Functioning Temperature: -46 C to +63 C
- Storage Temperature: -54 C to +71 C

Overview of JUNGHANS 40mm Products

JUNGHANS microtec
40mm Fuzes

- 40mm Low Velocity
  - DM411A1
  - DM361

- 40mm High Velocity
  - DM431A1
  - DM441
  - DM451 (IM)

A Diehl and Thales Company

Overview of Cartridges and Fuzes

JUNGHANS microtec

40mm Fuzes

- Low Velocity: DM411A1 and DM361
  - JUNGHANS has produced many thousands LV-fuzes

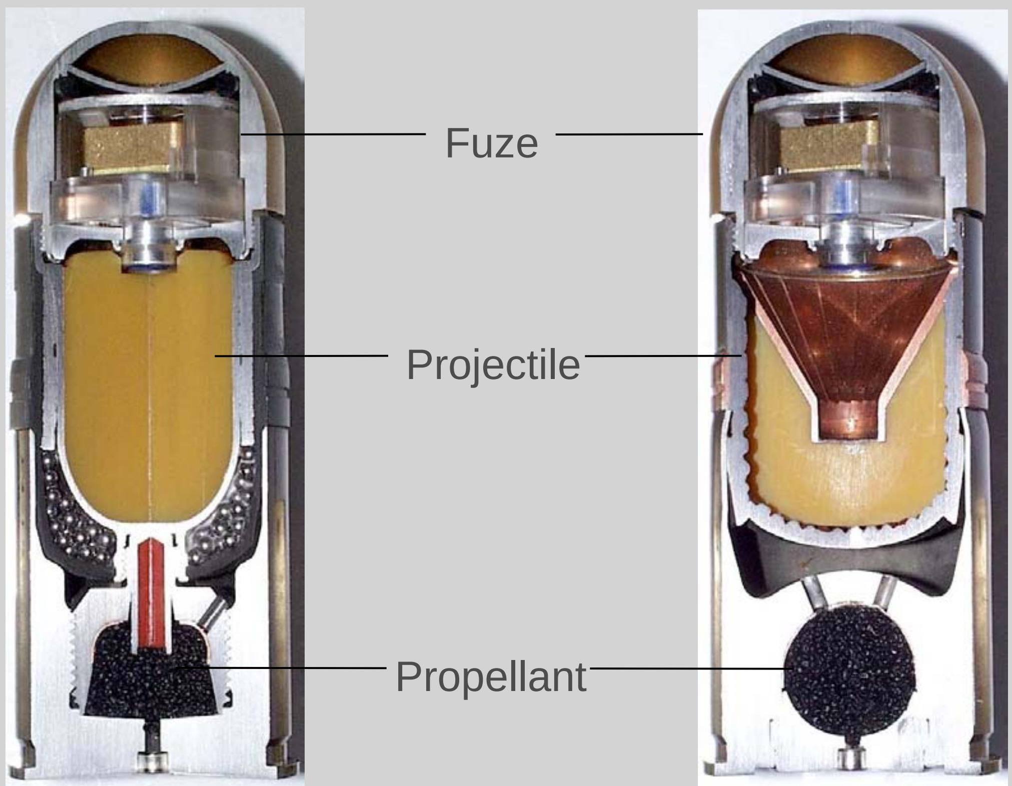
Technical Information:

- Muzzle safety distance (v_0=78m/s): 8m
- Arming distance: 15m
- Arming set back: 2.000g
- Arming rotation: 2.300rpm
- Functioning temperature: -35°C to +50°
- SD time (in the temperature range): >8s
- Weight: ~50,5g

Overview of Cartridges and Fuzes

- High Velocity Cartridges in Service

Fuze DM431A1 DM111 HE-PFF (Diehl)	Fuze DM441 / DM451 DM42 HEDP (e.g. Diehl)
High Explosive Pre-Formed Fragments	High Explosive Dual Purpose



DM431A1 IG HV fuze family

- DM431A1 IG HV and Variations

Background:

- Mechanical point detonating fuzes equipped with a pyrotechnic self-destruct mechanism

Technical Information:

Muzzle Safety Distance	≥ 18m
Arming Distance	≤ 40m
Arming set back:	22.500g
Arming rotation:	6.500rpm
Functioning Temperature:	-46 C to +63 C
Storage Temperature:	-54 C to +71 C
SD time (in the temperature range):	>14s

DM431A1 IG HV fuze family

- DM431A1 IG HV
  - PDSD fuze on HE-PFF (high explosive pre-formed fragments) round
  - To date, JUNGHANS has produced some 1 million DM431A1 fuzes
  - Reliability rate **99,7%** based on the results of the lot acceptance firings, in summary more than 7.400 rounds

DM431A1 IG HV fuze family

JUNGHANS microtec 40mm Fuzes

- DM441 IG HV
  - Used for HEDP ammunition on the DM32 round
  - For use against soft targets and light armored vehicles
  - Penetration performance of more than 70mm armor steel
  - More than hundred thousand fuzes DM441 have been produced

DM431A1 IG HV fuze family

JUNGHANS microtec
40mm Fuzes

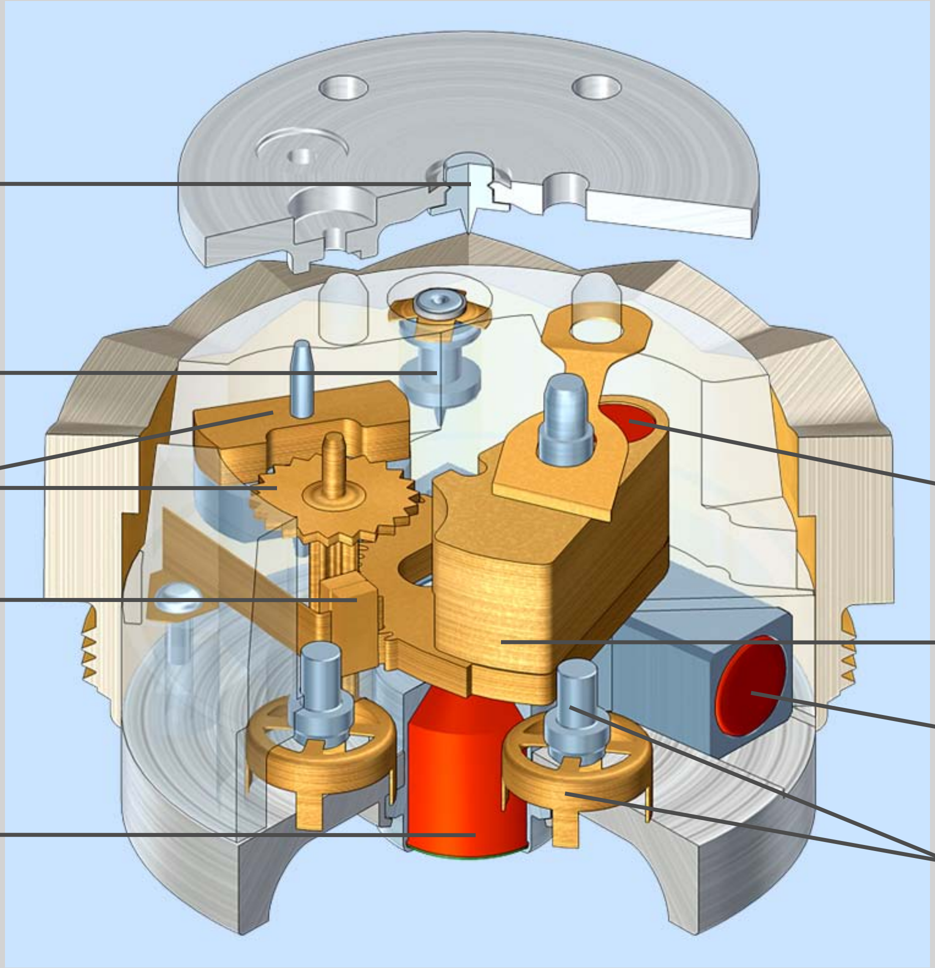
- DM451 IG HV
  - Latest addition to JUNGHANS 40mm fuzes
  - Used for insensitive HEDP ammunition on the DM42 round
  - Pilot lot acceptance in approval by GER
  - Serial production in progress
  - With insensitive spit back booster DM1603 (IM) and black ogive
  - For use against soft targets and light armored vehicles
  - High penetration performance of more than 70mm armor steel, high effectivity and robustness

DM431A1 – Fuze Design

JUNGHANS microtec

40mm Fuzes

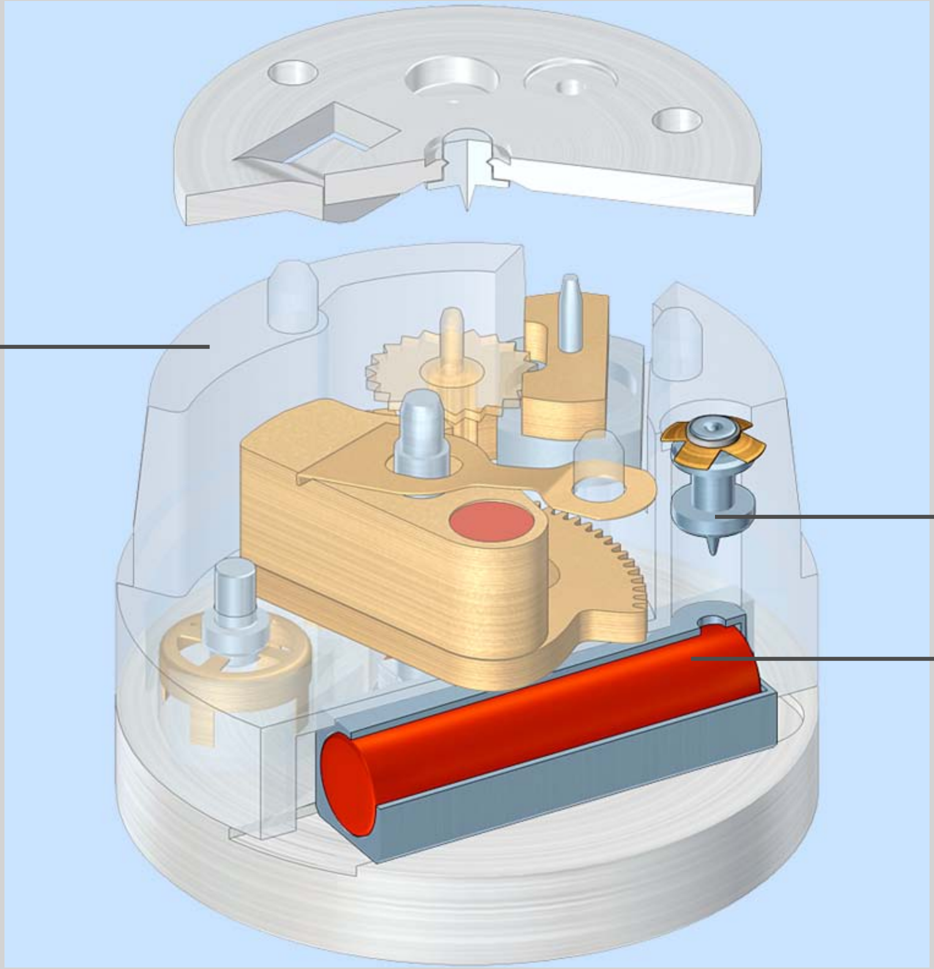
- Fuze Description in safe position



DM431A1 – Fuze Design

JUNGHANS microtec
40mm Fuzes

- Fuze description - integration of the SD mode



Fuze Functioning Modes

- Fuze Functioning Modes are:
  - Impact mode (PD-mode)
  - Pyrotechnical self-destruct function

- Evaluation of Fuze Functioning Modes within Lot Acceptance Firings:
  - Muzzle safety: target plate at 18m
  - PD function: target plate at 40m
  - Impact sensitivity: target plate with 70°NATO angle at 100m
  - Impact sensitivity: firing on soft ground at 300m
  - SD firing with AGL (according to German standards)

- Lot acceptance firings are conducted according to high German standards

Arming Criteria

STANAG 4187 Compliance

- The fuze has two independent safety features.
    1. acceleration-dependent safety elements: two setback springs
    2. rotation-dependent safety element: safety spring
- A mechanical delay mechanism guarantees the muzzle safety distance
- No manual manipulation possible due to closed fuze housing
- No stored energy for rotor movement prior to launch
- No duds due to self-destruct mode

Safety and Reliability

Why SD-mode ?

- Very high reliability rate (calculated with the results of the lot acceptance firings) of **99,7%** with all firings conducted on the specified ground / targets
- SD mode prevents (hazardous) duds in case of not specified target impact conditions:
  - High grass or bush
  - Snow
  - Water
  - Angle >70° NATO or ricochet

Trial Results

JUNGHANS microtec
40mm Fuzes

- DM431A1 – Firing against 3mm steel plate at 70°NATO

Trial Results

JUNGHANS microtec 40mm Fuzes

- DM431A1 – Firing against 2mm plate at arming distance 40m

Trial Results

JUNGHANS microtec
40mm Fuzes

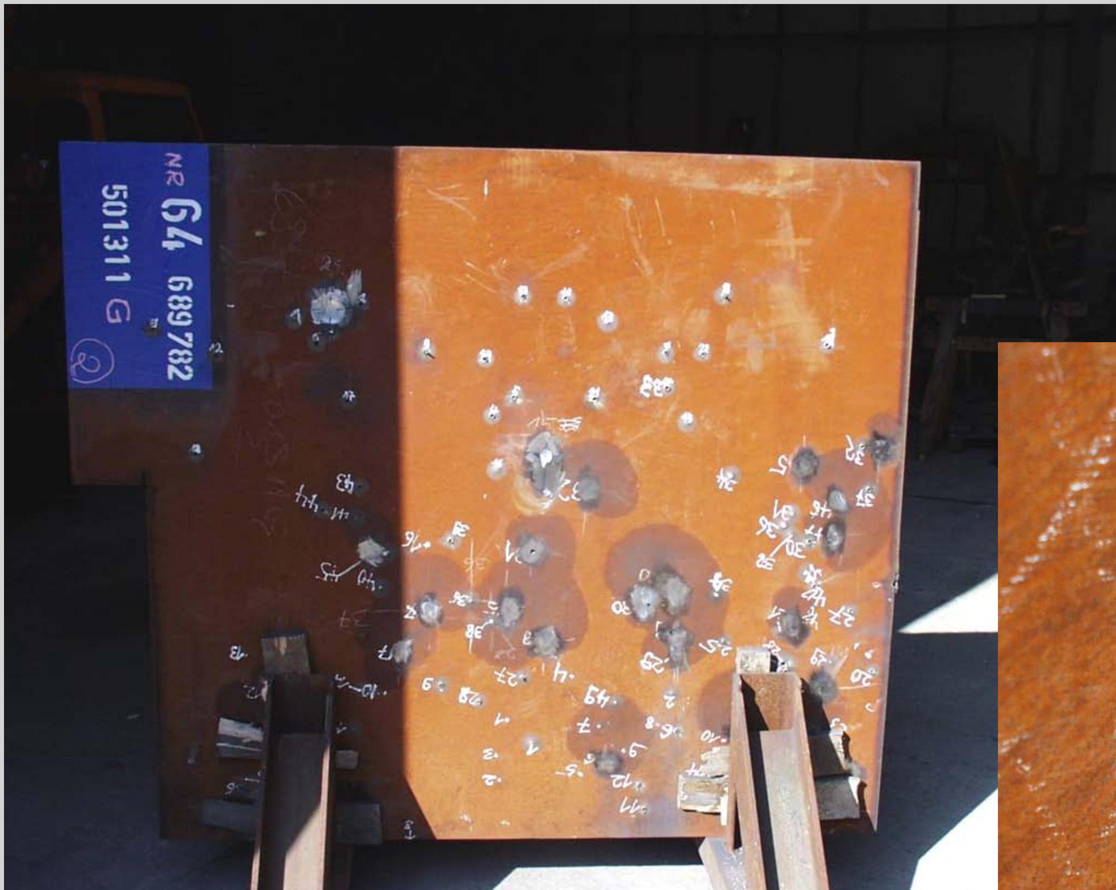
- DM451 HEDP – Pilot lot acceptance trials in GER

- Disciplines performed for this acceptance:
  - Dispersion pattern
  - Weapon function
  - Penetration performance: Firing against 70mm armor steel plate
    (in addition towards HE-PFF round)
  - Muzzle safety: target plate at 18m
  - PD function: target plate at 40m
  - Impact sensitivity: target plate with 70°NATO angle at 100m
  - Impact sensitivity: firing on soft ground at 300m
  - SD firing with AGL (according to German standards)
- Strongly convincing performance of the DM42 round with the DM451 fuze from JUNGHANS

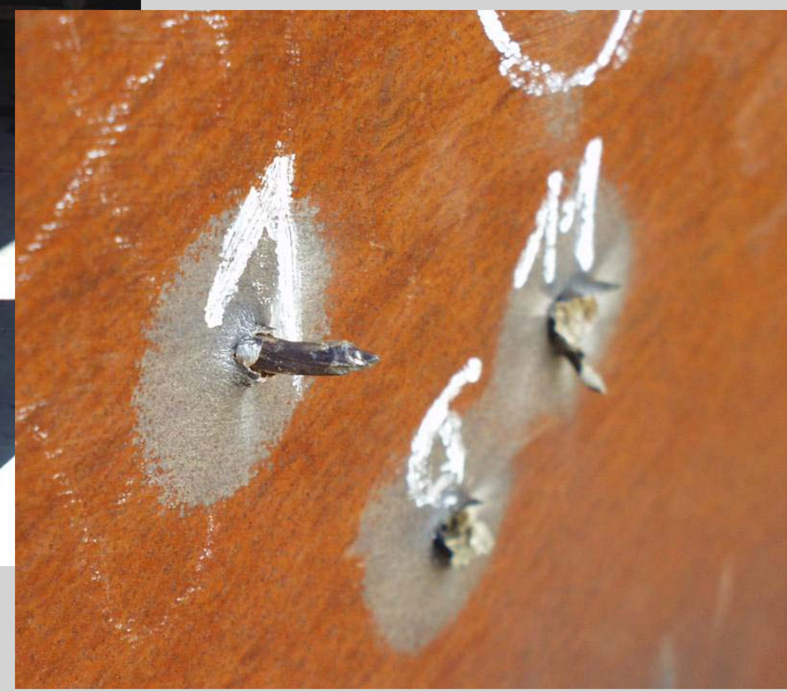
Trial Results

JUNGHANS microtec
40mm Fuzes

- DM451 HEDP – Firing against 70mm armor steel plate



- Complete Penetration of the ammunition



Conclusion

- JUNGHANS is offering very safe and reliable IG fuzes which fully meet the latest safety requirements of major international customers and different IG solutions for asymmetric combat situations
- JUNGHANS demonstrates an unmatched live firing reliability today on the IG market
- JUNGHANS, thanks to its background and technology in fuzing solutions is also considering new solutions for the future in the domain of IG fuzes
- JUNGHANS focusses on **Safety, Quality** and **Reliability** to provide customers with flexible solutions for improved operational efficiency

JUNGHANS *Microtec* GmbH

Thank you for your kind attention!

Michael BUTZ
Product Management
JUNGHANS Microtec
GERMANY
michael.butz@junghans-microtec.de

RF Programmable Signal Processor System for Fuze Programming

Douglas Cox,Trong Huynh,
John Ambrose
Presented by Douglas Cox
dougc@mix-sig.com

Mixed Signal Integration
2157F O'Toole Avenue
San Jose, CA 95131

MSI's Signal Processor ICs for Fuzing Applications

HDL304 for the 734A1 Fuze

HDL400 for fuzing 40mm

HDL401 for fuzing 30 mm

All developed for ARDEC

Mixed Signal Integration

2157F O'Toole Avenue

San Jose, CA 95131

www.mix-sig.com

Mixed Signal Integration

Introduction

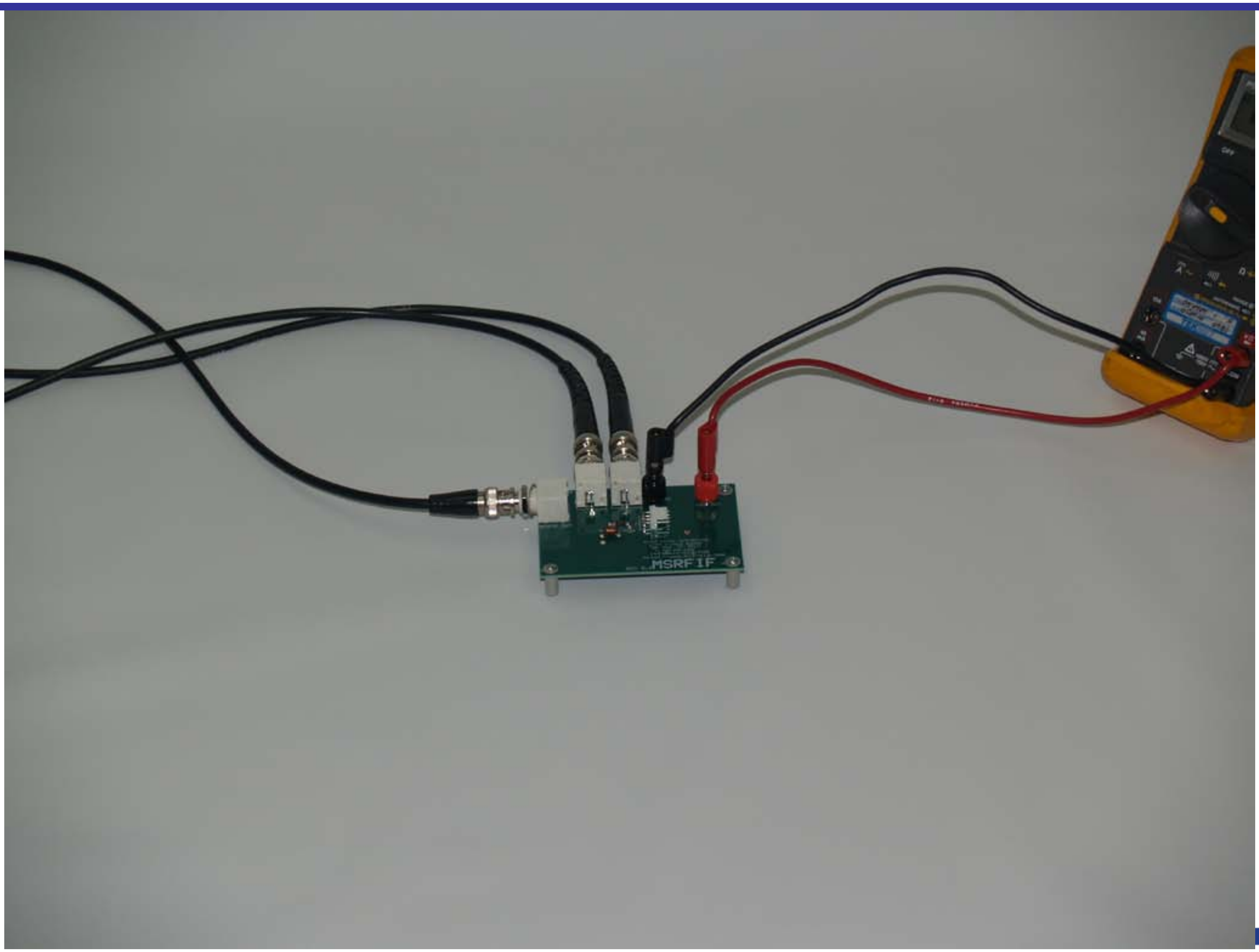
Electronic fuzing is moving to smaller cannon and even bullets.

- Design to program smaller munitions
- Need for fuze programming
- Proximity or Contact
  - Distance
    - for buried targets
    - hard targets
    - soft targets

One Solution: RF Programming Benefits

- Smaller Antenna
- Programming Speed
- Smaller Electronics

One Solution: RF Programming



Comparison of RF to Magnetic

- RF Options
  - Smaller Antenna
    - Higher Frequency allows smaller antennas
  - Distance programming: inches, not contact
  - Programming speed
    - High carrier frequency for higher data rates
  - Writer size
    - As with the receiver, transmitter is smaller

RF Options

- RF Options
  - Direct; stored for flight duration
  - Loaded to EE; for longer data storage

Technical Issues

- Getting the RF into the Bullet
- Programming Speed
- Antenna Size
  - Receiving enough RF energy in a short time
  - Forward acting antenna
- Unauthorized Programming
  - Can't program remotely; inches not feet
  - Encryption may be required for EEPROM
- Proving Safe and Arm not affected by RF

Possible RF path: Writer to Cartridge

Summary

Electronic fuzing is moving to smaller cannon and even bullets.

- Design to fit smaller munitions.
- RF approach provides smaller antennae, non-contact and faster programming.

Impact Switch Study

Modeling & Implications

Dr. Dave Frankman

May 13, 2010

NDIA 54th Annual Fuze Conference

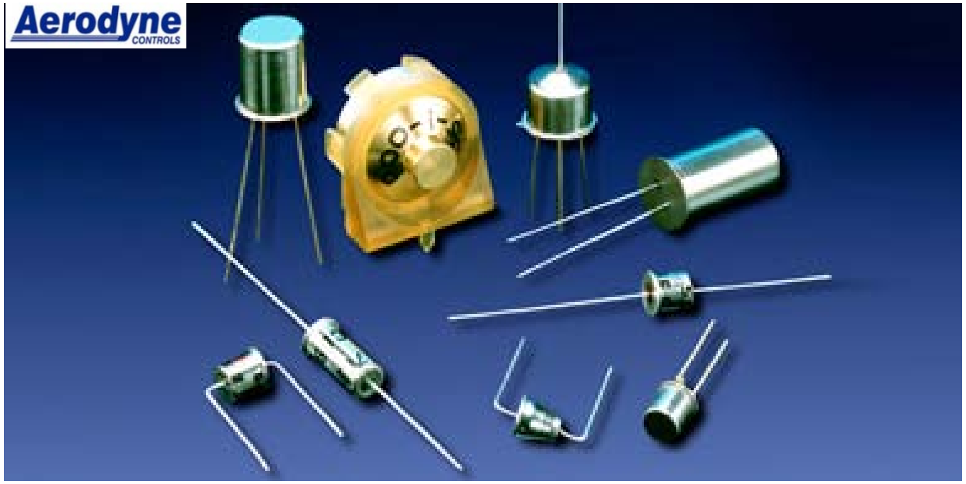
Agenda

- Study motivation
- Introduction to spring/mass impact switches
- Derivation of spring/mass governing equations from first principles
- Results of study
- Derivation of mass/spring/damper system
- Results of parametric damping study
- Conclusions

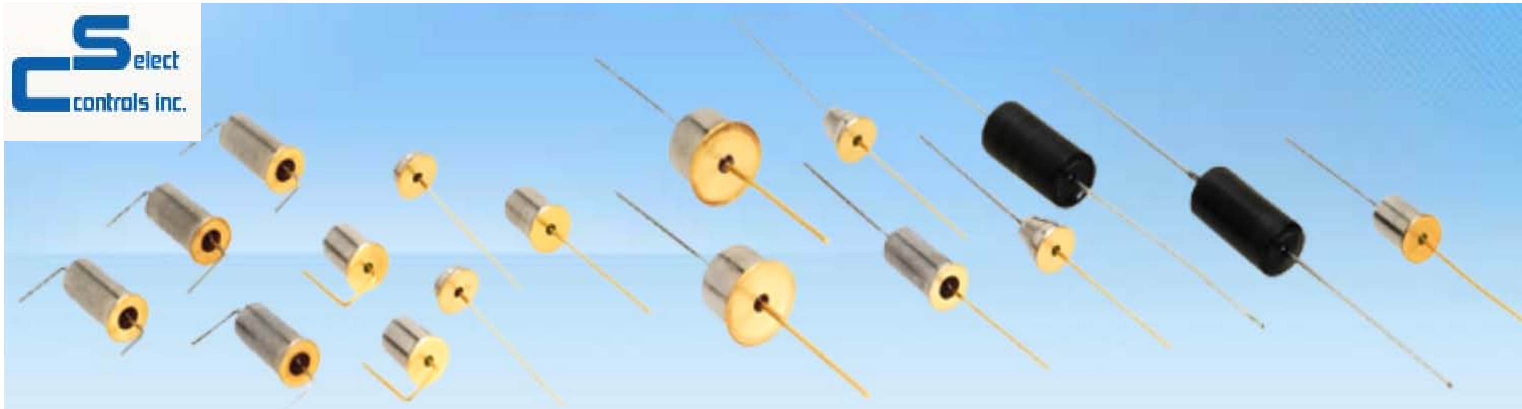
The information in this presentation is of general capabilities and open for public release

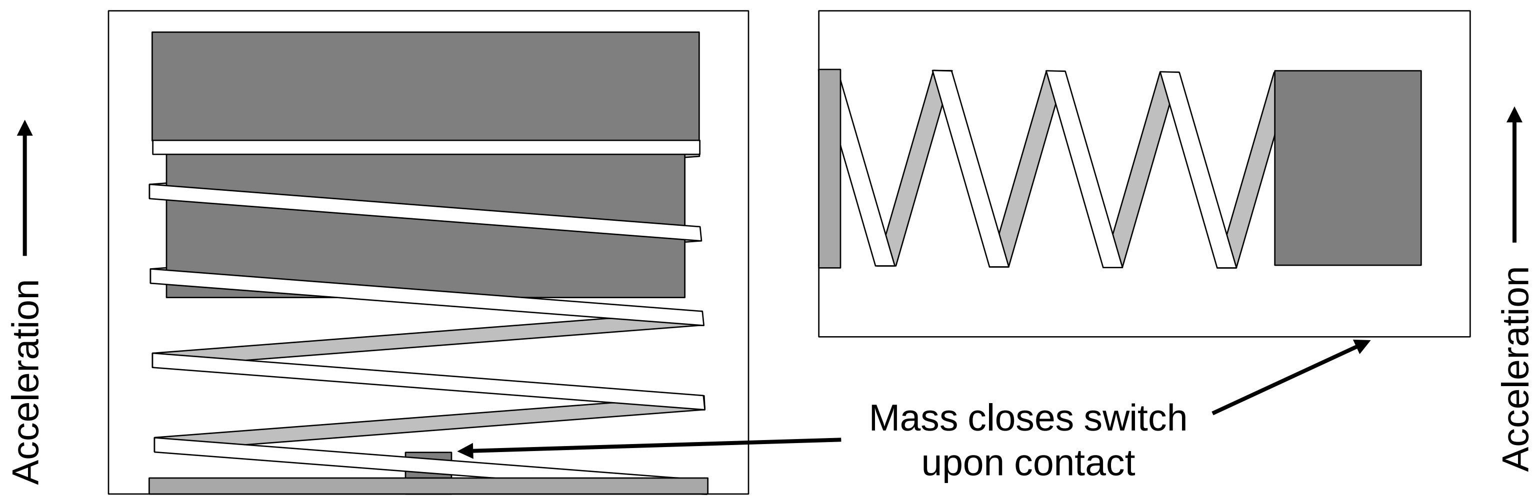
Motivation

- Dynamic/static behavior revealed
  – Switch closure is dependent on the amplitude and duration of shock
- Evaluate current testing practices
- Enable characterization of switch behavior analytically rather than empirically



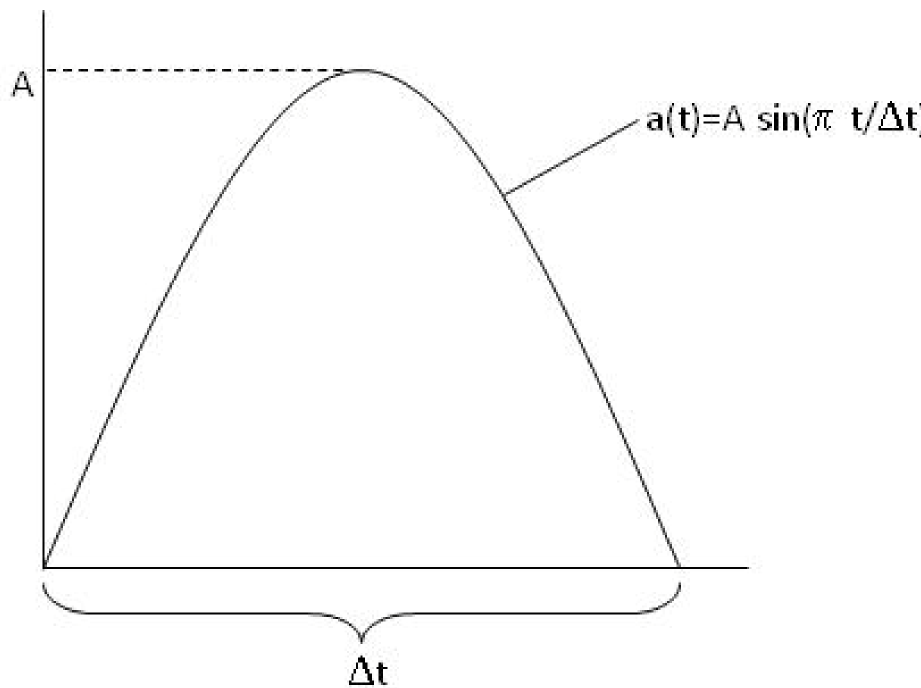
Impact Switches are Spring/Mass Systems





Spring/Mass Motion Derived from First Principles

- The governing inhomogeneous Ordinary Differential Equation (ODE) is derived from Newton's second law ($\Sigma F=ma$)
  - The spring mass system has a natural frequency of $\omega_o=\sqrt{(k/m)}$
  - A half sine acceleration pulse is applied to the switch



$$\sum F = m\ddot{x} = -kx + m\,a(t)$$

$$\Downarrow$$

$$\ddot{x} + \omega_o^2 x = a(t)$$
$$x(0) = 0$$
$$\dot{x}(0) = 0$$

ODE Solved via. Method of Undetermined Coef's

$$\ddot{x} + \omega_o^2 x = A \sin\left(\pi \frac{t}{\Delta t}\right) \qquad \begin{array}{l} x(0) = 0 \\ \dot{x}(0) = 0 \end{array}$$

$$x_h(t) = \frac{A \,{}^{\pi}\!/_{\Delta t}}{\omega_o \left({}^{\pi^2}\!/_{\Delta t^2} - \omega_o^{\,2}\right)} \sin(\omega_o t)$$

$$x_p(t) = \frac{-A}{\left({}^{\pi^2}\!/_{\Delta t^2} - \omega_o^{\,2}\right)} \sin\left({}^{\pi t}\!/_{\Delta t}\right)$$

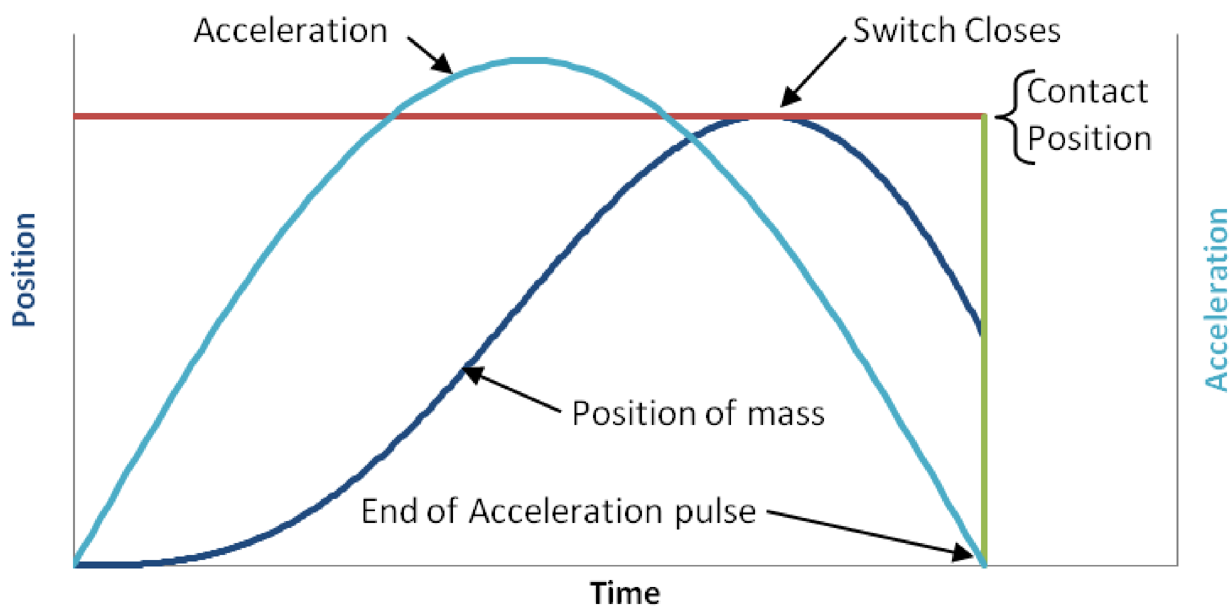
Homogeneous and particular solution are combined to form solution ($y=y_p+y_h$)

$$x(t) = \frac{A}{\omega_o \left({}^{\pi^2}\!/_{\Delta t^2} - \omega_o^{\,2}\right)} \left[\frac{\pi}{\Delta t} \sin(\omega_o t) - \omega_o \sin\left({}^{\pi t}\!/_{\Delta t}\right) \right]$$

Equation governing position of mass

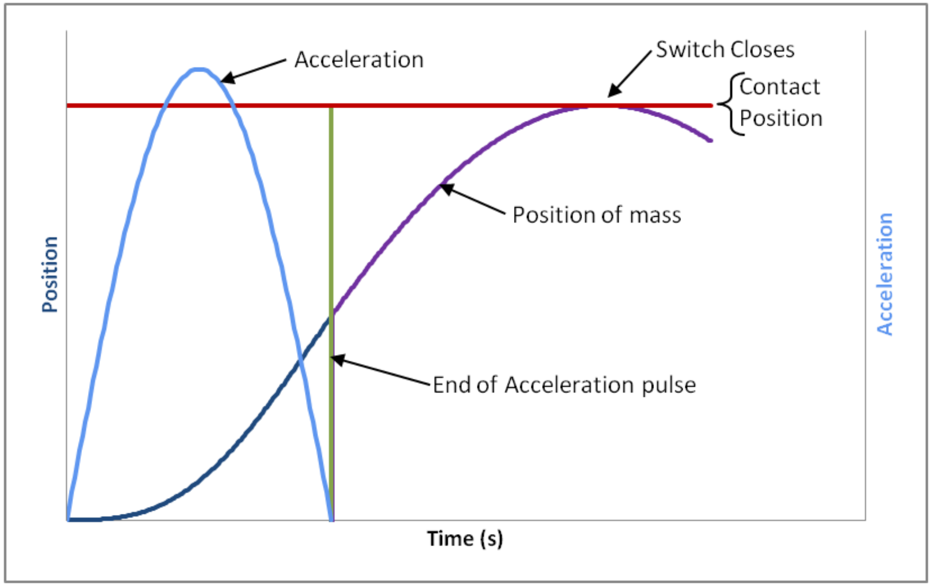
Switch Closure Before Pulse Ends

- Switch closes before acceleration pulse ends ($\Delta t < \pi/\omega_o$)
  - Mass moves at spring/mass natural frequency



Switch Closure After Pulse Ends

- Switch closes after acceleration pulse ends ($\Delta t > \pi/\omega_o$)
  - Mass has sufficient kinetic energy to close the switch after the acceleration pulse ends.
  - This scenario requires the solution of another ODE.



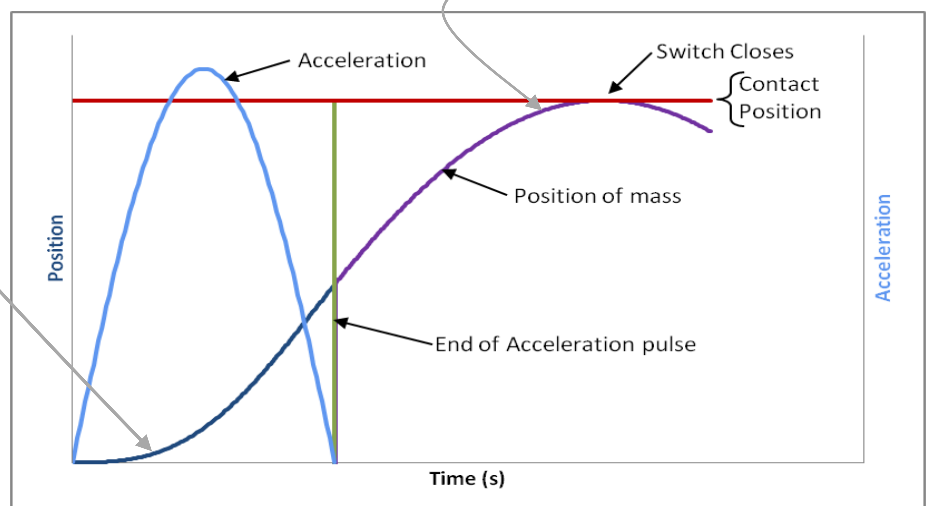
Motion of Mass After Pulse Requires Another ODE Solution

- Solution to the homogenous ODE is completed using the method of undetermined coefficients.

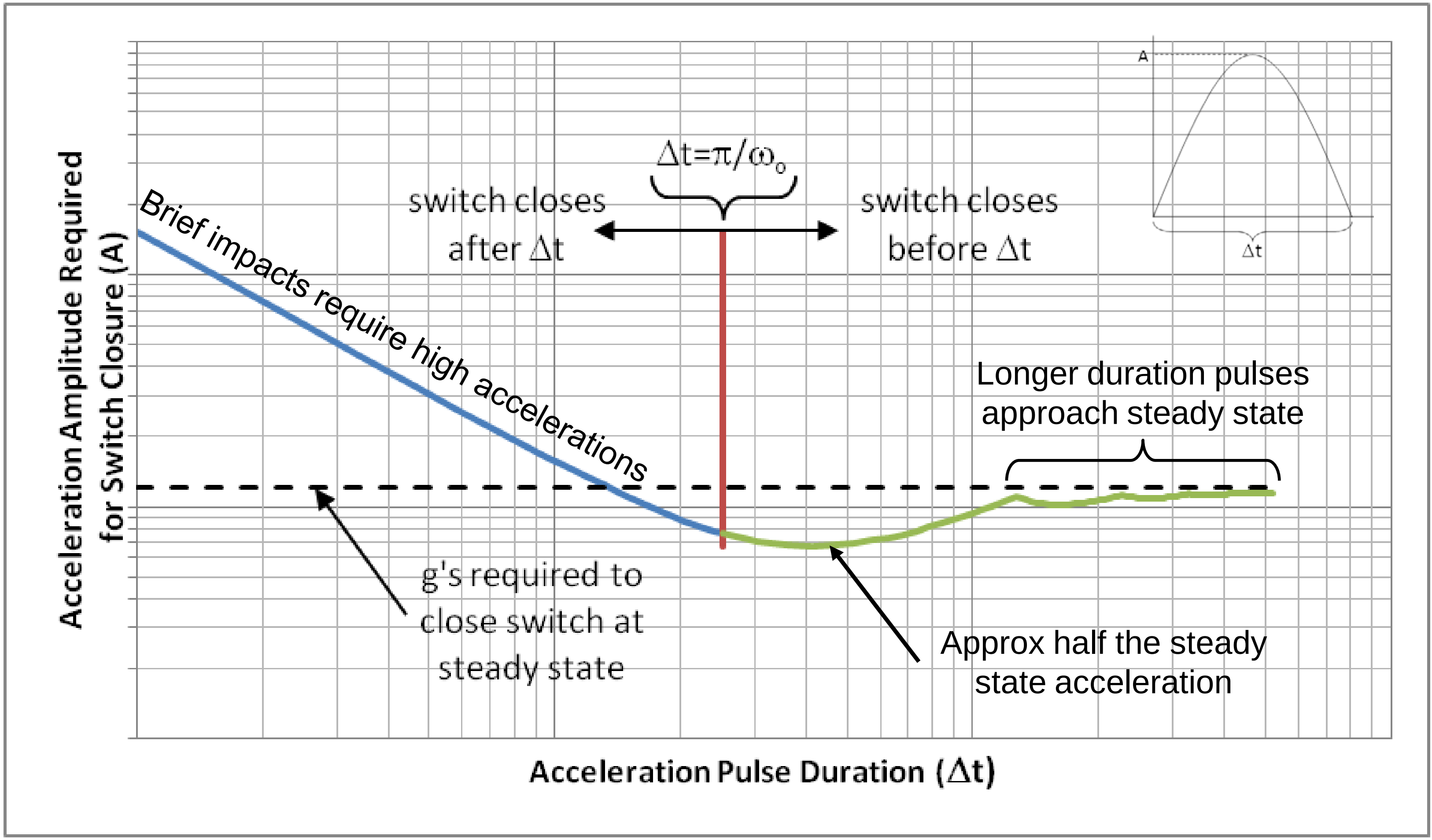
$$x(t) = \frac{A}{\omega_o\left(\pi^2/\Delta t^2 - \omega_o^2\right)}\left[\frac{\pi}{\Delta t}\sin(\omega_o t) - \omega_o \sin\left(\pi t/\Delta t\right)\right]$$

$$\ddot{x} + \frac{k}{m}x = 0$$
$$x(\Delta t) = x_i$$
$$\dot{x}(\Delta t) = V_i$$

$$x(t) = \frac{V_i}{\omega_o}\sin[\omega_o(t-\Delta t)] + x_i\cos[\omega_o(t-\Delta t)]$$

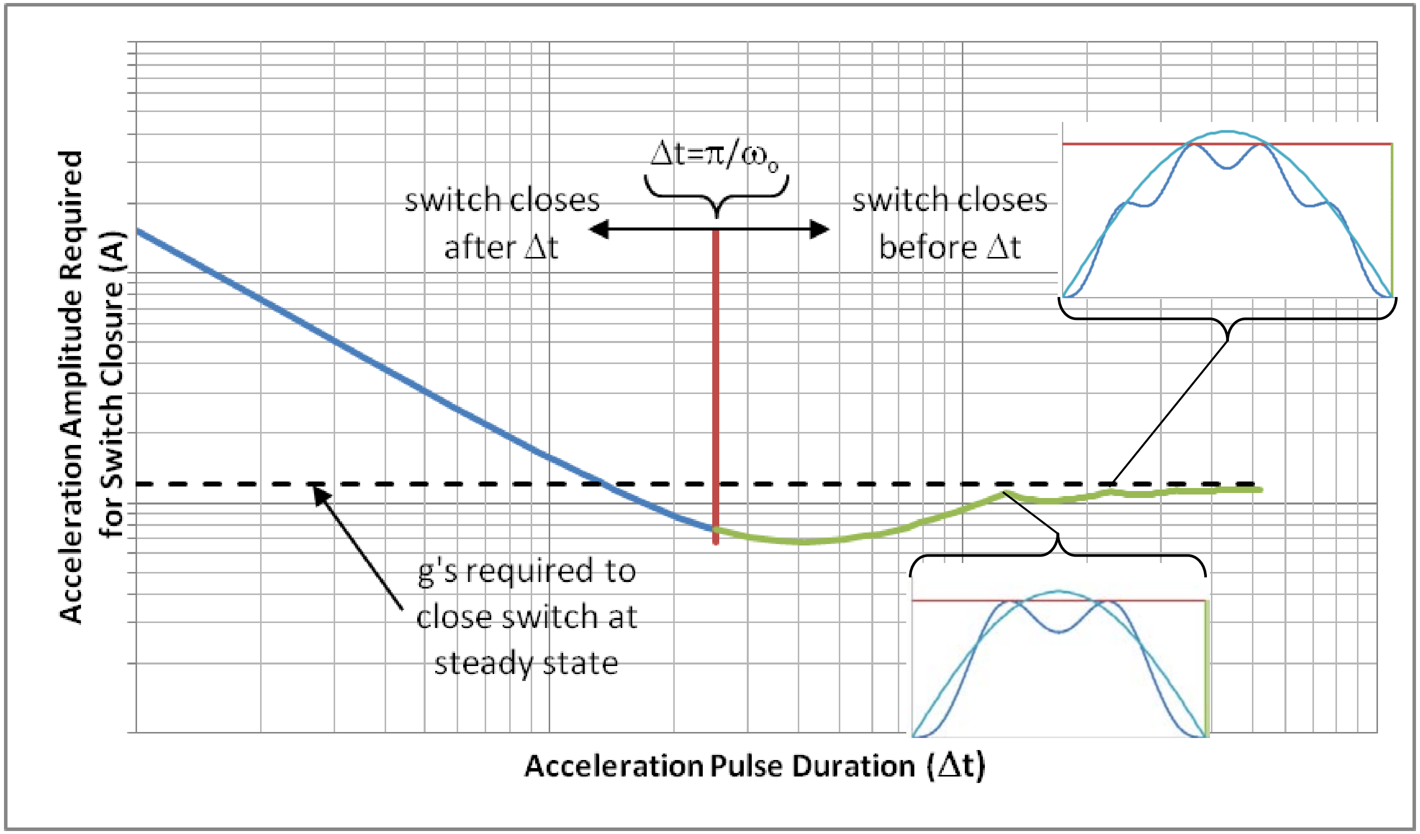


Switch Closes at Various Acceleration Levels



Unusual Behavior of Spring/Mass is Explained

- If the mass has zero net displacement and at rest at the end of the pulse, the solution approaches the steady state solution



Damping Was Also Studied

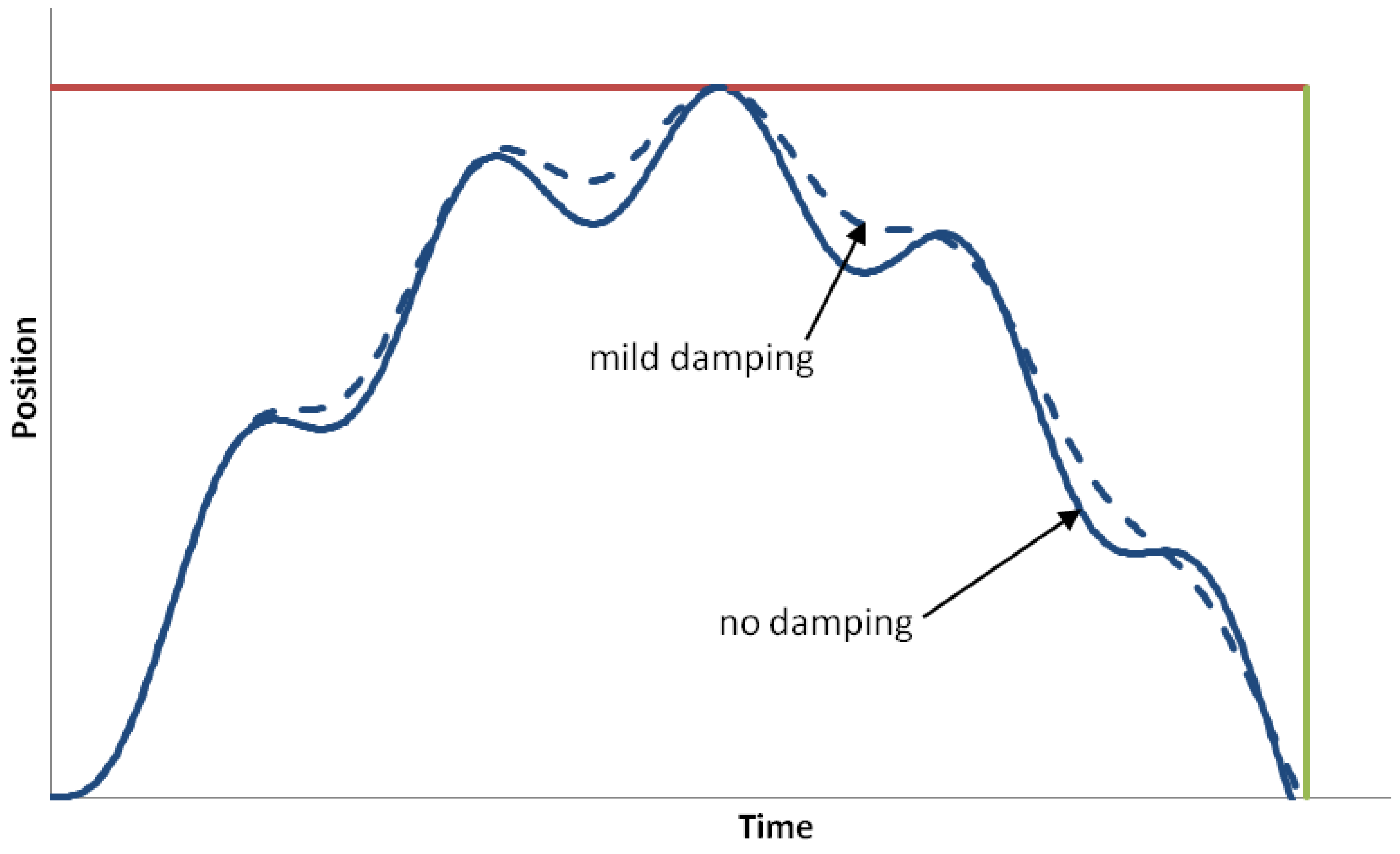
- Damping ratio was parametrically studied (0≤ζ<1)

$$\sum F = m\ddot{x} = -kx + m\,a(t) - c\dot{x} \rightarrow \ddot{x} + 2\zeta\omega_o\dot{x} + \omega_o^2 x = A\sin\left(\pi \, {}^{t}\!/\!_{\Delta t}\right)$$

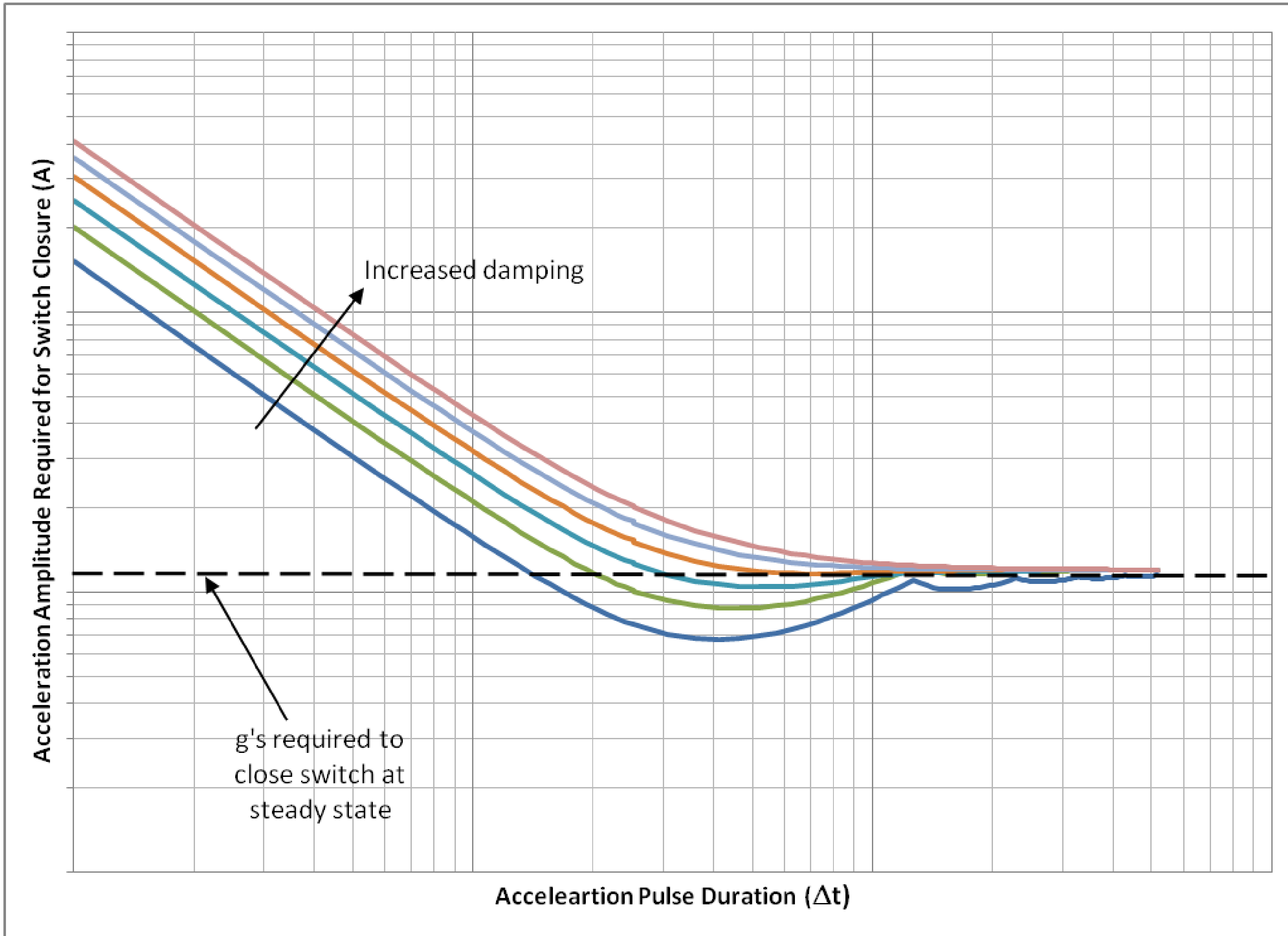
$$Where \quad \zeta = \frac{c}{2\sqrt{km}}$$

$$x(t) = \frac{A\left(\omega_o^2 - \pi^2/\Delta t^2\right)}{\omega_d\left(\left(2\zeta\omega_o \pi/\Delta t\right)^2 + \left(\omega_o^2 - \pi^2/\Delta t^2\right)^2\right)} \left[\begin{array}{l} \omega_d \sin\left(\pi\, t/\Delta t\right) - \pi/\Delta t \, e^{-\zeta\omega_o t}\sin(\omega_d t) \\ + \dfrac{2\zeta\omega_o \pi/\Delta t}{\omega_o^2 - \pi^2/\Delta t^2} \left\{ \begin{array}{l} \zeta\omega_o e^{-\zeta\omega_o t}\sin(\omega_d t) \\ + \omega_d e^{-\zeta\omega_o t}\cos(\omega_d t) \\ - \omega_d \cos\left(\pi\, t/\Delta t\right) \end{array} \right\} \end{array} \right]$$

Damping Mitigates Oscillations



Damping Suppresses the Spring/Mass Oscillations



Conclusions

- Impact switches will close at a variety of different acceleration levels
- Closure of the impact switch becomes independent of duration as the pulse is lengthened
- Damping increases the acceleration level required to close the switch
- Damping mitigates the switch natural frequency
- Predicting the behavior of the impact switch enables L-3 FOS to reduce development time

Safety Assessment of Fuzing Systems Using IEC 61508

Applicability, Safety Life-Cycle, Safety Function, Methods for Hardware and Software

54th Annual Fuze Conference
„The Fuzing Evolution
– Smaller, Smarter, Safer“

May 11-13, 2010
Kansas City, Missouri, USA

U. Siebold, M. Larisch, Dr. I. Häring

Contact: Technical Safety Group
Hazard and Risk Analysis Group
haering@emi.fraunhofer.de

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German Fraunhofer-Gesellschaft
Largest organization for applied research in Europe
59 Fraunhofer Institutes
17, 000 staff
€ 1.3 billion annual contract research
Customers: industry, service sector, public administration

Fraunhofer Group for Defense and Security
8 Fraunhofer Institutes
Customers: German federal ministry of defense, defense technology industry

Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institute, EMI
Department of safety technologies
Hazard and risk analysis group, Technical safety group

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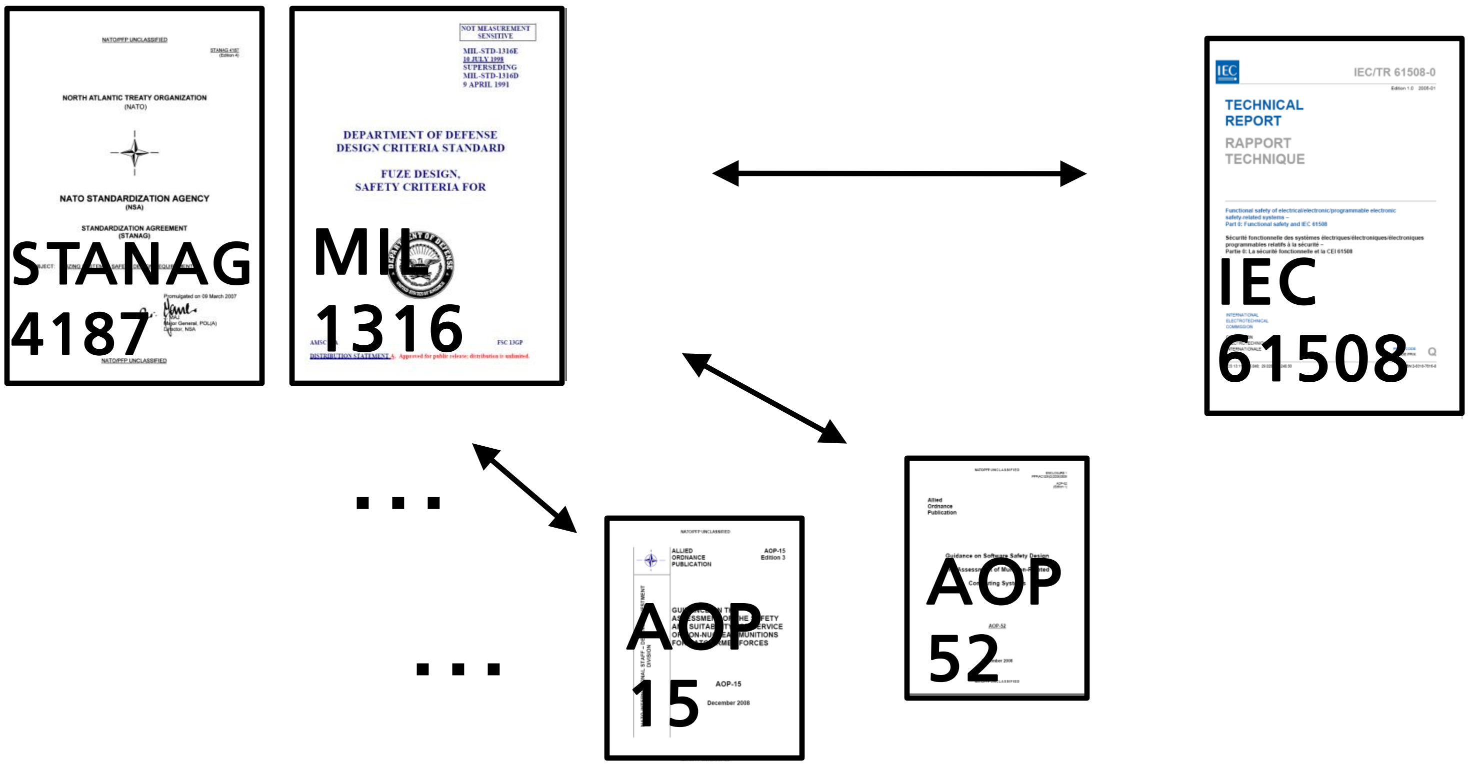
Approach



Use IEC 61508 to fulfill the requirements of STANAG 4187, MIL 1316 for electronic hardware and software

Overview

- Applicability of IEC 61508
- Safety life cycle of IEC 61508 and STANAG 4187 requirements
- Safety features are safety functions
- Specification and allocation of safety functions
- Methods for reliability: hardware and software

Applicability of IEC 61508

- **Generic standard for safety related and safety critical systems**
- **Applicable if electrical, electronic or programmable electronic (E/E/PE) (sub)systems, i.e. electronic hardware and software, perform safety functions**
- Formalism takes into account risk reduction with other technologies, e.g. precision and micro mechanics (MEMS)
- Focus on development of reliable safety functions with hardware and software
- Used in Germany also for weapon systems, active protection systems

- Application sector standards:
  IEC 61513: nuclear power plants,
  IEC 61511: process industry,
  IEC 62061: machinery,
  EN 50128, EN 50129: electronic, software of railway systems
- Drafts:
  IEC 61800-5-2: Adjustable speed electrical power drive systems,
  ISO 26262: automotive industry

Overview

- Applicability of IEC 61508
- **Safety life cycle of IEC 61508 and STANAG 4187 requirements**
- Safety features are safety functions
- Specification and allocation of safety functions
- Methods for reliability: hardware and software

Comparison of key concepts

STANAG 4187

- life cycle environmental profile
- **Safety feature**; includes independence of physical detection principle
- Some phases correspond directly to phases of IEC 61508 safety lifecycle
- **Quantitative** safety requirements: unintentional functioning/arming shall not exceed one in a thousand/ in a million
- At least two independent safety features till launch
- Some techniques and measures are given

IEC 61508

- **Safety lifecycle** and life cycle
- **Safety functions** reduce risks of the system to an acceptable level
- Risks of the system are identified based on system analysis
- Risk comparison with risk criteria determines necessary risk reduction
- **Quantification** of reliability of safety functions using safety integrity levels (SILs)
- Hardware redundancy for higher safety requirements (SIL 3, SIL 4). More than one independent E/E/PE safety function for high safety requirements (> SIL 4)
- **Techniques and measures for hardware and software**

Sorting STANAG 4187 requirements with IEC safety life cycle

STANAG 4187

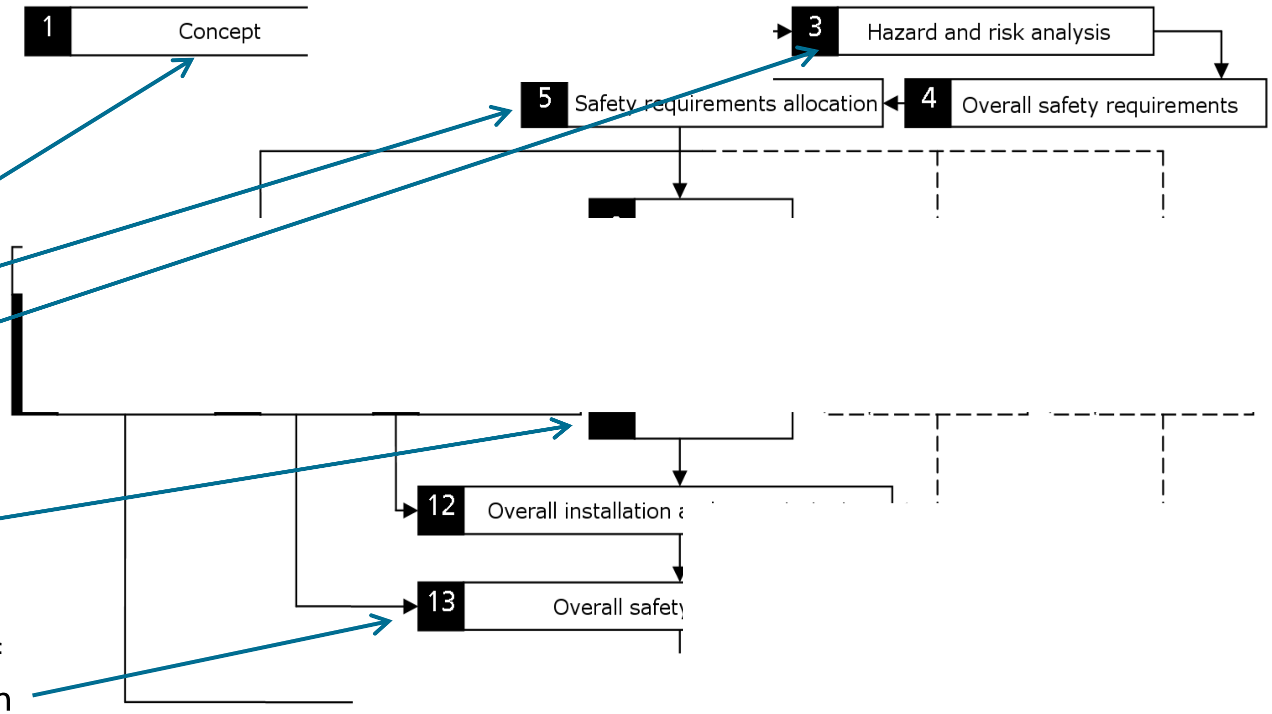
„concept development phase“

„design safety assessment“

„safety hazard analysis“

“only embedded software”

„demonstration of compliance of the fuzing system to safety design requirements“



IEC 61508-1

IEC 61508 suggests systematic (iterative) approach for development and assessment

Correspondence of sections of STANAG 4187, Ed. 4 to content of phases of IEC 61508

IEC phase No.	Safety lifecycle phase of IEC 61508	Section of STANAG 4187
1	[illegible]	3., 4., 5.b.
2	[illegible]	2., 5.a., 5.d.
3	[illegible]	5.d., 7.a., 7.e., 14.a., 14.c.
4	[illegible]	5.d, 6.a.(3), 6.b.(3), 7.b., 7.c., 8.a.(1)-(3), 8.b.(1), 9.c., 10.b.(1), 10.d., 10.f., 11.a.-f., 12.a.
5	[illegible]	5.a., 5.b, 14.f.
6	[illegible]	
7	[illegible]	5.b.
8	[illegible]	
9	[illegible]	5.d.
10	[illegible]	5.d.
11	[illegible]	5.d.
12	[illegible]	
13	[illegible]	14.b., 15
14	[illegible]	
15	[illegible]	
16	[illegible]	

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Overview

- Applicability of IEC 61508
- Safety life cycle of IEC 61508 and STANAG 4187 requirements
- **Safety features are safety functions**
- Specification and allocation of safety functions
- Methods for reliability: hardware and software

Definitions of safety feature and safety function

- **STANAG 4187, Ed. 4 – Safety Feature:**
  Section 6.a.(1):
  Fuzing systems shall include at least two safety features. The control and operation of these safety features are to be functionally isolated from other processes within the munition system and each of which shall prevent unintentional arming of the fuzing system. At least two of the safety features shall be independent and designed to minimize the potential for common cause failures.
  Section 6.a.(3):
  At least one of the independent safety features shall prevent arming after launch or deployment until the specified safe separation distance or equivalent delay has been achieved.

- **IEC 61508-4 – Safety Function:**
  Function to be implemented by an E/E/PE safety-related system, other technology safety related system or external risk reduction facilities, which is intended to achieve or maintain a safe state for the equipment under control, in respect of a specific hazardous event.

Overview

- Applicability of IEC 61508
- Safety life cycle of IEC 61508 and STANAG 4187 requirements
- Safety features are safety functions
- **Specification and allocation of safety functions**
- Methods for reliability: hardware and software

Quantitative measure for reliability of qualitatively described safety function: Safety Integrity Level (SIL)

IEC 61508-1

- Reliability of safety function greater than SIL 4: at least 2 independent safety functions
- Techniques and measures depend on required SIL
- Quantity and quality (rigor) of techniques and measures increase with increasing SIL

Low Demand Rate		High Demand Rate	
SIL	Probability of failure (PFD) on demand	SIL	Probability (Frequency) of failure (PFD) per hour
4	[1.e-5,1.e-4[	4	
3		3	
2		2	
1		1	

Example: the barrier has to be in safe position during overflight with a failure probability on demand (per life cycle) of less than 1.e-5 (SIL 4)

SIL determination for overall safety function for fuzing systems using STANAG 4187

Prevention of unintended arming/ functioning till launch/ safe separation

High demand rate:

(1) P = Required probability of **non**-arming/functioning per life cycle (e.g.1.e-6, 1.e-3)

(2) T = Average duration of considered life cycle phase of fuzing system (e.g. 1 s, 20 min 1 d, 1M, 1 y, 10 y)

(3) P/T <= PFD per hour = maximum failure rate per hour of overall safety function

Example, till launch: 1.e-6/10 y < 1.e-6/(10*1.e4 h) = 1. e-11/h < 1.e-9/h: more than SIL 4

If the *SIL definition is linearly continued* this corresponds to a "SIL 6" requirement.

Low demand rate:

(1) P = Required probability of **non**-arming/functioning on demand (e.g.1.e-6, 1.e-3)

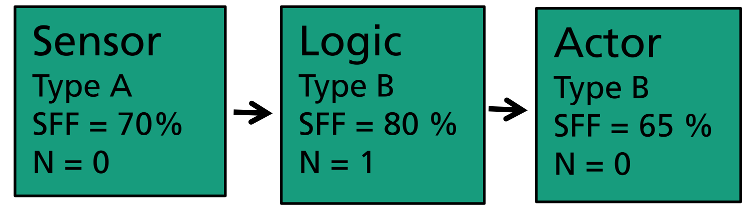
(2) P <= PFD on demand = maximum failure rate on demand of overall safety function

Example, till launch: 1.e-6 < 1.e-5: more than SIL 4, "SIL 5"

Till launch: At least two independent (E/E/PE) safety systems required by IEC 61508.

Architectural requirements: IEC Block diagrams, IEC estimate of achievable reliability of safety function (SIL)

- Block diagrams consider redundancy (serial, parallel) using "SIL decomposition rules"; similar to reliability block diagrams
- SIL (estimate) of hardware components is determined by: type, SFF, hardware fault tolerance



Sensor: SIL 2, Logic: SIL 2, Actor: SIL 1
➔ Safety function: SIL 1

Safe failure fraction (SFF)	Type A Non-complex component		
	Hardware fault tolerance N		
	N = 0	N = 1	N = 2
< 60%	SIL 1		

Safe failure fraction (SFF)	Type B Complex component		
	Hardware fault tolerance N		
	N = 0	N = 1	N = 2

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Overview

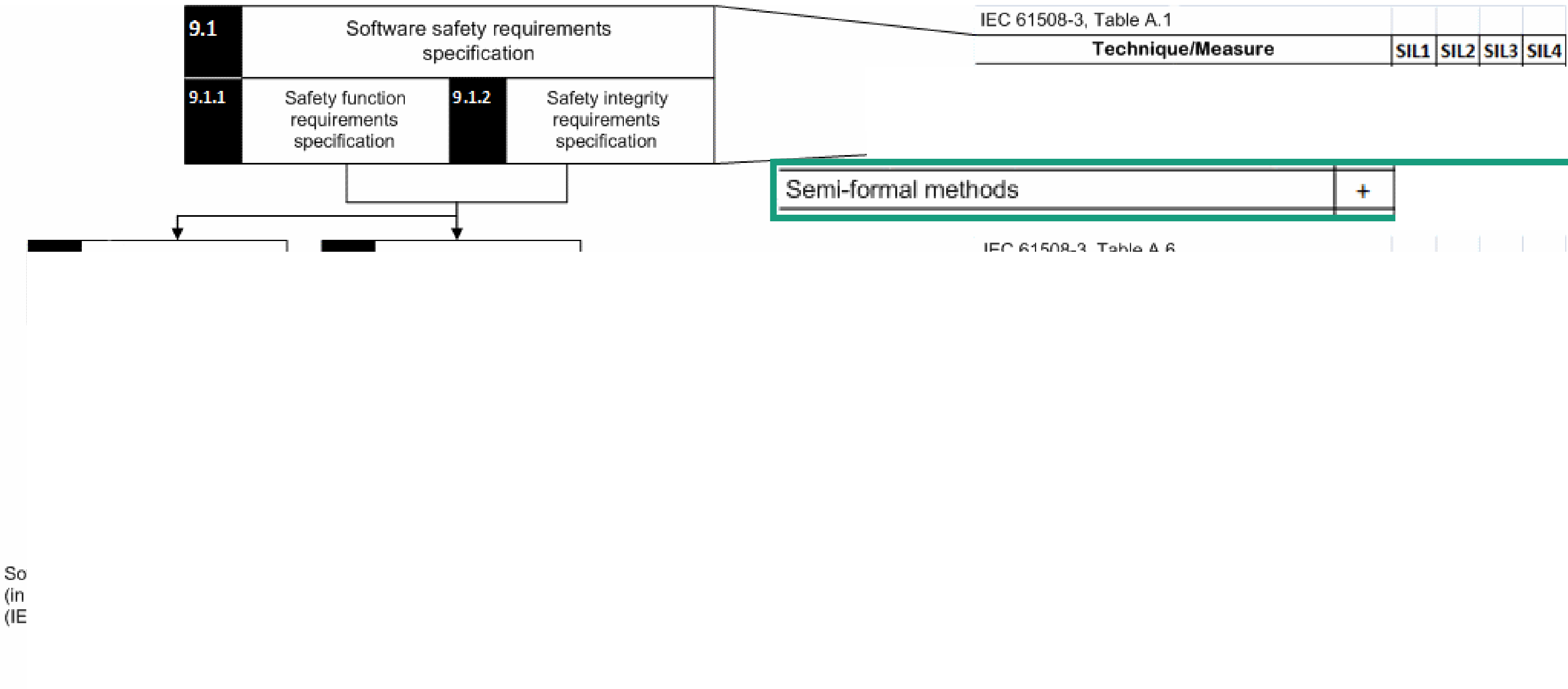
- Applicability of IEC 61508
- Safety life cycle of IEC 61508 and STANAG 4187 requirements
- Safety features are safety functions
- Specification and reliability of safety functions
- **Methods for reliability: hardware and software**

Selection of techniques and measures for hardware and software for the development of reliable (safety) functions

- Method pool: STANAG 4187, AOP 52, AOP 15, IEC 61508

- **IEC 61508 recommends or advises against techniques and measures depending on the required reliability of the safety function (SIL) and the safety life cycle phase**
- Techniques and measures for the control of **systematic software and hardware errors**, statistic errors, soft errors
- Methods for specification, development, testing, integration, verification, validation, includes organizational measures
- Description of methods, links to literature
- Updates of method list for new editions of standard (scheduled for 2010), domain specific methods can also be used

Techniques and measures for the realization of software safety functions according to IEC 61508



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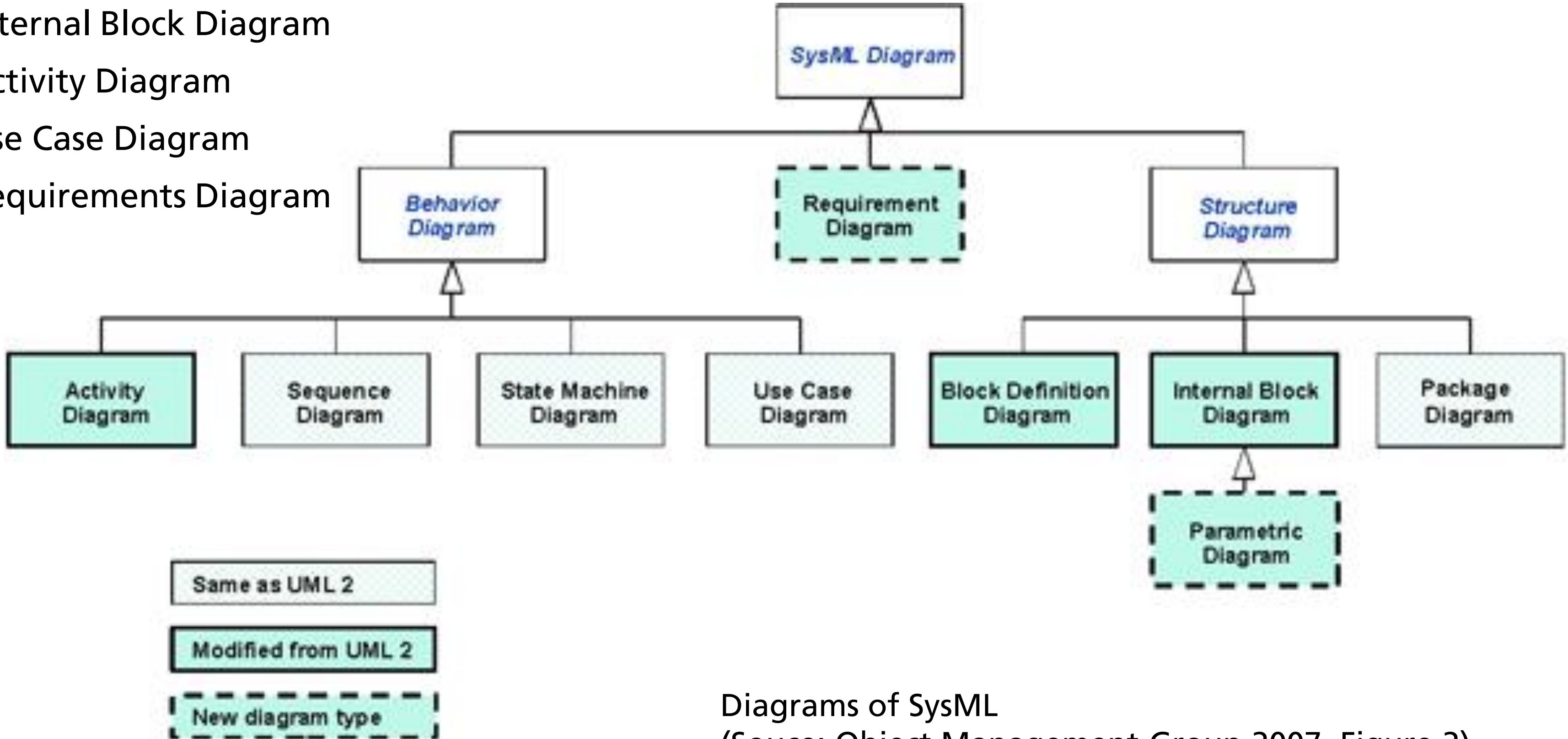
Example: semi-formal System Modeling Language (SysML) Diagrams

1) Block Definition Diagram
2) Internal Block Diagram
3) Activity Diagram
4) Use Case Diagram
5) Requirements Diagram



Diagrams of SysML
(Souce: Object Management Group 2007, Figure 2)

Appropriate SysML diagrams for all safety lifecylce phases of IEC 61508

Phase	Block Defi-nition D.	Internal Block D.	Activity Diagram	State Machine D.	Se-quence Diagram	Use Case Diagram	Require-ment D.
1	x	x	x				
2	x	x	x				
3			x	x	x		
4						x	x
5						x	x
6			x				
7			x				
8			x				
9	o	o	o	o	o	o	o
10							
11							
12			o				
13	o	o	o	o	o	o	o
14			o				
15							
16							

SysML can be used beyond realization phase

“x” means first use
“o” reuse in a later phase

When arriving at the realisation phase a rather detailed SysML model has been generated.

The SysML model of the Systems consists of all SysML diagrams.

We have only indicated the first and in our opinion most relevant use of the diagrams.

Structure diagrams are used in the early phases, behavior diagrams in later phases.

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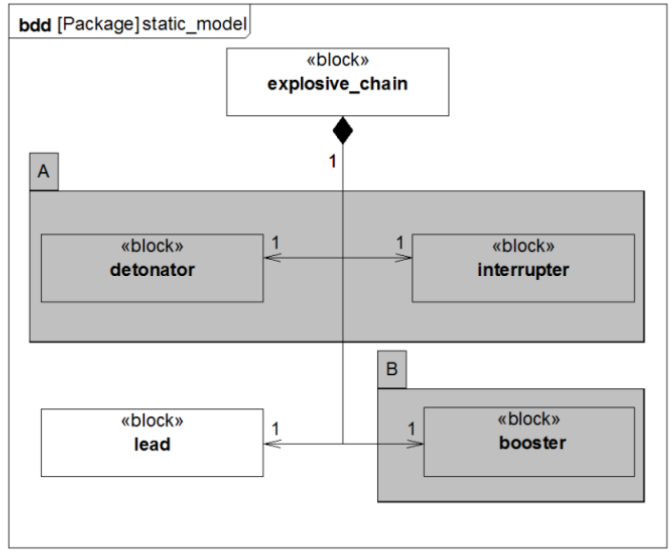
SysML: simple small generic sample system

SysML structure diagrams

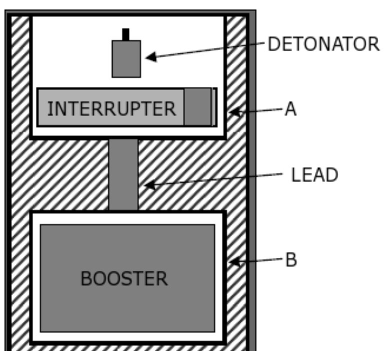
Standardized visualization with SysML – diagrams

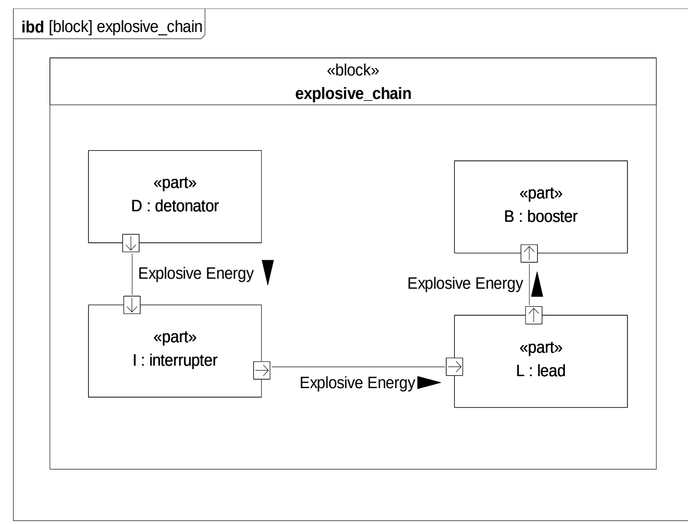


Block Definition Diagram

Internal Block Diagram

Example: Ad-Hoc visualization
of out-of-line fuzing chain





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Conclusions

The IEC 61508 can be applied to fuzing systems.

STANAG 4187/ MIL 1316 and IEC 61508 use similar concepts, e.g. safety functions.

Safety life cycle of IEC 61508 is a systematic approach for the development of safety critical systems:

system understanding, identification of risks of the system, determination of the necessary risk reduction, explicit qualitative and quantitative specification of safety functions, realistic architecture (no bottlenecks), development of hardware and software for safety functions applying appropriate techniques and measures.

If comfort functions and safety functions cannot be separated comfort functions must be treated as safety functions.

According to the required reliability of the safety functions suitable techniques and measures must be applied for hardware and software.

The active development of safety functions suits developers.

High Speed Digital Infrared Imaging of the M201A1 Grenade Fuze Initiation Train

Presented to the
NDIA Fuze Conference
May 2010

Co-Authors

- Dr. Ryan Olsen, T&E Board Chairman, NSWC Crane, Detachment Fallbrook, ESED
- Ms. Christine Grasinski, Mechanical Engineer, NSWC Crane, Detachment Fallbrook, ESED
- Mr. Jon Conner, Senior Scientist, National Technical Systems, Dana Point, CA
- Ms. Kathryn Hunt, Chemical Engineer, USMC MARCORSYSCOM, PM Ammo

Presentation Outline

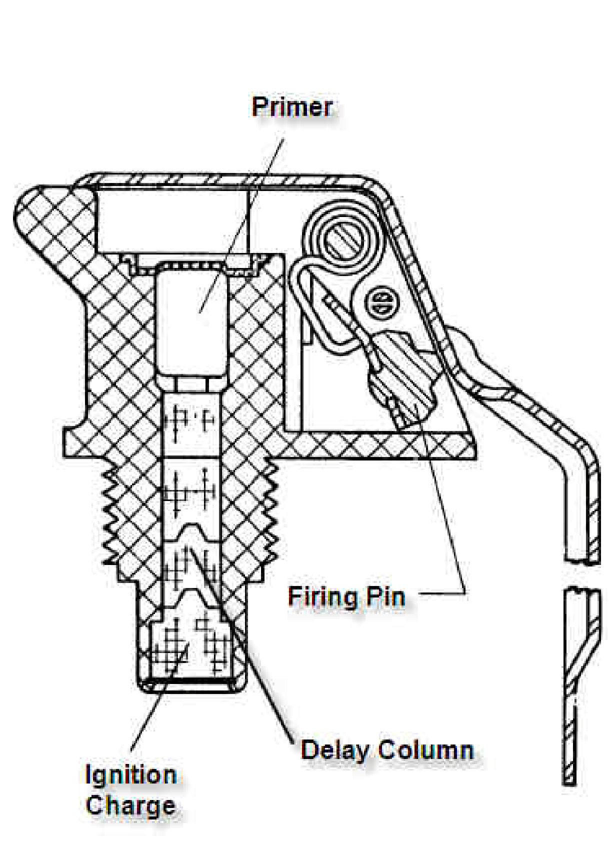
- Background
  - M201A1 Pyrotechnic Delay Hand Grenade Fuze Description
- Approach
  - Digital IR Camera Description
  - Test Setup
- Test Results
  - Data Reduction Methodology
- Summary and Conclusions

M201A1 Fuze Description

- The M201A1 Fuze is used on a number of hand grenades including:
  - M18 Colored Smoke
  - AN-M14 Incendiary Thermite (TH-3)
  - AN-M8 HC (Hexachloroethane) Smoke
  - M73A CS Riot Control
  - M83 TA Practice (Teraphthalic Acid) Smoke
- Failures of these grenades to function are often attributed to M201A1 Fuze misfire

M201A1 Fuze Description

- **Contains three stage initiation train:**
  - Primer
  - Delay Column
  - Ignition Charge
- **Functional Sequence**
  - Remove of Safety Pin
  - Release of Safety Lever
  - Spring loaded striker impacts Percussion Primer
  - Delay Column initiated (2 sec delay)
  - Ignition Charge fires



Approach

- **Typical thermal output assessment tools**
  - Disassembly and dissection of energetics
  - Bomb Calorimetry
  - DSC (Differential Scanning Calorimetry)
  - TGA (Thermal Gravimetric Analysis)
- **Approach**
  - Measure thermal output of fuze initiation train without disassembly
  - Perform high speed IR imaging of surface of fuze body
  - Quantify surface temperature profile during function

Digital IR Camera Description

- FLIR Systems Thermovision SC4000 InSb Camera System
  - Wavelength: 3.0-5.0 µm
  - Resolution: 320 x 256 Pixels
  - Full Frame Rate: 420 Hz
  - Sensor Cooling: Stirling Closed Cycle
  - Lens: 100 mm InSb lens, f/2.3
  - Sensitivity: 0.018 ºC
  - Thermovision ExaminIR MAX Software

- Sub-Windowing allowed higher effective frame rate
  - Max frame rate used in test: 160 x 128 pixel frame @ 1324 fps

Test Setup

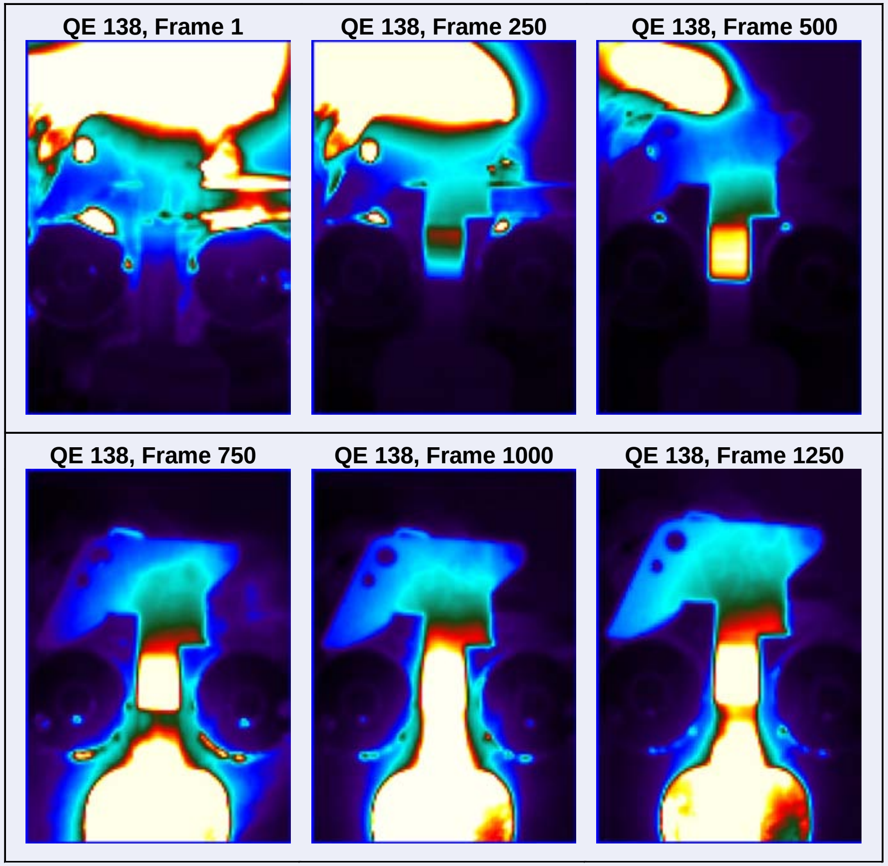
- Test Fixture Design
  - Rigid mount allowed viewing of the fuze body during function
  - Pneumatic actuator to remove safety pin

Test Setup

- **Test Layout**
  - **High speed digital IR Camera System Positioned to allow fuze body to fill the field of view**

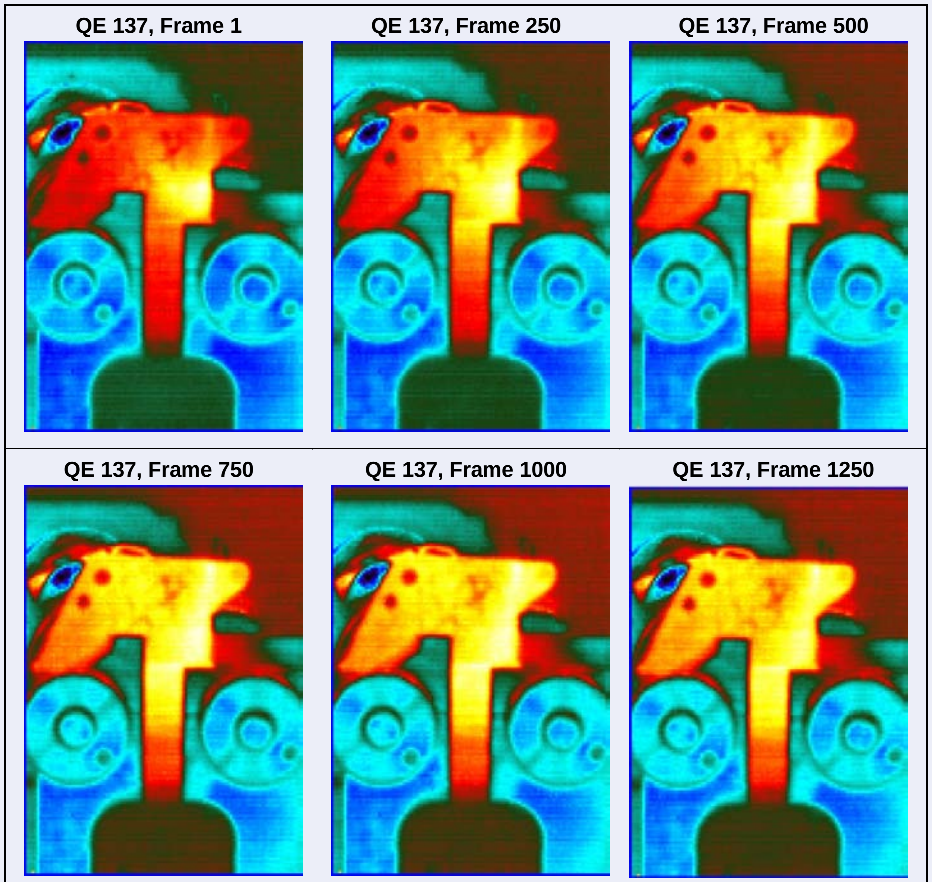
Test Results

- Pyrotechnic Reaction Sequence – "Good Fuze"



Test Results

- **Pyrotechnic Reaction Sequence – Misfire**



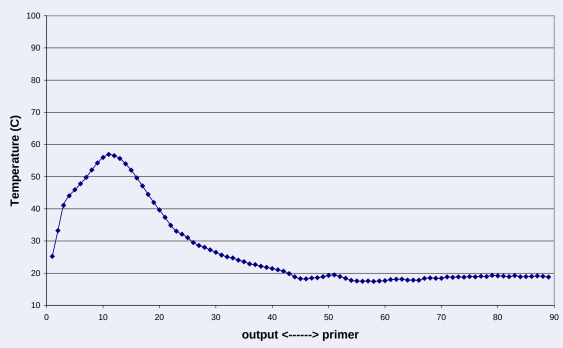
Comparative High Speed Video Images

QE 365, Manufactured in 2000	QE 429, Manufactured in 1968
	

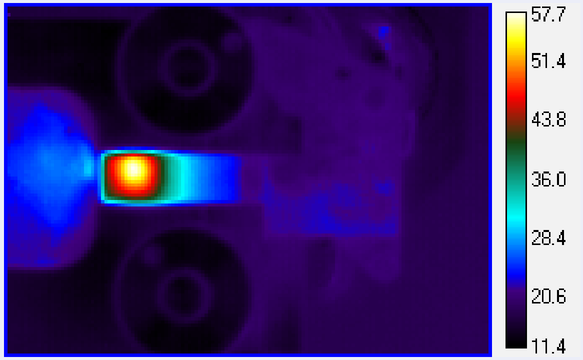
Data Reduction Methodology

Fuze Lot MEI85E001-005, QE #396
(approximately 24 years old at time of test)

Fuze Lot MEI85E001-005, QE #396

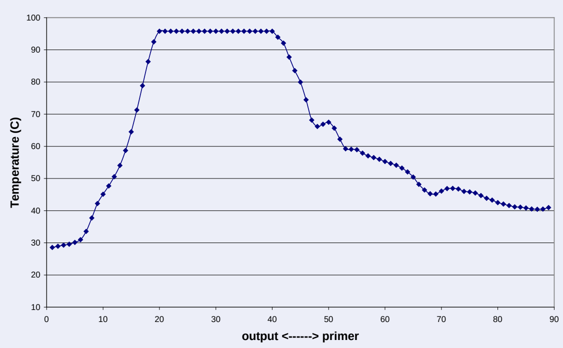


Frame 516, Just Prior to Output Charge

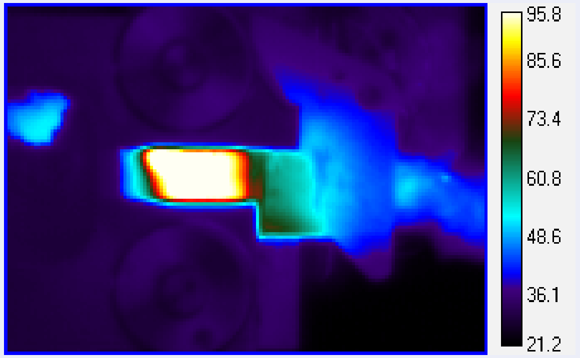


Fuze Lot NYI-1633-12, QE #3
(approximately 47 years old at time of test)

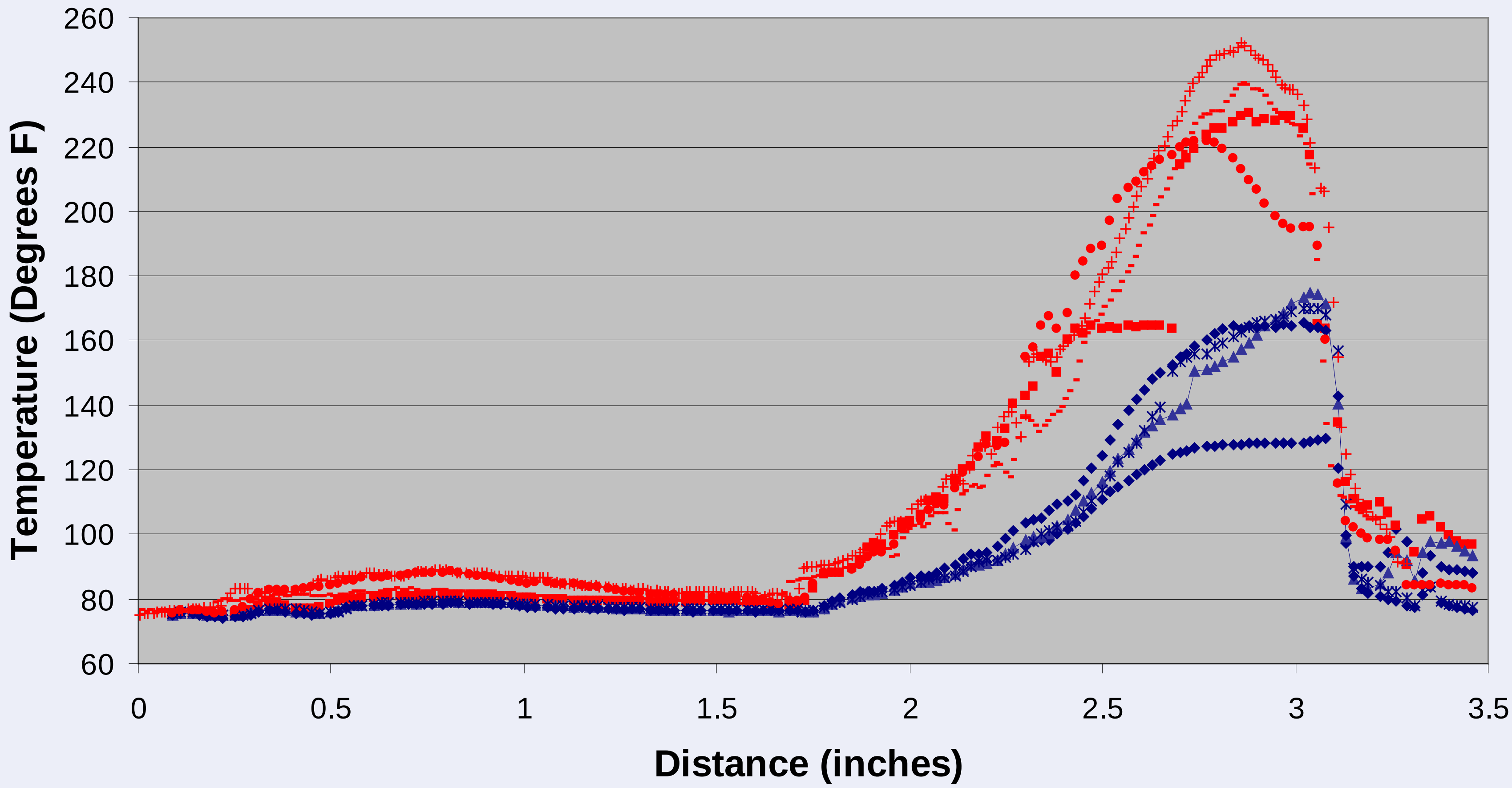
Fuze Lot NYI-1633-12, QE #3



Frame 467, Just Prior to Output Charge



Example Temperature Profiles



Summary and Conclusions

- **High Speed Digital IR Camera Systems are effective in quantifying thermal output of pyrotechnic initiation trains**
- **Technique may be utilized on other pyrotechnic type items**

RDECOM

Malcolm Baldrige National Quality Award 2007 Award Recipient

Programmable Initiators to Extend Functionality of Reserve Power Systems

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Carlos M. Pereira U.S. Army ARDEC
carlos.m.pereira1@us .army.mil
973-896-5909

Hai-Long Nguyen U.S. Army ARDEC
hailong.nguyen@us.army.mil
973-724-1543

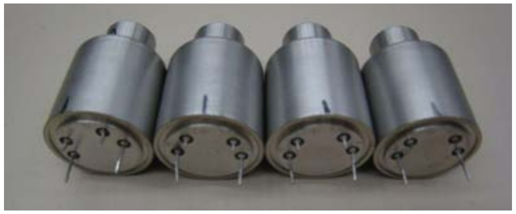
Charles McMullan U.S. Army ARDEC
chuck.mcmullan@us.army.mil
973-724-2755

Jahangir Rastegar PhD Omnitek Partners, LLC
j_rastegar@pmnitekpartners.com
631-665-4008

Thermal Batteries

- Ideal power source for many munitions
  - Long shelf life
  - Good temperature performance
  - High power capabilities

- Reserve battery
  - Initiated by a pyrotechnic device - Igniter
  - Heat generated melts electrolyte to activate the battery



Igniters

Main Functions

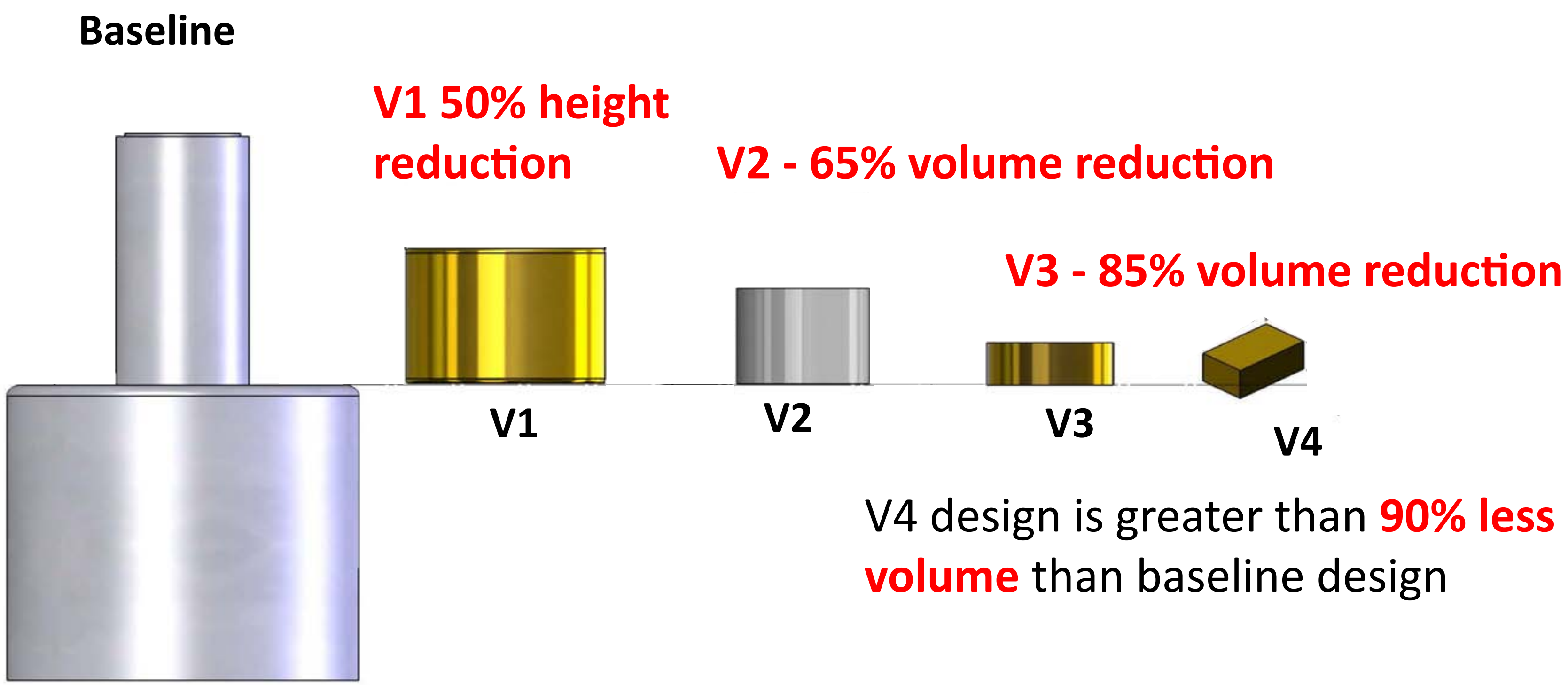
- Ignites pyrotechnics to heat up the battery
- Safety mechanism
  - Ideally the igniter only fires when shot from a gun
  - Differentiate between dropping events and gun launched events
    - Important to include magnitude and duration of impulse

- Classes of Igniters
  - Inertial Igniters – mechanically initiated pyrotechnics
  - Electrical igniters – electric matches, squibs – powered by some external power source and decision circuitry

Inertial Igniter Improvements

Family of Inertial Igniters

— Miniature, Scalable, Producible designs that can easily accommodate a wide variety of applications

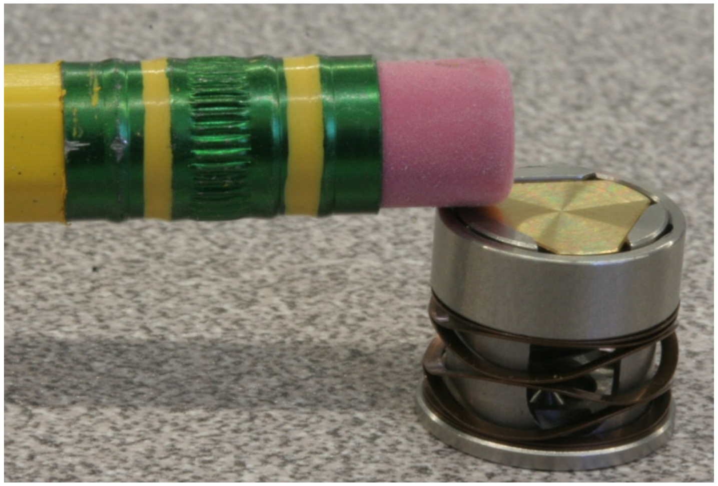


V4 design is greater than **90% less volume** than baseline design

* **Omnitek Partners, LLC,**
111 West Main St., Bay Shore, NY 11790

V2 Inertial Igniters

- V2 with Improved Producibility
  - Awarded Army CPP (Commercialization Pilot Program) to improve manufacturability
  - Reliability testing ongoing
  - ~ 65% smaller in volume w/ same functional requirements



V2 operation

V2 Inertial igniter operation

Locking sleeve under equilibrium

Under No-Fire acceleration locking sleeve will return back to equilibrium

Only under All-Fire does the locking sleeve unlock the striker.

Striker Released

Programmable Initiators

- Piezoelectric harvester converts forces from acceleration into electrical charge
  - Collected in main storage device
  - Activates safety circuit
    - Determines all-fire/no-fire levels
    - Enables power source to activate pyrotechnic device
- A simple counter could provide a delay of up to days after launch
- Acceleration inputs could also trigger events

Advantages of Programmable Initiators

- Inertial igniters activate upon setback - Turn battery on when it is actually needed allows for optimization of battery size
- No external power source/decision circuitry required
- Can easily satisfy a variety of all-fire & no-fire requirements
- Scalable – Flexible, low cost, and size

Summary

- Families of miniaturized igniters for thermal batteries are/have been developed
- Significant volume reduction of inertial igniters
- Programmable initiators offer significant gains in flexibility
- Improved igniters offer significant gains in miniaturization without affecting safety, reliability, functionality, or cost.

XM1156 Precision Guidance Kit (PGK) Overview

for

2010 Fuze Conference

12-13 May 2010

Peter J. Burke

Deputy Product Manager, Mortar Systems

email: peter.j.burke@us.army.mil

973-724-6059

Anthony Pergolizzi

Army Fuze Management Office

email: anthony.pergolizzi@us.army.mil

973-724-2361

PGK Overview

- **XM1156 Precision Guidance Kit (PGK) Is A GPS Guidance Kit with Fuzing Functions to Reduce Ballistic Dispersion of Artillery Projectiles**
  - Increment 1: $\leq$ 50m CEP for 155mm High Explosive (HE) projectiles
  - Future Increments will develop compatibility for 105mm projectiles, cargo projectiles, and future artillery platforms

- **Alliant Techsystems (ATK, Plymouth, Minnesota) was awarded the Increment 1 System Development and Demonstration (SDD) option based on competitive shoot-off**

- **PGK program has completed its Hardware Critical Design Review and is beginning government qualification testing this summer**

- **PGK is scheduled to begin production in 4Q US Fiscal Year 2010, and be fielded in US Fiscal Year 2011**

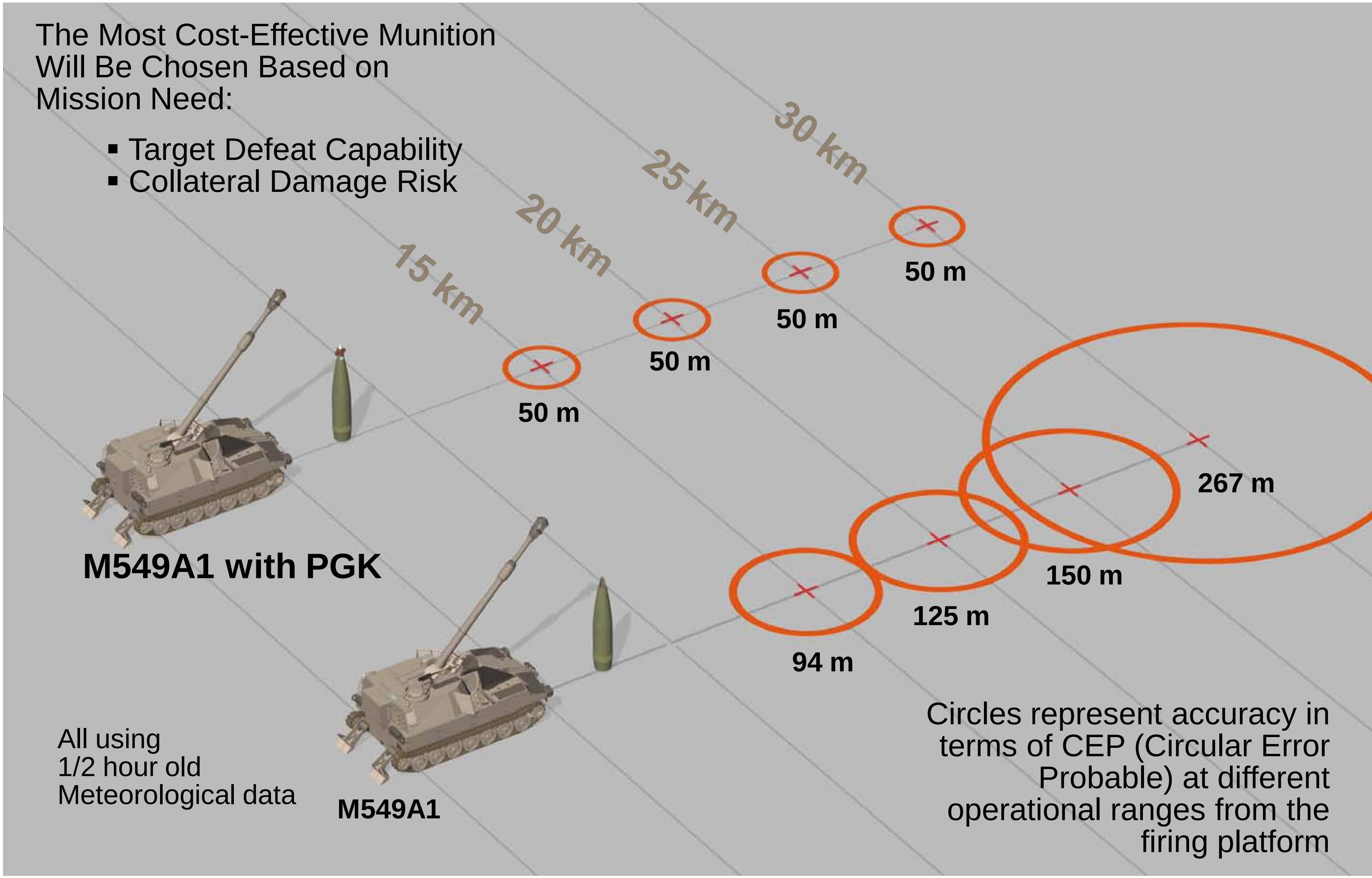
PGK Requirements

	Increment 1 IOC FY11	Increment 2 IOC FY15	Increment 3 IOC FY18
Key Performance Parameters			
1. Net Ready			
2. Reliability	92% (T); 97% (O)		
3. Accuracy	≤ 50m CEP (T); ≤ 30m CEP (O)	≤ 30m CEP (T=O)	≤ 30m CEP (T); ≤ 20m CEP (O)
Attributes			
Munition Type	155mm HE (M107, M795, M549A1)	Adds 105mm HE (T); 105/155mm HE & Cargo (O)	155mm HE (T); 105/155mm HE & Cargo (O)
Platform Types	M777A2, Paladin	Adds M119A3 (105mm) (T)	Adds Future Cannon (T); Paladin, M777A2, M119A3 (T)
Fuzing Function	PD, Proximity	Adds Delay & Time (O)	

Current Focus is Increment 1

T: Threshold Requirement
O: Objective Requirement

Comparative 155mm Projectile Accuracies



PGK Projectiles & Platforms

PGK Projectiles with M109A6 (Paladin)

M777A2

<u>M107</u>
- 95 lbs
- Max Range* 17.5Km
- Warhead 15 lbs

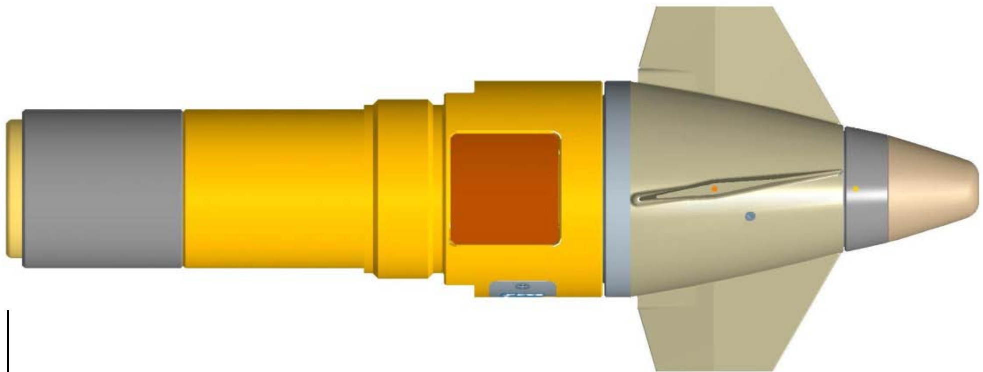
<u>M795</u>
- 103 lbs
- Max Range* 22.5Km
- Warhead 23.8 lbs

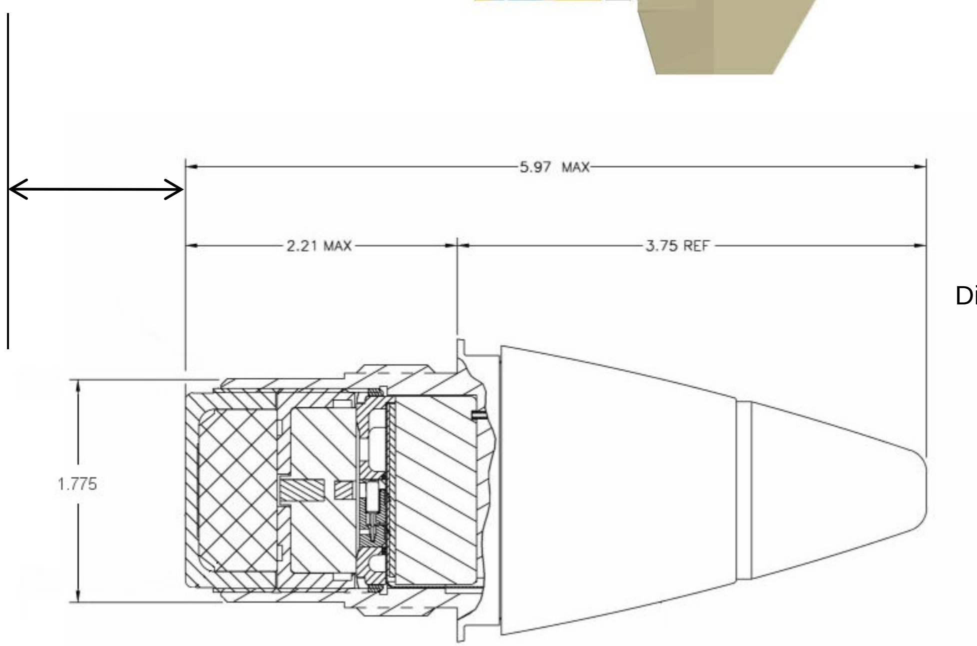
<u>M549/A1</u>
- 96 lbs
- Max Range* 30Km
- Rocket Assisted
- Warhead 15 lbs

* Maximum Range without PGK shown. Max Range will be reduced by no more than 10% with PGK

PGK External View (dimensioned)

2.70 inch (68.6 mm) longer than US Multi-Option Fuze, Artillery (MOFA)





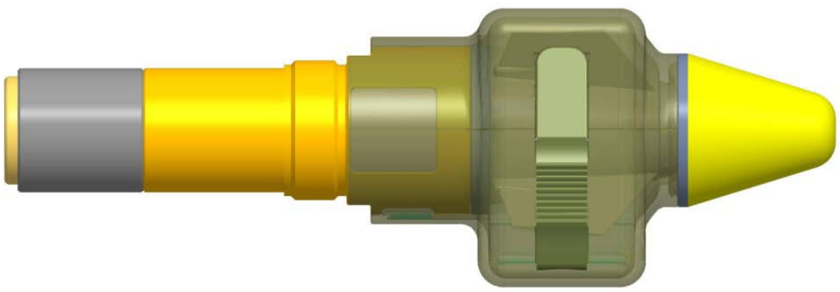
Dimensions in inches

PGK is only Compatible with Deep Intrusion Projectiles

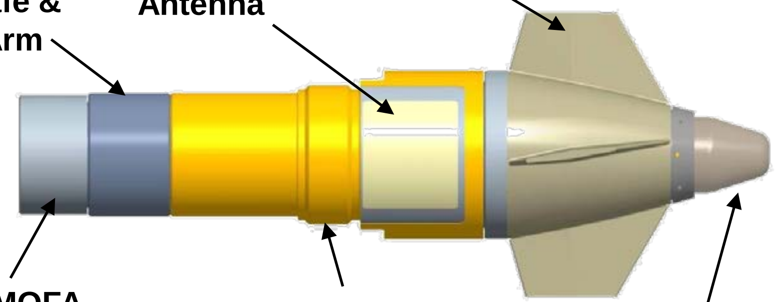
PGK Design Description

PGK With Cover

Cover Provides Environmental Protection & Interface to Fuze Setter



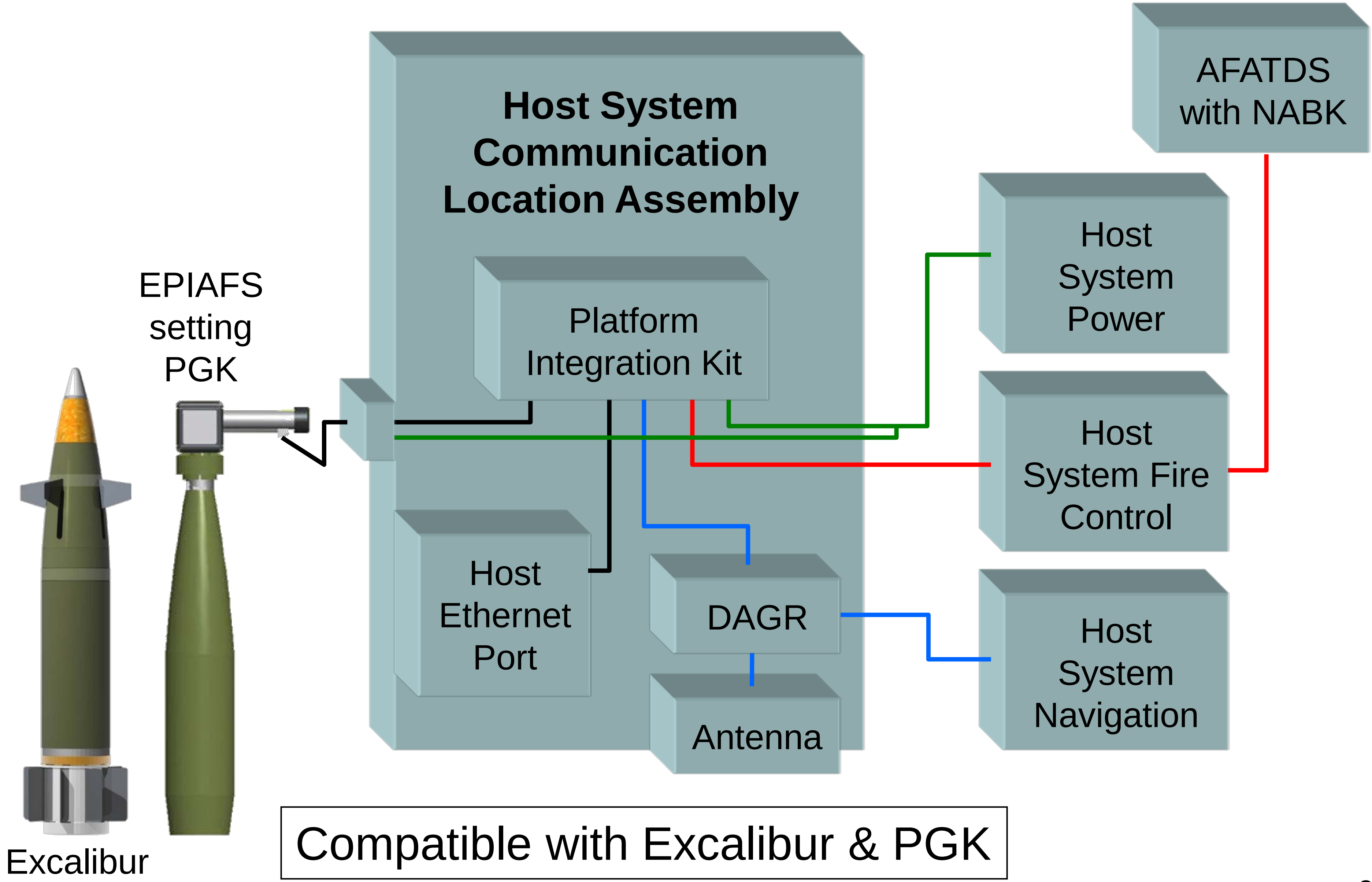
PGK with Cover Removed



- Fits In Std 155mm HE Artillery Projectile Fuze Wells (Deep Intrusion)
- GPS Guidance (With SAASM)
- 20 Year Storage Life (No Battery)
- Proximity & Point Detonating Fuzing

EPIAFS Interface & Host System Support

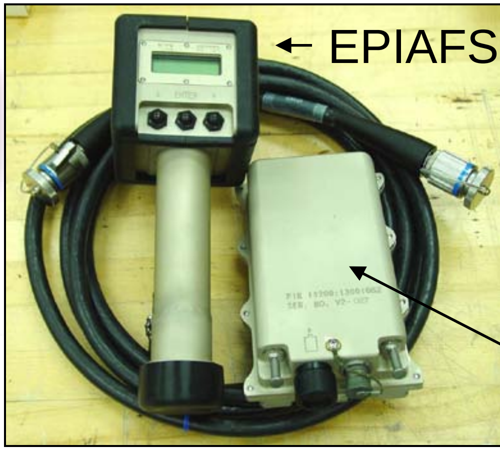
Enhanced Portable Inductive Artillery Fuze Setter



Compatible with Excalibur & PGK

Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS) and Platform Integration Kit (PIK)

DAGR



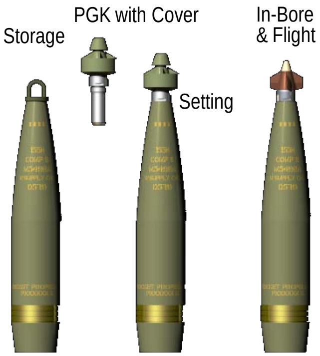
PIK

- EPIAFS:
  - Conventional Fuze & Excalibur/PGK Setter
  - Programs Excalibur & PGK with mission information
- Platform Integration Kit
  - Interface circuit from platform fire control systems, DAGR (GPS receiver) to EPIAFS

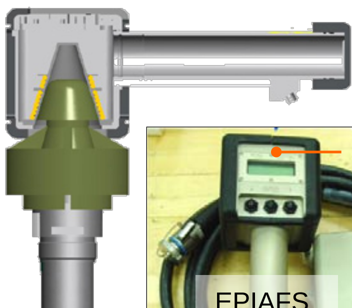
PIK in M109A6 (Paladin)

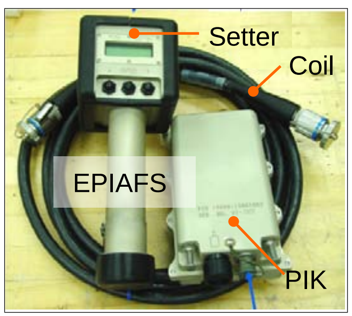
PIK on M777A2

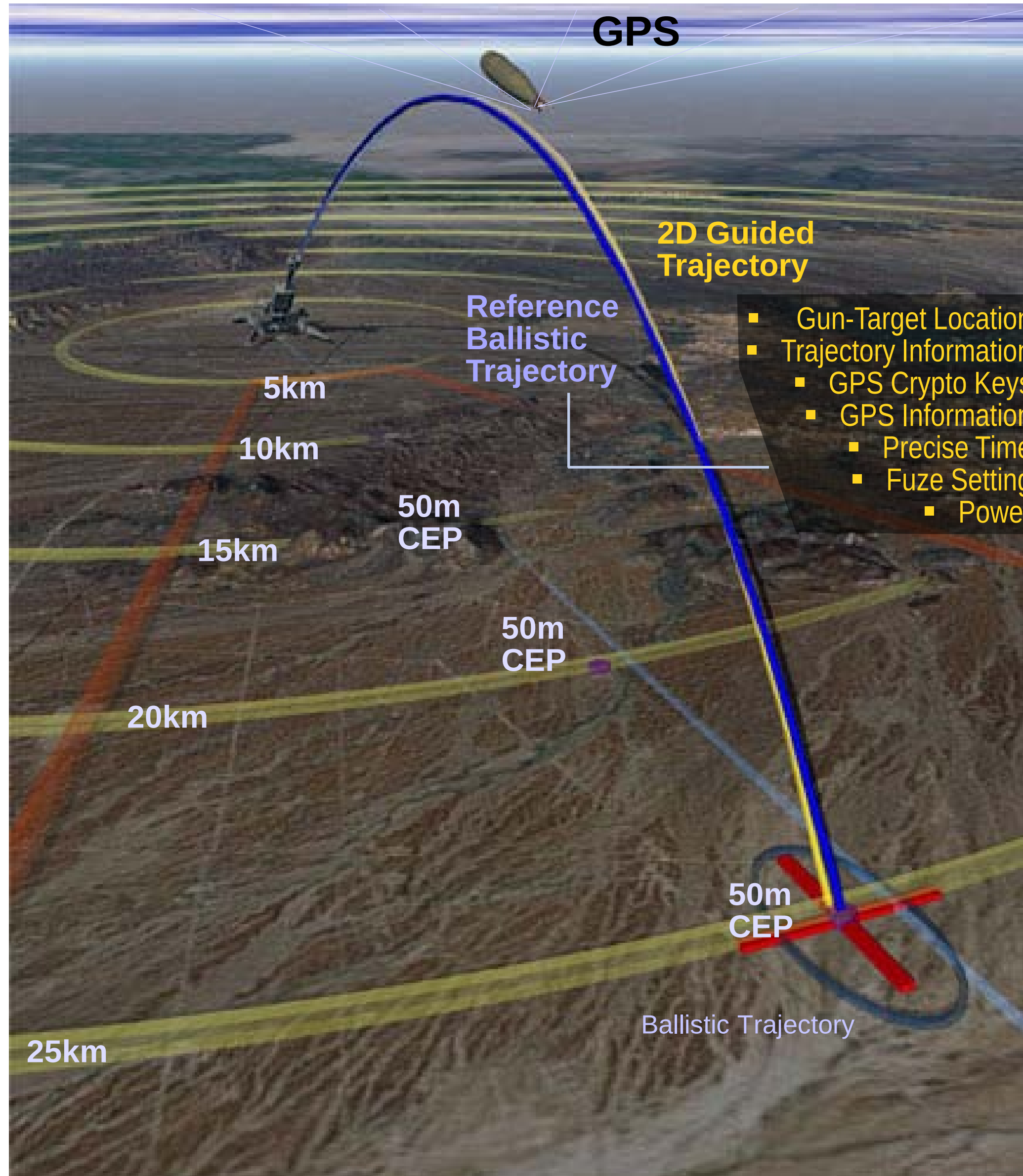
Precision PGK Mission



Planning the PGK Mission





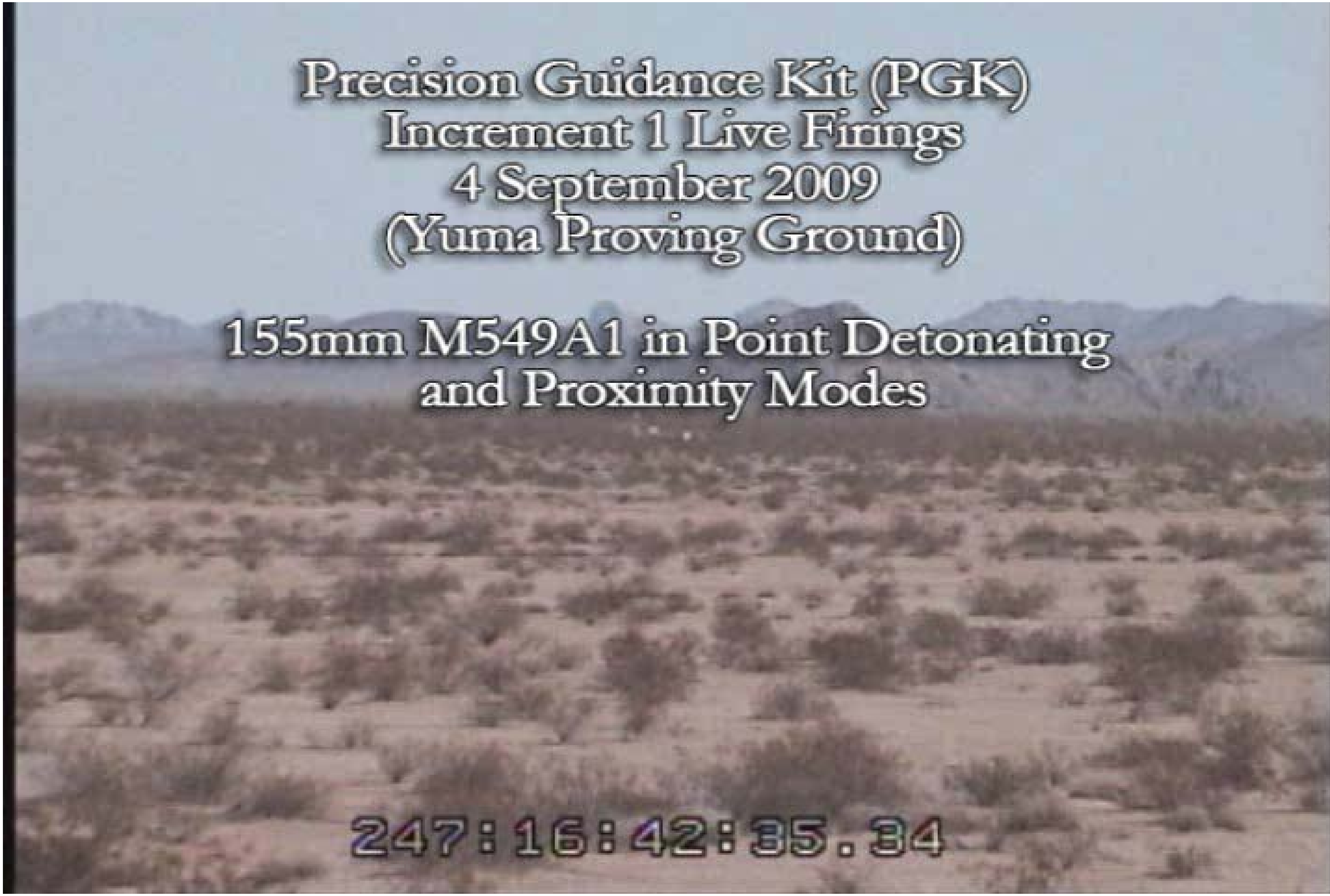


- Receive Fire Mission
- Unpack, Install PGK
- **Set PGK**
- **Remove PGK Cover**
- Load & Ram Projectile
- Load Propel-lant
- Close Breech
- Insert Primer
- Fire Projectile

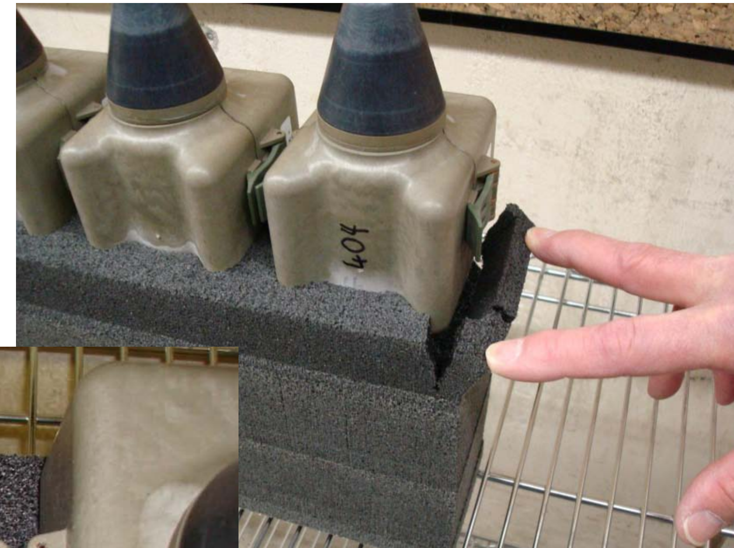
Contractor Fuze Qualification Test Results

- Test Standard: MIL-STD-331C
- Conditions:
    - Transportation/Vibration (Hot & Cold)
    - Temperature/Humidity
    - Storage at Extreme Hot & Cold
    - Thermal Shock
    - Loose Cargo & Tactical Vibration (Hot & Cold)
    - 2.1 meter drop (Hot & Cold)
- All PGKs then fired on M549A1 and M795 projectiles at Hot & Cold
- Results:
    - Safety = 100% (15 of 15)
    - Reliability Objectives = 100% (14 of 14; 1 no-test (M549A1 rocket motor did not ignite))
    - Performance Objectives = met < 50m CEP requirement

PGK Test Results



Dunnage from 2.1m Cold Drop Test



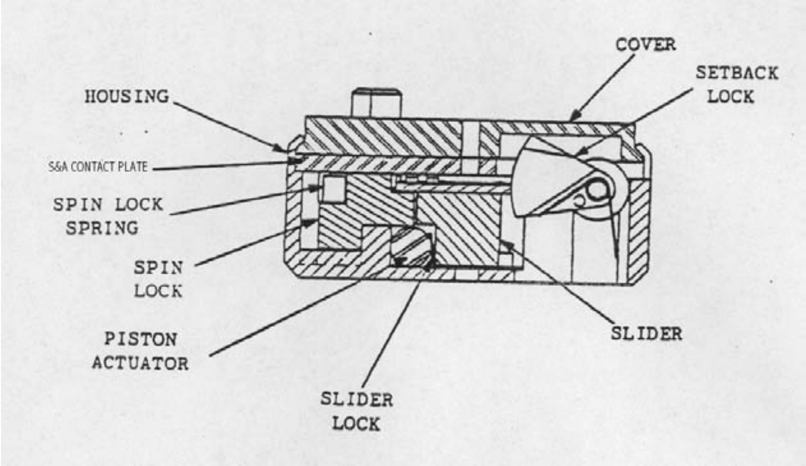
All units passed EPIAFS setting tests after drops tests

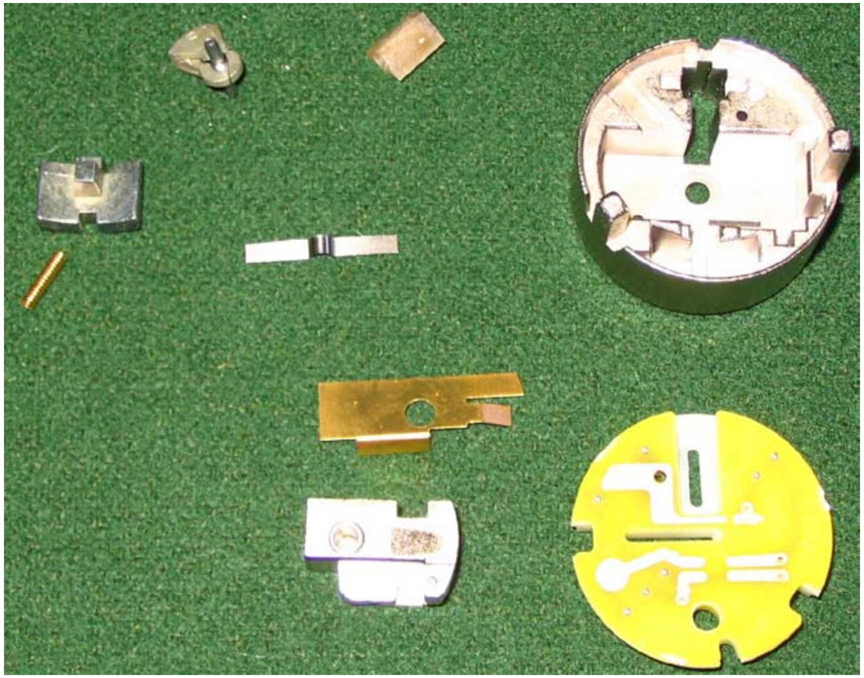
Minor damage to Cover Anti-Rotation Layer

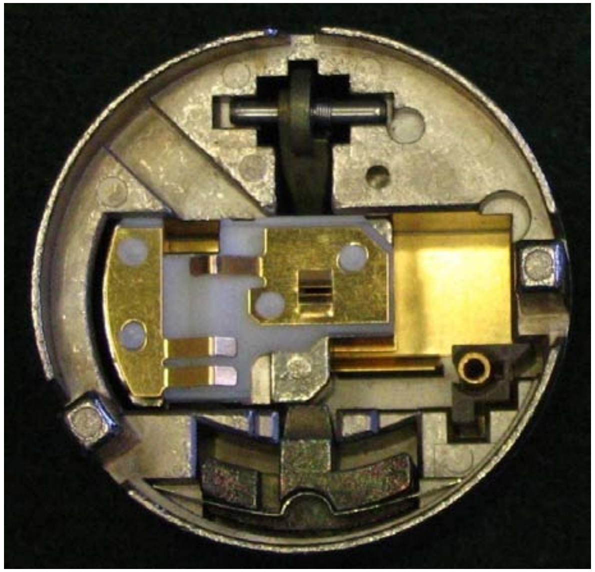
PGK Accomplishments & Up-Coming Events

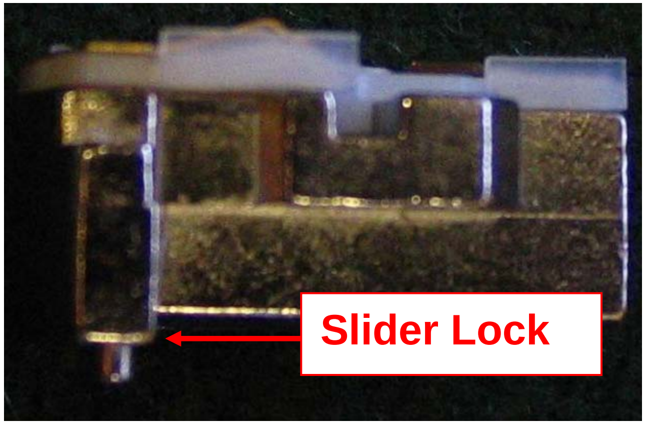
- Hardware Critical Design Review (CDR): Jan 09
  - Design Meets All Requirements Via Analysis or Testing
- AFSRB Initial Certification: Feb 09
- Guided Flight Tests: Apr 09
- Successful User Evaluation: Ft Sill, Apr 09
- Successful Vertical Gun Tests: May 09
- Algorithm CDR: July 09
- Successful Military Standard 331 Testing: Jun 09 through Mar 10
- Successful Electromagnetic Environmental Effects (E3) Testing: Nov 09 through Feb 10
- Sequential Environmental Safety - Safety: Jun 10
  - 64 PGKs fired after environmental conditioning (Hot & Cold)
- Sequential Environmental Tests - Performance: Jun 10
  - 20 PGKs fired after environmental conditioning (Hot); additional 20 planned for Cold portion of test in 1QUSFY11
- Milestone C (Production Decision): 4QUSFY10
- Initial Operational Capability (IOC): 4QUSFY11

M767A1 Safe & Arm (S&A) Mechanism



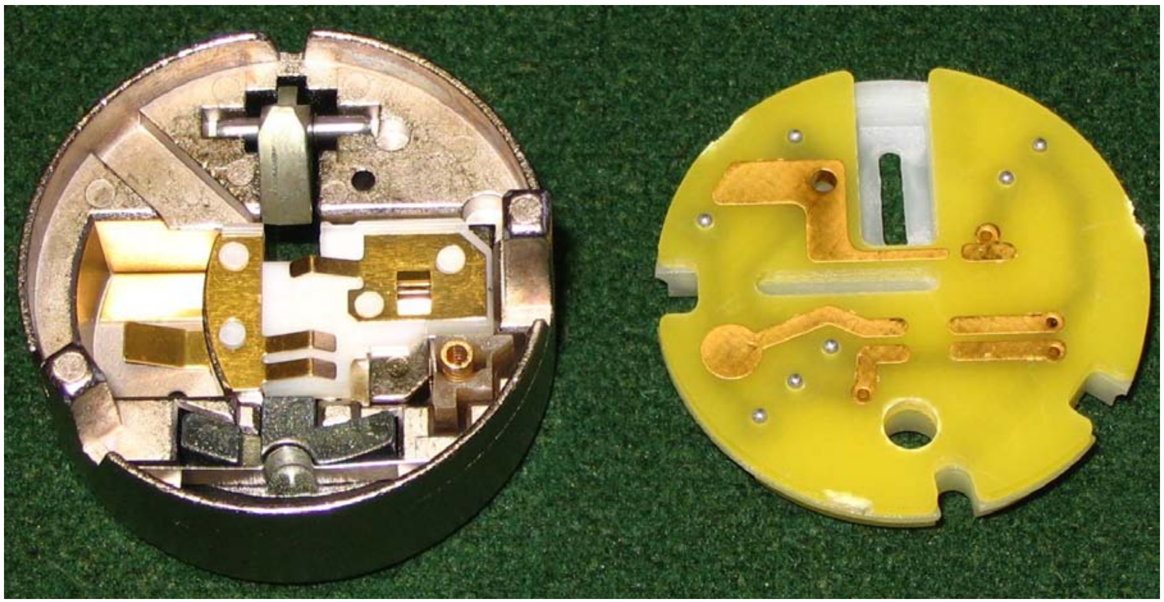


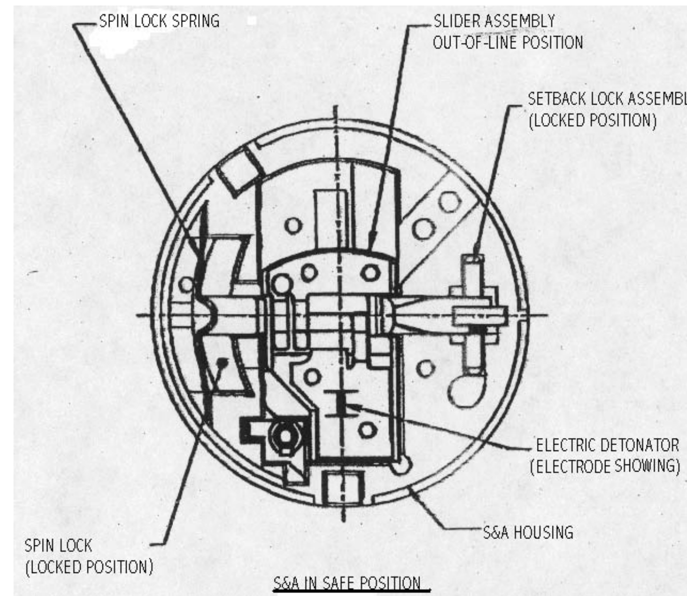




Safe Position

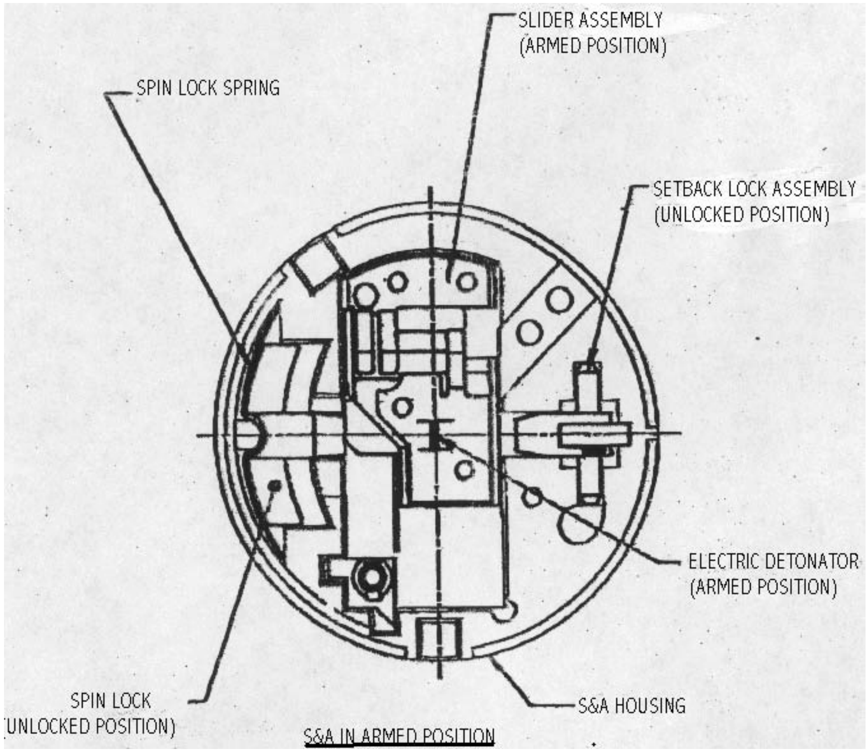
- Setback weight up
- Spin lock pushed in

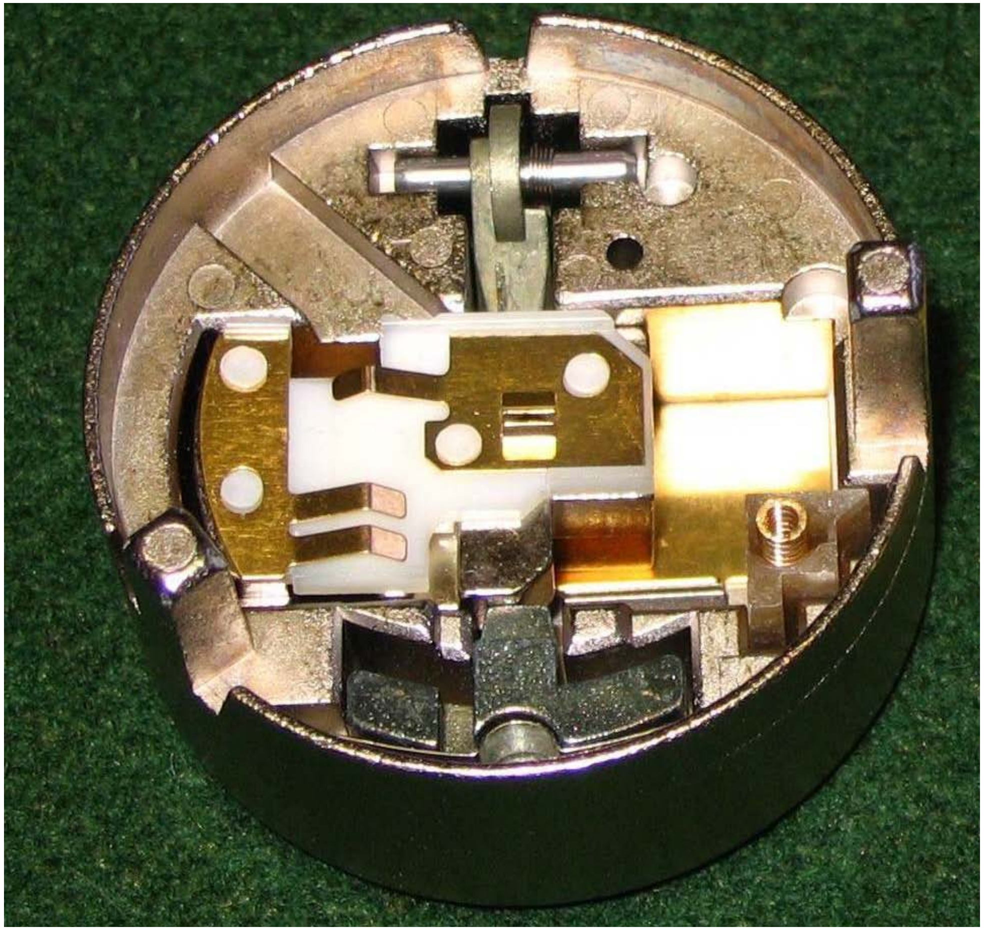




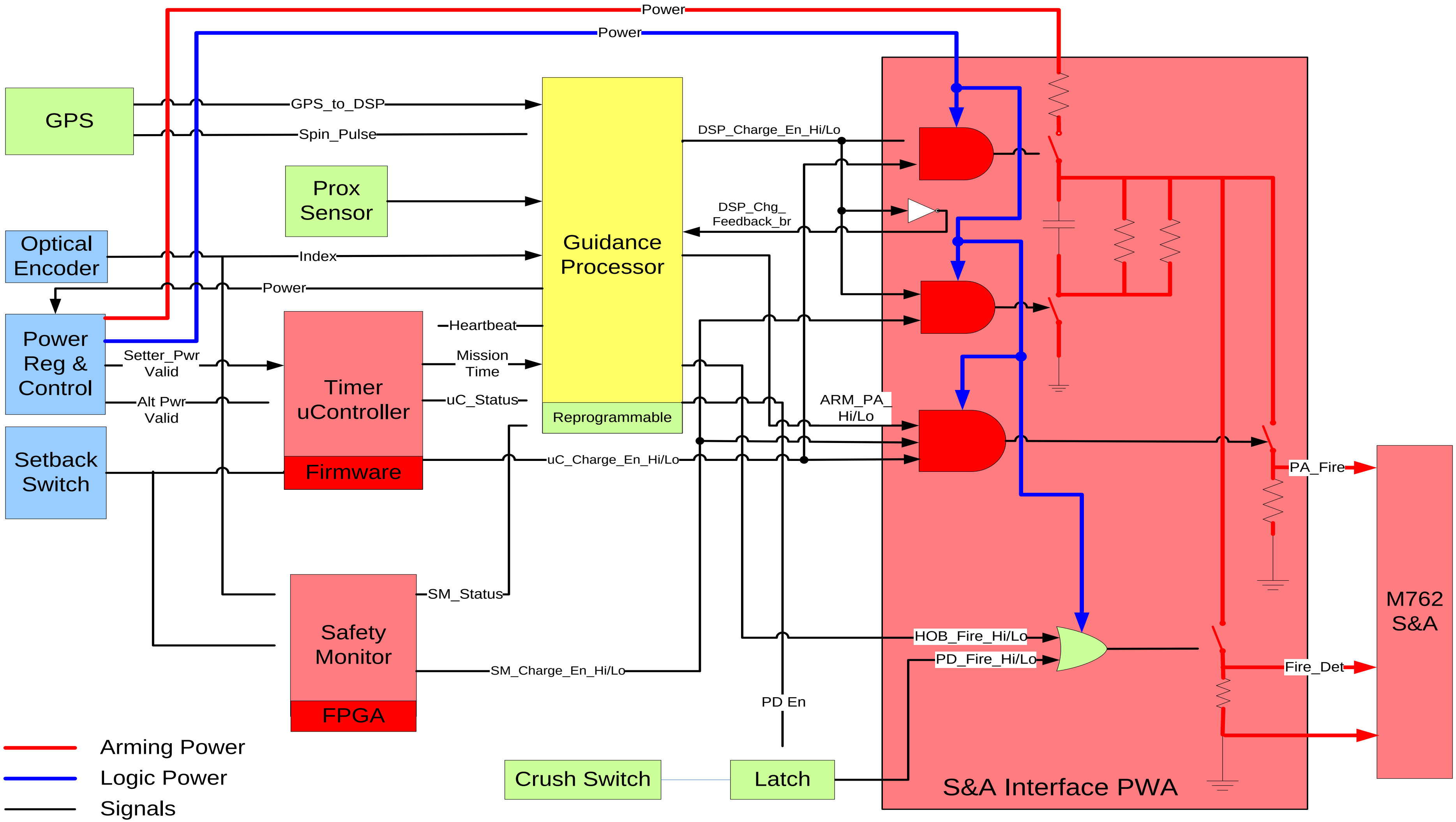
Armed Position

- Setback weight down
- Spin lock pushed out





PGK Fuzing Architecture



PGK Growth Potential

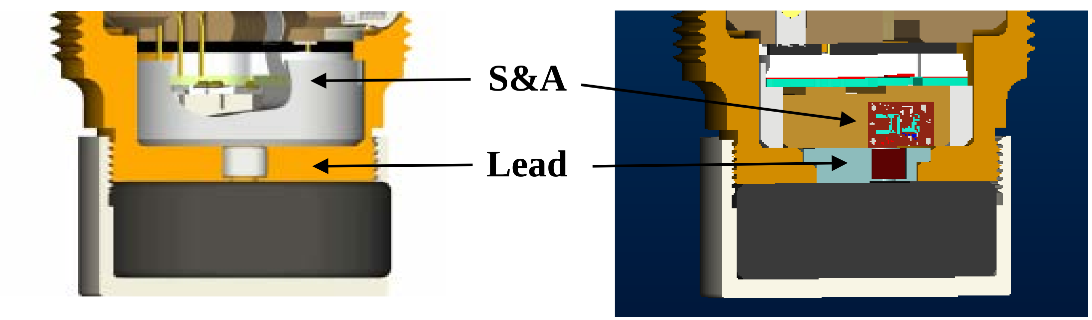
Potential Technology Insertions:

- MEMS S&A
  - Smaller / More Cost Effective
- Booster Modification
  - Initiates IM Energetics
  - Optimized Size
- Next Generation Proximity Technology
  - Small & Cost Effective

Micro-Electro Mechanical Systems (MEMS) S&A Development

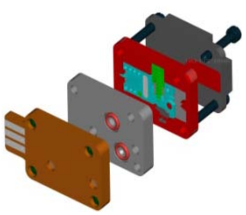
M762A1 Fuze Used To Evaluate MEMS S&A Performance For Artillery

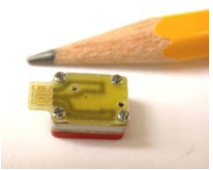
- Improved MEMS Design
- Suitable For High and Low Propellant Charges
- Command-To-Arm Feature
- ***S&A Volumetric Savings = 95%***



M762A1/M767A1

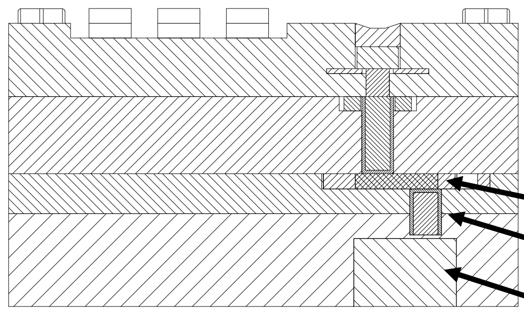
MEMS Integrated



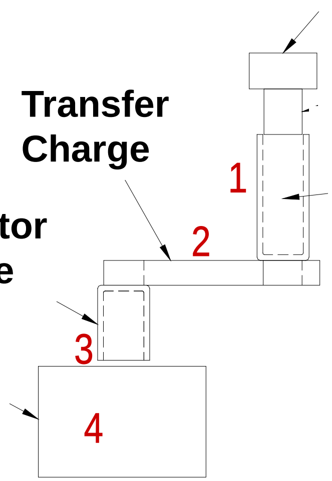


Micro-Scale Firetrain (MSF)

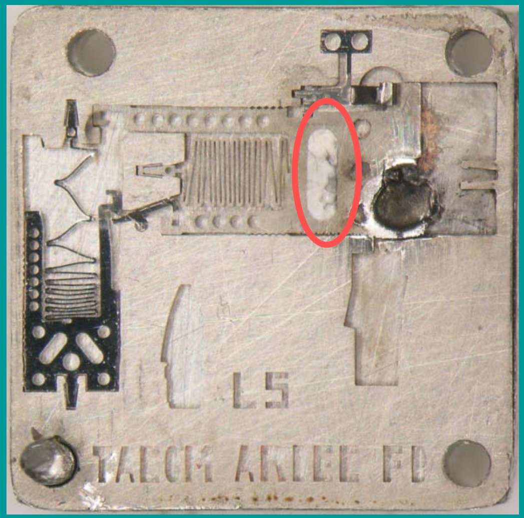
U.S. Patents 7055437 and 7069861

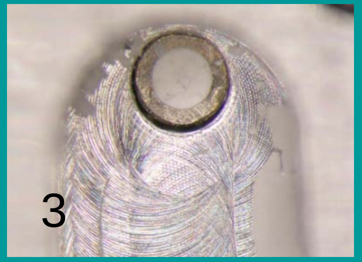


Cross-section, MEMS S&A Assembly



Barrier Safety

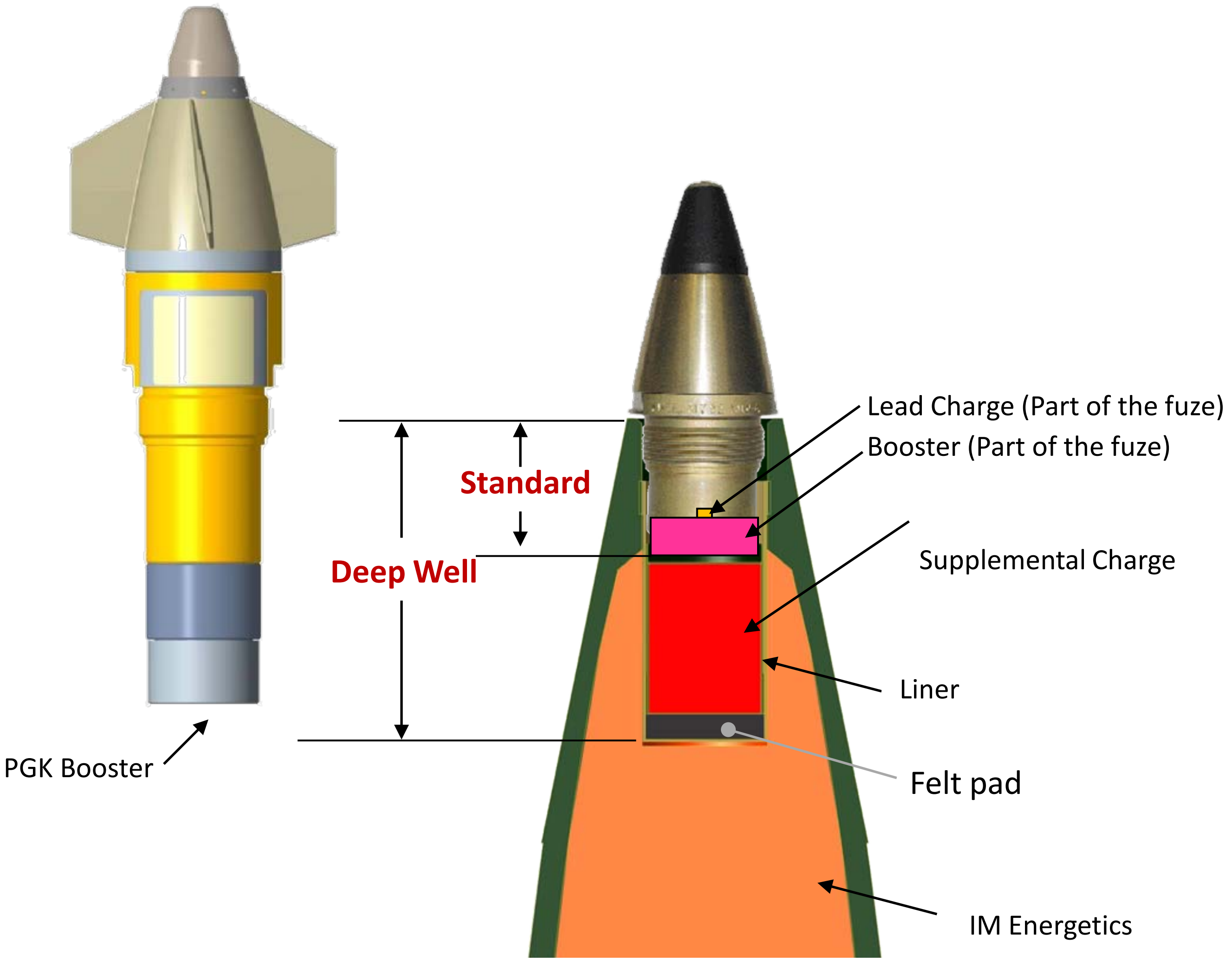




Charge 1 Function
Charge 2 (Transfer) Safe

Charge 3 (Receptor) Safe
Charge 4 (Output) Safe

Potential PGK Booster Re-Design



Develop Optimized Booster for use in Projectiles with Insensitive Munition Fill

Summary

- PGK (Increment 1) Provides Warfighter ≤ 50m (CEP)
  - 155mm High Explosive Projectiles
  - Future Increments Increase Capabilities For 105mm & 155mm Projectiles
- PGK Design Leverages Existing Technology (High Maturity)
- PGK Safety Design
  - Uses Proven M762 S&A Design
  - Redundant Electronic Architecture
- Warfighter Benefits Include:
  - Improves Munition Accuracy
  - Improves Munition Efficiency
  - Increased Number of Stowed Kills (Reduces Logistics Burden)
  - Greatly Reduces Possibility of Collateral Damage
- PGK Increment 1 Fielding Planned in US Fiscal Year 2011

JUNGHANS microtec

New Safety Requirements For Munitions Fuzing System Solutions

54th Annual Fuze Conference

"The Fuzing Evolution – Smaller, Smarter and Safer"

Kansas City, MO - May 11-13, 2010

Max Perrin
JUNGHANS Microtec

Outline

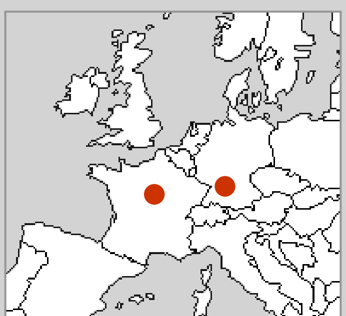
JUNGHANS microtec

- Safety Issues
- Conventional Requirements
- New Safety Requirements – Trends
- Fuze Safety - Technical Solutions
  - Before safe-separation phase
  - After safe-separation phase
  - Post-conflict phase
- Fuze Technologies

Company Presentation

JUNGHANS microtec

- **A global leader in the field of ammunition fuzes and S&A devices**
- **Full range of products**
- **Key competences in**
  - Fuzing technologies
  - Micro-technologies
  - Ammunition electronics



A Diehl and Thales Company

Munitions – Safety issues

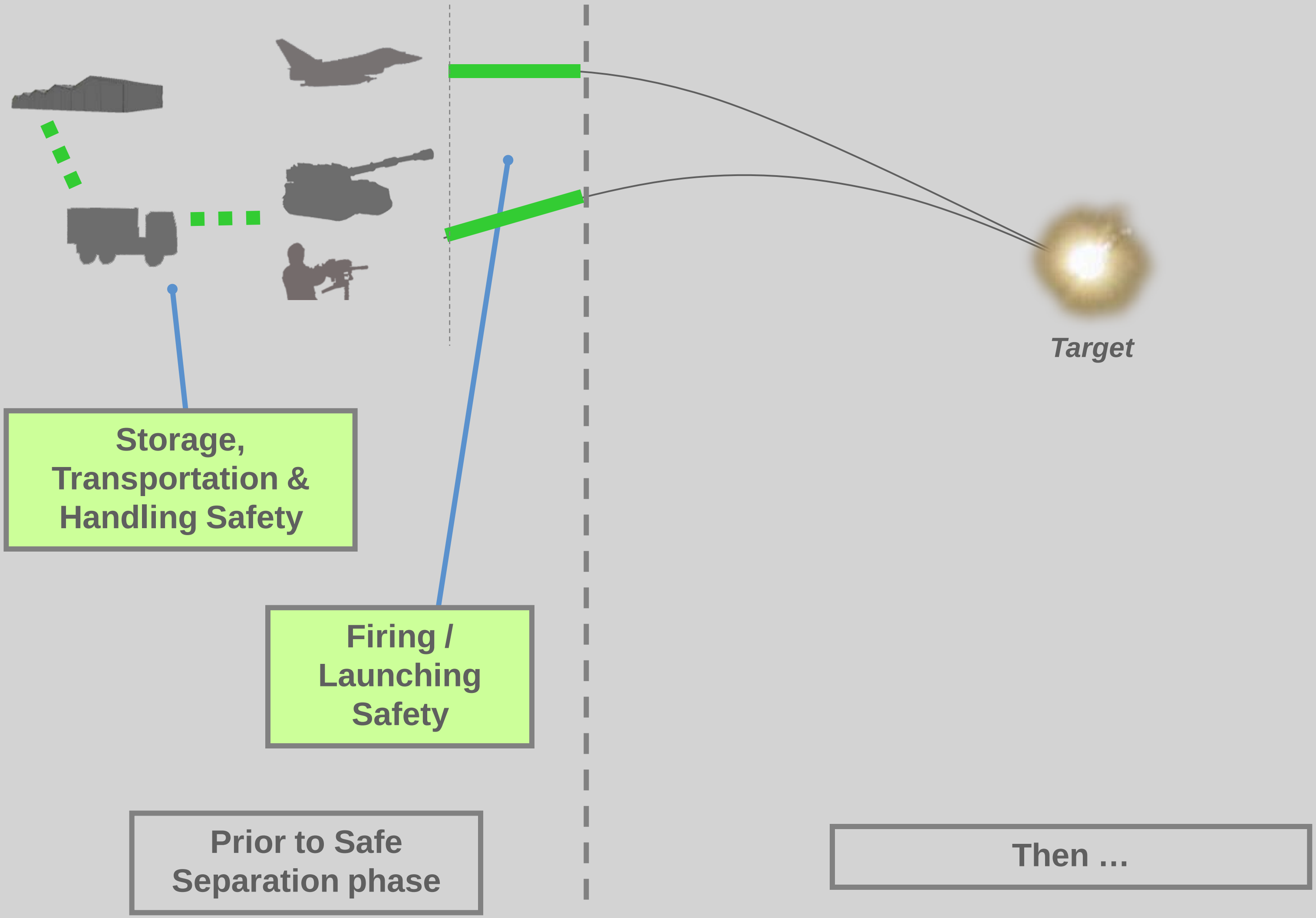
JUNGHANS microtec

- The Fuze is the key element to guarantee safety and protection to the crew throughout the logistical and tactical cycles
- Modern warfare means new safety requirements for munitions
- This leads to new challenges for the fuze designer, who will have to implement new safety concepts and technical solutions

… while

- Keeping and enhancing the fuze reliability
- Dealing with munition constraints as small size and low cost

Safety: Conventional Requirements



Safety: New Requirements

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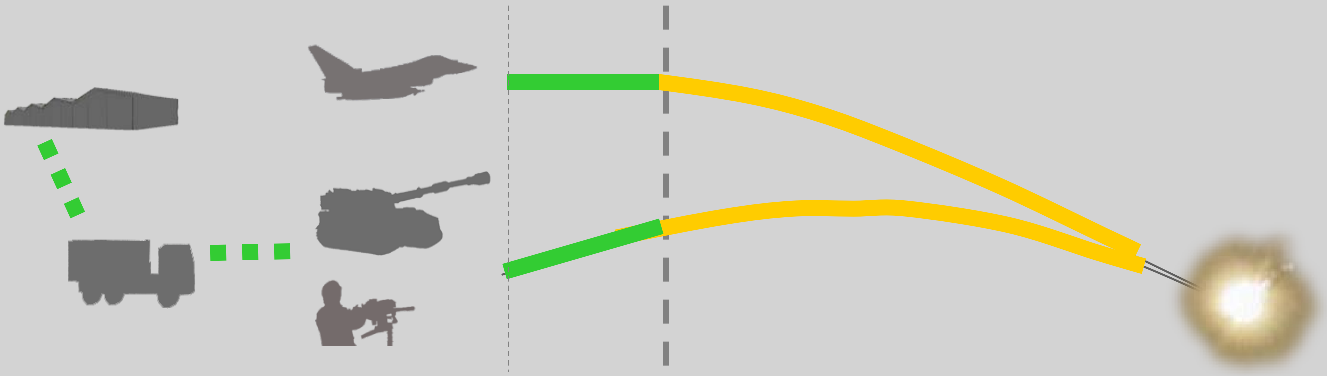


Storage, Transportation & Handling Safety

Firing / Launching Safety

Enhanced safety

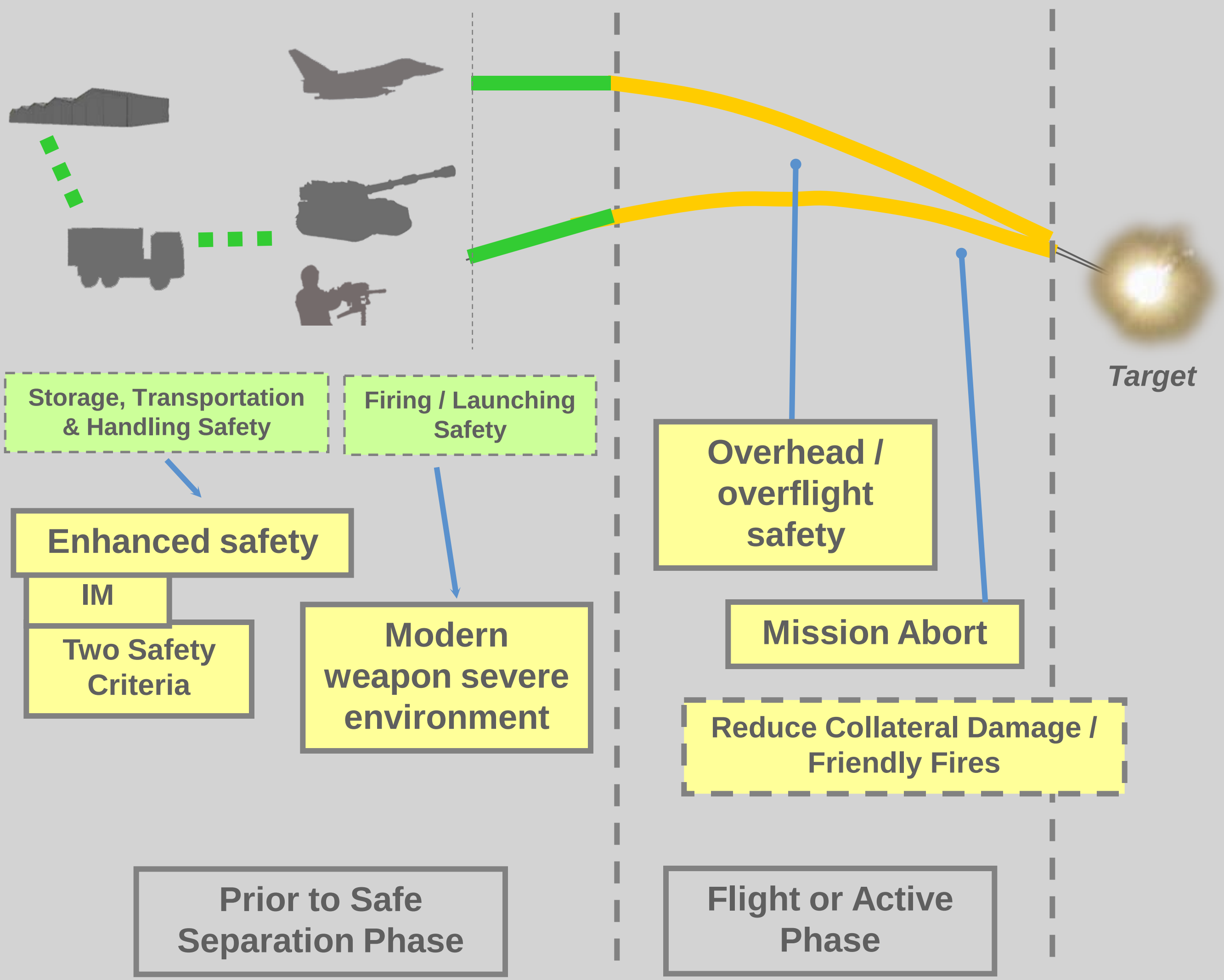
IM

Two Safety Criteria

Modern weapon severe environment

Prior to Safe Separation Phase

Safety: New Requirements



Safety: New Requirements

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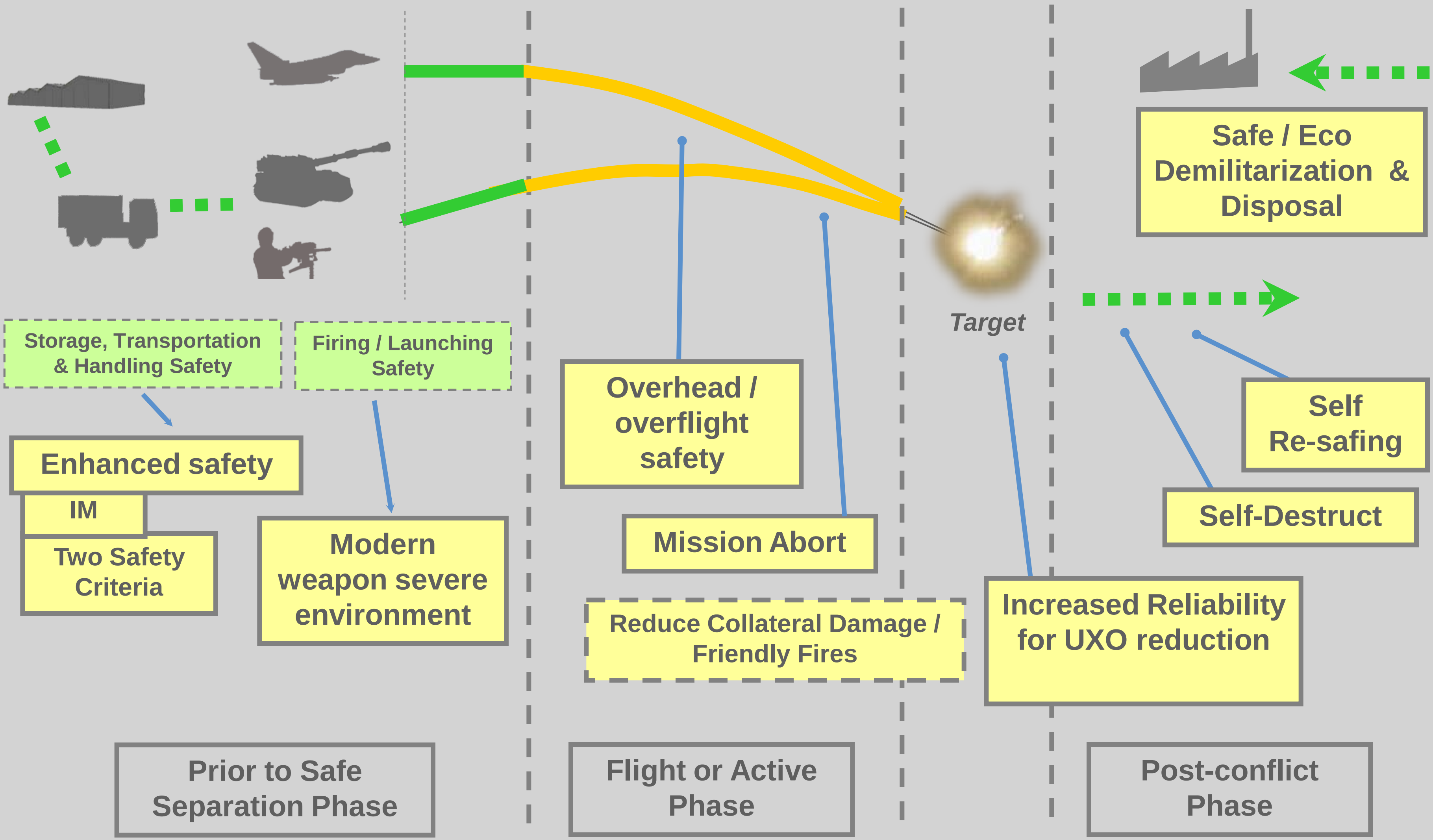

Safety Requirements: Standards and Trends

- Still usual safety related standards, with continuous improvements, + issue with new technologies
  - e.g STANAG 4187, STANAG 4170, STANAG 4368

- New International agreements and protocols, which lead to obligations or recommendations
  - Mainly related to post-conflict hazards: e.g CCW / CCM UN Protocol
  - Not strictly regulatory but require consideration for any country armies and industry (political issue)
  - Sometimes extended by some governements to other related products

- Media and public opinion pressure
  - Beyond strict regulation
  - Environmentally friendly policy
  - NGO pressure
  - Relevance: sometimes questionnable ?

Fuze Safety Requirement and Solutions (Before Safe Separation)

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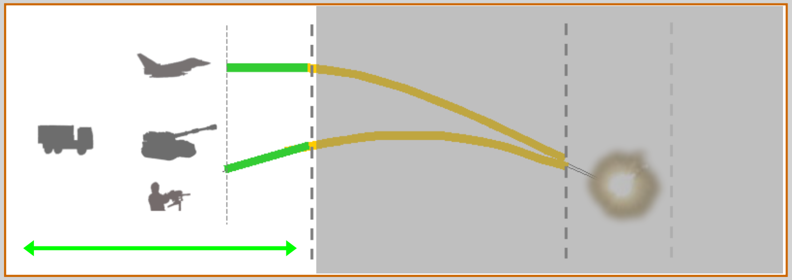
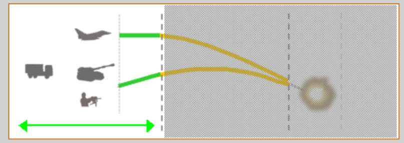


- Main requirements
  - Capability to withstand more and more severe firing/launching environments, e.g with modern howitzer systems or longer carriage time for air-launched munitions
  - IM (Insensitive Munition) capability
  - Full compliance with STANAG 4187 mainly regarding the 2nd safety feature

- Technical solutions
  - More G-hardened fuzing solutions
  - Implementation of 2nd environment sensor : mechanical or electronic
  - IM explosive trains: IM materials, ESAD technology

Fuze Safety Solutions (Before Safe Separation)



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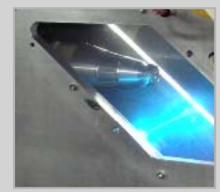
- Hardened design
  - Design able to withstand harsh environment: 52 cal. gun, Flickramming systems
  - Examples:
    - New generation MOFA fuzes
    - New generation PD fuzes

DM84 / L166

FRAPPE

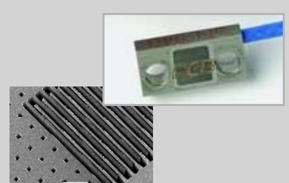
PD 544

- 2nd environment sensors, in particular for non-spinning projectile
  - Mechanical sensor (e.g relative wind detection)
    - New generation of mortar mechanical fuzes
    - Bomb fuzes



DM 93-S

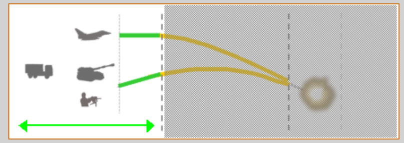
- Electronic sensors and signal processing
  - Wind sensors
  - Magnetic sensors
  - Pressure sensors
  - Accelerometers
  - MEMS technology



Bomb Fuze Sensor

MFZM

Fuze Safety Solutions (Before Safe Separation)



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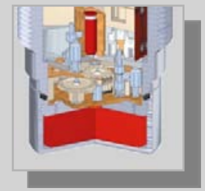
- IM explosive train
  - Use of IM energetics material and appropriate safety design
    - Issue for the fuze designer: Need to keep a high energetic power as the munition material is more difficult to initiate!
  - Specific packaging design
  - Relevance of IM single fuze testing vs complete round ?
    - Depends on the ammunition type



New Generation Artillery Fuzes

Specific Packaging

Infantry Grenade Fuzes

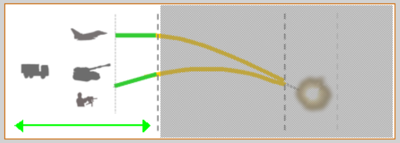
Tank Ammunition Fuze

New Generation Mortar Fuze

Upgraded Version of Mortar Fuze

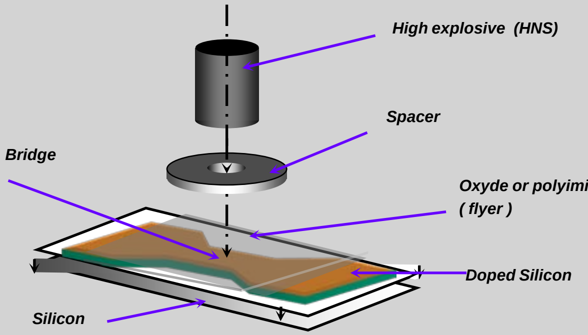
Air Bomb Fuze and booster

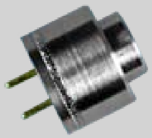
Fuze Safety Solutions (Before Safe Separation)



- IM Fuze : Use of ESAD / EFI technology
  - Naturally Insensitive solution, in particular with respect to ECM, ESD and shocks
  - In-Line SAU
  - Electronic control of the arming sequence
  - Testing capability
  - Re-safing capability

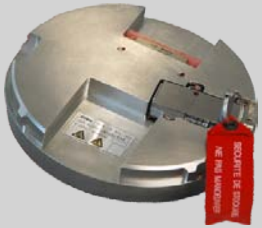
  - Today applied on "high-value" fuzes
    - Air-bomb fuze
    - Missile SAU





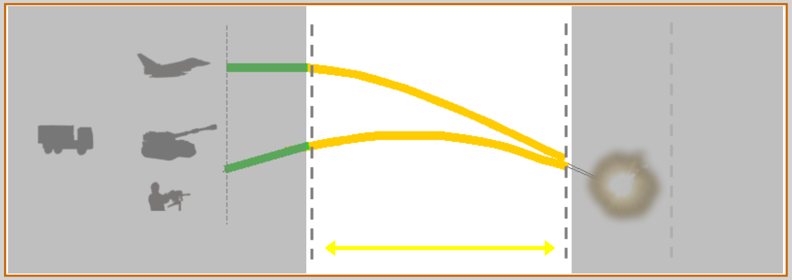
Slapper Detonator (EFI Exploding Foil Initiator)

FBM21 Bomb Fuze



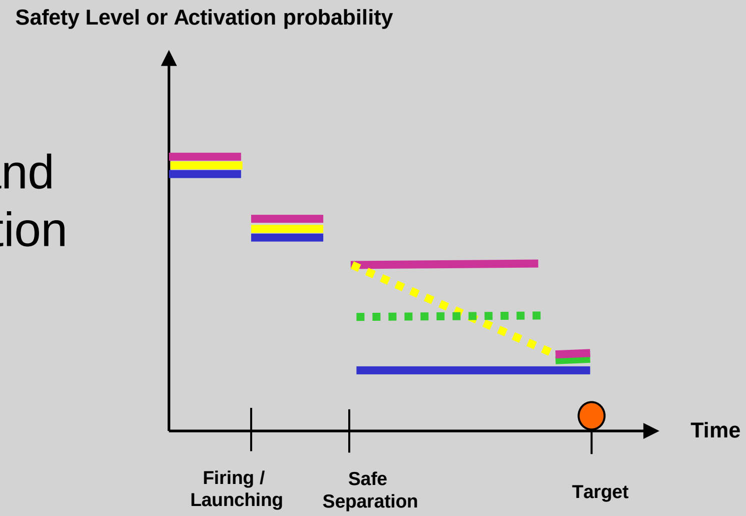
Missile ESAD

Fuze Safety Requirement and Solutions (After Safe Separation)

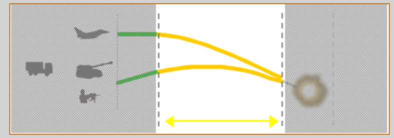


- Main requirements
  - Overhead / overflight safety: no early burst when flying over friendly forces
  - Mission abort: control the fuze or munition status/behaviour during flight when an unexpected event, possibly hazardous, is detected

- Solutions
  - Management of the fuze activation and status during flight from safe separation to target vicinity



Fuze Safety Solutions (After Safe Separation)



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- Overhead Safety

  - Inhibition of fuze operating in flight (electronic)

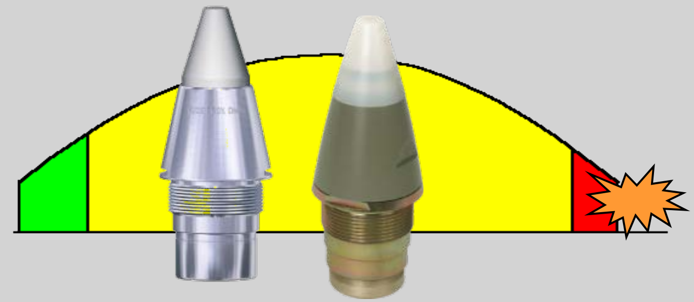
  or

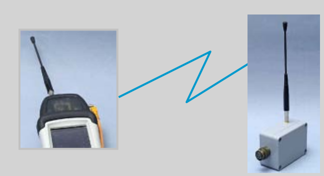
  - Late arming of the SAU, just before intended function on target

  - Possible use of environmental sensors providing flight condition information

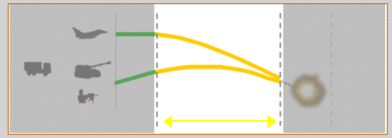
  - Linked to the programming capability , (or remote control) of the fuze :
    - Inhibition or arming time to be set in the fuze control electronics
    - Real-time activity control

  - Supposes safe design and architecture, for hardware but also software, incl. data link protocol





Fuze Safety Solutions (After Safe Separation)



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- Mission abort function:
- New requirement, now necessary with guided munitions (land or airborne) or with course correction fuzes, when:
  - Detection of internal operating fault (built-in test)
  - Guidance problem or target identification issue, internally detected or controlled by the weapon system
  - Main issues: Define the appropriate behaviour? What is the safest action? What is a fail-safe design in that case ?
  - Fuze functions offer various type of “safe” actions
    - De-activation
    - Self-destruction
    - Self-neutralization or Self-sterilization
  - The relevance of the action to achieve depends on the flight phase or on the specific operational configuration

Fuze Safety Requirement and Solutions (Post-conflict Safety)

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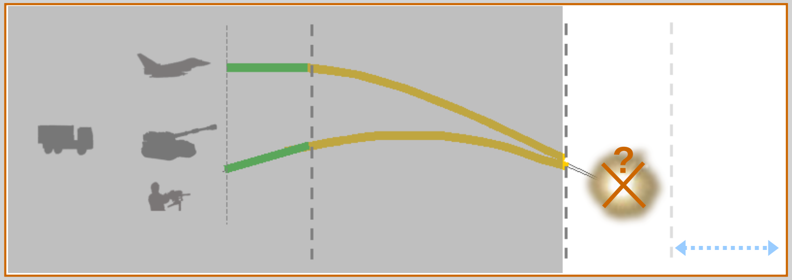
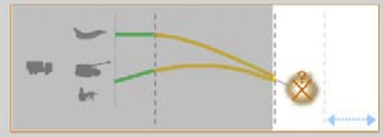


- Main requirements
  - Preventing hazards after the “military” mission is finished:
    - Enable friendly force manoeuvre in the area where munitions have been used (short term)
    - Keep conflict area safe and cleared for any UXO and ERW prior to civilian population returning (medium/long term)
  - + safe disposal and demilitarization of stockpile
- Solutions
  - Best solution: get high reliability of the fuze functions and of the operating on target
  - When difficult to achieve, not because of the fuze function, but due to the target configuration: ➔ safe fuzing backup functions

Fuze Safety Solutions (Post-conflict Safety)



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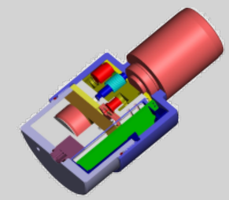
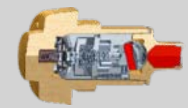
- UXO reduction: Safe backup functions

  - **Self-destruct function**
  - Various solutions: pyrotechnical / pyro-mechanical / electronic
    - Infantry grenade fuze
    - Direct fire fuzes
      - Medium caliber
      - Tank ammunition
      - With and without air-burst function





  - **PD backup**
  - **Self Re-safing**
  - … **High reliability fuze**

New Safety Requirements
Common Needs – Common Technologies

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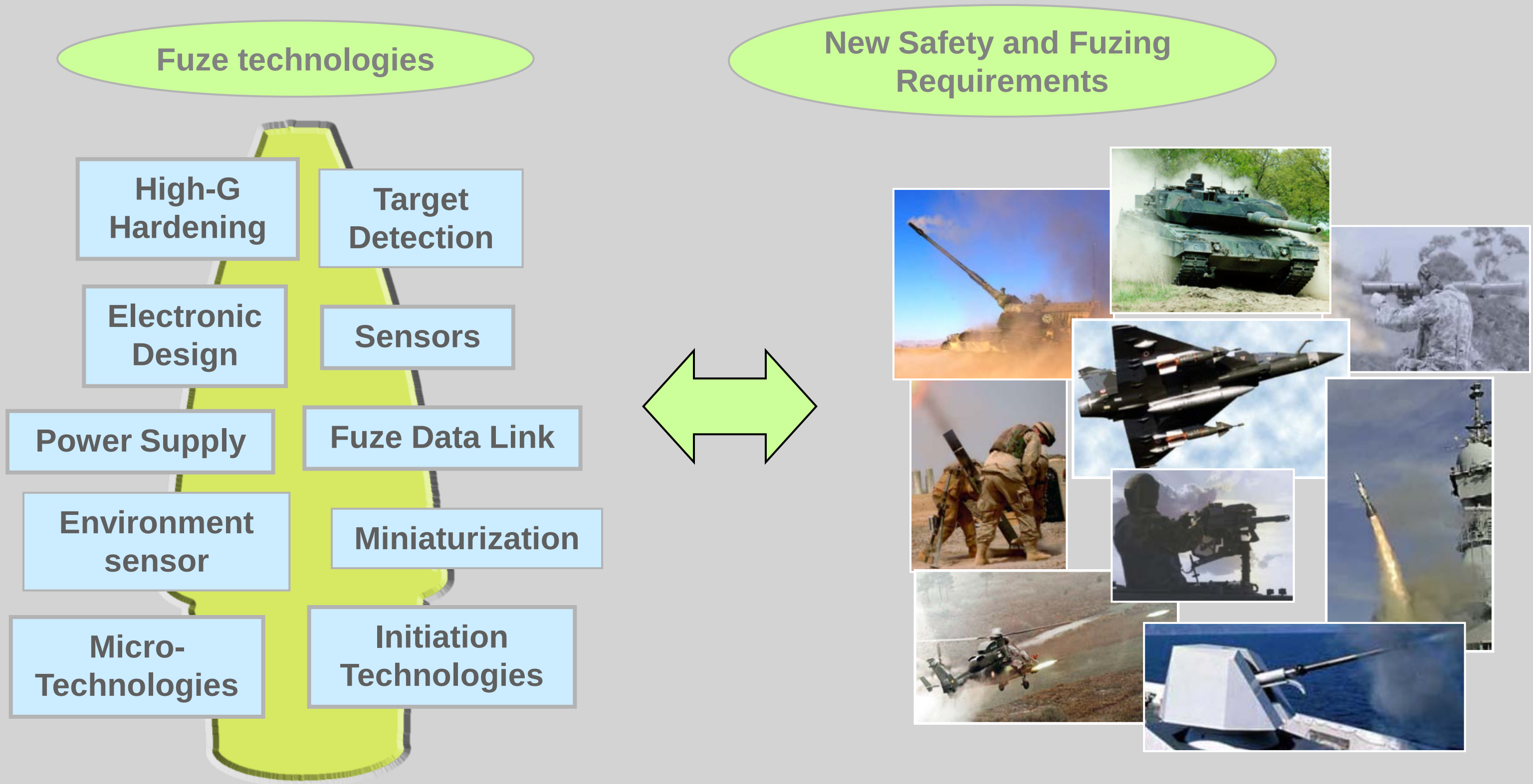
- The new needs and requirements applies to all arms:



Common fuzing technologies and technical solutions can be shared with various applications

Conclusion

- The fuze designer / producer has a key role in the munitions performances and in particular with respect to the reliability and safety requirements

- Dealing with the new safety requirements, for all arms, suppose the implementation of more complex, but reliable, safety solutions using various technologies,

  … and always: low cost / small size / low power

- Thanks to its technological leadership **JUNGHANS** is able to take up technological challenges to provide the user with
  - Safe, reliable and affordable fuzes
  - For current and next generation fuzing systems

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Thank You

Max PERRIN
Chief Technical Officer
max.perrin@junghans-microtec.de
max.perrin@junghans-t2m.fr

Improved Energetic Materials as Fuze Ingredients:

TATB

Dr. David Price

BAE Systems/HSAAP

May 2010

TATB Applications

- Besides the two biggest users of PBXN-7 (FMU-139 and FMU-152 bomb fuze programs) there are also other users of PBXN-7 which include FMU-143 (BLU-116, BLU-109), FMU-148A/B (Tomahawk), FMU-155/B (SLAM ER), MK436 fuze (MK146 warhead 2.75) , M734A1, M934, and JSOW
- PBXW-14
- LX-17
- PBX-9502
- And many others

A Brief History of TATB

- 1888: TATB first described (no mention of use as explosive)
- 1950s: TATB evaluated as high-temperature resistant explosive for space applications
- 1960s:
  - TATB evaluated for use in nuclear weapons
  - Benziger process initially developed
  - Initial formulations developed with TATB and polymeric binders
- 2003-2005: OSI Scientists develop TATB manufacturing process starting from dibromoanisole.
  - Process affords 5 micron TATB
- 2007-2009: OSI Scientists develop TATB manufacturing process starting from dichloropropoxybenzene.
  - Process affords 30-40 micron TATB (very similar to Benziger TATB)

TATB Program Goals

We are proposing a new nomenclature system for TATB to avoid confusion and offer standardization when discussing and using TATB:

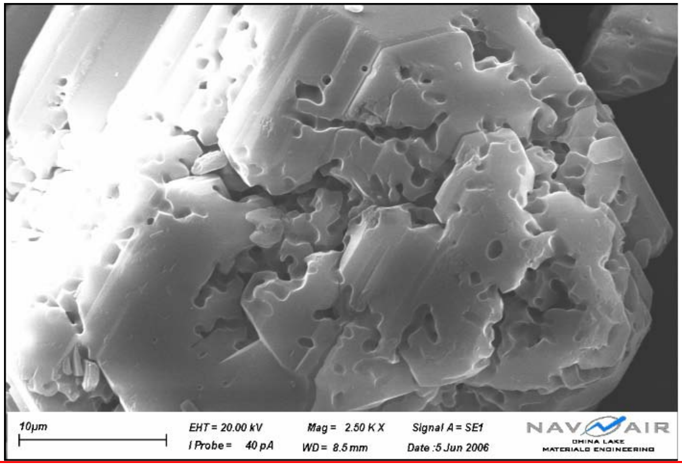
- **(Holston) Type 1**: Traditional Benziger TATB
- **(Holston) Type 2**: Small particle size (5 micron) TATB made from alkylated phenols
- **(Holston) Type 3**: Large particle size (30-50 micron) TATB made from alkylated phenols

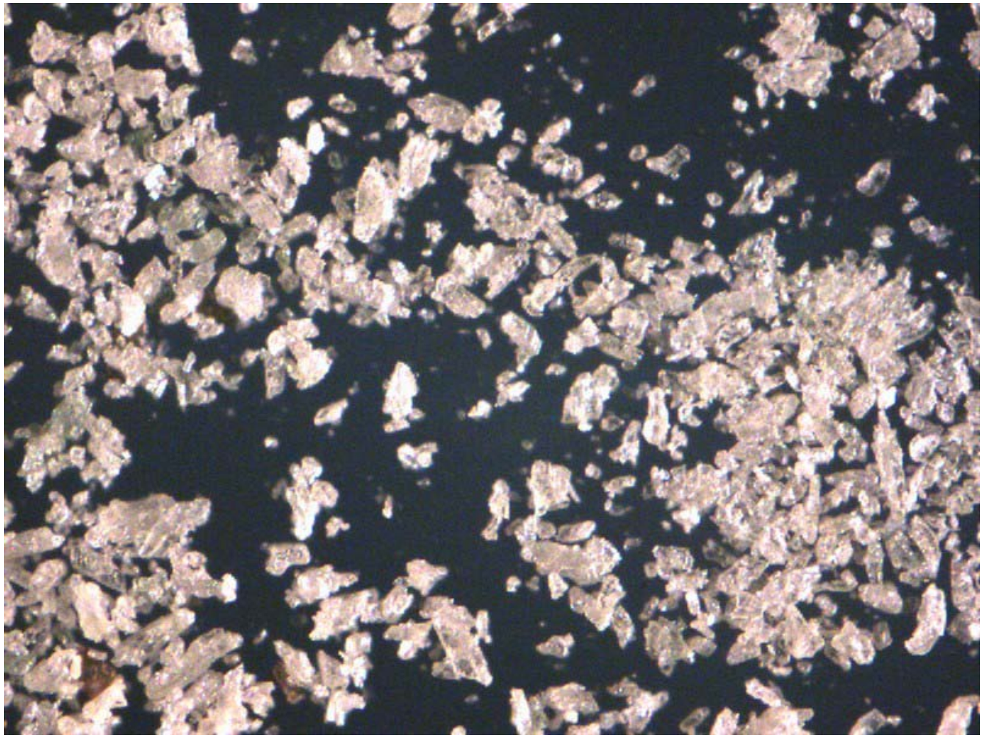
Benziger TATB: Type 1

- Benziger TATB starts with trichlorobenzene, an environmentally-unfriendly compound which is also not available from a US supplier.
- The nitration conditions are rather severe, requiring mixed acids and high temperatures.
- The nitration to obtain the desired TCTNB is also complicated by the generation of significant amounts of impurities (T3 and T4).
  - TCTNB purity is typically only 87-90%.
  - T3 and T4 are impurities that will be present in the final TATB and must be reduced to very low levels.

Benziger TATB: Type 1

- TCTNB is then aminated in toluene at high temperatures to form Benziger (Type 1) TATB.
- Conversion of TCTNB to TATB is nearly quantitative





Holston Type 2 TATB Synthesis Method

- Based on Chemistry Developed by Benziger and Ott
- New Process/Synthesis Route Developed by OSI Scientists
- Readily Scalable (and scaled) on the Holston Infrastructure
- Good Fit for Agile Manufacturing Plant (G-10)
- Multiple Sources Identified for Raw Materials
  - Including CONUS
- Affords 5 micron (nominal) TATB

Type 2 TATB Production at Agile Manufacturing Plant

- Nitration
- 3,5-Dibromoanisole (2500 lbs) is Melted and Fed as a Liquid into 98% Nitric Acid at or Below 50 C in a 2000 gal. glass-lined reactor
- Initial Reaction is Mildly Exothermic
- Reaction is Complete in 4-5 hrs. at Reflux, or 24 hrs. at Ambient Temperature
- Yield is Essentially Quantitative (~3600 lbs. DBTNA after quench and wash)
- Product (DBTNA):
  - Insensitive Intermediate
  - Melting Point = 140 C
  - Exotherm Onset = 288 C
  - Impact Sensitivity > 80 cm (Holston Method)
  - DBTNA not isolated; Slurried and pumped directly to amination vessel

Type 2 TATB Production at Agile Manufacturing Plant

- Amination
  - DBTNA slurry is pumped to 6000 gal. still
  - Slurry is dewatered with wand filter
  - 29% aqueous ammonia is pumped in; agitation started
- Reaction Occurs Over 36 hours at 25 C
- Main By-Product is NH_4Br
- Known Impurities
  - Ammonium diaminopicrate (ADAP)
  - Starting material - DBTNA
- Yields are ~ 90%

Type 2 TATB Production at Agile Manufacturing Plant

- Collection in Filter Press
  - TATB slurry is pumped to filter press
  - Blown down and collected; nominal yields ca. 2150 lbs.
  - NH_3 is stripped from reaction filtrate using eductor
  - Used to neutralize spent acid from nitration step

Nutsches of Type 2 TATB

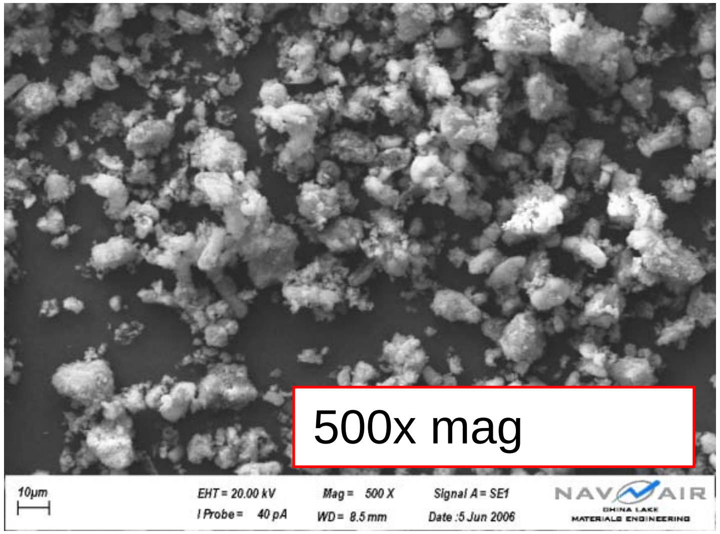
Technical Issues of Early Type 2 TATB Efforts

- In PBXN-7, OSI Type 2 TATB (5 micron) performed well in all examined aspects except:
  - Shock sensitivity:

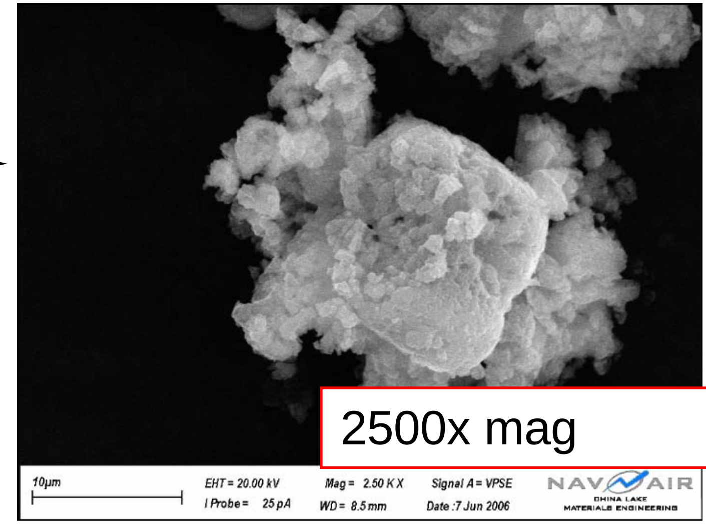
Material Tested	Average Pellet Density, g/cm^3	NOL LSGT, cards/kbars	Detonation Velocity, m/s
PBXN-7 with OSI TATB (supplied by OSI)	1.789	70% kbar increase	7572
Historical data [a]	1.78		7660

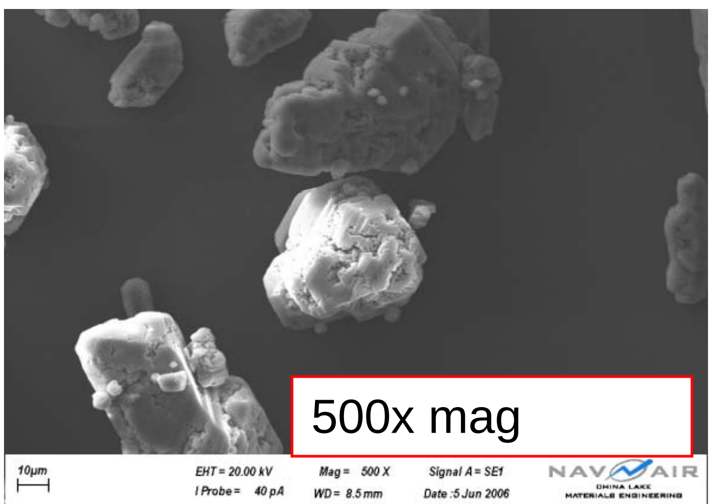
  - Reduction in sensitivity thought to be caused by small particle size and/or crystal morphology (lack of voids) of TATB (as compared to traditional TATB (50 micron)…

SEM Analysis

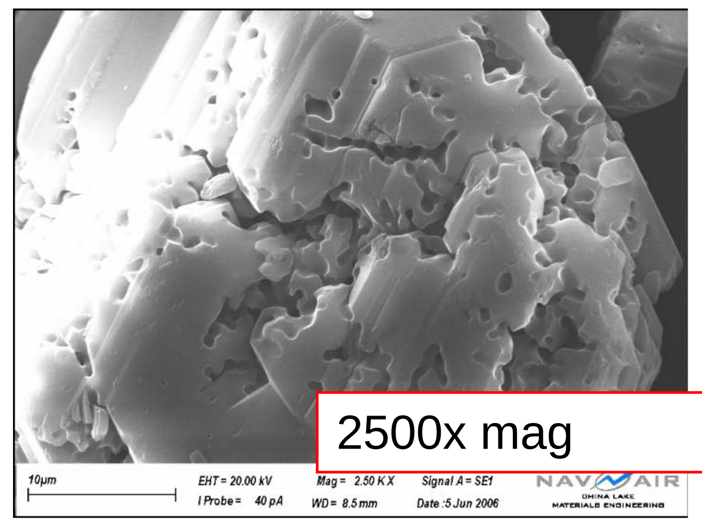


Holston Type 2 TATB





Traditional Type 1 TATB



Holston Type 3 TATB Synthesis Method

New 2-Step Process/Synthesis Route Developed by OSI Scientists

- Scalable on the Holston Infrastructure
- Good Fit for Agile Manufacturing Plant (G-10)
- Multiple Sources Identified for Raw Materials-Including CONUS

- Purity comparable to reference Type 1 TATB
- Particle size typically 30-40 microns
- Produced ~20 lbs TATB to date

Nitration of DCPB

- DCPB is fed as a liquid into nitric acid
- Initial reaction is mildly exothermic
- Reaction performed several times in 5 gal reactor (10 lb batch size)
- DCTNPB (product):
  - Yields > 95%
  - Purity typically >99%
  - Insensitive Intermediate
  - Melting Point = 121 C
  - Exotherm Onset = 220 C (as determined by DSC)
  - Impact Sensitivity > 80 cm (Holston Method)

Amination of DCTNPB

- DCTNPB is aminated in toluene with gaseous ammonia at high temperature and under pressure (similar to Benziger route)
- Reaction Scaled to 1 mole (2 gal Parr)
- Yields are ~ 75%
- **Known Impurities:**
  - -Ammonium diaminopicrate (ADAP)
    - -Mp = 214 C
    - -Accounts for most of missing mass

Formation and Elimination of Ammonium Diaminopicrate (ADAP)

Average % ADAP Pre-Wash

Lot 1	0.15%
Lot 2	0.15%
Lot 3	0.58%

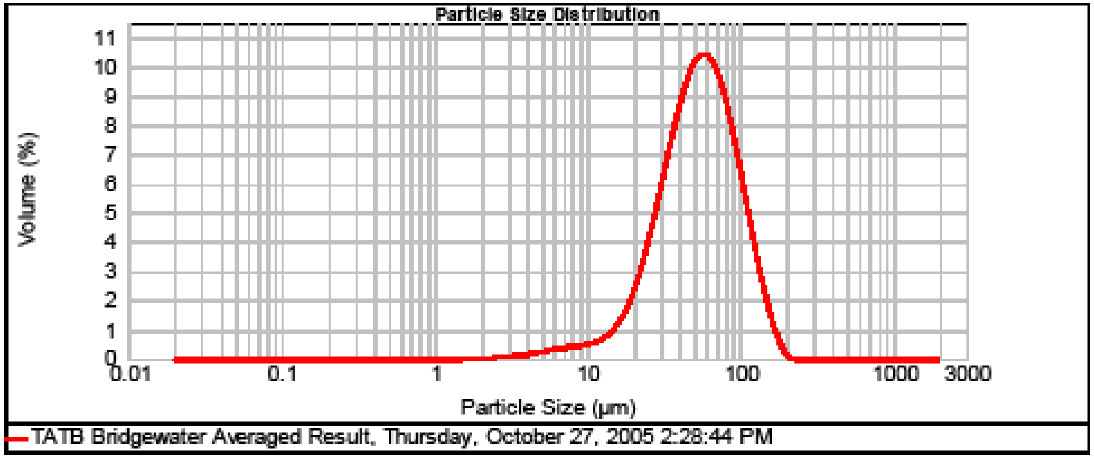
Average % ADAP Post-Wash

Lot 1	0.04%
Lot 2	0.02%
Lot 3	0.02%

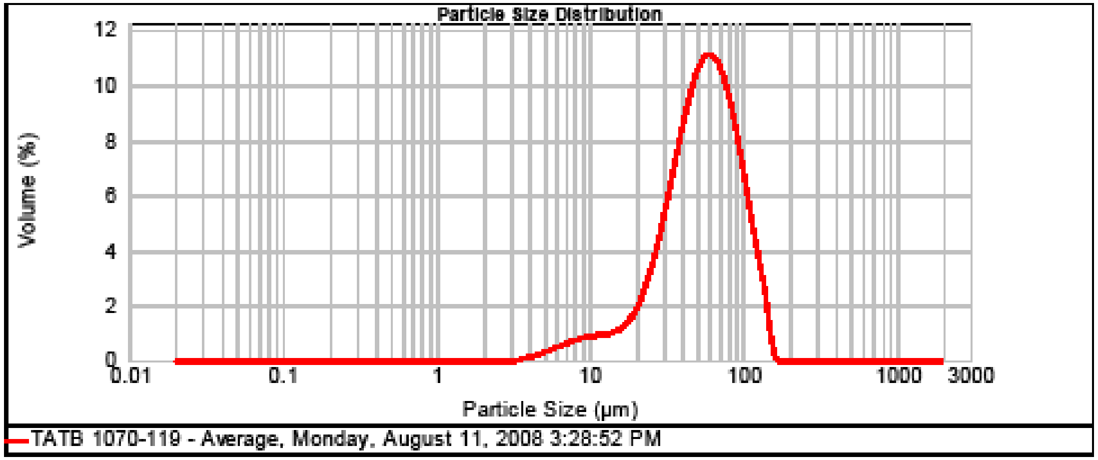
•Washing with hot water until wash water becomes light yellow lowers ADAP contamination considerably

Type 3 TATB: Particle Size Analysis

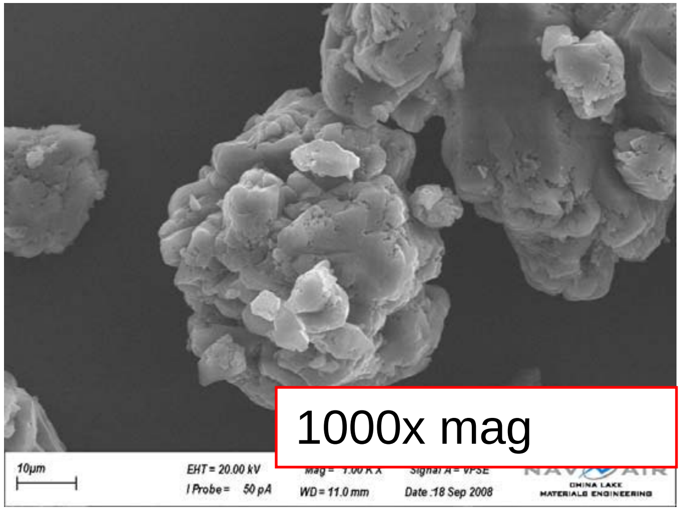
d(0.1): 22.889 um   d(0.5): 52.910 um   d(0.9): 104.938 um



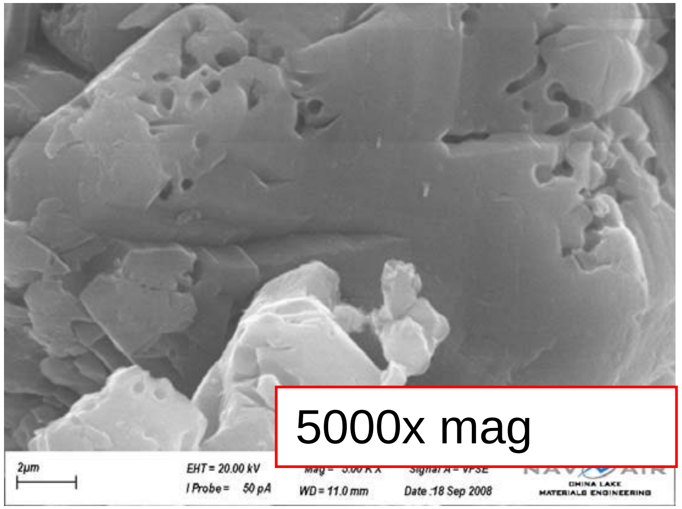
d(0.1): 22.216 um   d(0.5): 53.906 um   d(0.9): 100.625 um

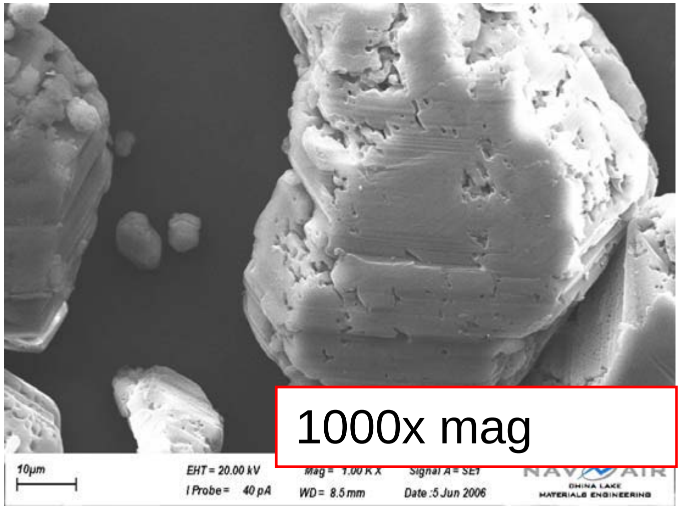


SEM Analysis

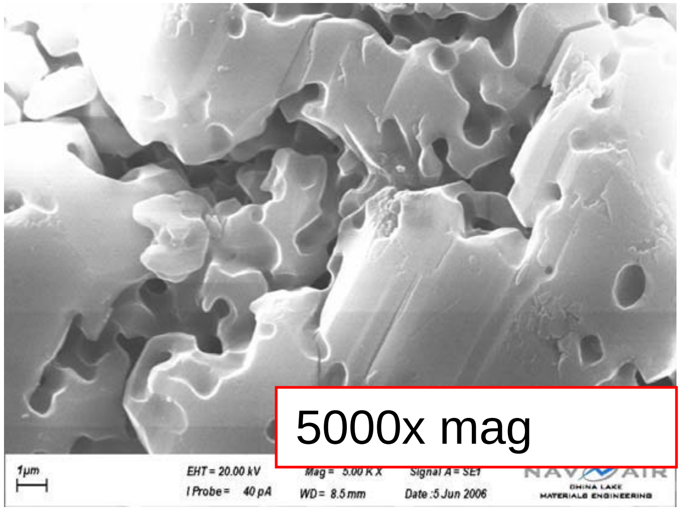


Holston Type 3 TATB





Traditional Type 1 TATB



BAE SYSTEMS

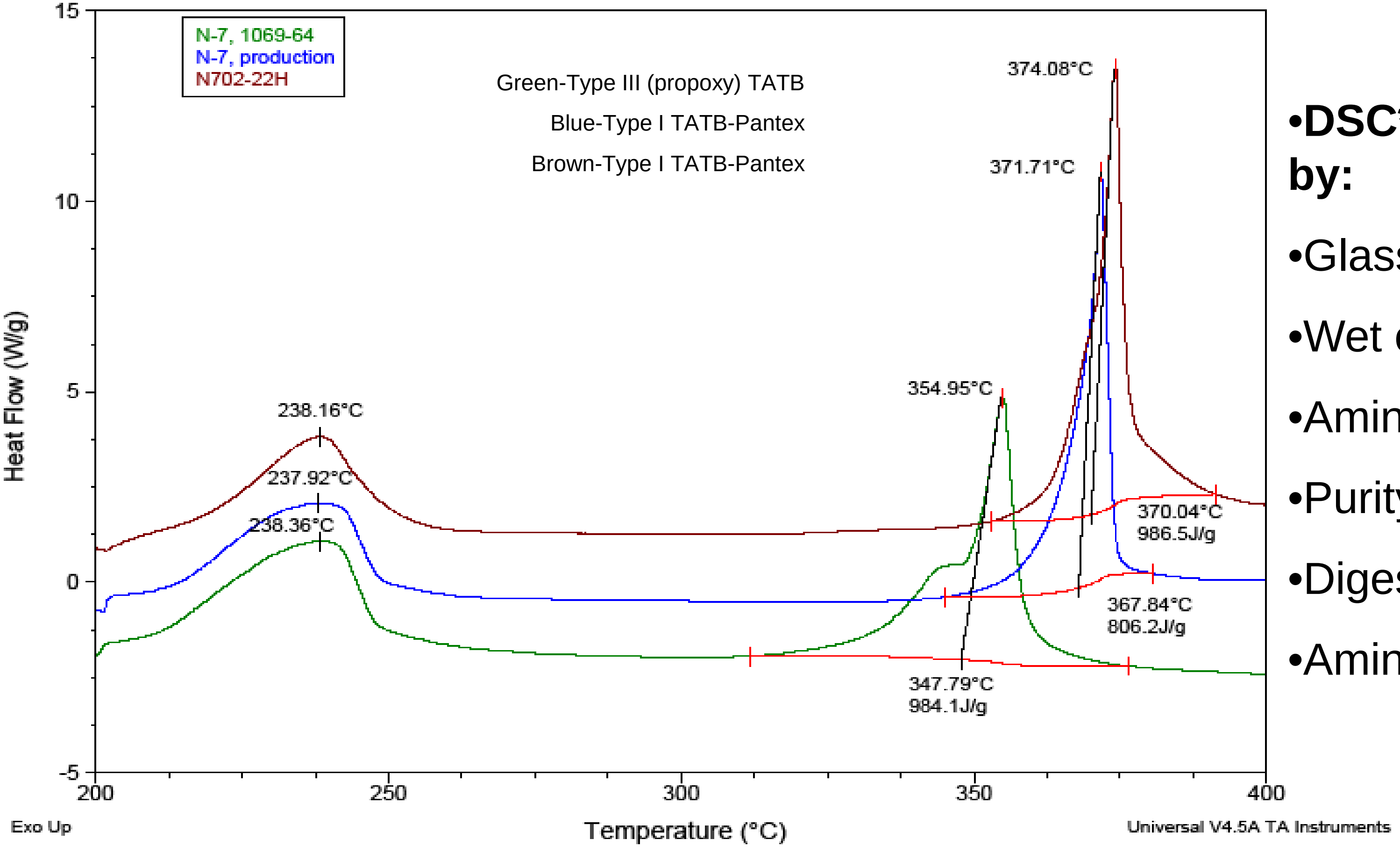
Formulations: PBXN-7

- Several lab batches made with Type 3 TATB
- Consistent process and product

Screens (%Pass)	batch 1	batch 2	batch 3	composite
#6	met spec	met spec	met spec	met spec
#14	met spec	met spec	met spec	met spec
#18	met spec	slightly out	met spec	met spec
#100	met spec	met spec	met spec	met spec
Bulk Density (g/cm^3) (Naval)	met spec	met spec	met spec	met spec
Composition	met spec	met spec	met spec	met spec
Moisture	N/A	N/A	N/A	met spec
Impact Sensitivity (ERL, cm)	N/A	N/A	N/A	met spec
VTS by PT Method (100°C, 48h)(mL/g)	N/A	N/A	N/A	met spec
Press Density (g/cm^3)	N/A	N/A	N/A	slightly out (low)
Comments				Blend of 1,2,and 3

PBXN-7 comparisons

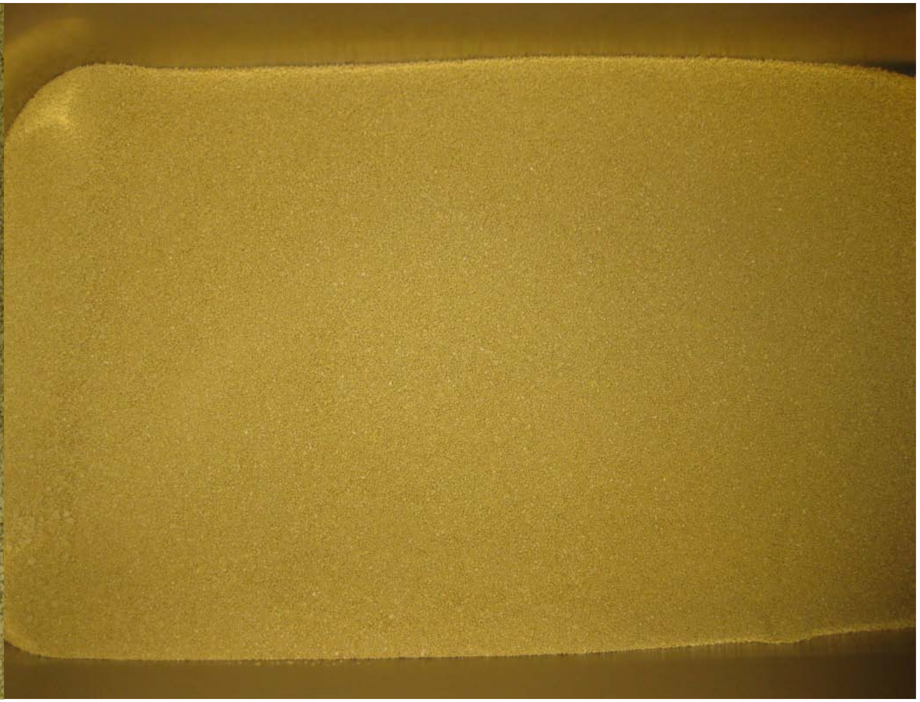
- DSC of new TATB (Type 2 and 3) found to be different than Type 1 TATB
- Phenomenon appears to be caused by presence of ADAP in amination



- **DSC* not affected by:**
- Glass vs SS reactor
- Wet or dry amination
- Amination temp.
- Purity
- Digestion in DMSO
- Amination under N2

Formulations: PBXW-14

- One batch made in lab with Type 3 TATB.
- Successful integration of TATB made from the new OSI method into the existing W-14 formulation procedure.
- No performance data at this time.



TATB Safety Data

Material	Source	ERL Impact Sensitivity	ABL Friction Sensitivity at 1000 lb	ESD Sensitivity at 0.25 J
Type 2	OSI	1/18 fires at 200 cm 2/2 no-fires at 158 cm	10/10 no-fires	10/10 no-fires
Type 2	OSI	4/15 fires at 200 cm 5/5 no-fires at 158 cm	10/10 no-fires	10/10 no-fires
Type 2	OSI	3/16 fires at 200 cm 4/4 no-fires at 158 cm	10/10 no-fires	10/10 no-fires
Type 3	OSI	10/10 no-fires at 200 cm	10/10 no-fires	10/10 no-fires
Standard-Type 1	DOE	10/10 no-fires at 200 cm	10/10 no-fires	10/10 no-fires
RDX standard	N/A	17 cm	550 lb_f	10/10 no-fires

PBXN-7 Qualification Small Scale Safety Data

PBXN-7, BAE06L382-015, OSI Type 2 TATB					
Parameter	Aged “0” months	Aged “2” months	Aged “4” months	Aged “6” months	Units
Impact Sensitivity	103.1	110.3	107.2	108.2	cm
Impact Reference (RDX)	16.6	16.6	16.6	16.6	cm
Friction	>360	>360	>360	>360	Newt.
PETN Reference	48	48	48	48	Newt.
VTS	0.09			0.02	ml/g
DSC	242.3	242.6	242.3	242.3	º C

PBXN-7 Qualification LSGT Data

		Baseline "0" Months		Aged "6" Months	
Material Tested	Ave. Pressed Density gm/cc	Shock Sensitivity Cards	Shock Sensitivity kbar Pressure	Shock Sensitivity Cards	Shock Sensitivity kbar Pressure
PBXN-7 Manufactured with **Benziger TATB Type 1** Lot # BAE07B382-014	1.79	205 - 210	18.621 – 19.627	206.1	19.398
PBXN-7 Manufactured with **OSI TATB Type 3**	1.78	203.8	19.883	---	---
PBXN-7 Manufactured with **OSI TATB Type 2** Lot # BAE06L382-013	1.79	155.8	35.939	165.8	31.517

BAE SYSTEMS

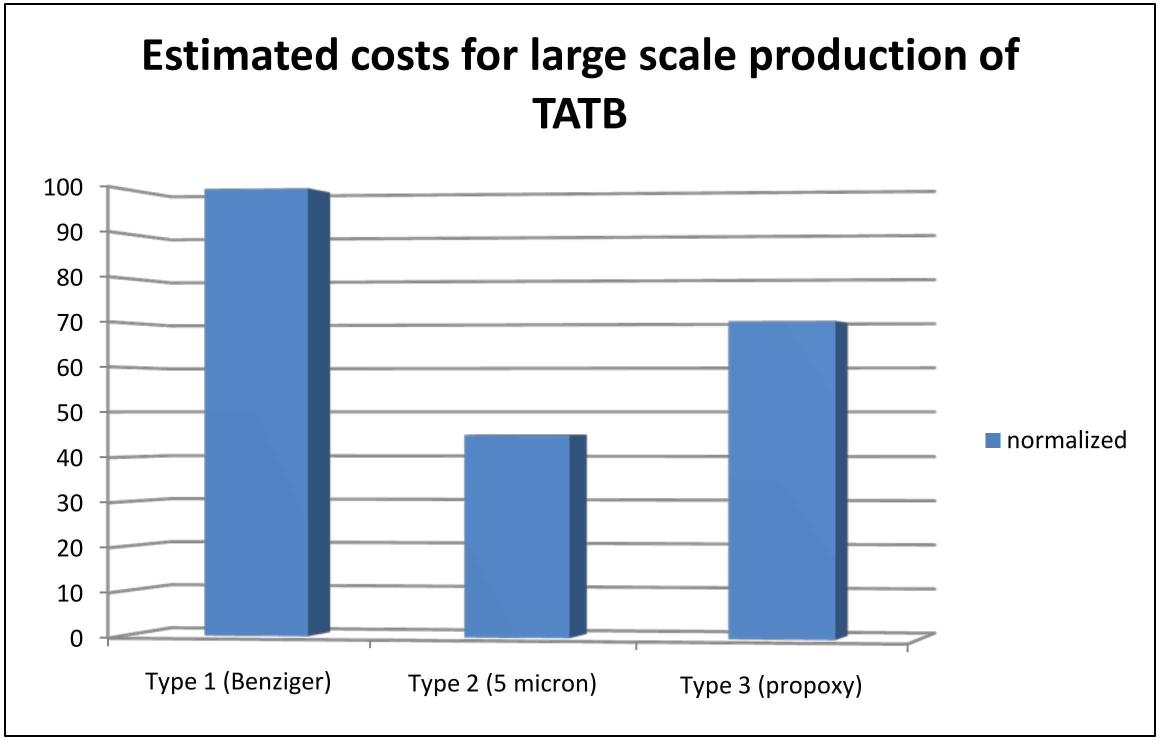
Initiation Validation Test at Cold Temperature

PBXN-7 LOT # BAE06L382-013 Manufactured with OSI Holston Type 2 TATB

Fuze Configuration	Pellet Density (gm/cc)	Dent Plate Hardness	Dent Depth (inches)	Dent Depth GO Criteria (inches)	GO/ NO GO
FMU-139	1.760	90	0.0565	0.0425	GO
FMU-139	1.760	90	0.0525		GO
FMU-139	1.800	82	0.0580		GO
FMU-139	1.800	88	0.0580		GO
FMU-139	1.800	85	0.0585		GO
FMU-152	1.760	90	0.0425	0.0346	GO
FMU-152	1.760	88	No Dent		NO GO
FMU-152	1.800	84	No Dent		NO GO
FMU-152	1.800	86	No Dent		NO GO
FMU-152	1.800	87	No Dent		NO GO

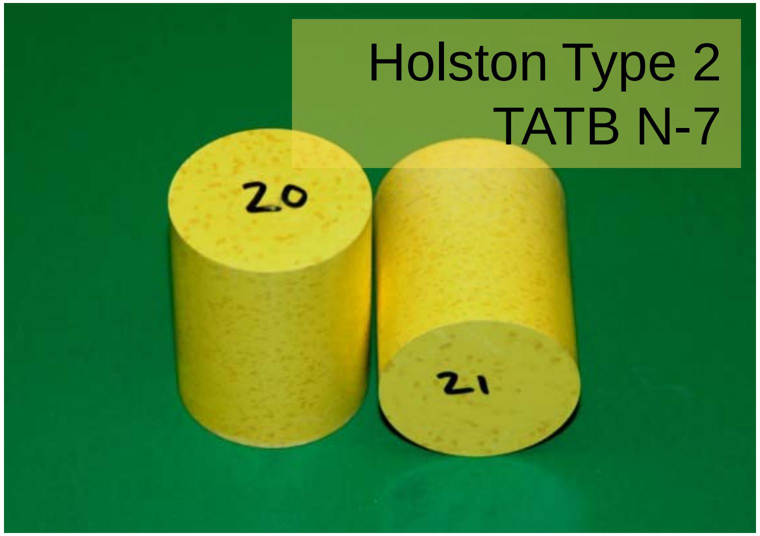
TATB Costs

- Estimates are based on R&D efforts, production efforts, and prior experience and knowledge.
- Costs are normalized to Type 1 cost estimates.
- Type 2 is less than half of the cost of Type 1, due to the simplicity of the process.



Conclusions

- Two TATB manufacturing processes developed at HSAAP (Type 2 and Type 3)
- Processes are robust and safe
- Competitive costs to Type 1 TATB
- Process and cost optimization ongoing
- Quality equivalent to traditional sources of "DOD grade" material
- Difference in thermal properties (DSC) appear to be caused by ADAP impurity in process
- Type 3 TATB currently appears to be a "drop-in" replacement in DOD formulations (waiting for further performance testing)

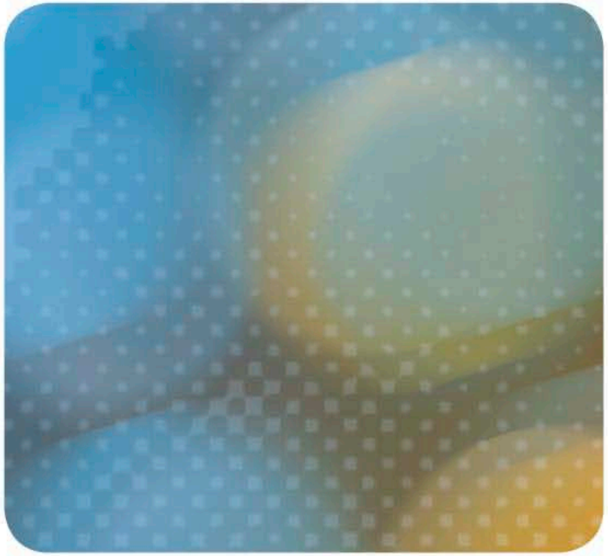


Acknowledgments

- BAE Systems:
  - Neil Tucker and Jim Haynes-Nitrations and Aminations (lots of them!)
  - Ed LeClaire - Agile Plant Mgr. & Process Development
  - Lisa Hale and Kelly Guntrum– Analytical Support
  - Brian Alexander - PBXN-7 and PBXW-14 formulation
- Navy:
  - Al Stern, Brad Sleadd, Tim Mahoney -Useful discussions, suggestions, testing and direction
- ONR Mantech Program-Funding
- Chuck Painter-Mantech director

FFI Forsvarets forskningsinstitutt

Use of Conductive Adhesive in Fuze Applications



J.Gakkestad, P.Dalsjø

FFI

H.Kristiansen

Conpart A/S

R.Johannessen, M.M.V Taklo

Sintef ICT

54TH Annual Fuze Conference

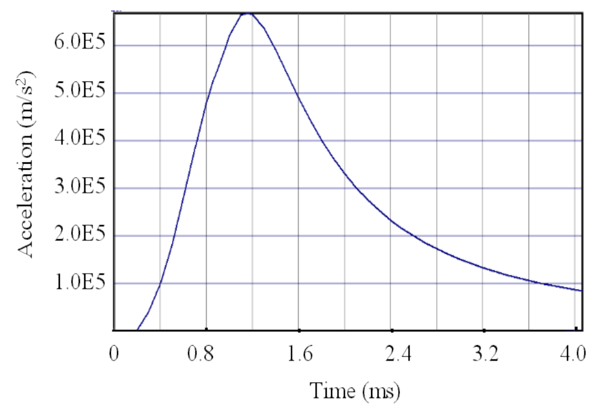
Kansas City, USA

Outline

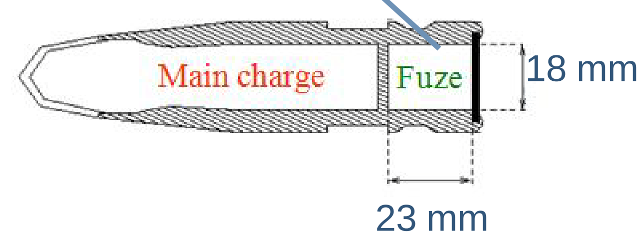
- Background and motivation.
- Conductive adhesive.
- Experiments.
- Characterization.
- Conclusion.

Background and motivation

- The electronic components in a fuze are exposed to severe mechanical forces during firing.
- For 30 mm ammunition, setback acceleration exceeds 60 000 g and the centripetal acceleration is 9000g/mm out of center.
- In 30 mm ammunition, the electronic components should not occupy more than 1-3 cm^3.

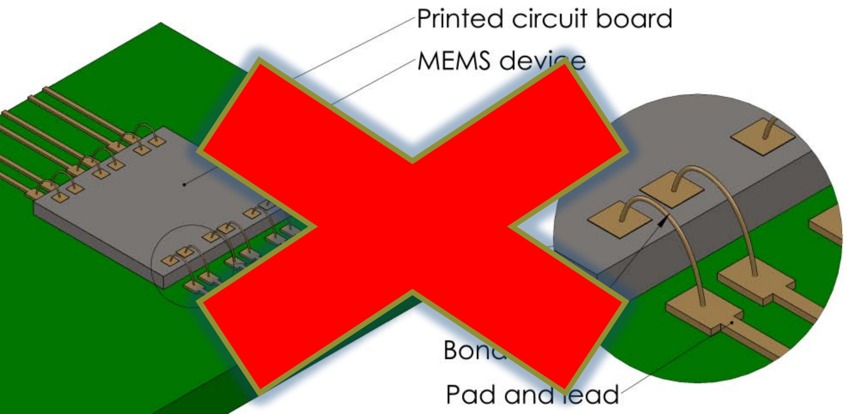


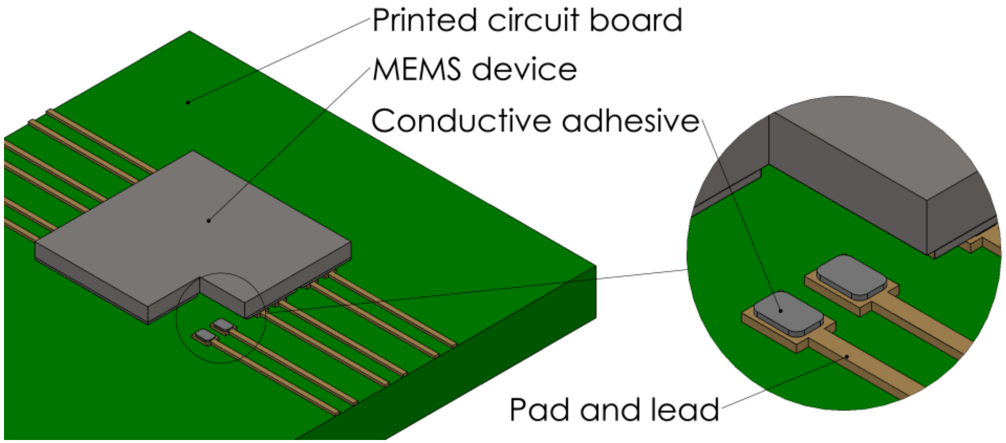
MEMS & electronic components e.g. programmable unit, power supply ++



Mounting of MEMS to PCB

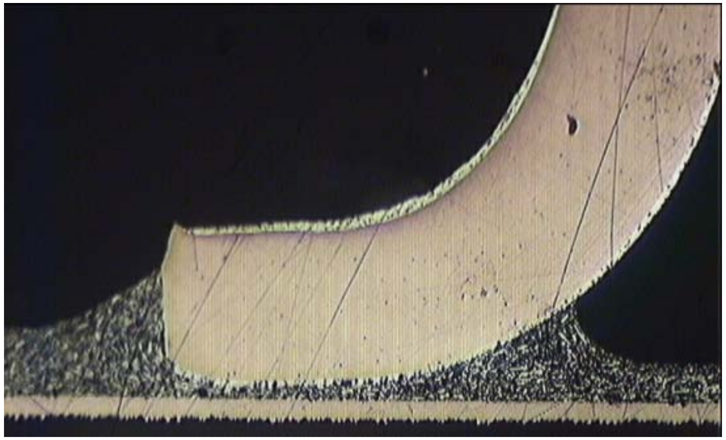
- It is advantageous to mount the MEMS chip directly to PCB omitting extra packaging level. This will require less space and cost saving is possible.
- Using wire bonding for direct contact between MEMS and PCB is not a favorable option.
- Using isotropic conductive adhesive (ICA) for interconnection between MEMS and PCB could be a possibility. However, performance of ICA in this demanding environment must be investigated.





Isotropic Conductive Adhesive

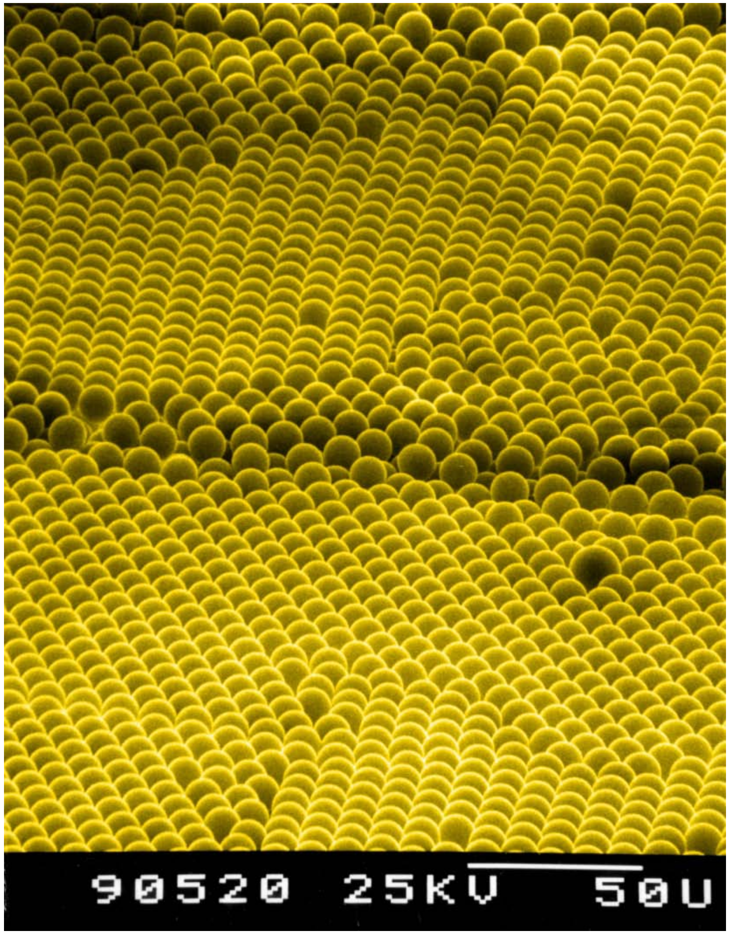
- ICA has been used for electronic packaging and interconnect for several decades.
- Composite material
  - Adhesive resin
  - Conductive material
- Silver particles are commonly used as conductive material.
- Common problem is brittleness due to CTE mismatch between filler and metal particles.



J.E. Morris, Portland State University

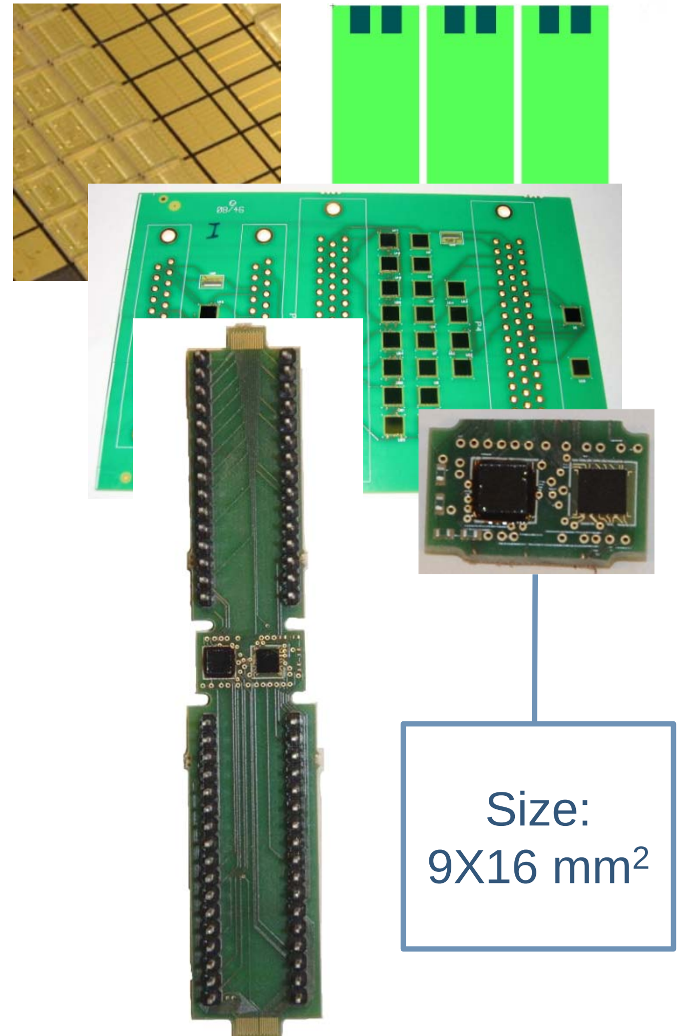
ICA based on metallized polymer spheres

- Replace e.g. silver flakes with highly uniform metallized polymer spheres.
- Size of the polymer spheres can be custom tailored.
- Different core material can be used:
  - Optimization of Tg.
  - Match the CTE to the adhesive matrix.
  - Mechanical energy absorption.
- Noble metals may be used for metallization at relatively low cost.



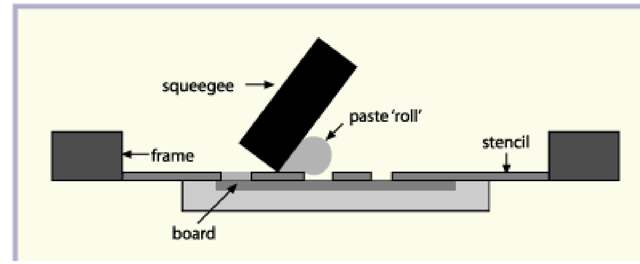
Test structures and test boards

- MEMS test structures for interconnect testing were designed and fabricated on the same SOI wafers as the real MEMS devices.
- Board used for temperature cycling test. Contains daisy-chain structures and structures for Kelvin measurement of contact resistances.
- Board used for firing tests contains 2 test structures and 4 pcs of 0402 resistances on each side. Kelvin measurement of contact resistances before and after firing test.

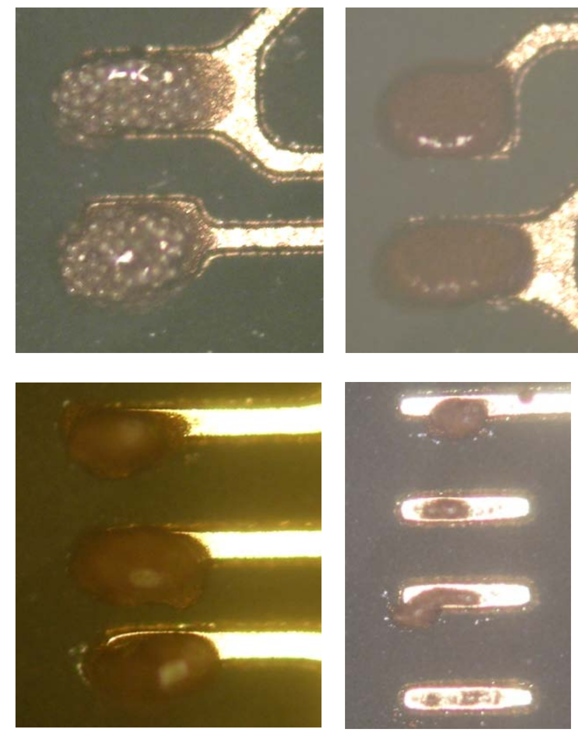


Stencile printing of ICA

- Used ICA with different sized polymer spheres.
  - 30 µm : silver coated (ICA-A).
  - 4µm : gold coated (ICA-B).



- ~50% volume fraction of spheres is used.



- Printing results dependent upon many factors such as:
  - Viscosity
  - Shear thinning
  - Stencil +++

Experiments

- Temperature test between -46°C and +70°C. Compare performance of ICA-A adhesive vs. H20, a commercially available isotropic conductive adhesive.

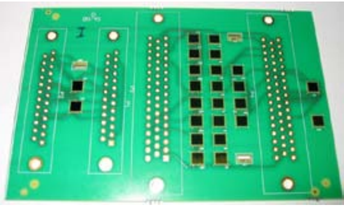
- Temperature cycling test according to MIL-STD-883 G method 1010.8 test condition B (-55°C - 125°C).
  - 10 cycles
  - 100 cycles

- Vibration tests.

- Recovery firing tests. Temperature cycled samples were used in this experiment.

Comparison: ICA-A vs H20

- H20 is a silver epoxy based adhesive. The test structures were mounted by a commercial supplier.



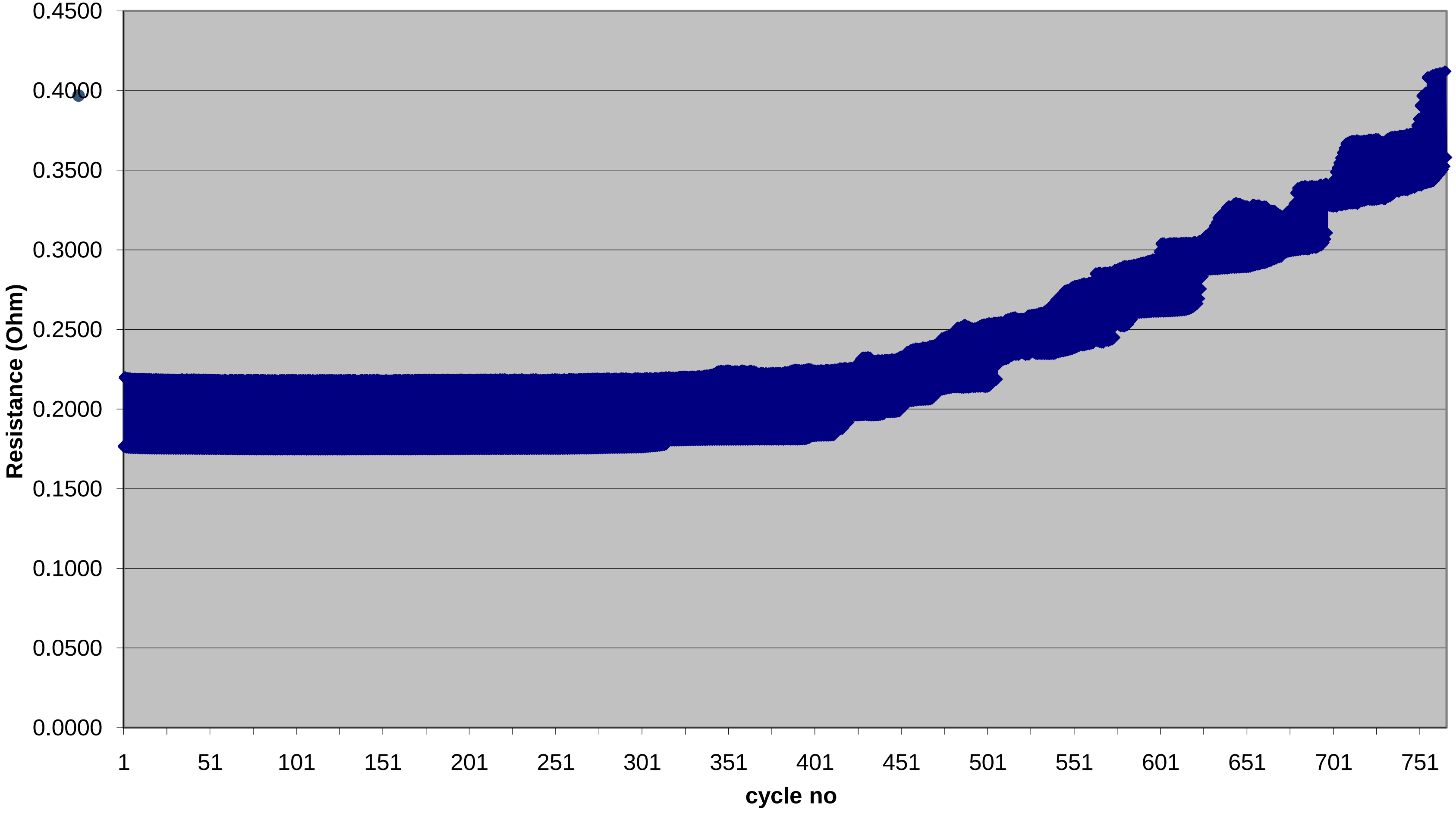
- ICA-A adhesive consists of 30 µm silver coated polymer spheres and EPO_TEK®353ND.

- Initial values for contact resistances:

Adhesive	R average (Ω)	Rmax (Ω)	Rmin (Ω)
H-20	0.061	0.098	0.048
ICA-A	0.549	1.394	0.182

Temperature performance: ICA-A vs H20

- H20: 14 of 23 CR passed 100 temperature cycles (60%).



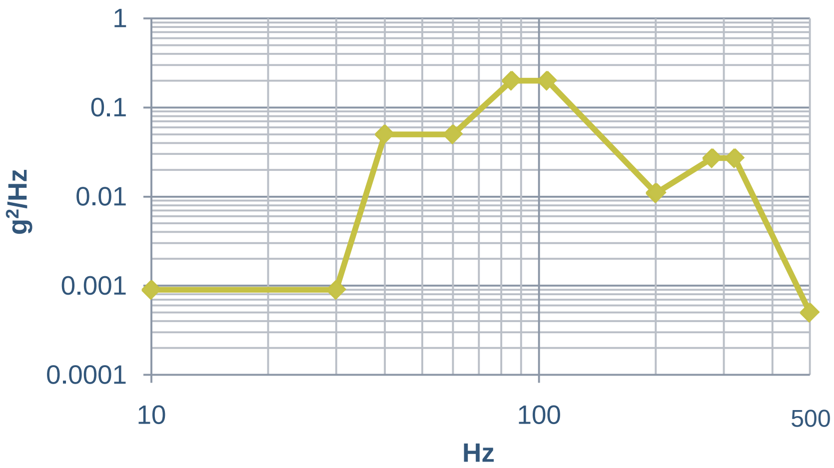
Temperature tests

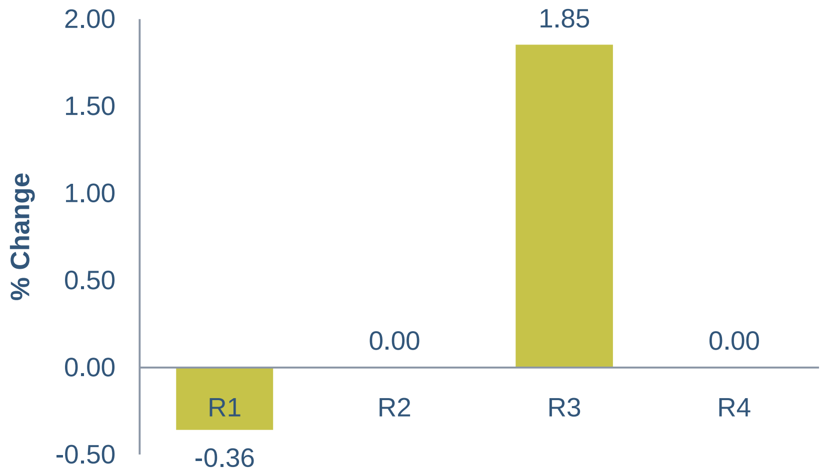
- Temperature cycling test according to MIL-STD-883 G method 1010.8 test condition B (-55°C - 125°C).
- No underfill on the test structures
- No resistances failed for the I-100 test structures.

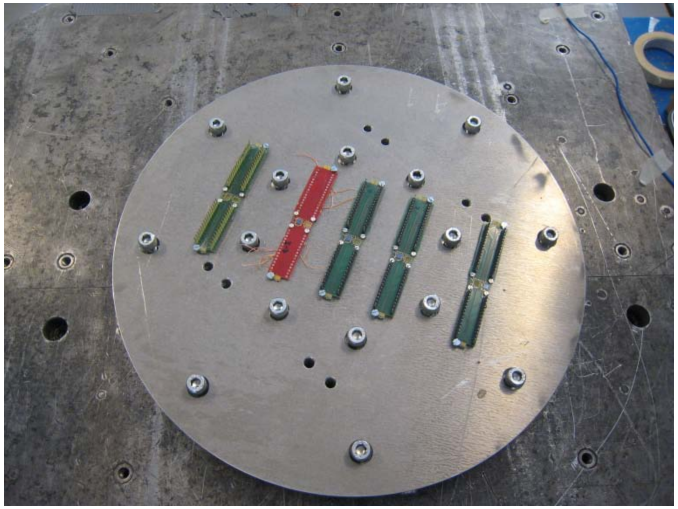
ICA with	No of cycles	Ω before	Ω after	% change
ICA-A (30µm silver spheres)	10	0.317	0.366	15.5
ICA-B (4 µm gold spheres)	10	0.091	0.079	-13.2
ICA-A	100	0.361	0.675	87
ICA-B	100	0.112	0.217	93.7

Vibration test

- Simulated transport vibration on tracked vehicle. Used acceleration spectral density from CV90 armoured combat vehicle.
- 1 hour test in each direction.
- Test structure mounted with ICA-A performed well.



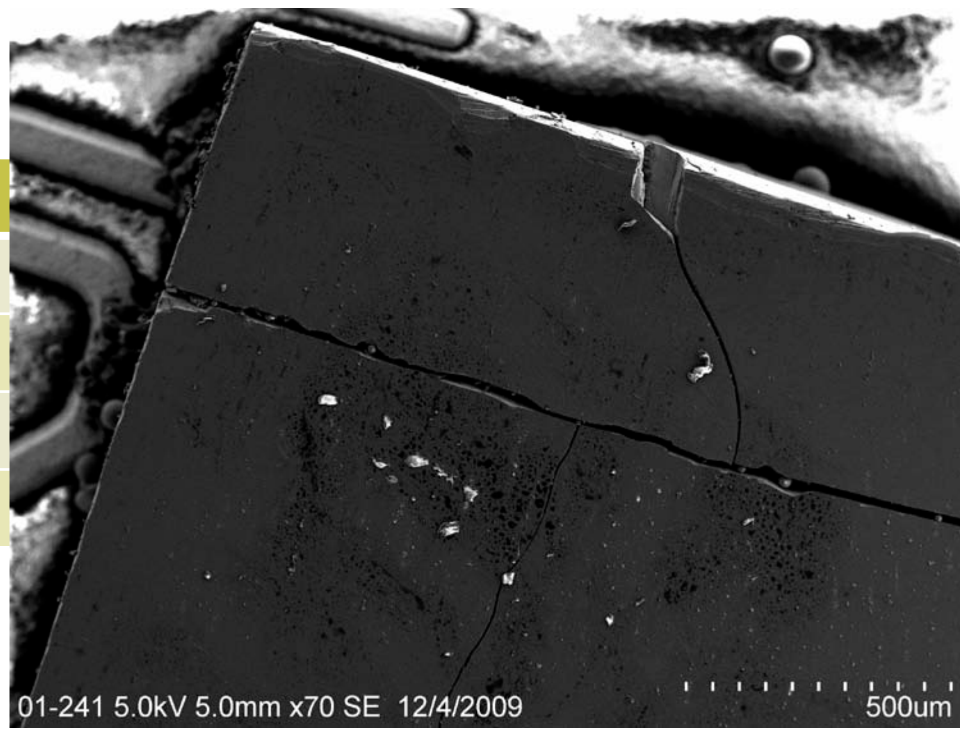




Firing test

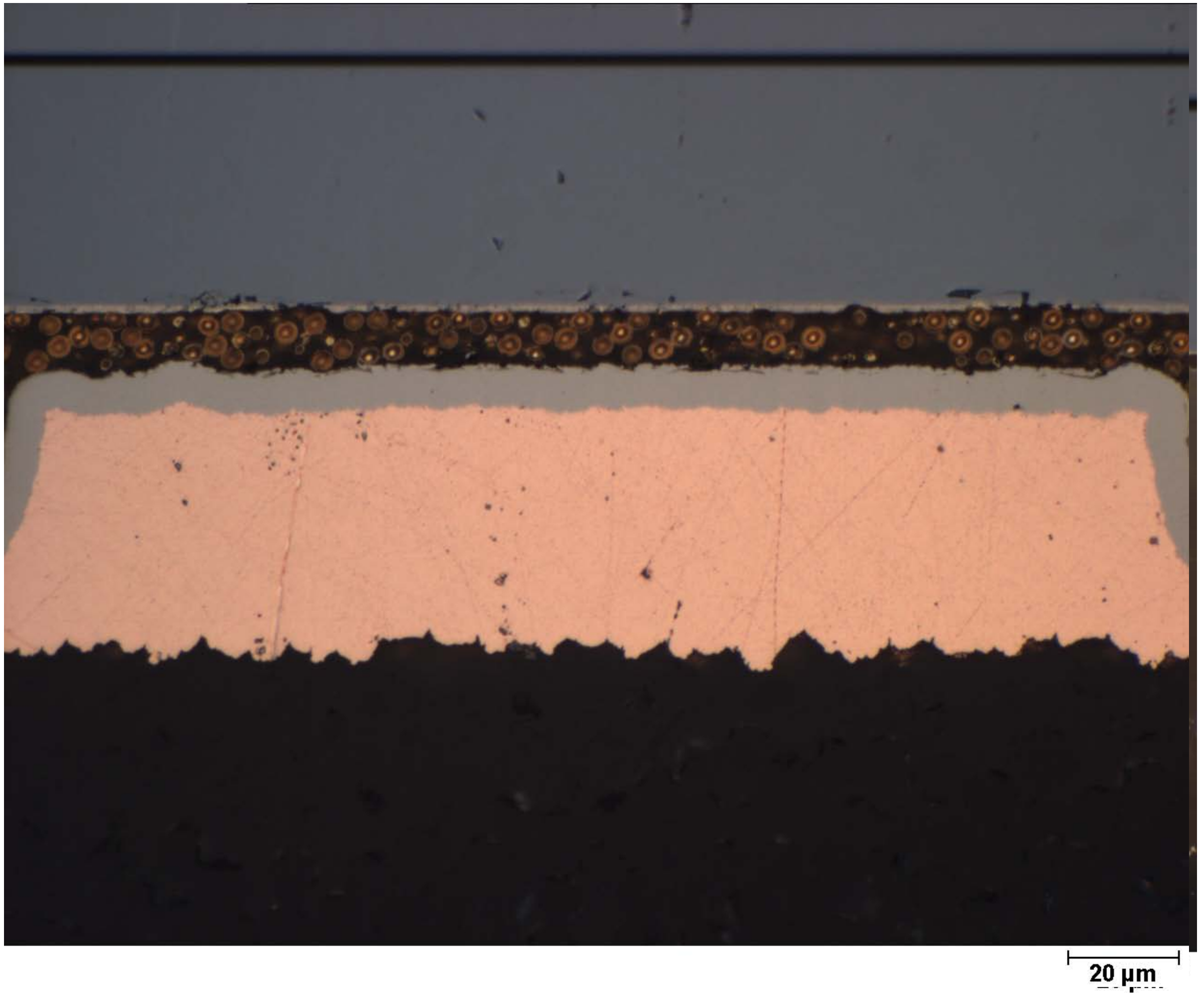
Firing test results

- All fired test structures have been exposed to temperature tests.
- 31 out of 36 contact resistances passed recovery firing test.
- Two test structures without underfill cracked.



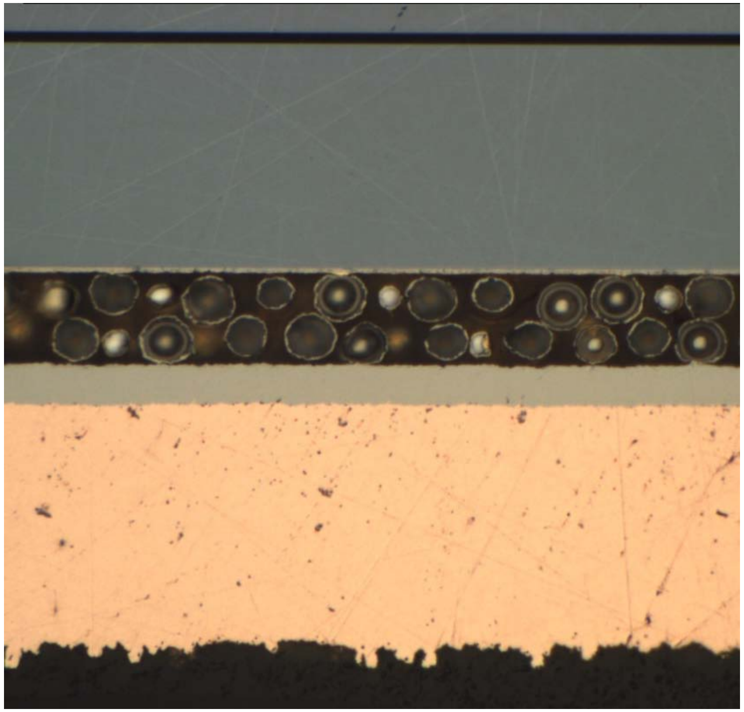
ICA with	r	% change
ICA-A		-8.5
ICA-B		18.3
ICA-A		8.6
ICA-B		18.4

Cross sections



Conclusion

- ICA based on highly uniform metal coated polymer spheres seems to be a viable technology for mounting MEMS devices directly to PCB.
- Using this ICA technology may give higher packaging densities and reduced cost in future fuze applications. However, the stencil printing process must be improved.



Acknowledgement

- Part of this work have been sponsored by the Norwegian Research Council grant no. 187971/140 and the Norwegian MoD.

- Thanks to Thorkild Kaasa, Tone Somme, Atle Skaugen and Oystein Lundberg, FFI and Joachim Moe Graff, Sintef for valuable assistance during this work.

About the partners

- More information about the Norwegian Defence Research Establishment (FFI), Conpart and Sintef ICT can be found here:

- FFI: www.ffi.no

- Conpart: www.conpart.no

- Sintef ICT: www.sintef.no

Low-Cost MEMS Initiators

Chopin Hua

MicroAssembly Technologies, Inc.

ARMAMENT RESEARCH, DEVELOPMENT & ENGINEERING CENTER
PICATINNY, NJ

STRESAU LABORATORY, INC

Team

MicroAssembly Technologies, Inc.

Chopin Hua

Dr. Michael Cohn

Kevin Chang

Brian Kirby

Ross Millenacker

Dr. Brian Fuchs

Anthony DiStasio

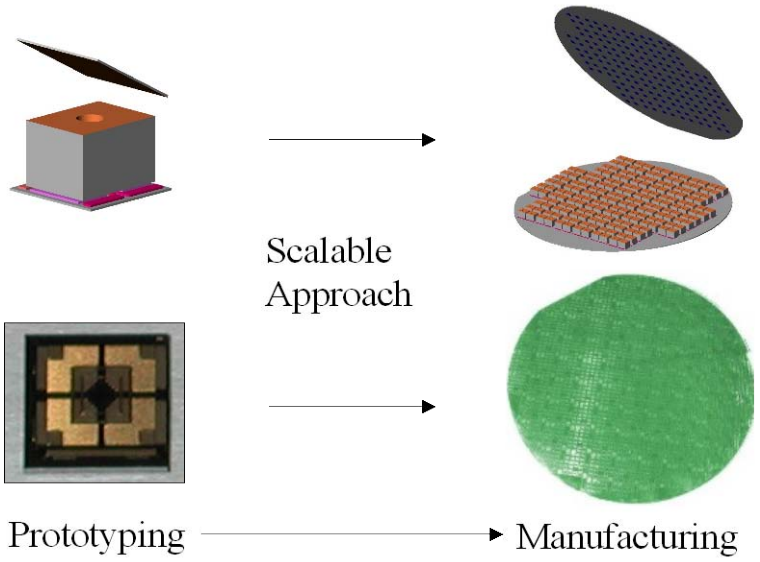
STRESAU LABORATORY, INC

Becki Amendt

Wayne Hanson

MEMS Background

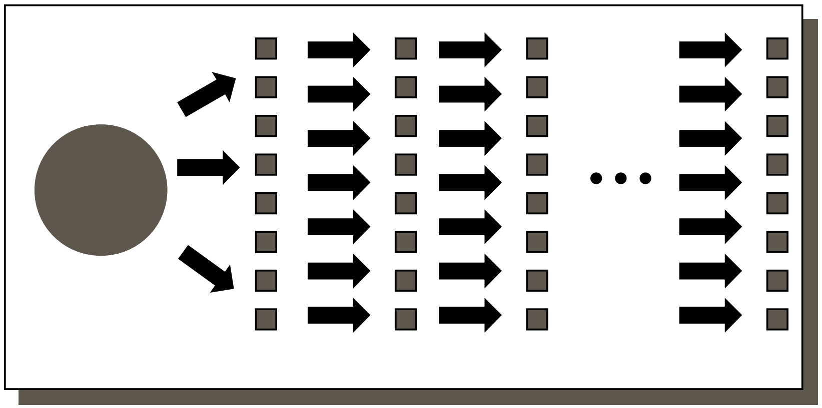
- Applications beyond Munitions
  - Airbag initiators
  - Stability Control
  - Televisions
- Benefits using MEMS
  - Low cost
  - Reliability
  - More intelligent systems
  - Scalability



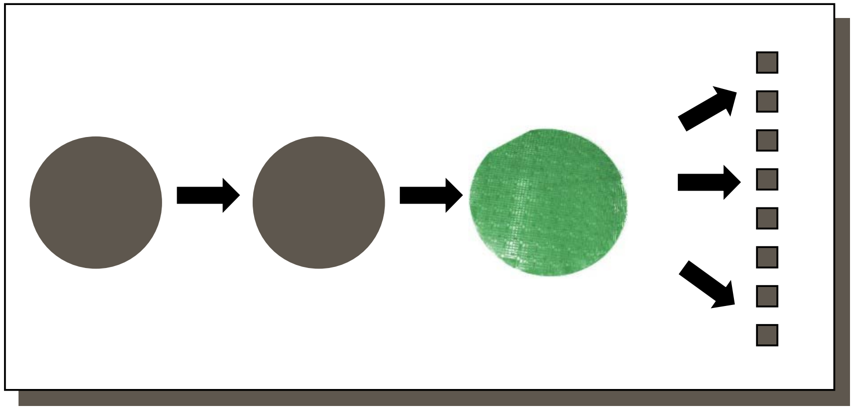
Batch Assembly

- Assembly/Packaging is Expensive
  - Each Part Must Undergo Many Steps
- Unique Capability
  - One Hundred Steps vs. Tens of Thousands
  - Reduce Cost by >10X

Conventional One-at-a-Time



Our Solution: Thousands-at-a Time

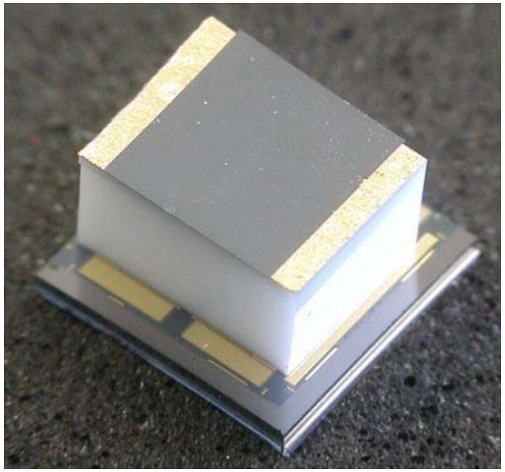


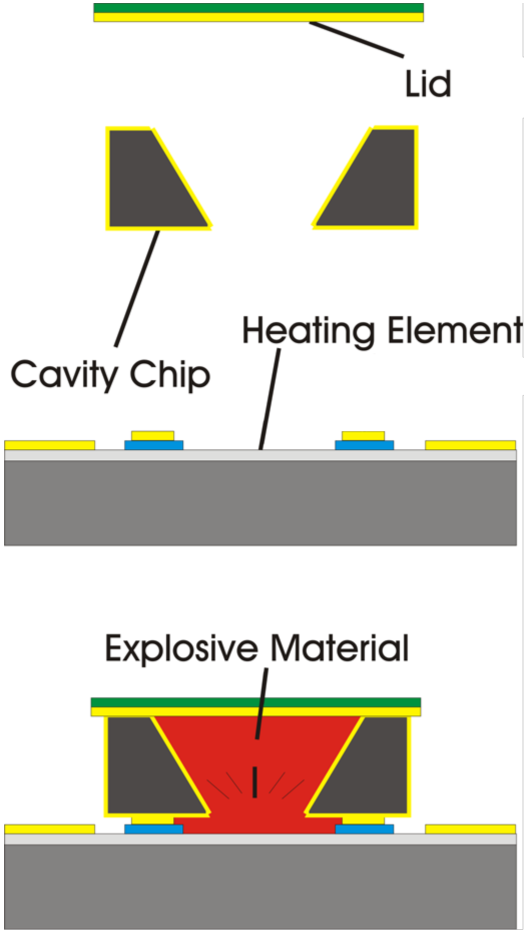
MEMS Initiators

- M100 Drop-In Replacement
  - Batch Processing = Lower Cost, Higher Reliability
  - Commercial Applications
    - Mining, Construction, Oil Drilling
- Silicon Bridge Initiator
  - For Navy IHDIV S&A devices
  - Applications
    - 40 MM Grenades
    - Mine Countermeasure Dart

Initiators for M100 Replacement

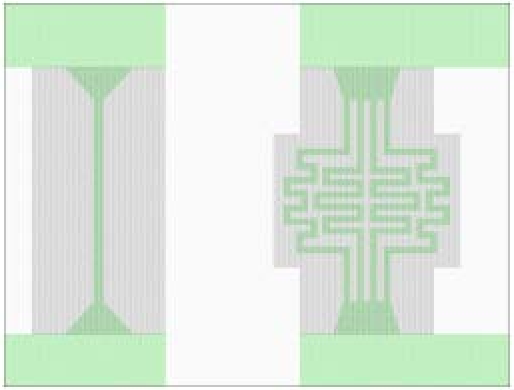
- Three Layer Design
- Tungsten Heating Element
- Batch Processes
  - Fabrication
  - Loading
  - Packaging



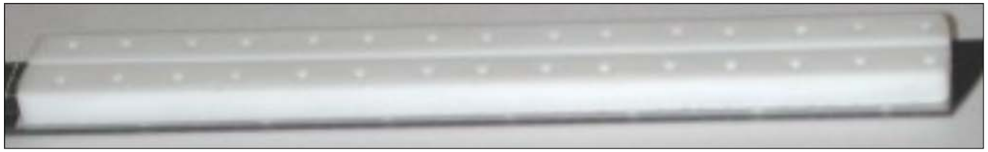


1st Generation M100 Replacement

- Pyrex Substrate
- Tungsten Bridgewire
- Fired at 3V off 100µF cap
- Pyrex Substrates Pose Process Issues



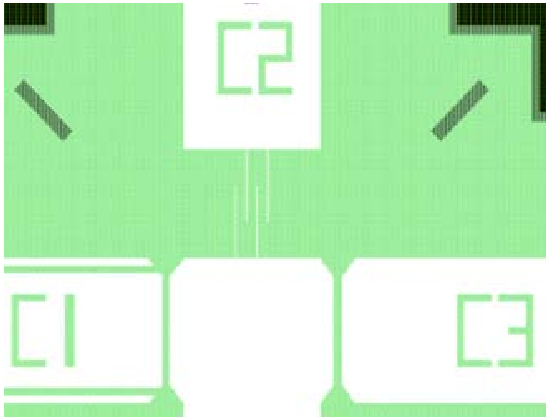
Heater Devices

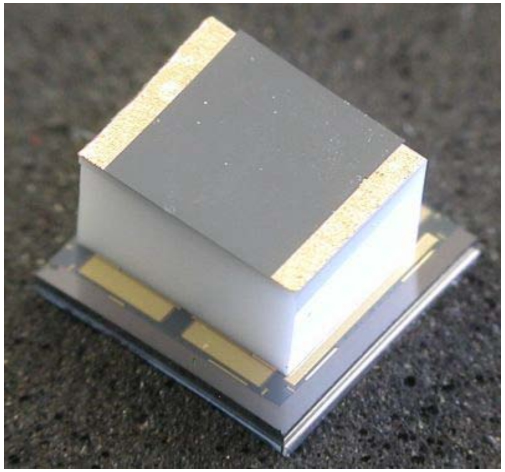


Microdetonator Devices

2nd Generation M100 Replacement

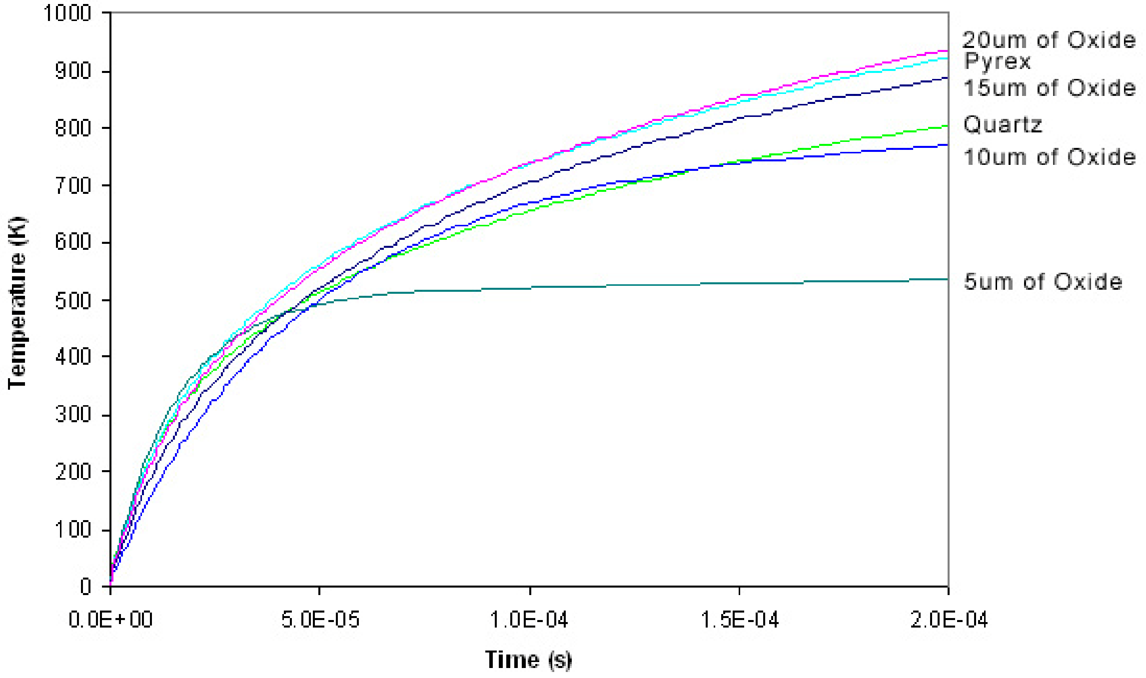
- Pyrex Substrates and Silicon Substrates
- Devices on Pyrex Substrate fired at 3V
- Devices on Silicon Substrate fired at 5V (thermal loss)





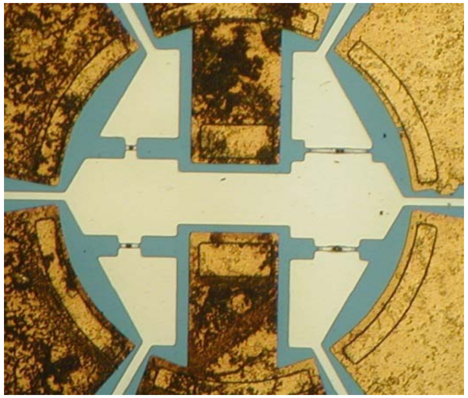
Heater Substrate Modeling

- Silicon with thick oxide layer possible
- Long CVD process is not ideal
- Quartz substrate more cost effective



3rd Generation M100 Replacement

- Quartz Substrate
- Lower parasitic resistances
- Higher energy dissipation over bridgewire
- Neyer Test on 3rd generation devices
  - 23 devices tested
  - μ=1.6088 V σ=0.0966 V
  - All-fire at 2.0 V
  - No-fire at 1.2 V

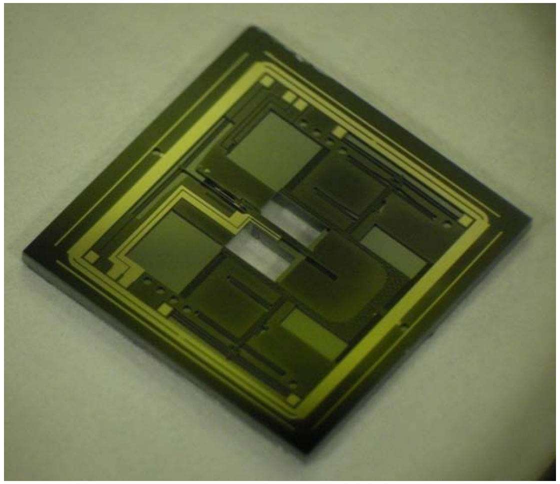


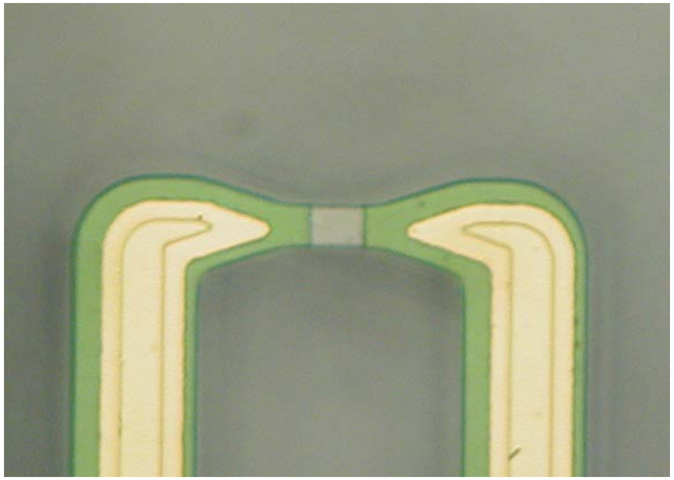
4th Generation M100 Replacement

- Lower parasitic resistances
- Higher energy dissipation over bridgewire
- Neyer Test on 4th generation devices
    - 30 devices tested
    - μ=1.2097 V σ=0.0220 V
    - All-fire at 1.6 V
    - No-fire at 0.7 V
    - Dent into Aluminum: 0.020”

Initiators for S&A Device

- Navy IHDIV S&A devices
- SOI MEMS Process for Safe & Arm Device
- Silicon Semiconductor Bridge (SCB) Initiator
- Integrated Initiators Fabricated in Batch Semiconductor Processes

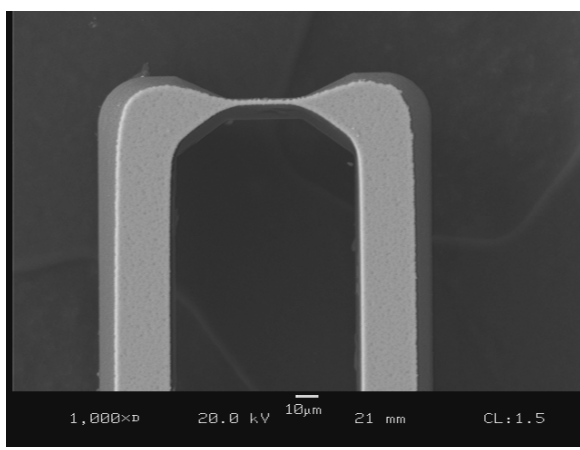


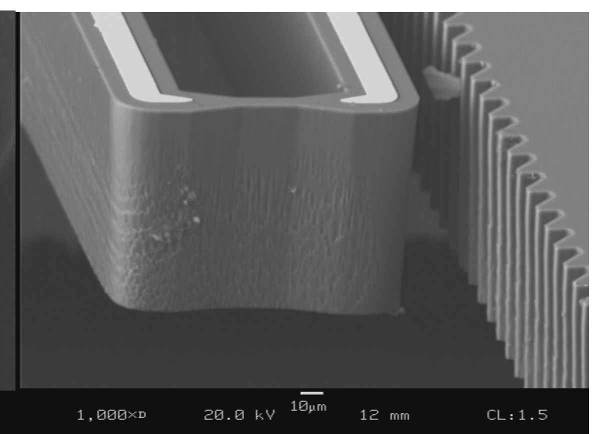


NSWC Silicon Bridge Initiator

- Composed of a silicon bridge
- Unique geometry used for MEMS S&A device (bridge volume ~ 20,000 µm^3, dimensions in the 10's of µm)
- Bursts and forms plasma when voltage is applied
- Plasma crosses air gap (2-5 µm) to initiate primary explosive

WARFARE CENTERS
INDIAN HEAD

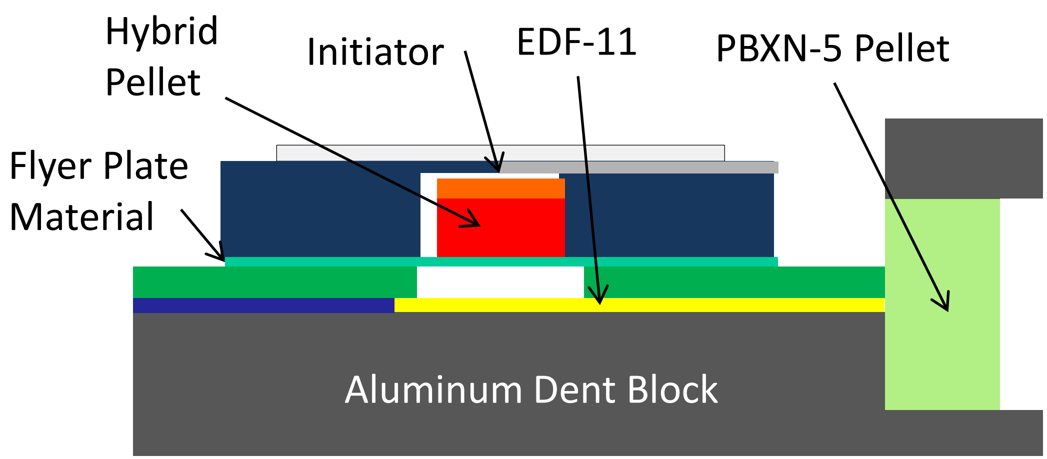




Silicon Bridge Test Setup

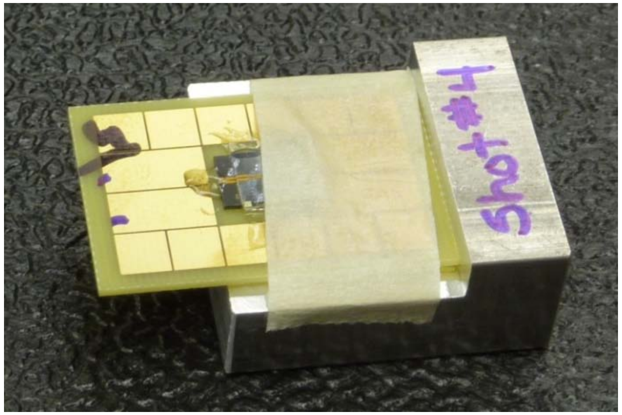
- Navy IHDIV devices
- Explosive train feasibility study with various geometries tested
- Plasma initiates lead styphnate/silver azide pellet
- Sending metal flyer into and initiating EDF-11 strip (12-40 mils thick)
- EDF-11 charge transfers to PBXN-5 pellet

NAVSEA WARFARE CENTERS INDIAN HEAD



Silicon Bridge Testing

- Flyer successfully initiated thin layer of EDF-11 (15/17 times in various geometries / thicknesses)
- EDF-11 successfully initiated PBXN-5 pellet (4/6 times)
- Dent block analysis underway at NSWC IH



Initiator with Aluminum Dent Block

Dent Block After Successful Charge Transfer

Summary

- M100 Drop-In Replacement
  - More Reliable (σ=0.0220 V)
  - Meets Firing Requirements
    - All-Fire at 1.6 V off 100µF cap
    - No-Fire at 0.7 V off 100µF cap
- Silicon Bridge Initiator
  - Successfully Initiated Explosive Train
  - Semiconductor processing: Firing characteristics can be easily changed per application
  - Fast Acting (µs range), Low Energy (~5 mJ), Very Efficient

Results from preliminary testing of a new generation of high-shock accelerometers with extreme survivability performance

Randy Martin, George Pender, James Letterneau, Tom Kwa

National Defense Industries Assn 54th Fuze Conference
May 13, 2010
Kansas City, MO

Presentation by Randy Martin

Meggitt Sensing Systems, San Juan Capistrano
(also known as Endevco)
30700 Rancho Viejo Road
San Juan Capistrano, CA 92675

Initial development and testing

- MSS, SJC (Endevco) has been developing a lightly damped accelerometer for fuze applications
  - Silicon MEMS sensor
  - High-g shock
  - Mechanical stops
  - High survivability
  - Complements the silicon MEMS sensor which is currently the industry standard
- Previous papers describe initial development work
  - NDIA 53rd annual Fuze Conference (2009)
  - 80th SAVIAC Symposium (2009)
- Basic design and performance characteristics
  - Light damping, high resonant frequency, stops, low power
  - Sensitivity, ZMO, Survivability

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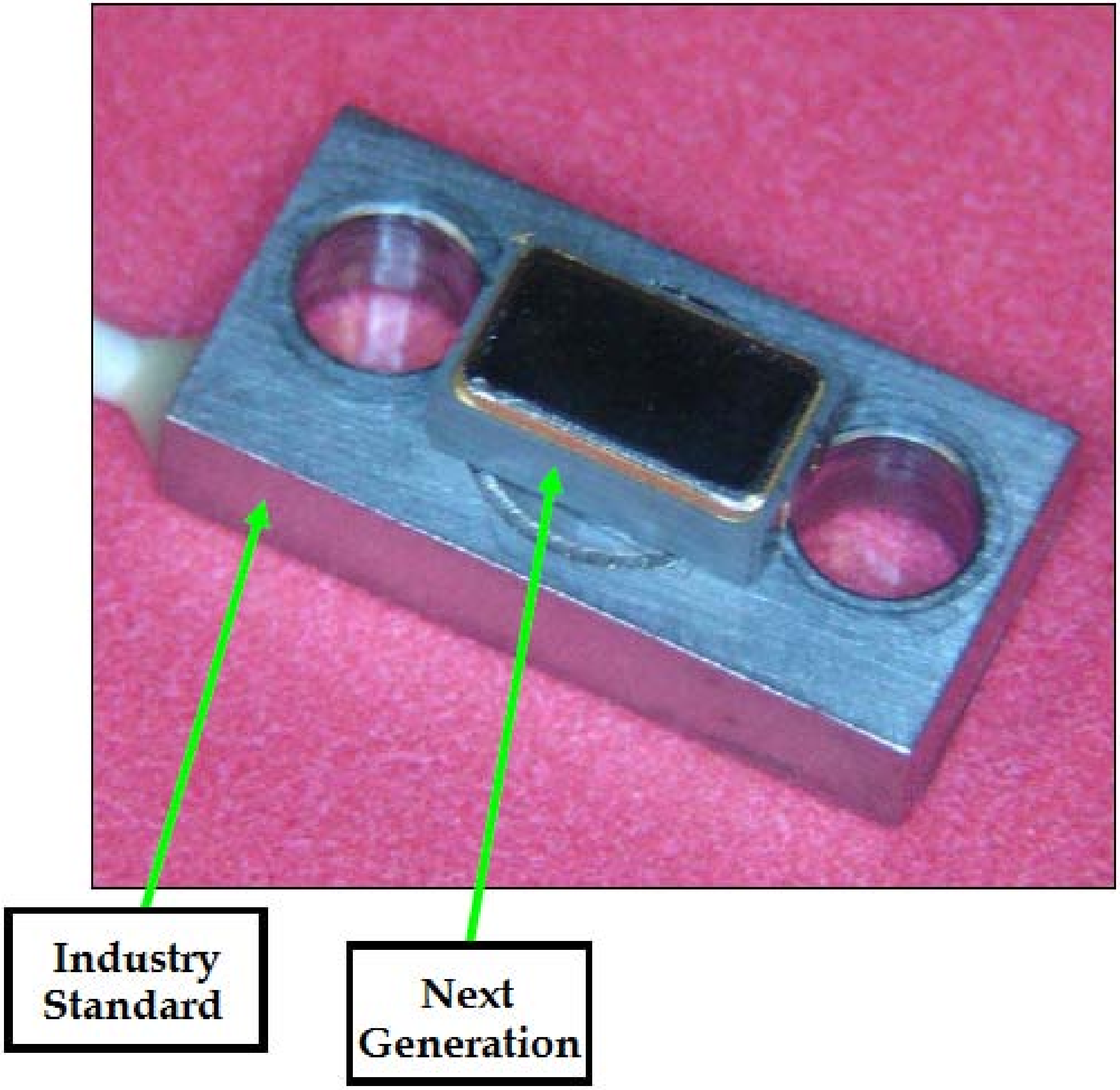
Recent test results

- Test results on new damped/stopped unit
  - 20,000 g full scale range
  - Conducted at high-g shock lab at Eglin AFB
  - Under the direction of Jason Foley (AFRL) and Alain Beliveau of Applied Research Associates.
- Testing designed to:
  - Characterize performance of the prototype damped/stopped MEMS accelerometer
  - Evaluate a new fixture designed by MSS-SJC for use in testing a high-g accelerometer which is housed in an SMT mounted LCC package.

Package comparison



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Test methods and equipment

- It is anticipated that the new accelerometer will be controlled under the ITAR regulations
  - References to specific model numbers, test equipment, etc. are limited.
  - However these details can be divulged to properly vetted persons in industry, academics, or government.
- Series of tests performed on new damped/stopped accelerometer at AFRL Fuzes Lab at Eglin AFB
  - Testing performed on a new 1.5 inch diameter Hopkinson bar.
  - Outputs referenced to a laser vibrometer
  - Also referenced to the industry standard accelerometer for high g shock.

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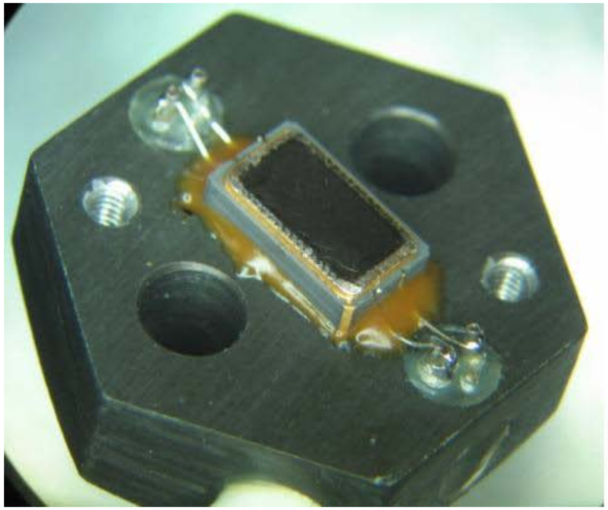
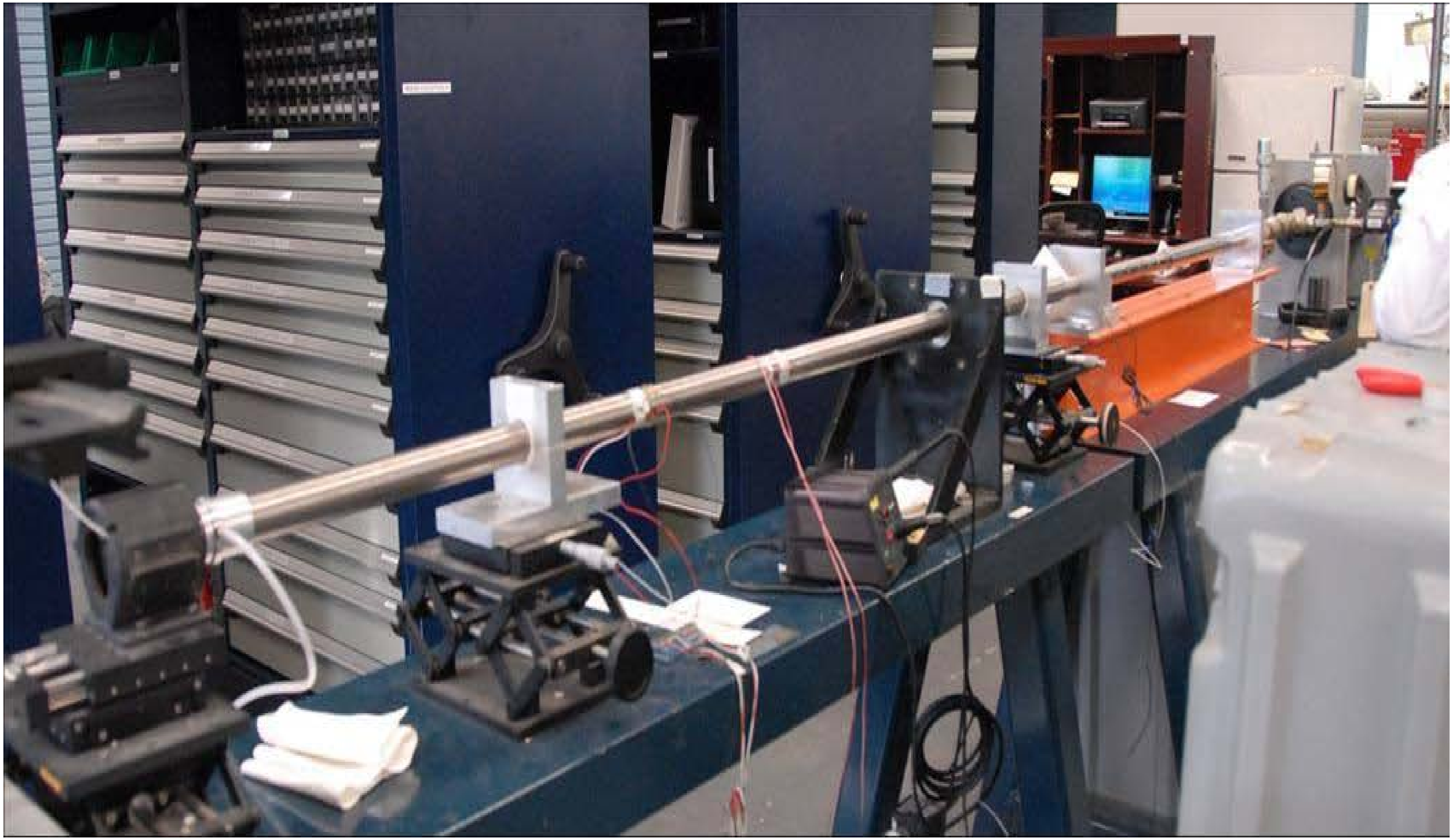
Test fixture



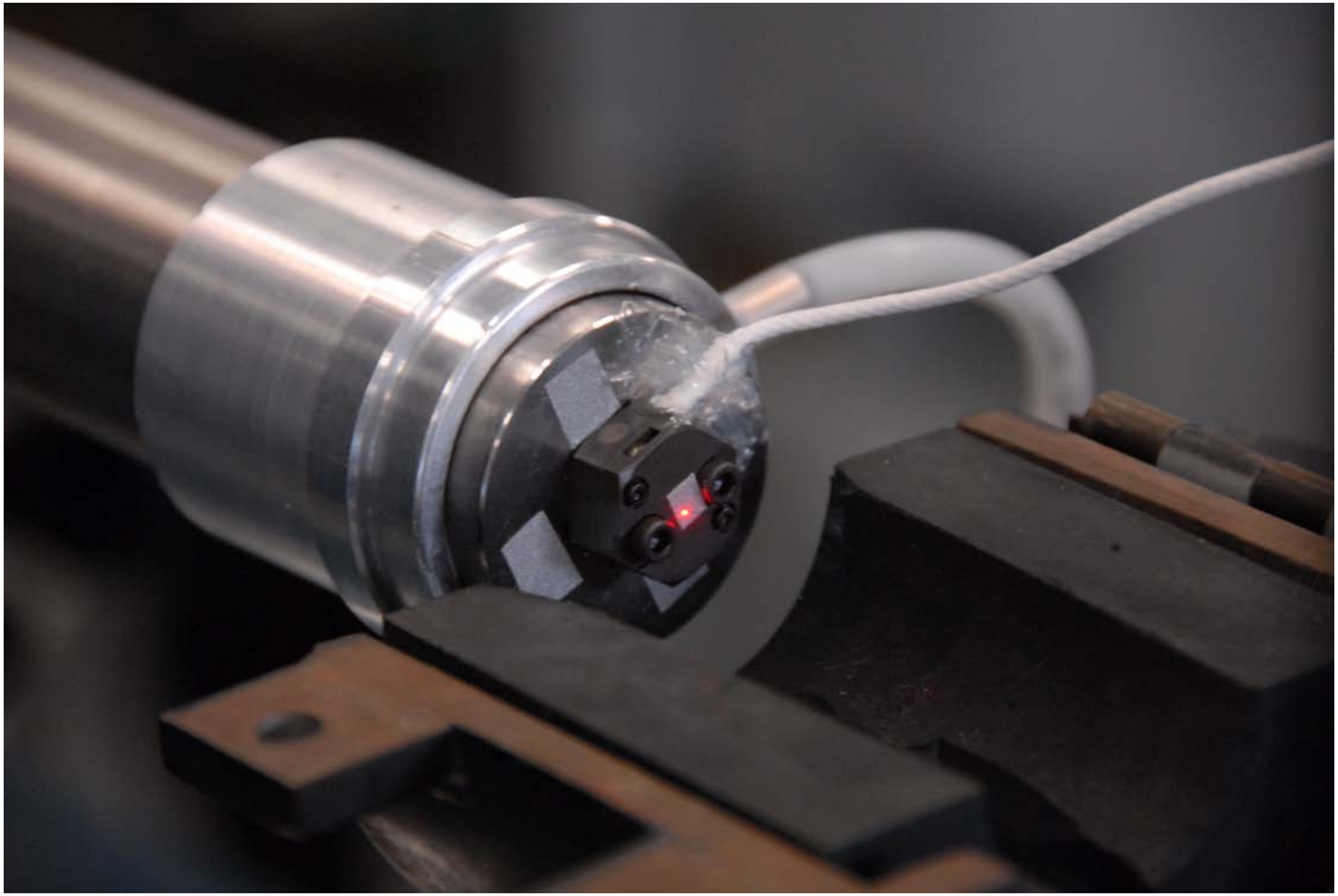
- SMT packages are a particular problem for high g shock testing
  - Custom fixture was designed
  - Easy installation and removal
  - Retains test unit at 180,000 g shocks

Hopkinson bar



MEGGiTT

Laser vibrometer



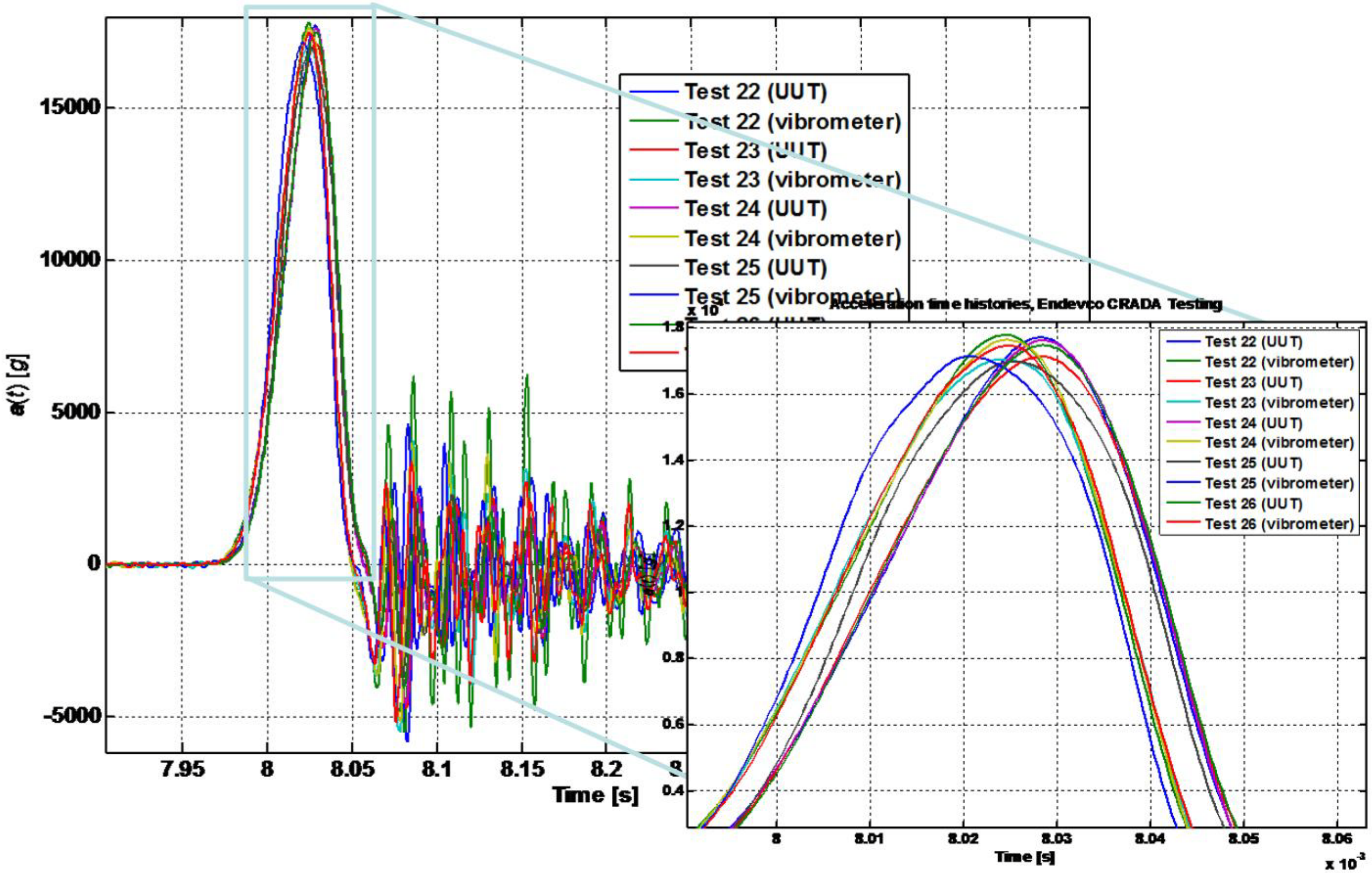
Tests conducted

- Testing was conducted to determine the following performance characteristics:

- 1. Survivability to 4 x rated range (80,000 g)
- 2. Zero shift following shock
- 3. Damping
- 4. Stop effects
- 5. Frequency response

MEGGITT

Test repeatability



- Time histories of multiple tests conducted at full range acceleration.

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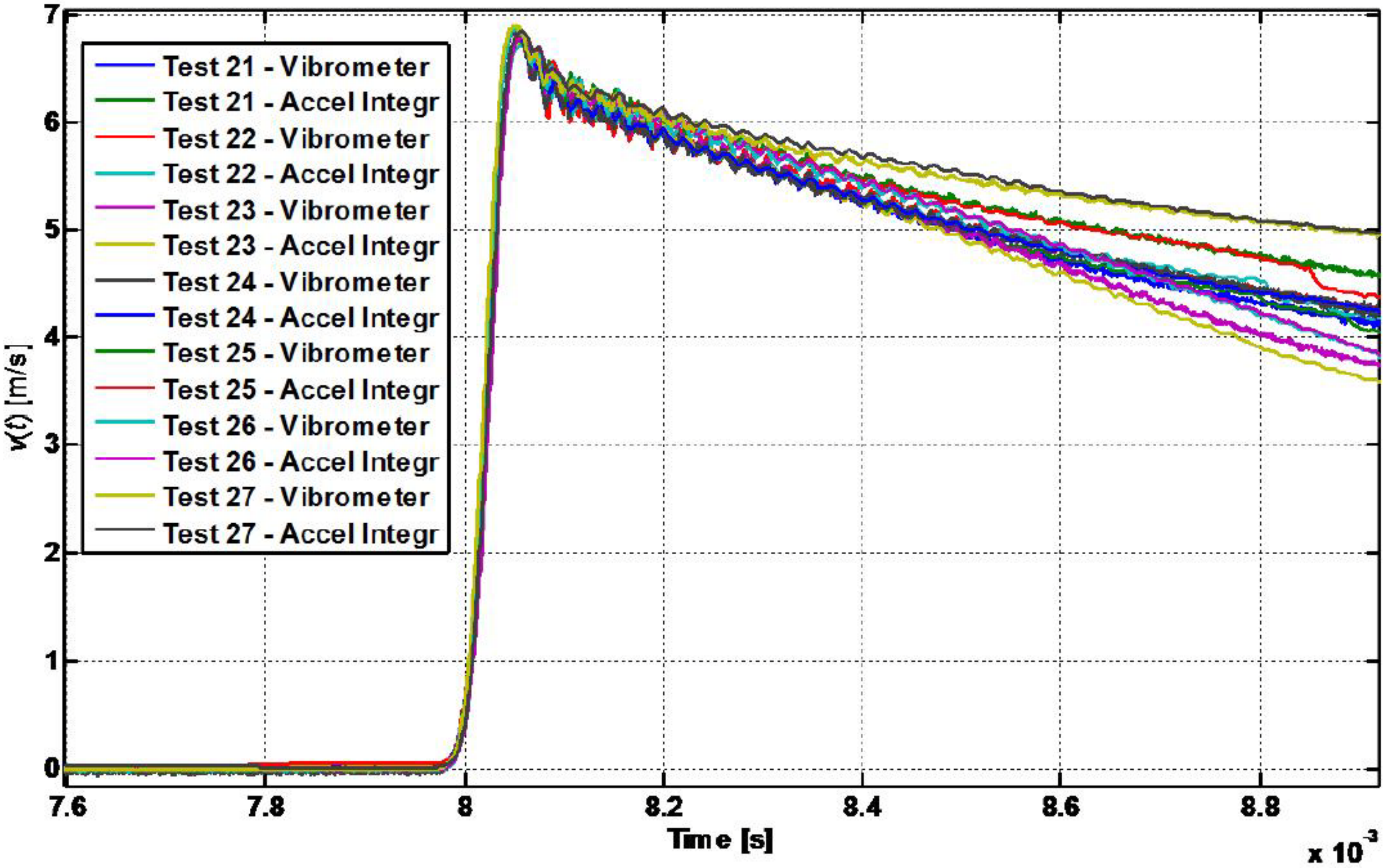
Test Repeatability



- Integrated accelerometer time history vs. laser vibrometer velocity data taken over seven consecutive 20,000 g shocks.

Survivability

- A total of 50 high-g shock tests were conducted on two different prototypes of the new damped accelerometer.
  - There were no out of spec readings noted during the testing
  - The worst case zero shift observed was 0.15 mV at 5.0 Vdc excitation
- The highest g level impact recorded was 84 kg (approximately 4 times full range).

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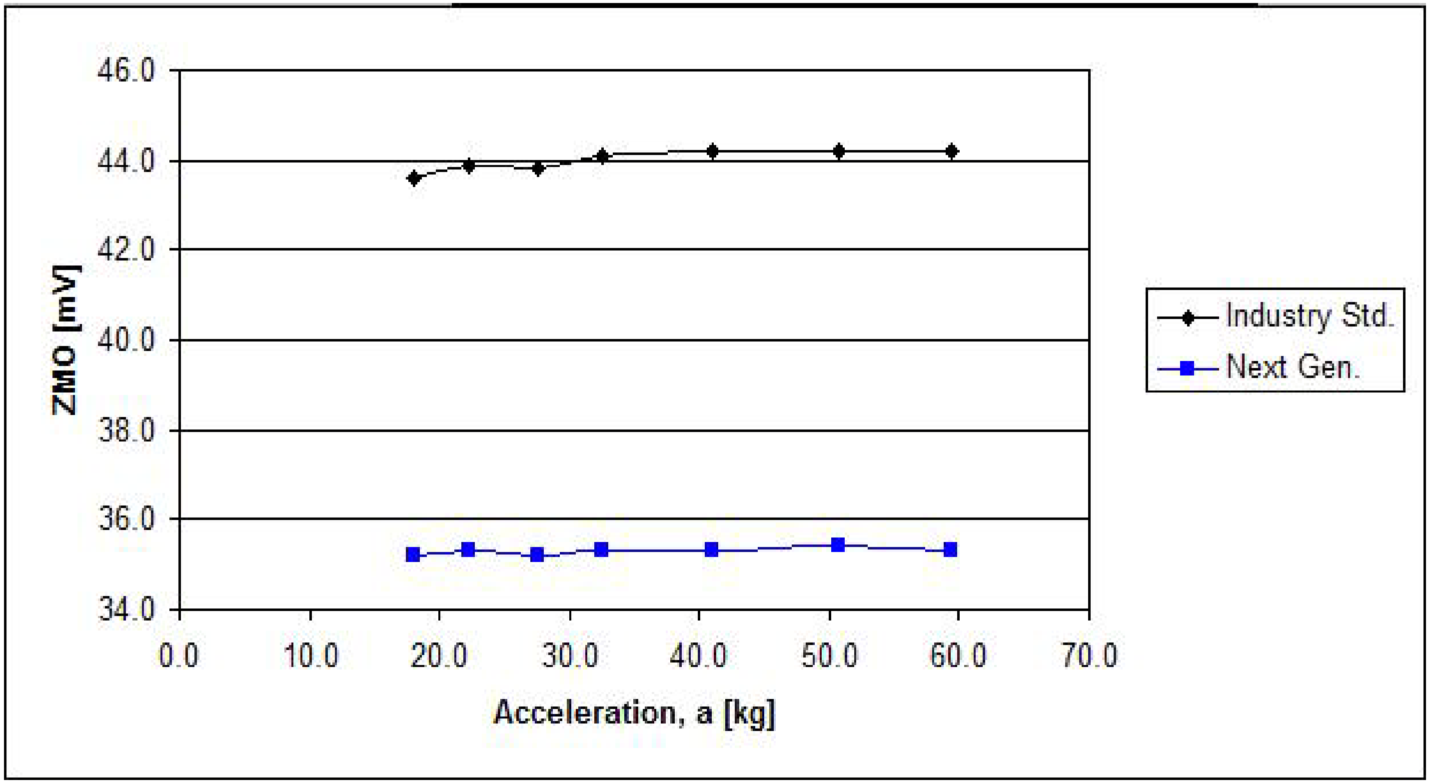
Zero shift after shock



Typical zero shift following a shock event

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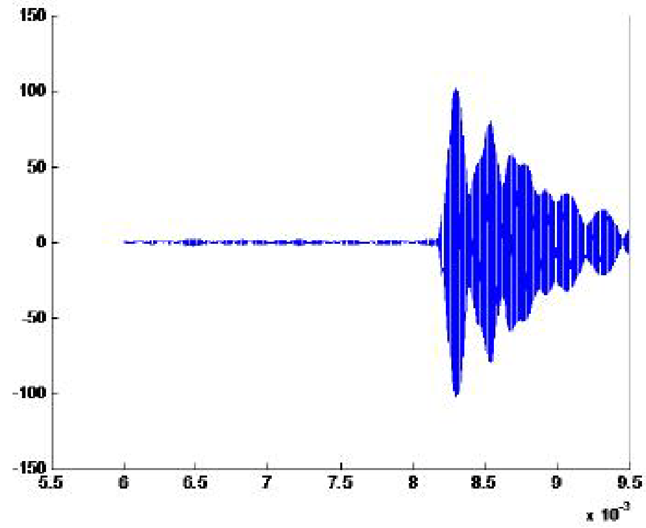
Damping – Log decrement method

- Measure amplitude of two successive peaks
  - A_k and A_{k+1}
- The ratio of the two is δ
- Damping can be found

$$\delta = \ln\left(\frac{A_k}{A_{k+1}}\right) = \frac{2\xi\pi}{\sqrt{1-\xi}}$$

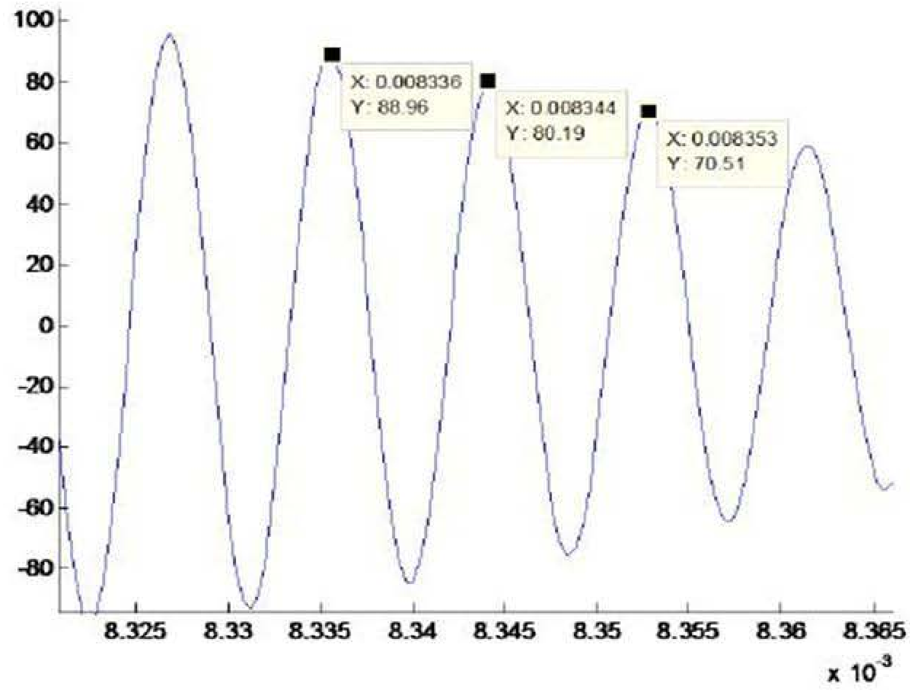
$$\xi = \frac{\delta}{\sqrt{4\pi^2 - \delta^2}}$$

- Utilize bandpass filter
  - 1st resonance at 113.4 kHz



Damping calculation

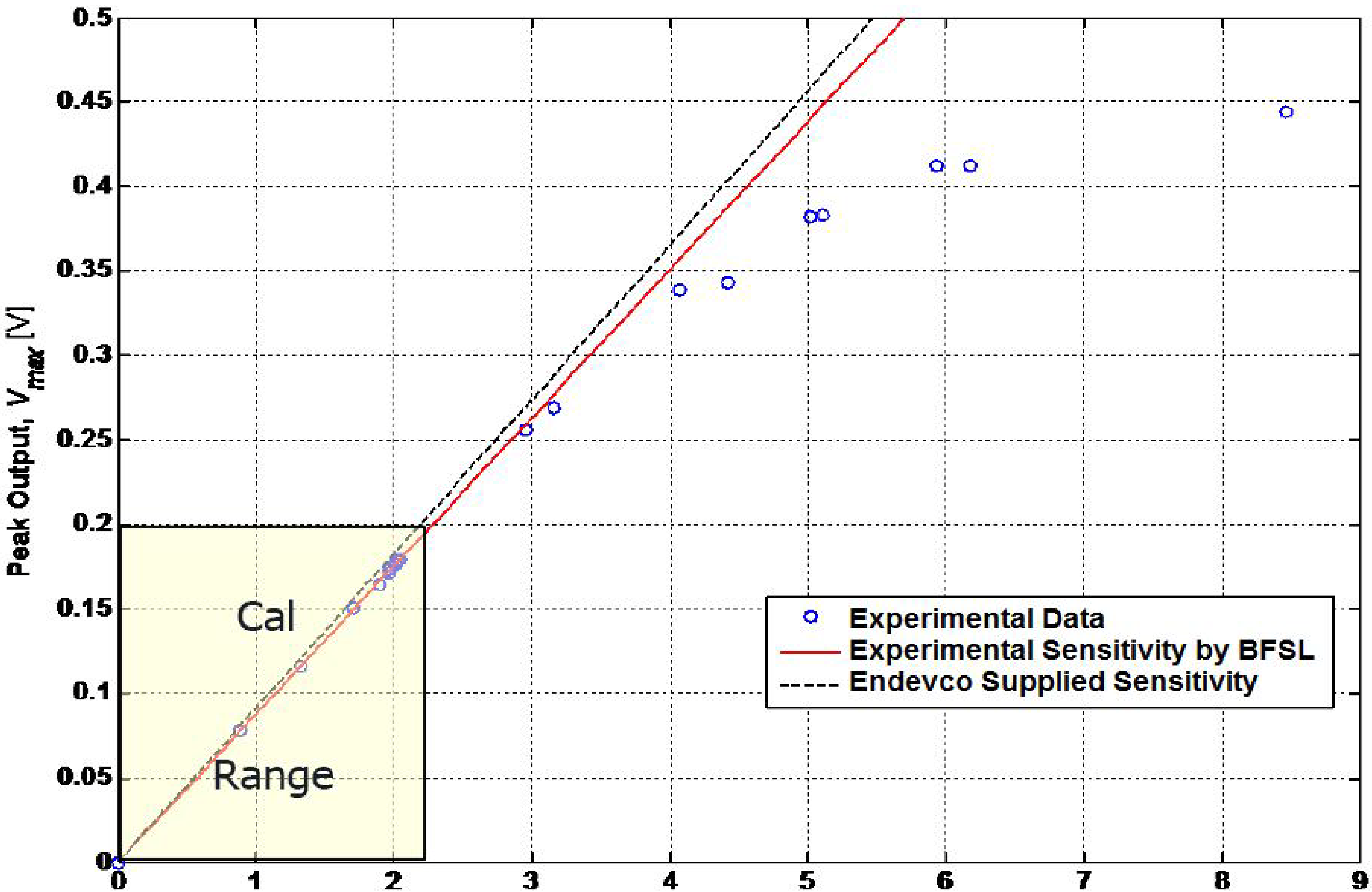
- Damping at 113.6 kHz is thus $\xi = 0.0165$ and 0.0205, or 1.65-2% (consistent with narrow peaks)



In-house damping calculation

- Similar damping testing at our Sunnyvale silicon foundry measured closer to 10% damping.
  - In-house testing was done at full range (mechanical displacement of the proof mass from the stops)
  - Eglin AFB testing was done at 100 g.
  - It is likely that the damping varies with displacement.

Linearity



Acceleration measured by laser vibrometer in kg

Linearity

- Experimental data for the new damped accelerometer fits very nicely to a straight line in the 20,000 g range
- Note the multiple readings at approximately full scale
- An extrapolation of the sensitivity measured at MSS-SJC indicates an error in our calibration.
  - Further testing is needed to validate the calibration methodology for damped high-g shock accelerometers

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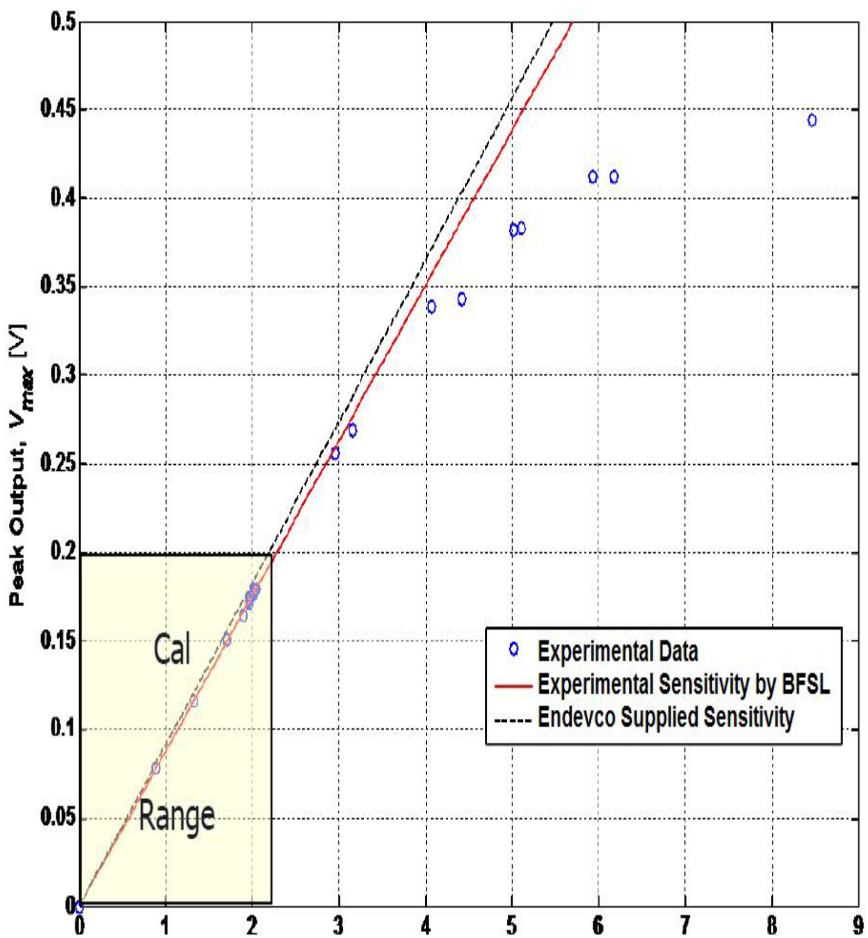
Mechanical Stops

- Gradual roll-off of sensitivity as g level increases.
- Such "soft" stops are almost ideal; there is no sudden change in momentum of the proof mass as the stops are engaged - just a gradual or progressive decrease in displacement.



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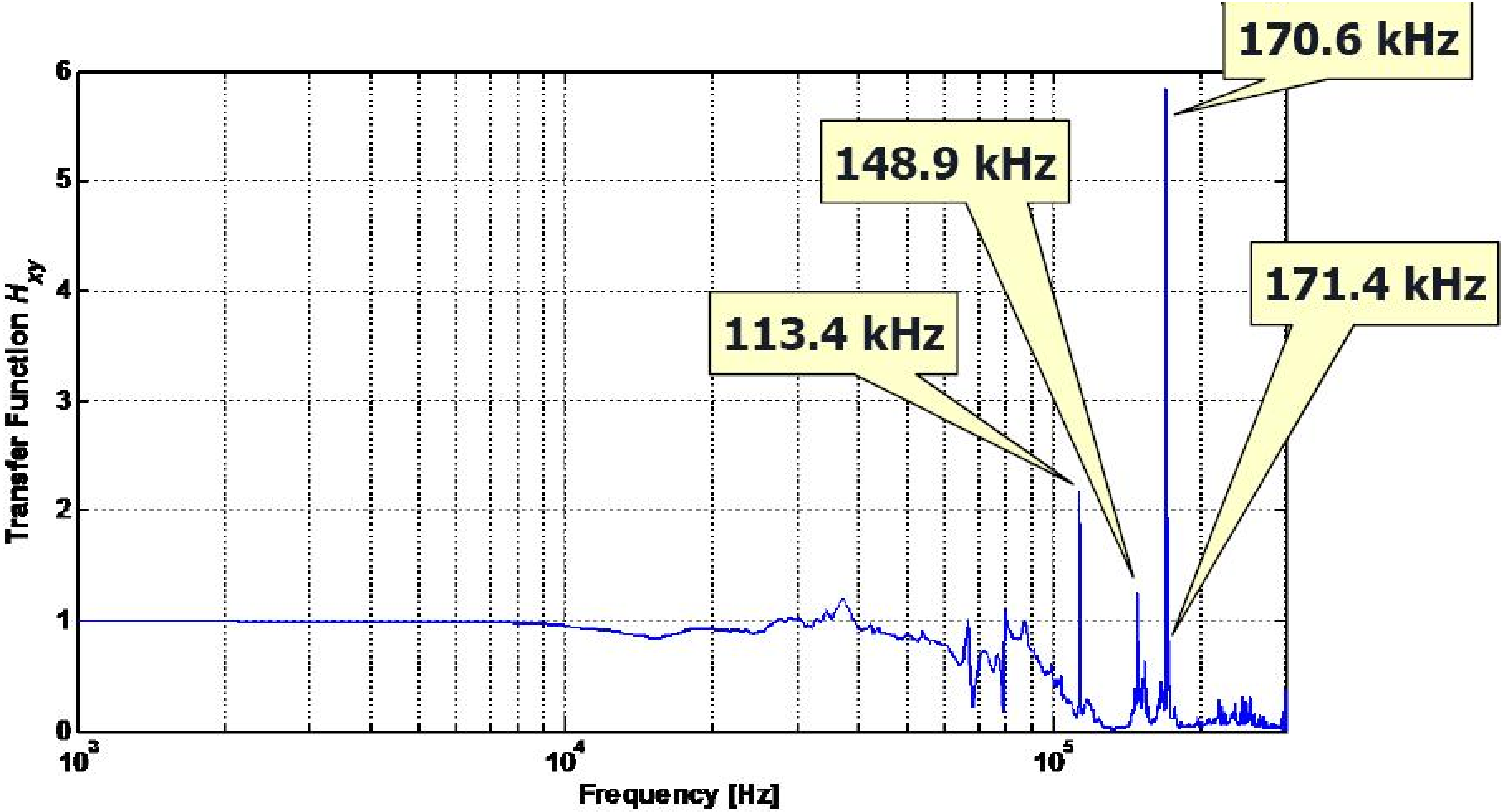
Frequency response

- Frequency response is measured by graphing the transfer function between the test accelerometer and the laser vibrometer.
- The “flat” bandwidth is close to 10 kHz, with reasonable bandwidth to 40 kHz.
- The resonances noted at 150 kHz and 170 kHz are above the natural frequency at 113 kHz and are thought to be caused by higher frequency modes of the seismic system.

FREQUENCY RESPONSE



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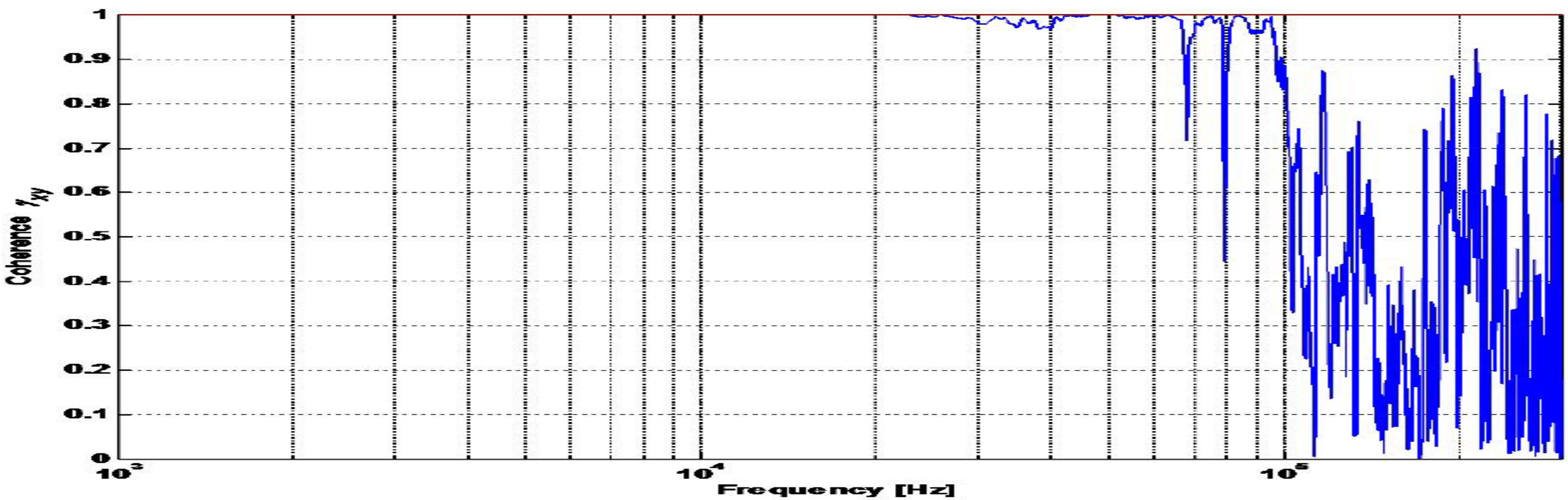
Coherence

- Coherence plot generated from multiple data sets and is confirmation of both the performance of the accelerometer and the test equipment.
- Coherence out to 80 kHz indicates the accelerometer output is only a function of the shock input. Dips near 68 and 80 kHz are likely due to resonant modes in the flyaway test fixture.



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Summary

- Further characterization of a damped/stopped MEMS accelerometer was conducted at the AFRL shock laboratory of Eglin AFB. The testing confirms the new damped/stopped accelerometer has:
  - **High shock survivability of 4x full range**
  - **Minimum ZMO shift following shocks**
  - **Damping between 2 and 10%**
  - **Linearity through full scale range**
  - **“Soft” stops**
  - **Frequency response flat to 10 kHz**

MEGGITT

Acknowledgements

- The authors would like to thank Zhixiong Xiao at Meggitt Sensing Systems, Sunnyvale (MSS, SV) for his work in MEMS development and damping experiments.

- The authors would like to thank the team at the Dynamic Shock Facility of AFRL at Eglin AFB for their high quality, thorough evaluation of our next generation damped accelerometer.

- Note: The data from testing conducted at Eglin AFB presented in this paper was cleared for public release by Eglin AFB Public Affairs liaison officials (ref: case number 96ABW-2010-0288).

Distribution Statement: Approved for Public Release

Meggitt Sensing Systems, San Juan Capistrano
(formerly Endevco Corporation)
30700 Rancho Viejo Road
San Juan Capistrano, CA 92675

MEMS Retard & Impact Sensors

Principal: Walter Maurer, NAWCWD China Lake

Contributors:

Dr. Daniel Jean, NSWC Indian Head

Ryan Knight, ARDEC

Objective

- ***Exploit existing MEMS microfabrication and packaging technologies to realize DoD retard and impact sensors with improved performance:***
  - ***precision***
  - ***reliability***
  - ***producibility***
  - ***cost effectiveness***

Potential Payoff

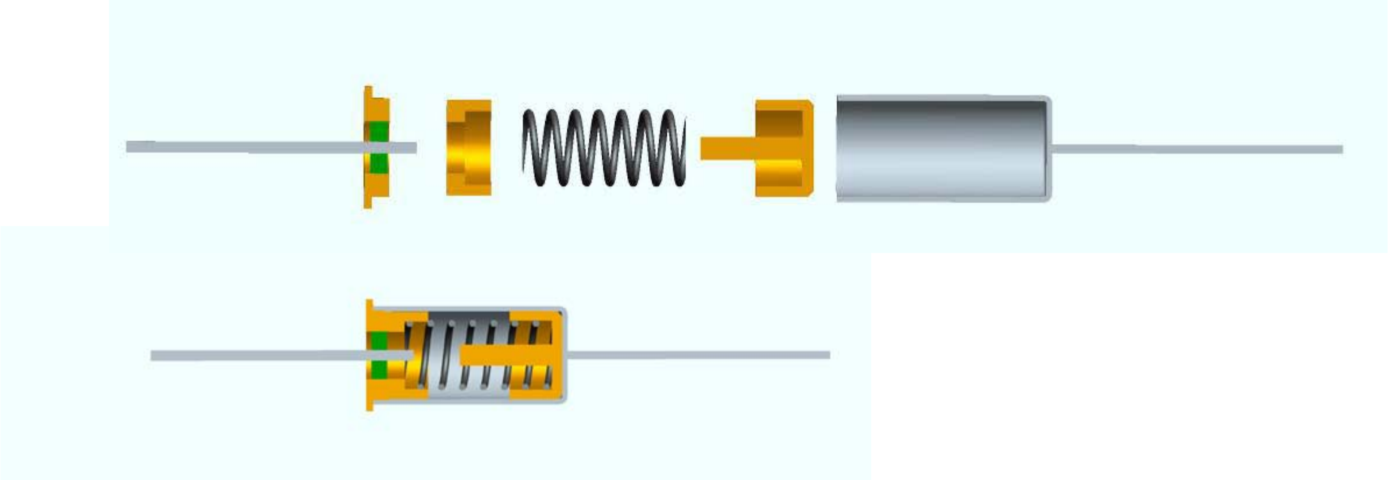
- **_<u>Improved G-sensor performance</u> for existing & future fuzes including:_**

  - **_FMU-139 (impact sensor; retard sensor)_**
  - **_FMU-143 (impact sensor)_**
  - **_High Reliability Fuze (impact sensor)_**
  - **_Hardened freefall weapon fuzing applications_**

Background

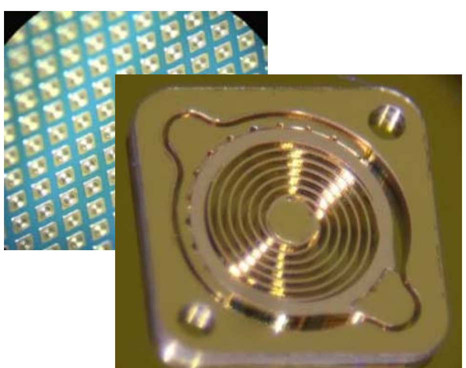
➢ ***Traditional coilspring-mass technology:***

- ***Wider variability in performance than MEMS***
  - *wire & coil dimensional tolerances*
  - *coil winding stresses & annealing*
- ***Difficult to precisely sense low G's with "macro world" springs***

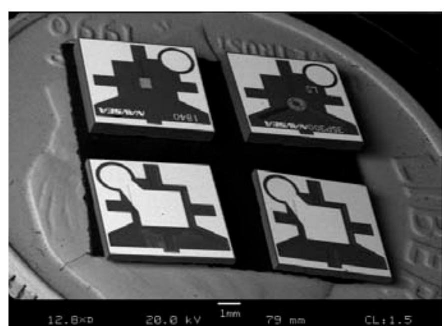


Background (cont.)

- ***Newer MEMS-technology appears well-suited for making improved low-G sensors per DoD exploratory work to date:***
  - ***ARDEC: metal G-sensors and packaging***
  - ***NSWCIH: silicon G-sensors and packaging***
  - ***NAWCWD: precision-electroplated G-sensors***



Courtesy of ARDEC

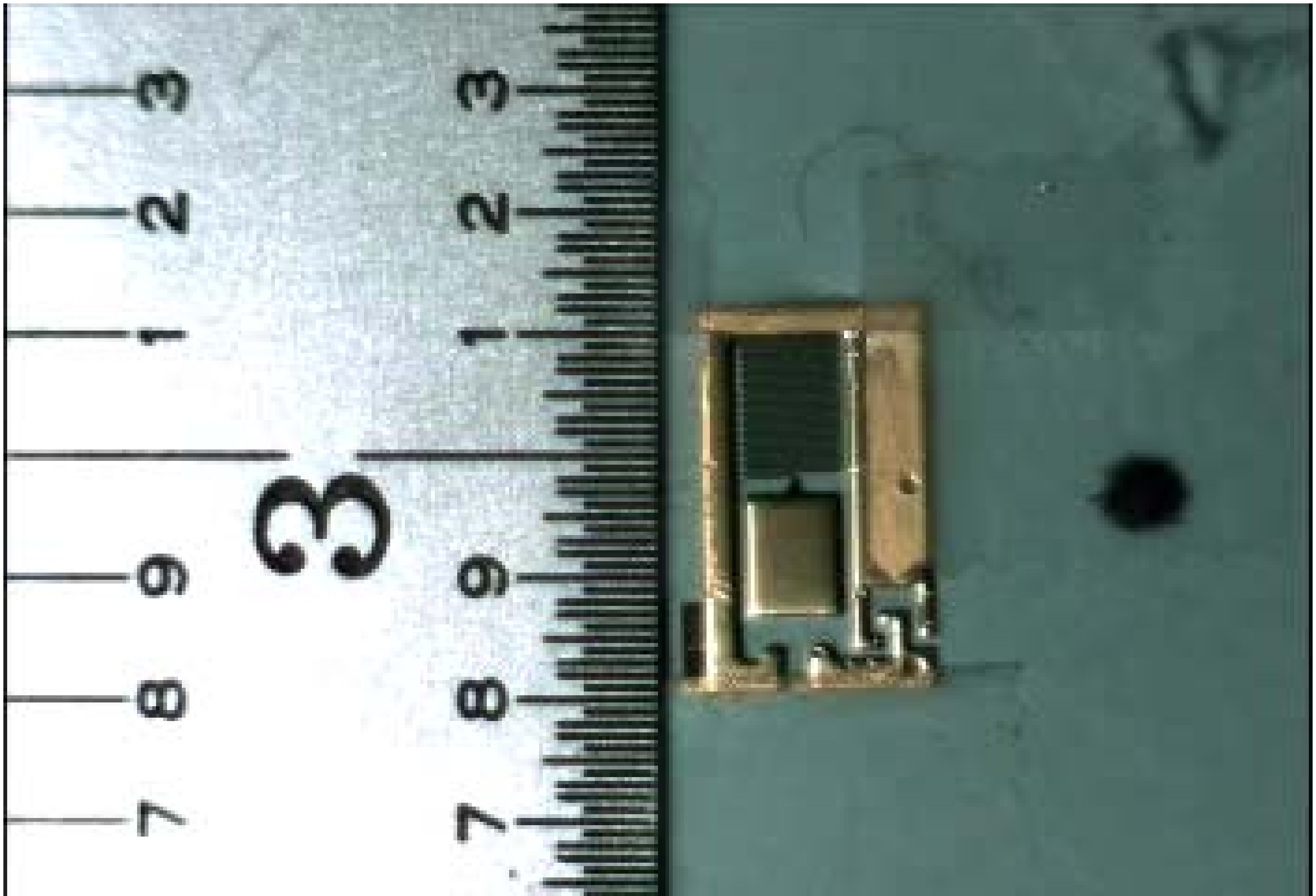


Courtesy of NSWCIH

NAWCWD 5G Sensor (2005)

Background (cont.)

Centrifuge Test of Low-G Sensor in 1G Increments



Technical Approach

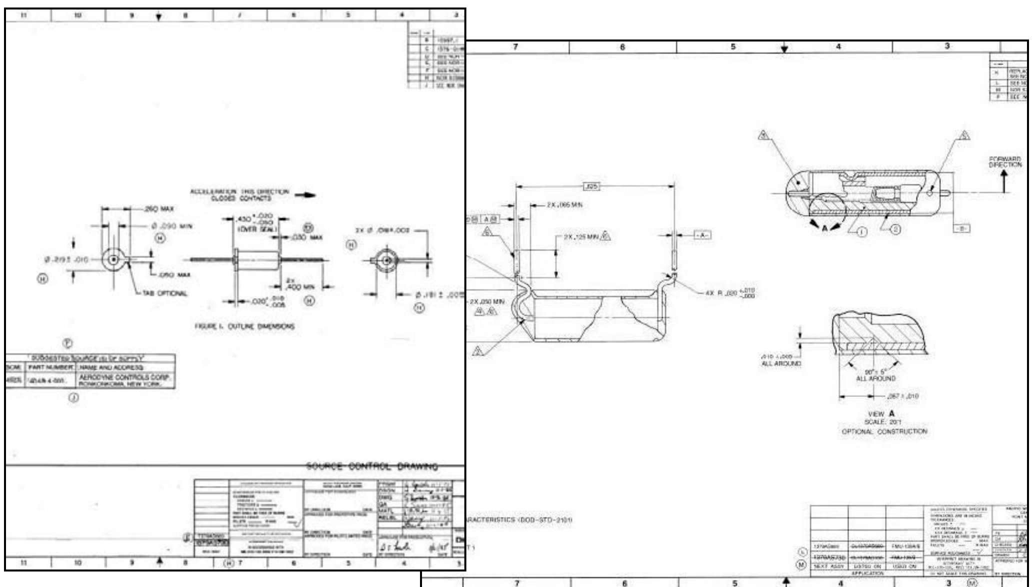
- ***Modify existing NSWC and ARDEC sensor designs to duplicate performance of currently-fielded non-MEMS sensors***
  - ***low-G impact sensors (<100G)***
  - ***very low-G retard sensors (<5G)***
- ***Fabrication***
  - ***ARL (NSWC sensors); HT-Micro (ARDEC sensors)***
- ***In-House Packaging & Testing***

1st-Year Progress

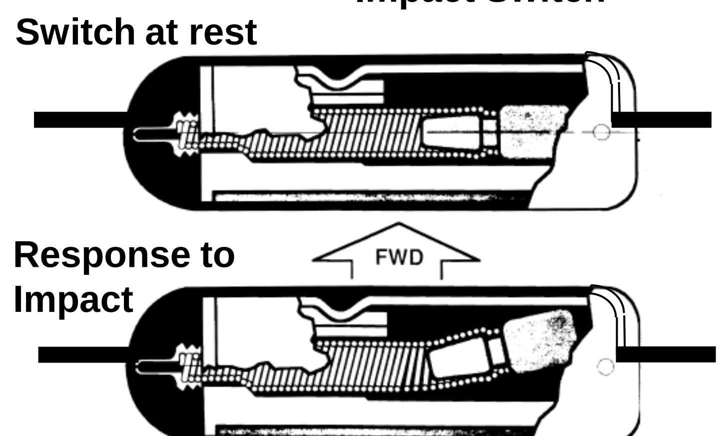
NDIA'10 National Defense Industrial Association

- ***Requirements obtained for bomb fuze sensors***
  - Retard sensor: 1.9G no-go, 2.3 all-go
  - Impact sensor: 40G no-go, 80G all-go. Velocity change of 2 fps will cause closure.

Impact Switch



Production Drawings of Retard Sensor (left) & Impact Switch

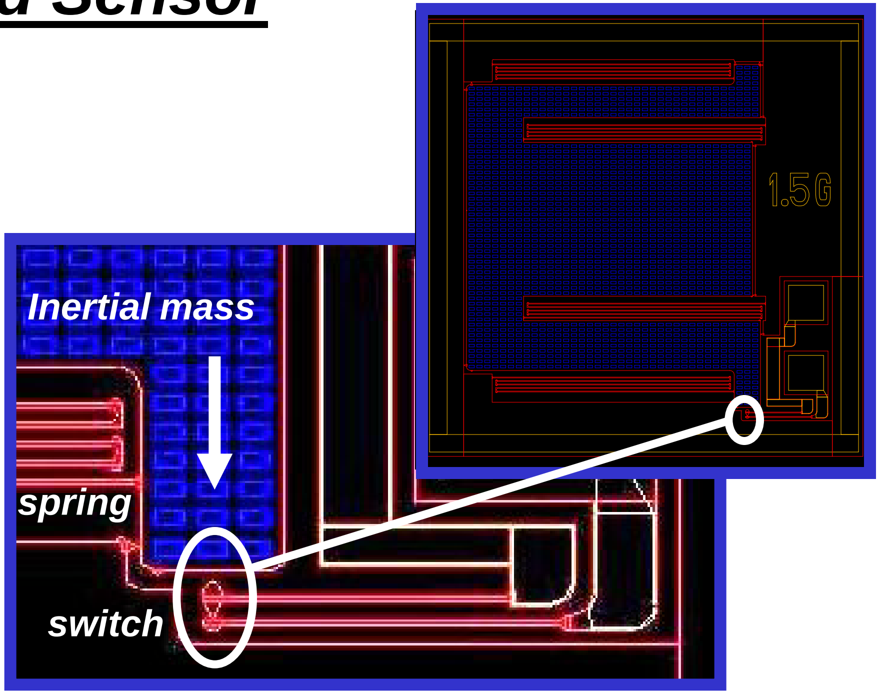


1st-Year Progress (cont.)

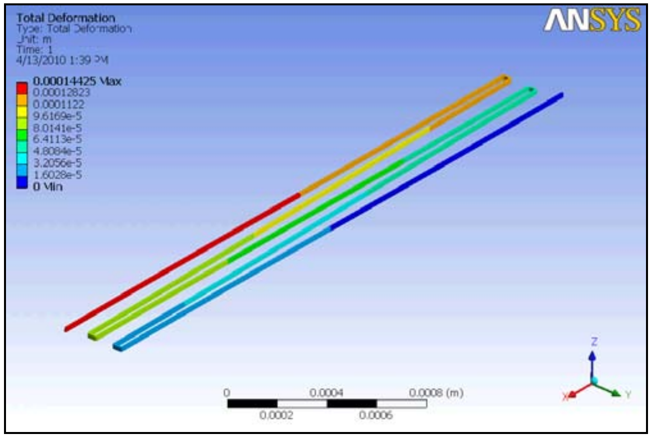
NDIA'10 National Defense Industrial Association

NSWCIH Retard Sensor

- ***Design layout completed***
  - Deep Reactive Ion Etching (DRIE)
  - Design variations: 1.5, 2.1, 3.0, 4.0, and 5.0 G
  - Unidirectional
  - In-plane contact switch
  - Chip size 5 x 5 mm



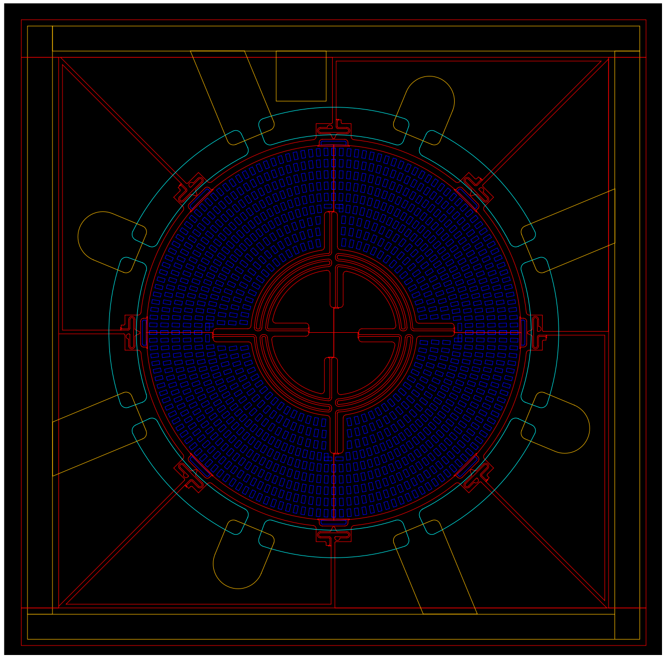
- ***Simulation completed***
  - Spring deflection under a static load (k = 0.139 N/m)



1st-Year Progress (cont.)

NSWCIH Impact Sensor

- ***Design layout completed***
  - Deep Reactive Ion Etching (DRIE)
  - Various closure levels to bracket target performance
  - Hemispherical contacts
    - 8 in-plane, 1 out-of-plane
  - Chip size 5 x 5 mm

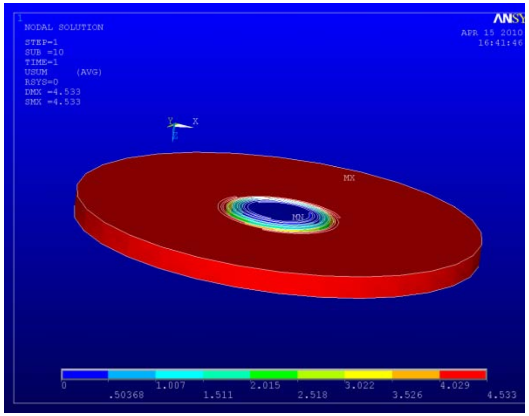


- ***Simulation nearly completed***
  - MATLAB-based dynamic modeling

1st-Year Progress (cont.)

ARDEC Retard Sensor

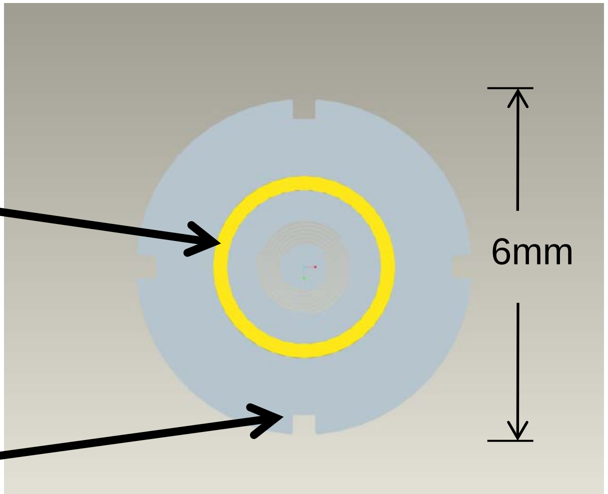
- ***Preliminary modeling completed***
  - Metal MEMS design to be made by htmicro
  - 2.1 G
  - Size ~ 6 x 6 x 1 mm



Preliminary FEA

Interior gold contact which only detects z-direction movements (will not detect rocking motion)

Anti-rotational features. Locks to keep proofmass from rotating

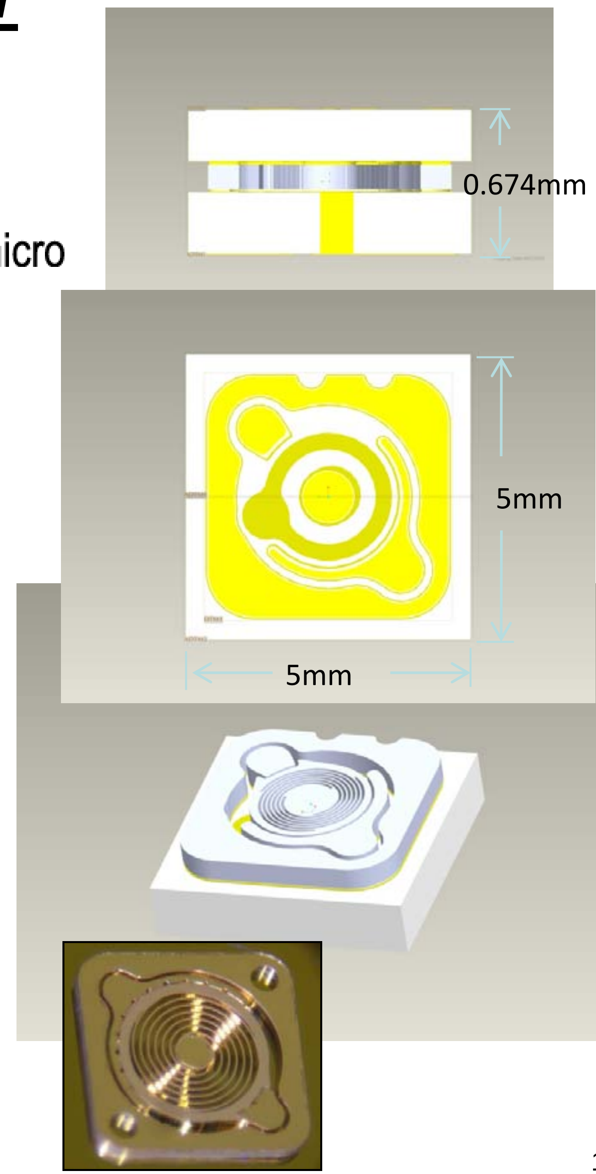


Preliminary ProE layout of MEMS 2.1G Retard Sensor

1st-Year Progress (cont.)

ARDEC Impact Sensor

- ***Preliminary modeling completed***
  - Metal MEMS design to be made by htmicro
  - Size ~ 5 x 5 x 0.67 mm
  - Scaled version of successfully demonstrated 500G Impact Sensor
    - Over 100 data points collected with Mk19 40mm MEMS Integration fuze
    - Only two known failures
    - More data points to be collected in May 2010



1st-Year Progress (cont.)

ARDEC Impact Sensor (cont.)

- ***Design Issues:***
  - Tends to make contact in a rocking/rolling mode (similar to contact that a spinning penny makes as its spinning dies down). Thus, squeeze-film air damping is not utilized very well.
  - This rocking motion will make contact under considerably lower inertial forces due to the moment created, thus affecting closure threshold.

1st-Year Progress (cont.)

Other ARDEC Design Issues

- ***Sensitivity to short duration impulses***
  - increasing surface area will increase squeeze film and Couette damping, thus increasing sensor's g-seconds
  - Higher nitrogen pressure during packaging
- ***Contact sticking***
  - increase sputtered-gold contact's rhodium concentration
- ***Gap dimensions***
  - ensure that spring remains in linear bending regime
  - must be large enough to prevent lockup

1st-Year Summary

- ***G-sensor basic requirements have been identified***
- ***1st-iteration sensors have been designed & modeled***
- ***Layouts are nearly ready for fabrication***
- ***Fab contracts/delivery orders are in place***
- ***Additional info to be obtained for existing sensors:***
  - ***Resonance & response to orientation***
  - ***Production/Acceptance test requirements, methods & data***

US ARMY RDECOM

U.S. Army Research, Development and Engineering Command

Malcolm Baldrige National Quality Award

2007 Award Recipient

ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

PICATINNY ARSENAL, NJ

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Non-Lethal Fuzing Requirements

40mm Proximity Fuze Design Team

US Army RDECOM ARDEC Fuze Division
Picatinny Arsenal, NJ 07806-5000

C. Scott Lyon, PE

Timothy M. Mohan

Steven E. Stephey

May 13, 2010

NDIA 54th Fuze Conference – Kansas City

NON-LETHAL FUZE REQUIREMENTS

- Non-Lethal requirements need to be understood to progress and refine a fuze design.
  - How is the fuze required to perform?
  - How will the munition be used?
  - How will it be identified as non-lethal?

- What is non-lethal?
  - What effect will non-lethal requirements have on fuzing?

- XM1158 fuze has been designed for non-lethal use.
  - For the XM1112 Airburst Non-Lethal Munition (ANLM)
  - Proximity function

WHY NON-LETHAL?

What are the Military’s Escalation of Force options?

Shout…..then Shoot?

WHAT IS NON-LETHAL? - DEFINITION

Weapons, devices, and munitions that are **explicitly designed** and primarily employed to **incapacitate targeted personnel or materiel immediately**, while minimizing fatalities, permanent injury to personnel, and undesired damage to property in the target area or environment. Non-lethal weapons are intended to have **reversible effects** on personnel or materiel. (paraphrased from DoDD 3000.3)

Counter-Personnel

Counter-Materiel

Key Attributes: Explicitly Designed, Immediate Incapacitation, and Reversibility

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

NON-LETHAL SPECTRUM OF RESPONSE

MILITARY PRESENCE | NON-LETHAL WEAPONS | LETHAL FORCE

"NLWs Provide Operating Forces Needed Capabilities"

"Increasing RANGE increases OPTIONS"

Target selected individuals

Clear personnel

Control group movements

Secure without Destroying

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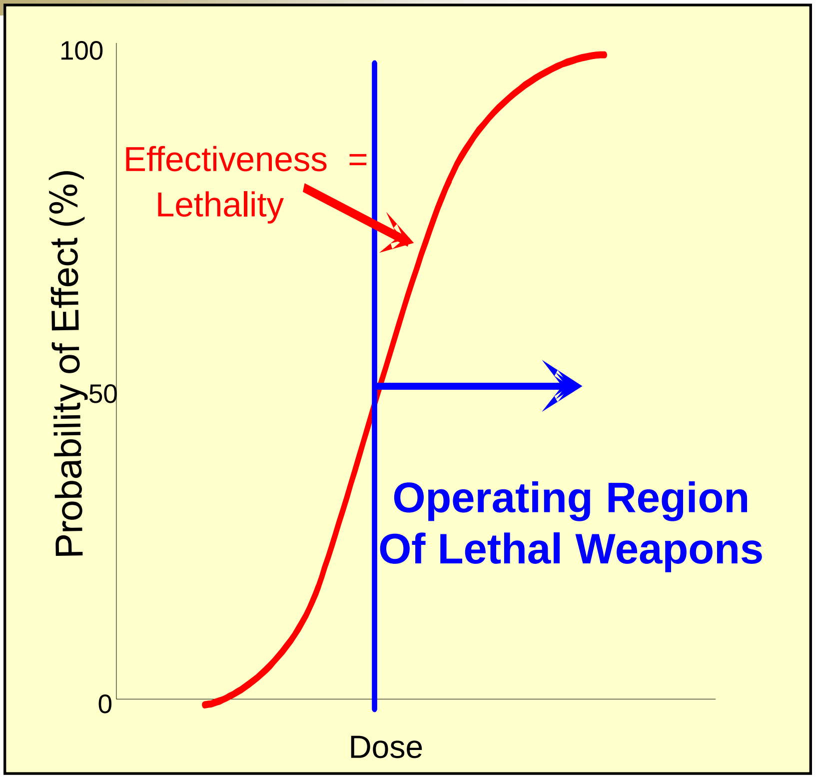
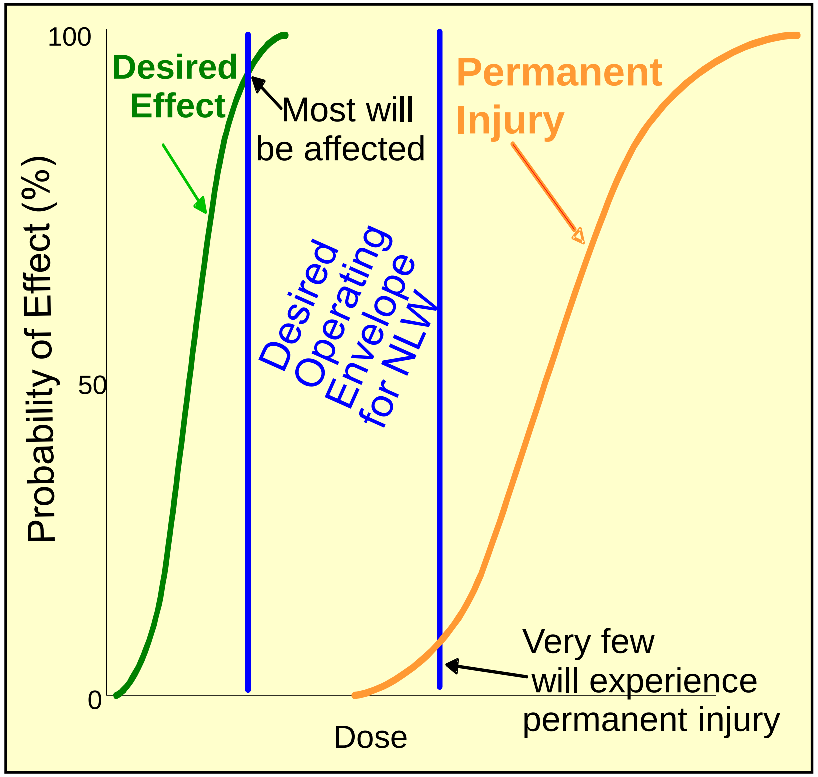
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

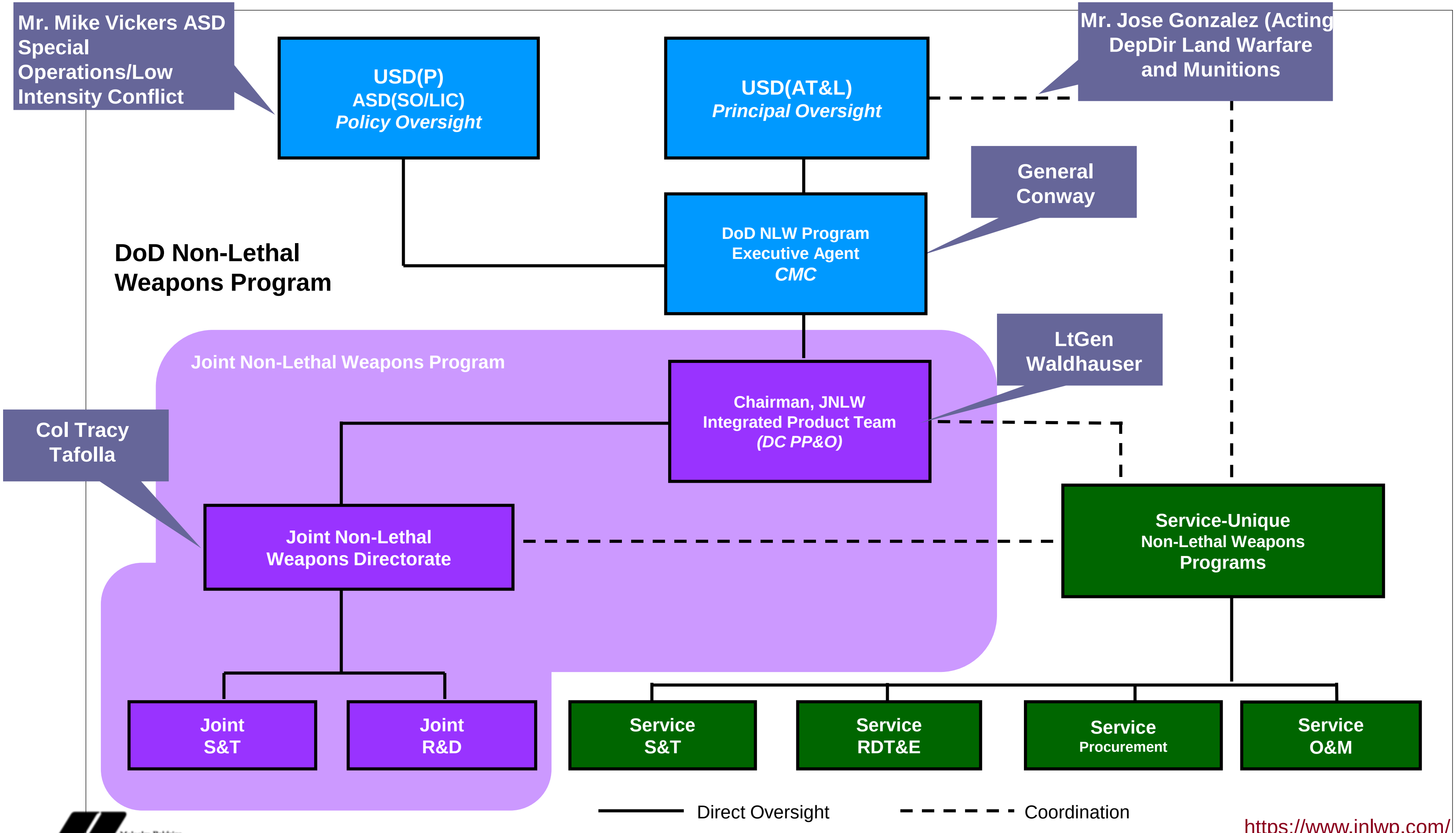
NON-LETHAL HUMAN EFFECTS CHARACTERIZATION





- Non-Lethal Weapons have two competing objectives: cause desired effect, while minimizing permanent injury.
- Understanding human effects is critical for legal/treaty reviews, policy acceptability, and warfighter awareness.
- Human Effects Center of Excellence (HECOE), Brooks AFB, provides human effects models & expertise

DoD NON-LETHAL WEAPONS PROGRAM MANAGEMENT STRUCTURE



https://www.jnlwp.com/

Established by DoDD 3000.3 (1996)

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

U.S. ARMY NON-LETHAL WEAPON PROGRAM ORGAINIZATION

Army Lead for NL Capabilities

The U.S. Army Military Police School* located at Ft. Leonard Wood, MO, has the overall lead for all Army Non-Lethal capabilities and corresponding combat developments and concepts.

Project Manager for Close Combat Systems

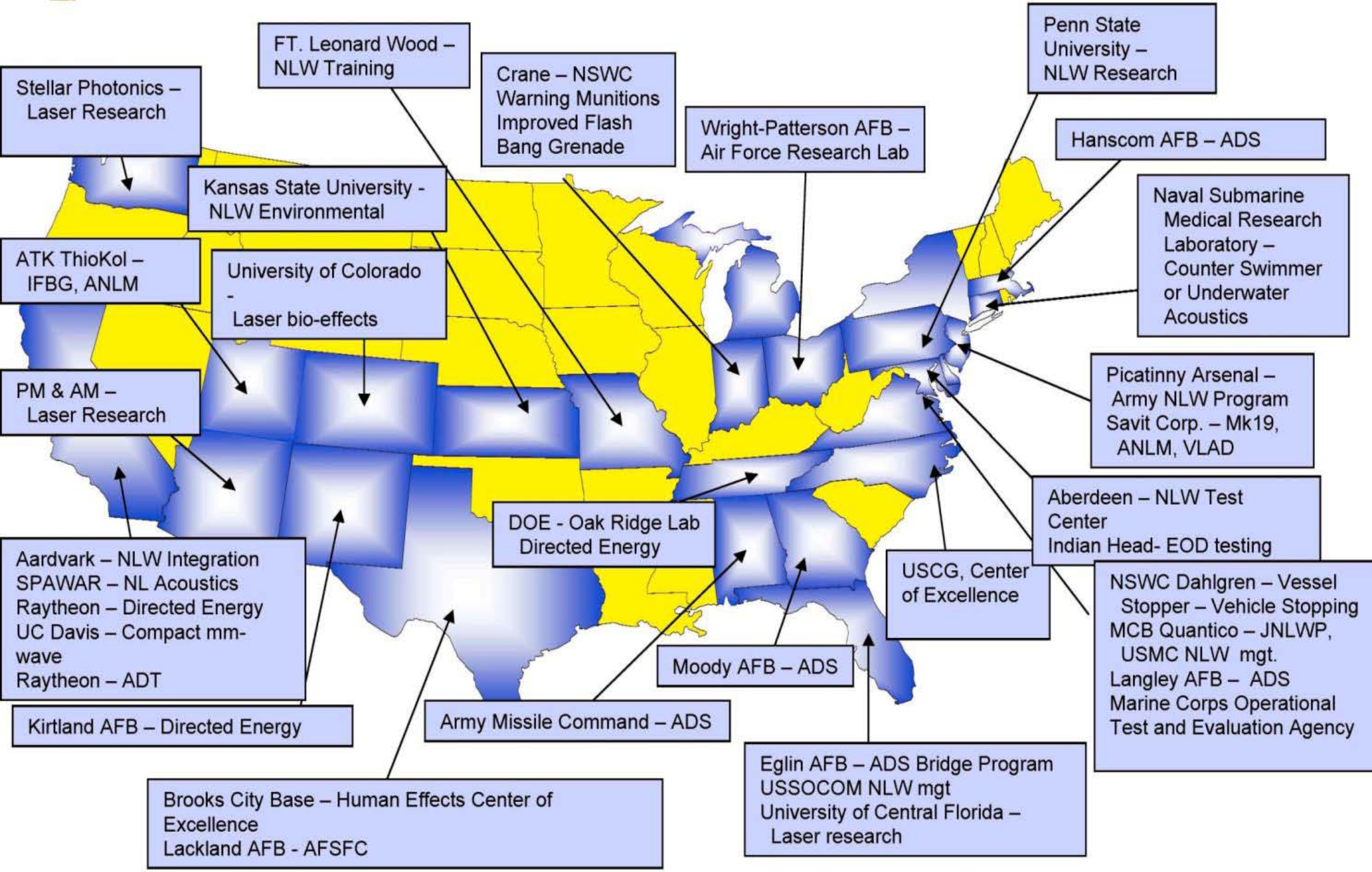
The Project Manager – Close Combat Systems located at Picatinny, NJ, has program management responsibility for Army Non-Lethal Materiel programs, and fielding the Army's Non-Lethal Capabilities Sets.

Systems Manager for Army NL Technology Integration

The Research Development and Engineering Command - Armament, Research, Development and Engineering Center (RDECOM-ARDEC), located at Picatinny, NJ, has responsibility for leading the coordination of Army Non-Lethal Technology integration & development.

* Army Nonlethal Scaleable Effects Center (ANSEC)

DoD NON-LETHAL WEAPONS PROGRAM EFFORTS



DoD NON-LETHAL TECHNOLOGIES

Technology Bins	Vehicle Stopping	Warning Devices	Launcher Systems ⟷	Non-Lethal Munitions
Technologies	• Nets • Spikes • High Power Microwave (HPM) or Radio Frequency (RF) Based • Laser Based • High Voltage Based • Obscurants	• Ocular • Acoustics	• Human Electro-Muscular Incapacitation (HEMI) • NL Capable Launchers • NL Capable Remote Weapon Systems (RWS) • Active Denial Technology	• Blunt Impact • Flash Bang • Air Burst • HEMI • HPM/RF

NL Systems (Examples)

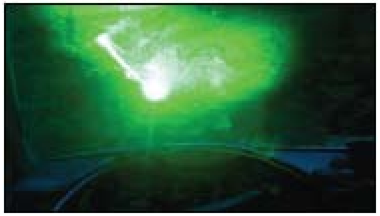
Portable Vehicle Arresting Device

Acoustic Hailing Device

X26 Taser

12 Ga , 40mm & 66mm Munitions, Hand Grenades, and NL “Claymore”

Single Net Solution (SNS)



Green Laser Dazzler effect on driver windshield

FN303

ADS/ADT

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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

AXM1112 AIRBURST NON-LETHAL MUNITION PROJECT OVERVIEW

- The XM1112 Airburst Non-Lethal Munition (ANLM)
  - Provides selective area denial, crowd dispersion, or individual/crowd behavior control capability
    - Two mode operation: proximity & proximity delay
  - The system will provide consistent non-lethal effects & increase range capabilities.
  - The XM1158 proximity fuze enables airburst delivery of NL payloads throughout the operational range

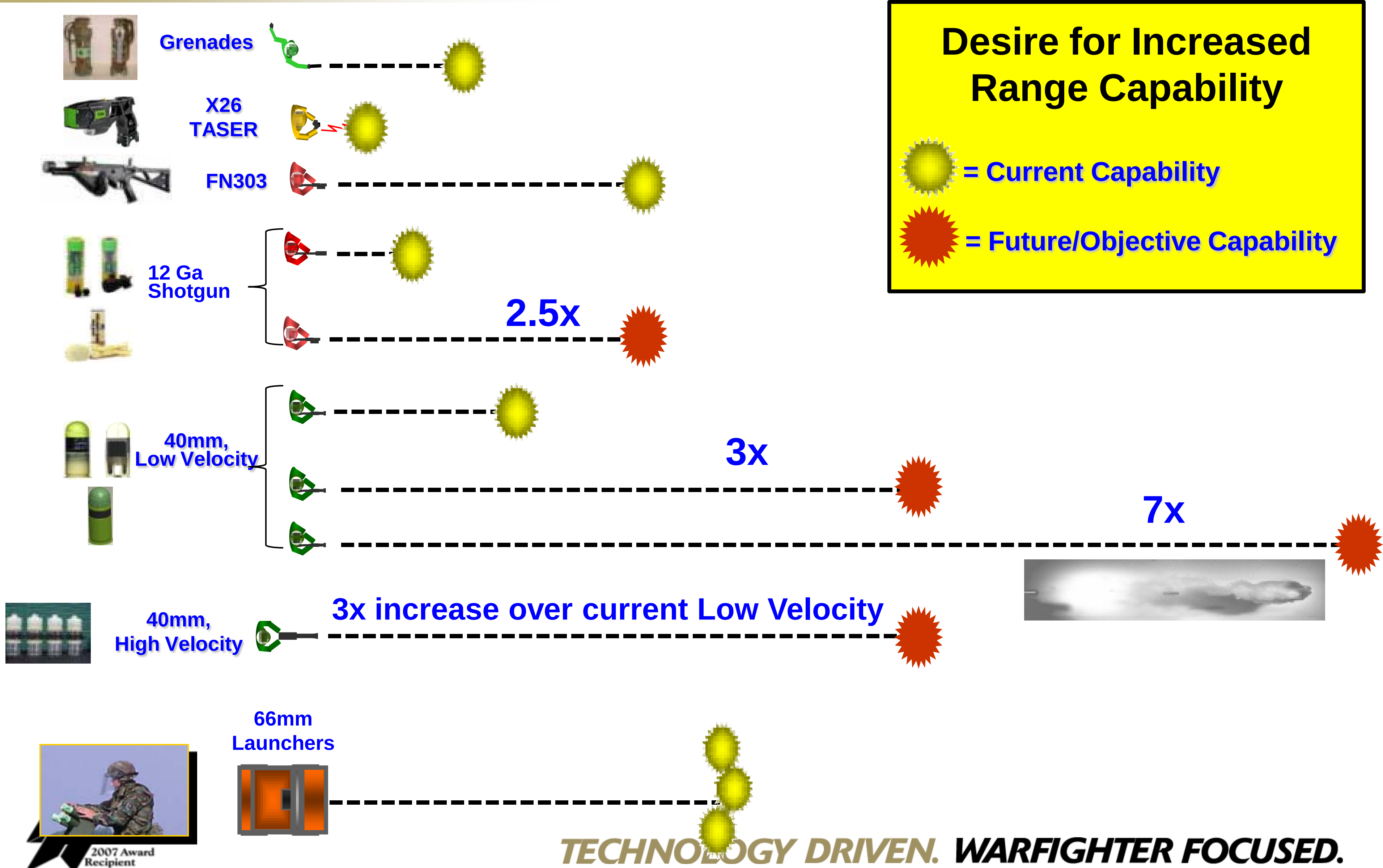
- Program Sponsors
  - DoD Non-Lethal Executive Agent: Joint Non-Lethal Weapons Directorate (JNLWD)
  - U.S. Army PM Soldier Weapons

- The XM1112 Program Management - US Army Lead Service
  - Until MS C - PM Soldier Weapons
  - After MS C - PM Close Combat Systems

ANLM FUZE DESIGN APPROACH

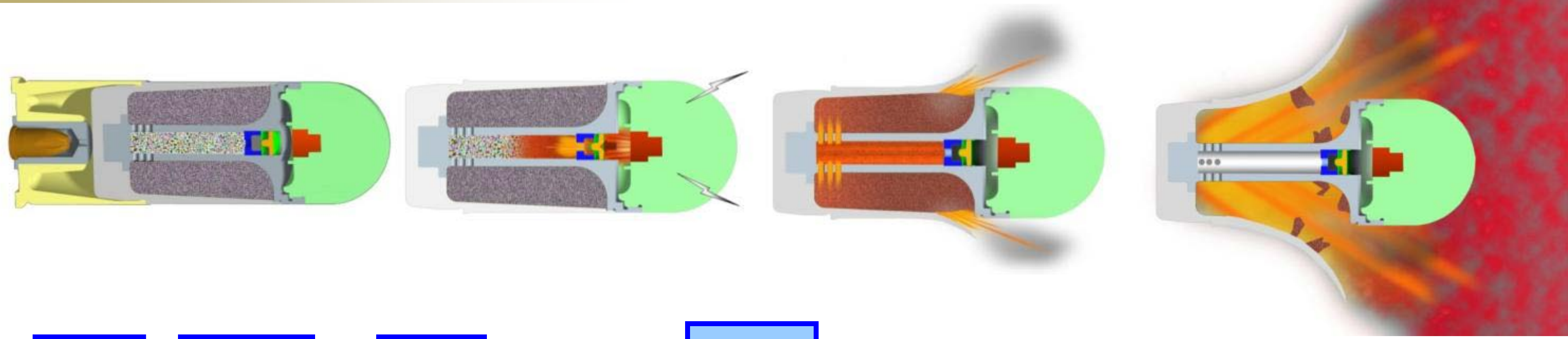
- Emphasis on leveraging existing technologies from other fuzes
  - Proximity technology for use in Direct-Fire scenario (EX433 & M734A1)
  - Existing mechanical S&A – M550
  - Lithium liquid reserve-cell battery
  - Piston actuator
- U.S. Army ARDEC Fuze Division developed, designed, and demonstrated this proximity fuze.
- Transitioned the ARDEC XM1158 Fuze Design in 2008 to Savit Corp for design refinements
- The XM1112 ANLM is the first low velocity 40mm non-lethal munition with a fuze.
  - Consistent standoff distance provides consistent non-lethal effect
  - Munition identified by lime green projectile nose – proposed non-lethal color standard

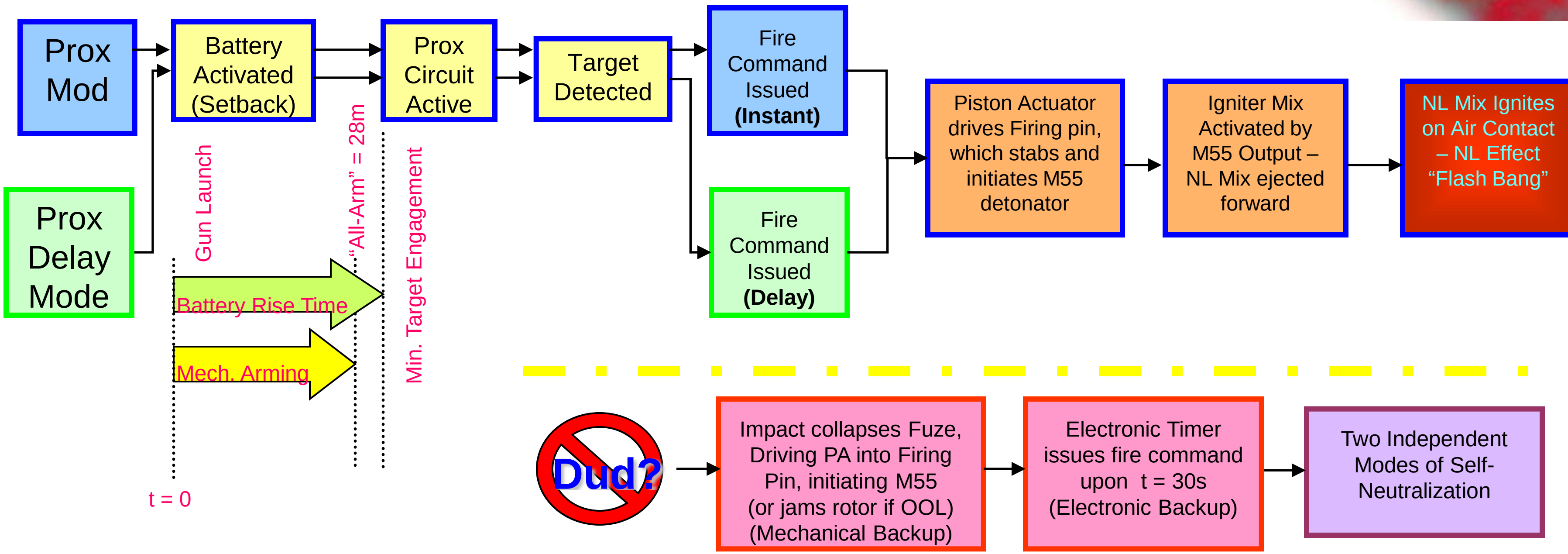
U.S. ARMY NON-LETHAL MUNITIONS MAXIMUM RANGE COMPARISON



XM1158 – 40mm Proximity Fuze – Non-Lethal Fuzing Requirements

ANLM SEQUENCE OF OPERATION





Malcolm Baldrige National Quality Award 2007 Award Recipient

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

NON-LETHAL FUZE REQUIREMENTS

- Non-lethal fuzing requirements are the same as lethal but must take into account additional non-lethal requirements

- Requirements that are the same as lethal munitions
  - Fuze safety to shooter & weapon
    - MIL-STD-1316
    - MIL-STD-1911
  - Munition unique Requirement Document(s)
    - CDD, CPD, etc. - Key Performance Parameter & Key System Attribute

- Requirements that are unique to non-lethal munitions
  - Munition unique Requirement Document(s)
    - P(nle/s) : probability of non-lethal effect per shot
    - Non-lethal effect duration
    - P(RSI) : probability of risk of significant injury
  - Human Effect Center of Excellence (HECOE)
    - Defining non-lethal effect & duration models
      - Different targets will experience different effects
    - Developing non-lethal standard for Risk of Significant Injury
      - Plan Tri-Service Validation

NON-LETHAL OVERVIEW & FUZE REQUIREMENTS SUMMARY

- Non-Lethal Weapons
  - Employed against personnel, material, and capabilities
  - Immediate & reversible effect (temporary disable)
  - Expands military's escalation of force options

- Non-lethal fuze safety requirements are currently the same for lethal applications plus
  - Non-lethal munition unique Requirement(s)
  - Non-lethal standard being developed

- XM1158 Fuze will provide
  - Fuzing to the XM1112 Airburst Non-Lethal Munition
  - Uniform proximity initiation resulting in a consistent non-lethal effect

NON-LETHAL RESOURSES

- DoD Directive 3000.3 - Nonlethal Weapon Policy http://www.dtic.mil/whs/directives/corres/pdf/300003p.pdf
- DoD Joint Non-Lethal Weapons Program https://www.jnlwp.com/
- USAF AFRL Human Effect Center of Excellence (HECOE), Brooks AFB, TX
  https://www.jnlwp.com/future_capabilities/organizations.asp POC:James.Simonds@brooks.af.mil
- US Army Non-Lethal Scalable Effects Center, Fort Wood, MO
  atsjdsn@wood.army.mil, http://www.wood.army.mil/usamps/usamps_non-lethal.htm
- US Army Non-Lethal Weapons, PM CCS, http://www.pica.army.mil/pmccs/D3IEDProtect/D3_2NLCS/Default.htm
- Doctrine: FM 3-19.15, FM 3-22.40, 3-19.1, 3-19.4, 3-19.10, 3-19.11, 3-19.40, AR 190-14 Use of Force, DA Pam 350-38 (STRAC),TRADOC Pamphlet 525-99 (Nonlethal Capabilities in Army Operations)
- NLW Tactical Employment of Nonlethal Weapons, 15 JAN 2003
  FM 3-22.40, MCRP 3-15.8, NTTP 3-07.3.2, AFTTP(I) 3-2.45, USCG 3-07.31
  https://www.us.army.mil/suite/doc/16548186
- TRADOC Pam 525-99 - Concept for NL in Army Ops

Development of Low-Cost, Compact, Reliable, High Energy Density Ceramic Nanocomposite Capacitors

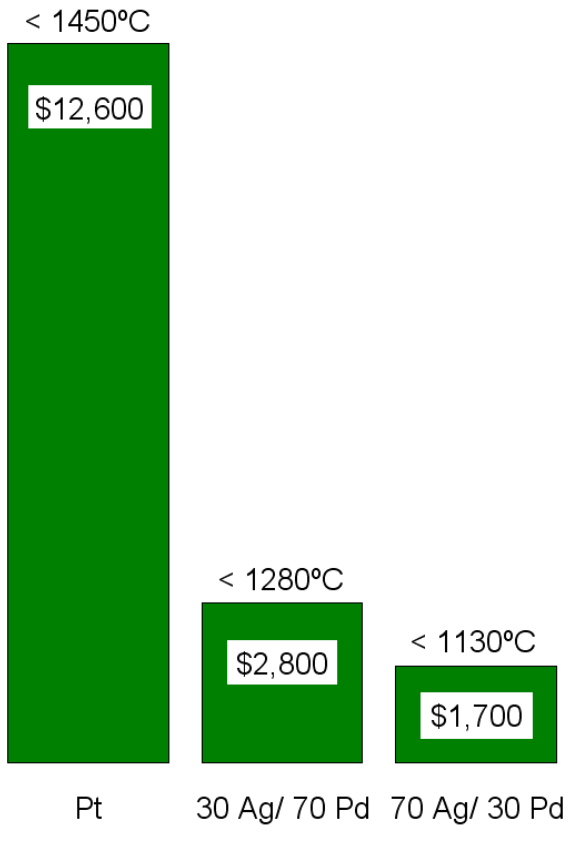
Todd C. Monson, Chris B. Diantonio, Michael R. Winter, Dale L. Huber, Alex W. Roesler, Tom P. Chavez, Tyler E. Stevens, Benjamin D. Fellows, Erika J. Cooley

tmonson@sandia.gov

May, 2010

Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Ceramic Nanocomposite Capacitor Goals



- **More than double energy density of ceramic capacitors (cutting size and weight by more than half)**
- **Potential cost reduction (factor of >4) due to decreased sintering temperature (allowing the use of lower cost electrode materials such as 70/30 Ag/Pd)**
- **Lower sintering temperature will allow co-firing with other electrical components**

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Benefits of Nanocrystalline Dielectrics

Nanocrystalline ceramics show much higher breakdown strength (BDS) compared to coarse grain ceramics ➔ higher energy density

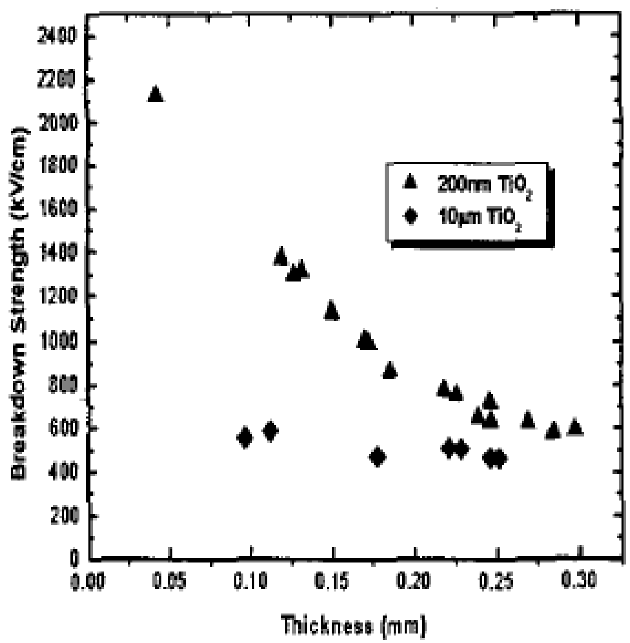

Figure 5. BDS as a function of dielectric thickness for nanocrystalline- and coarse-grained TiO_2.

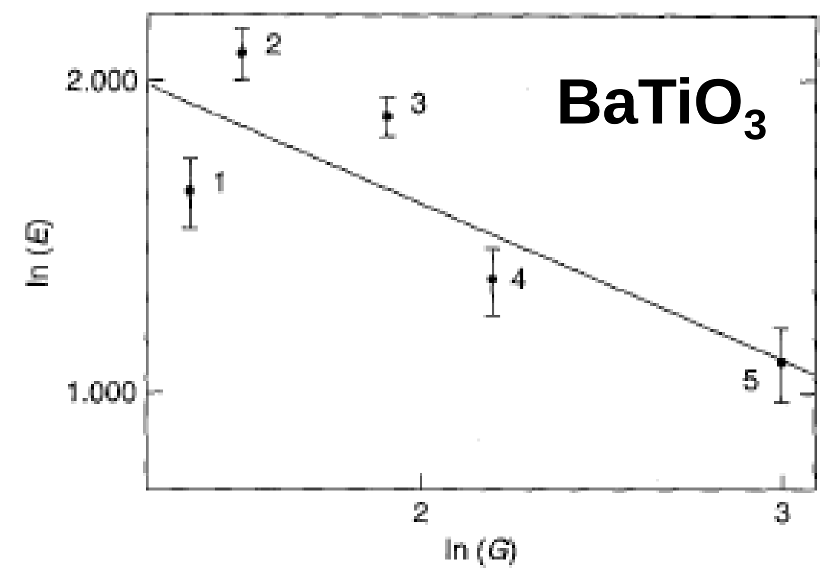

Figure 2 Grain size dependence on dielectric strength. Numbers indicate sintering temperatures: (1) 1320 °C, (2) 1330 °C, (3) 1350 °C, (4) 1380 °C, (5) 1400 °C.

Ye et. al., "Influence of nanocrystalline grain size on the breakdown strength of ceramic dielectrics", 2003

Tunkasiri and Rujijanaul, J. Mater. Sci. Lett. **15** 1767 (1996)

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Benefits of Nanocrystalline Ferroelectrics

- **For ferroelectric (FE) dielectrics, there are additional benefits:**
  - **Permittivity increases with decreasing grain size down to a critical size dimension (higher energy density)**
  - **High frequency performance improves with decreasing grain size (maintain permittivity and low loss to higher frequencies)**
  - **Field dependence of permittivity may improve (i.e. lower voltage coefficient of capacitance or VCC)**

Ying and Hsieh, *Mater. Sci. Eng., B* **138** 241 (2007)

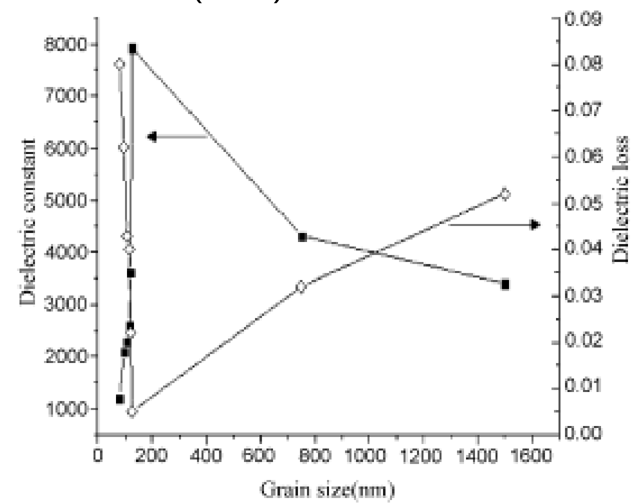


Fig. 7. 1 kHz dielectric constant and dielectric loss vs. grain sizes of nano-$BaTiO_3$ sintered at 1100 °C.

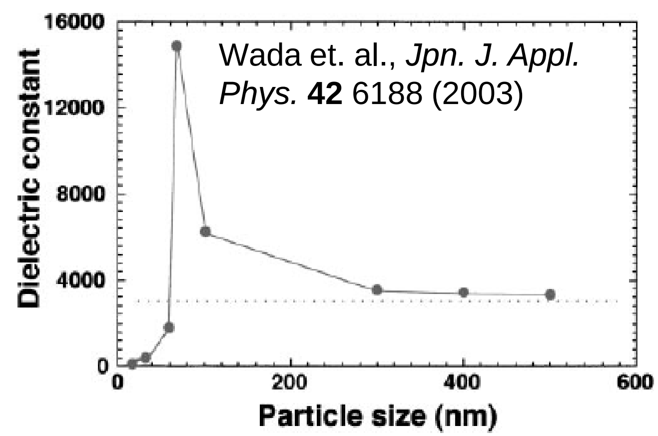


Fig. 15. Particle size dependence of the dielectric constants of the $BaTiO_3$ powders.

Benefits of Nanocrystalline Ferroelectrics

- **Nano-scale grains lose long range ordering**
- **Reduce lattice coupling and hence reduce strain ➔**
- **Better electromechanical performance and increased shot life**

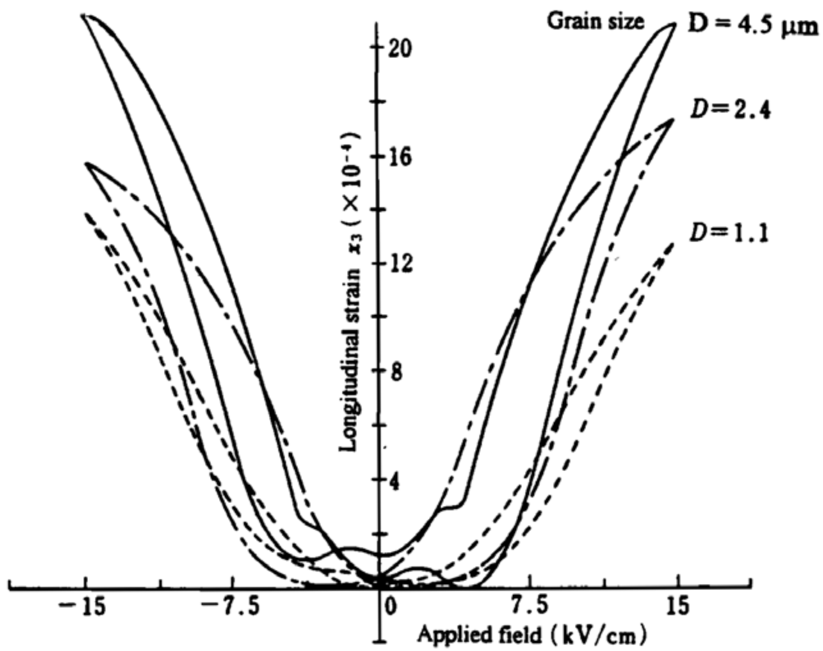
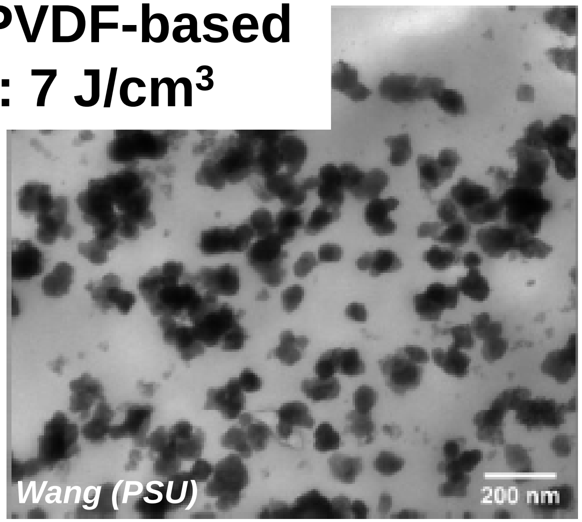


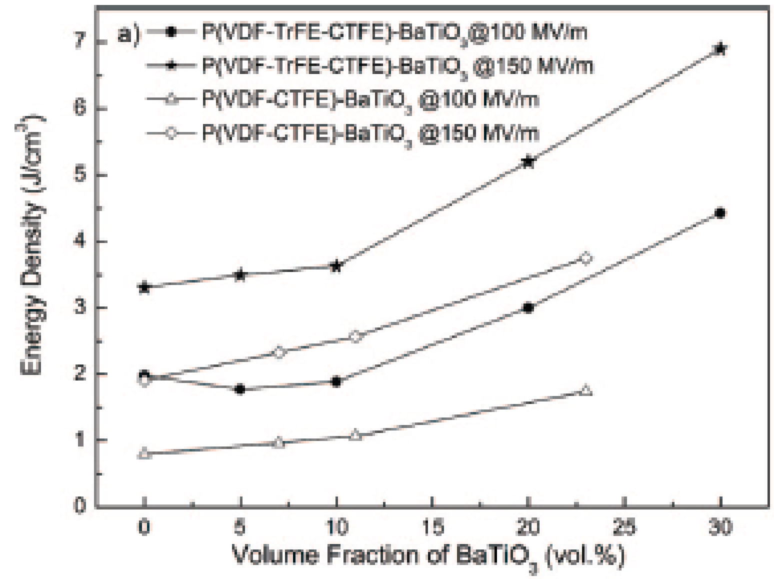
Fig. 3.28 Grain size dependence of the induced strain in PLZT ceramics.

from Kenji Uchino's book, Ferroelectric Devices

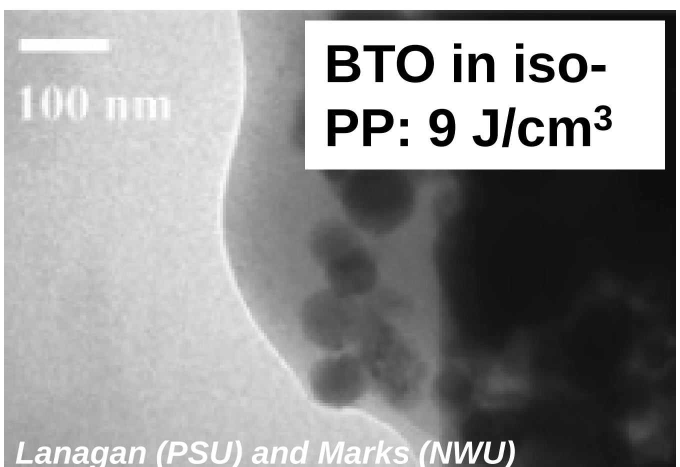
Polymer-Based Nanocomposite Dielectric Films

BTO in PVDF-based polymer: 7 J/cm³





BTO in iso-PP: 9 J/cm³



- **High energy densities demonstrated, but proof of performance in devices is lacking**
- **Low volumetric fraction of the inorganic particles (~ 25-30% loading)**
- **Size effects in ferroics not exploited**

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Ceramic/Glass Nanocomposite Solution

- Greater energy density through higher volumetric loading of the high permittivity dielectric
  - Glass based nanocomposite matrix provides a method for obtaining >90% loading of the nanoceramic ➔ higher energy density

Volume mixing law: $\log \varepsilon = v_1 \times \log \varepsilon_1 + v_2 \times \log \varepsilon_2$

Energy Density: $EnergyDensity = \frac{1}{2}\varepsilon_0 \varepsilon_r E^2$

Assumptions:
10% glass by volume, ε_r=3
90% $BaTiO_3$ by volume, ε_r=8000
➔ ε_{eff} = 3635

Additional Benefits of Ceramic/Glass Nanocomposite Solution

- **Glass matrix should provide better thermal stability than polymer materials for improved TCC (Temperature Coefficient of Capacitance)**
- **Glass phase has been shown to improve electromechanical reliability (higher BDS & shot life)**
  - **Composite structure can support electric fields in excess of 500 V/mil**
- **More robust devices**

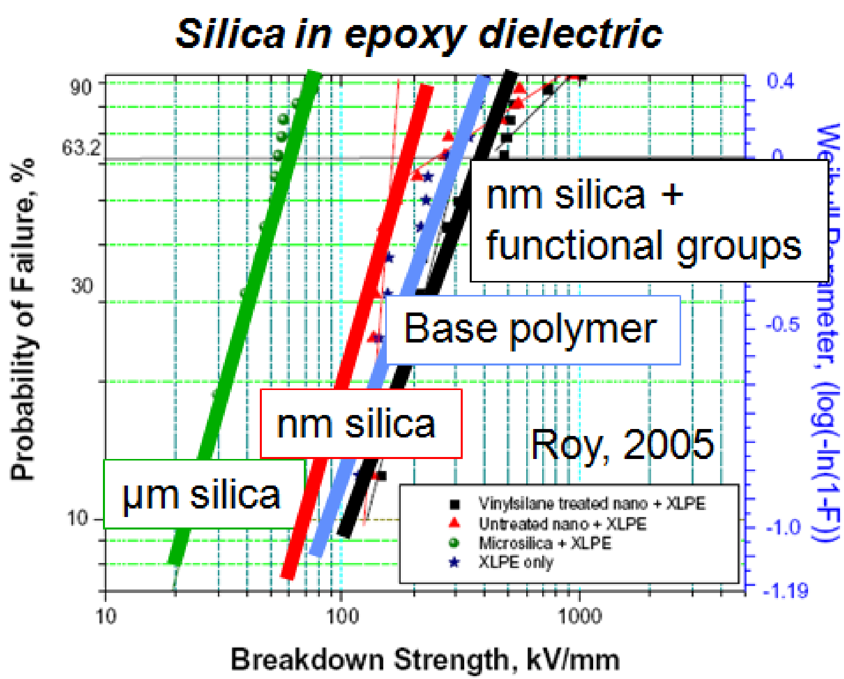
Integration into Multilayer Configuration

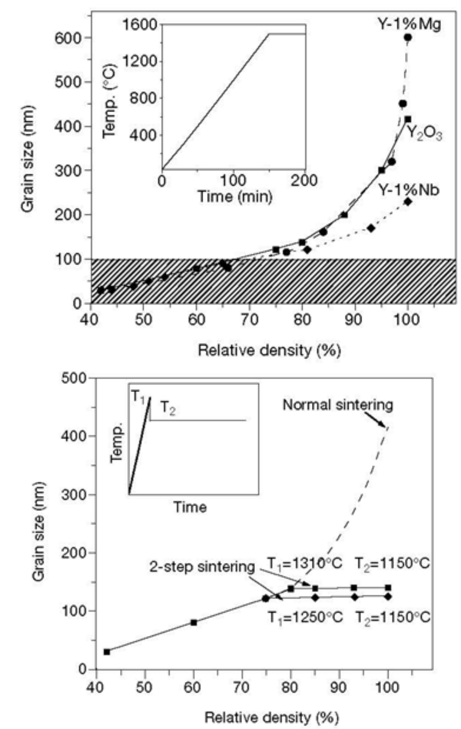
Lab-scale tape casting setup

- **The technology for fabricating multilayer polymer-based nanocomposite capacitors for pulsed energy applications is not mature**
- **This effort uses ceramic tape casting routes for casting, laminating, and firing multilayer parts**

Ceramic Nanocomposite Capacitor Challenges

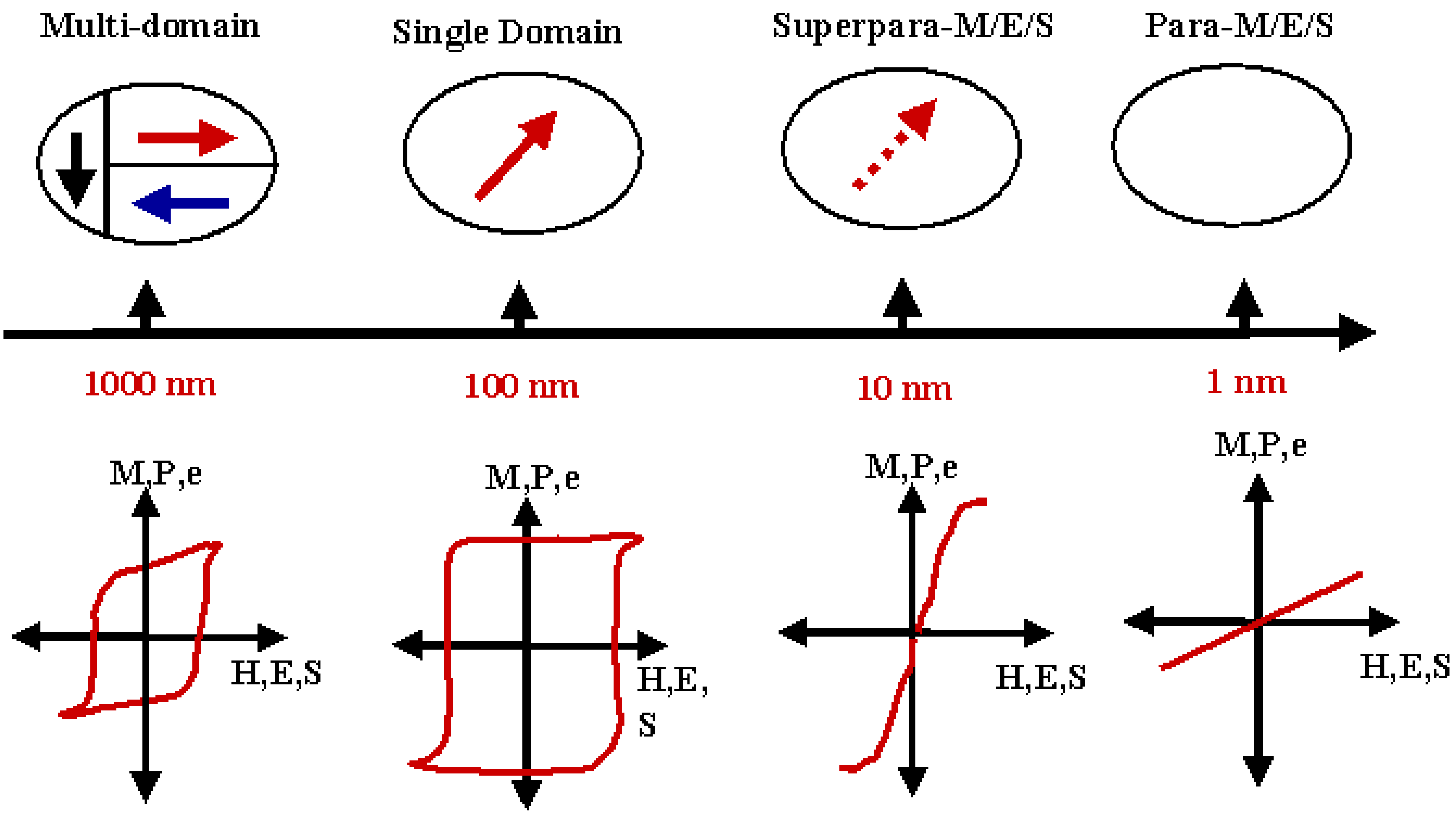
- **Challenges**
  - **Nanocrystalline material synthesis, particle size and distribution**
  - **Processing and forming**
    - **Agglomeration/dispersion, minimizing porosity, high material density**
  - **Suitable and compatible matrix material, maintain desired crystal structure/phase**
  - **Prevent activation of excessive grain growth, maintain nano-sized grains**





Chen, Nature, Vol 404, March 9, 2000

SIZE EFFECTS IN FERROICS (R. E. Newnham, 1992)

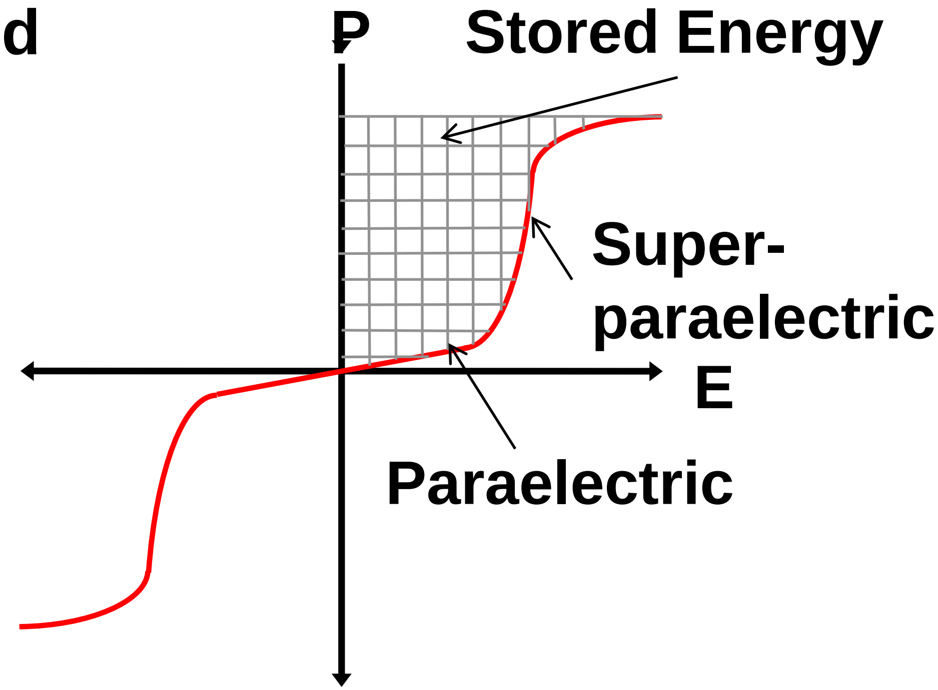


Transitions expected in *Ferromagnetics*, *Ferroelectrics* and *Ferroelastics* as a function of size.....

http://www.rci.rutgers.edu/~ecerg/pp_pres/eka1PHD/sld004.htm

Increased Energy Density Through Phase Transformation

- **Increased energy storage possible through field induced phase transformation**
- **Transition from cubic (paraelectric) to tetragonal (ferroelectric)**
- **Nanoscale ferroelectric domains exhibit superparaelectric effect**
- **Device hysteresis will allow energy densities > 10 J/cc**



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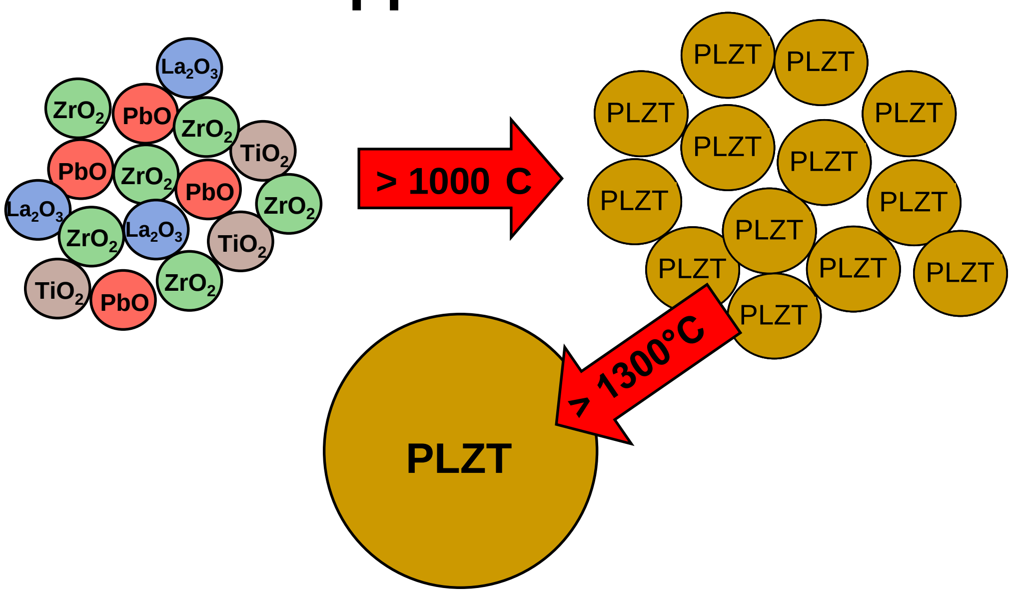
Materials Approach

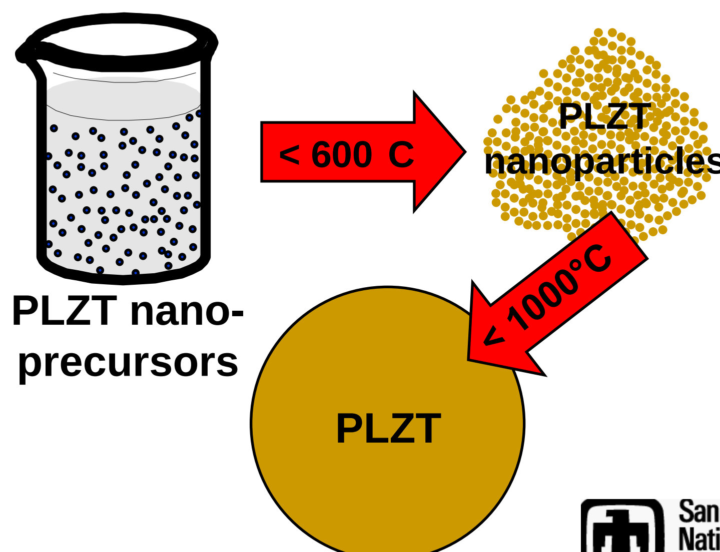
Approach:

- **Synthesize nanoscale precursors for ceramic capacitors using room temperature solution based chemistry**
- **Develop sintering profile for nanoscale precursors and incorporate grain growth inhibitors and/or sintering aids to decrease firing temperature further and improve device performance**

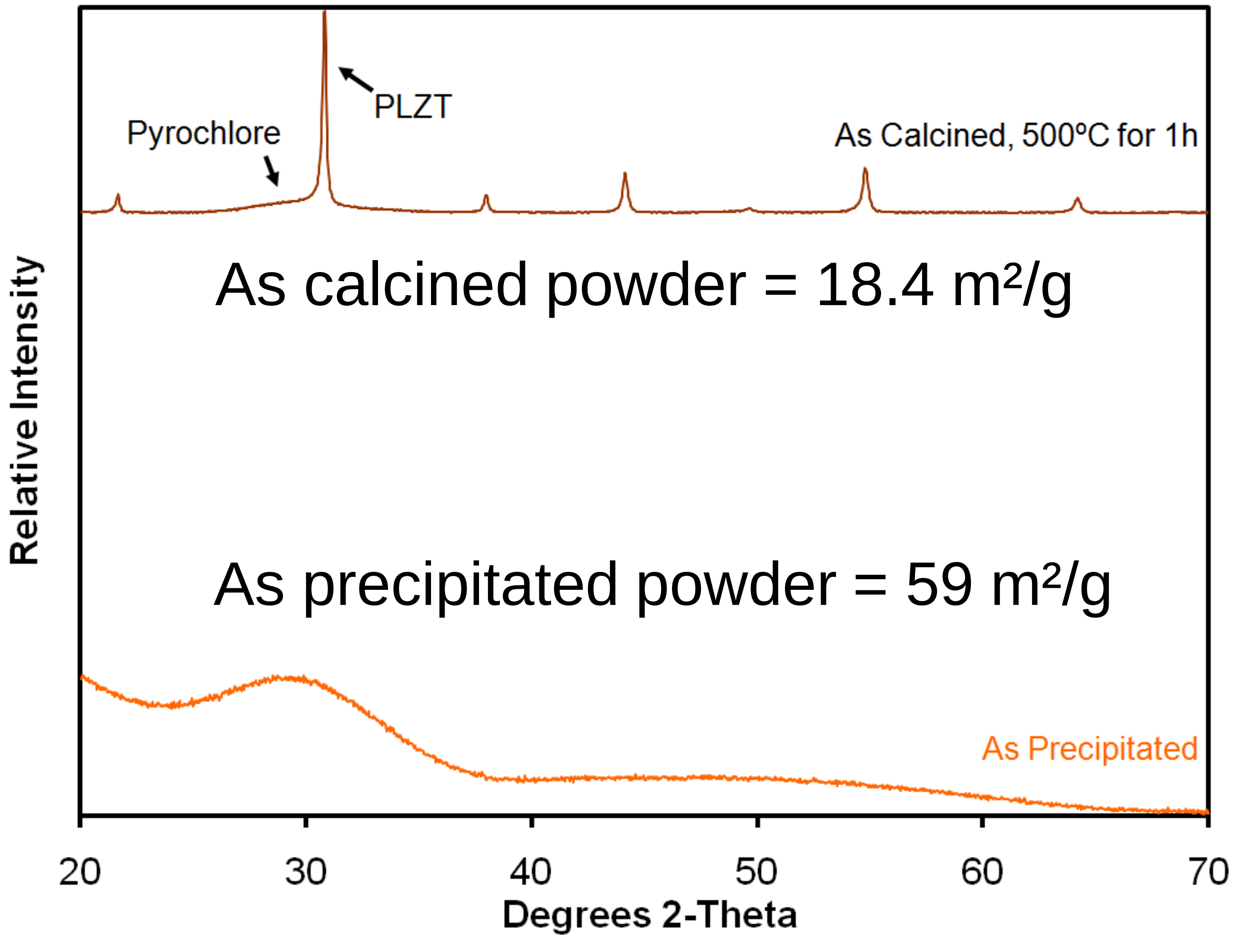
Traditional approach:



Our approach:



PLZT Nanoscale Precursor Synthesis and Calcination



Scherrer equation analysis of XRD data gives a crystallite size of 38.5 nm

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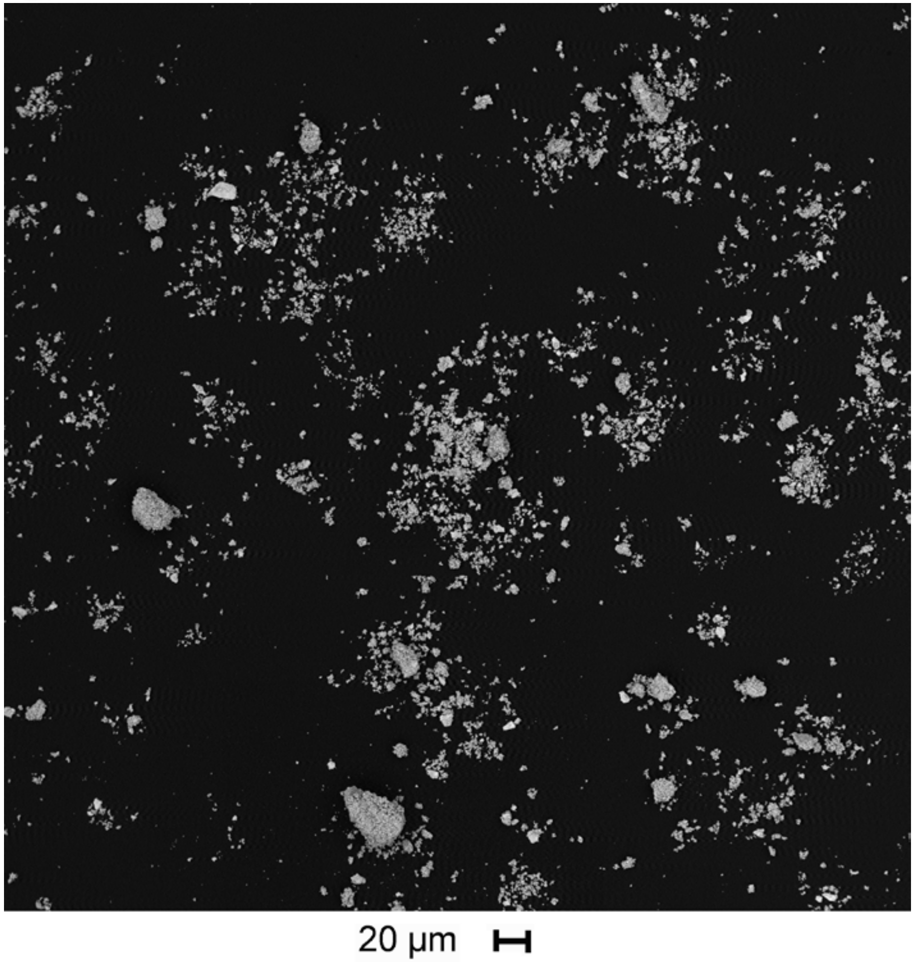
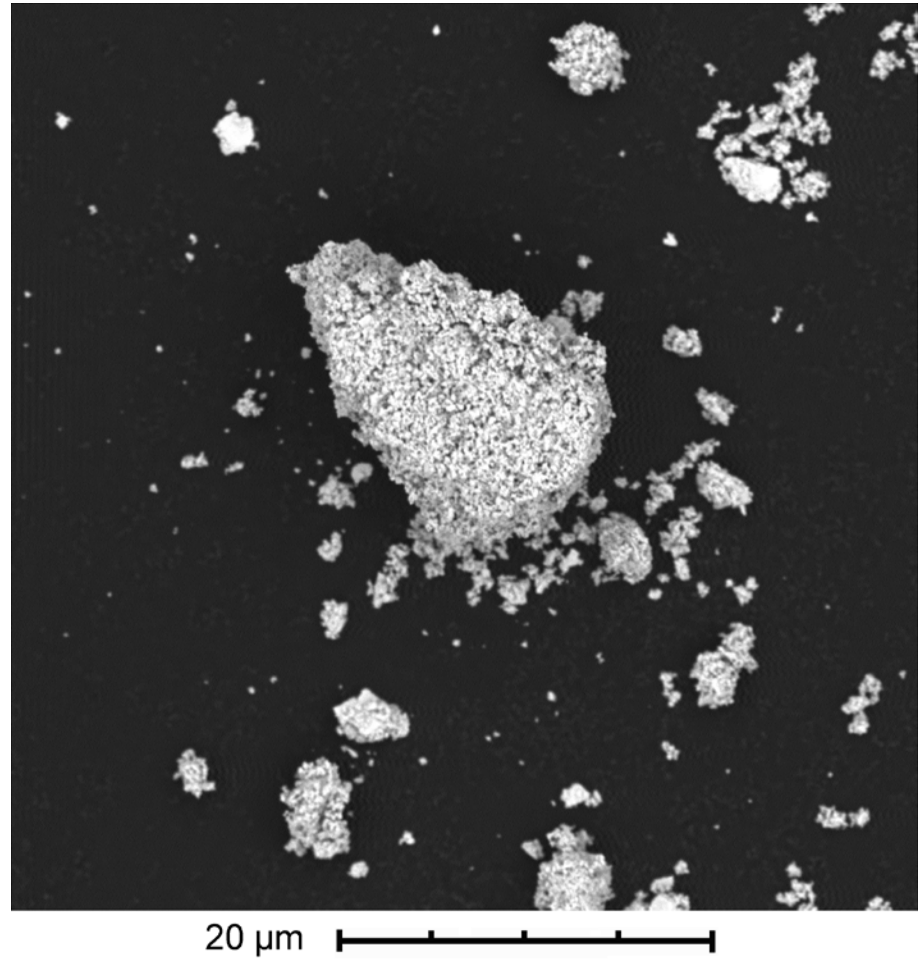
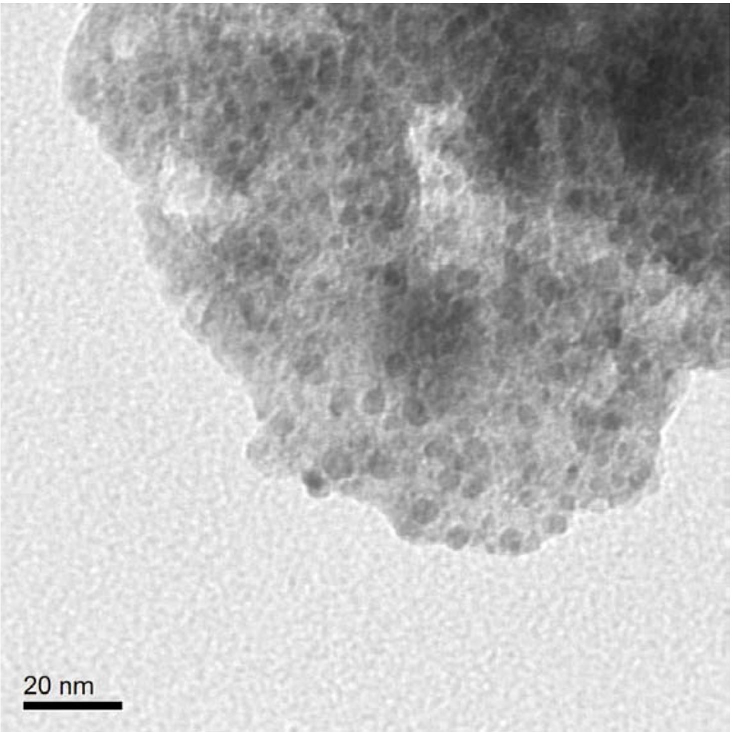
Large calcined particle size, nanoscale crystallite size

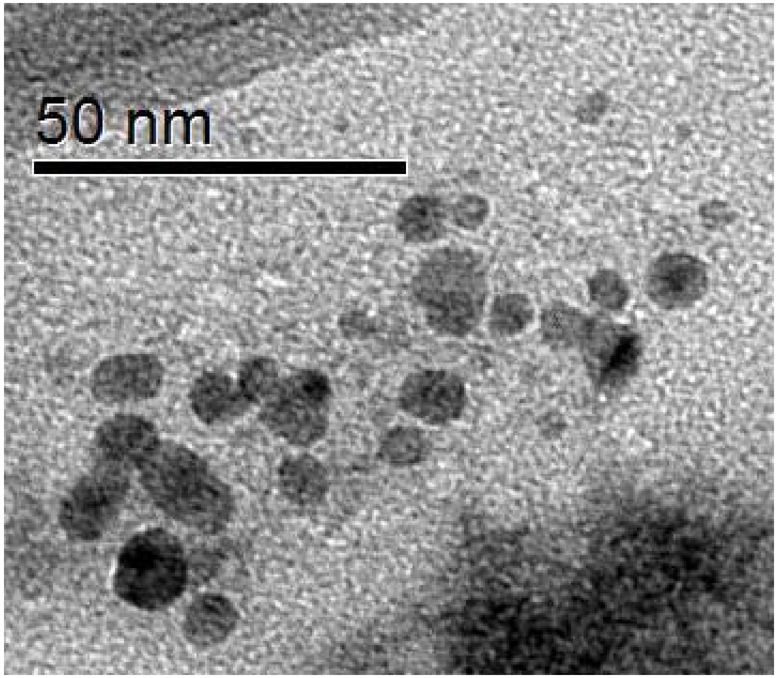




While this result was not anticipated, it may facilitate sample fabrication by easing safety issues

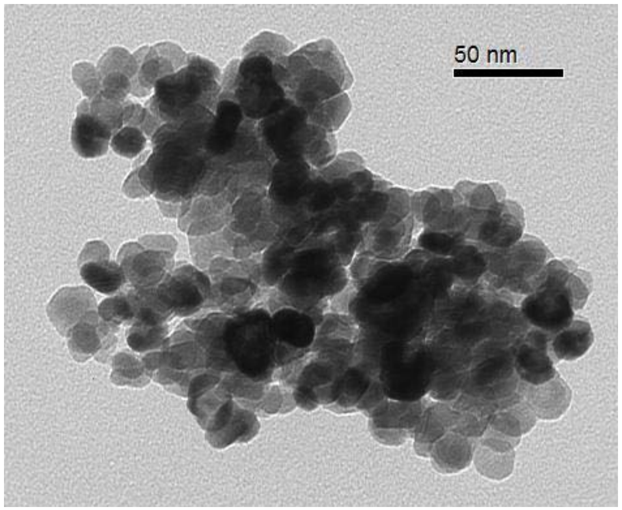
TEM of nanocrystalline grains

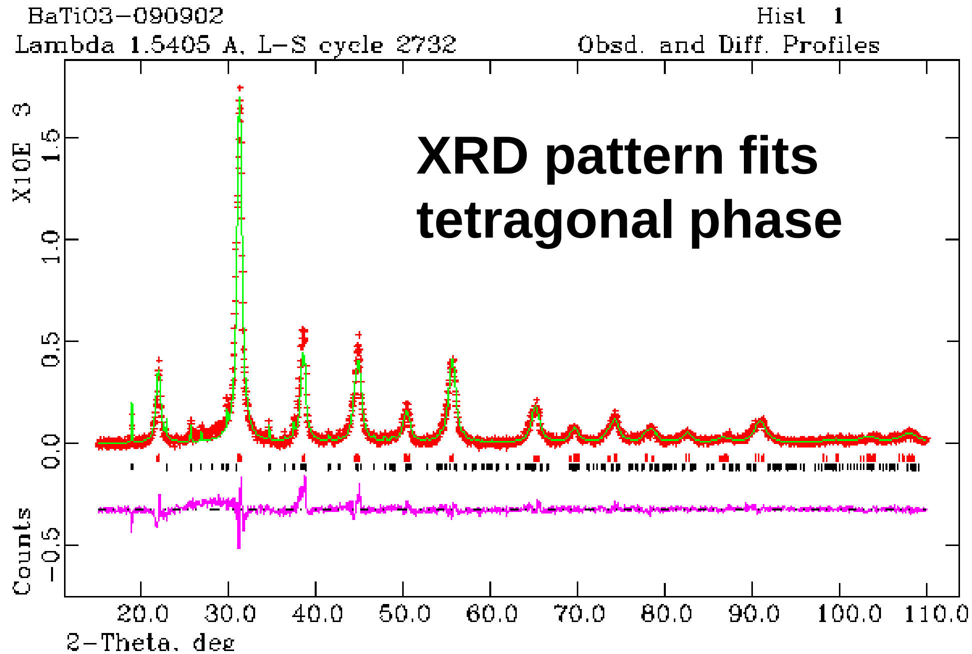




TEM imaging reveals nanocrystalline grains in calcined PLZT

BaTiO$_3$ Nanoparticle Synthesis, Ba(OH)$_2$·8H$_2$O Reagent





- **Ba(OH)$_2$·8H$_2$O and Ti(OPr)$_4$ precursors**
- **Redesigned synthesis using air-free chemistry and with improved control over water addition**
- **Modified synthesis for our dry environment through extra H$_2$O addition**
- **XRD indicates tetragonal phase present when particles synthesized with 0.5 and 0.6 mol H$_2$O**

Yoon et. al., *J. Am. Ceram. Soc.* **90** 311 (2007)

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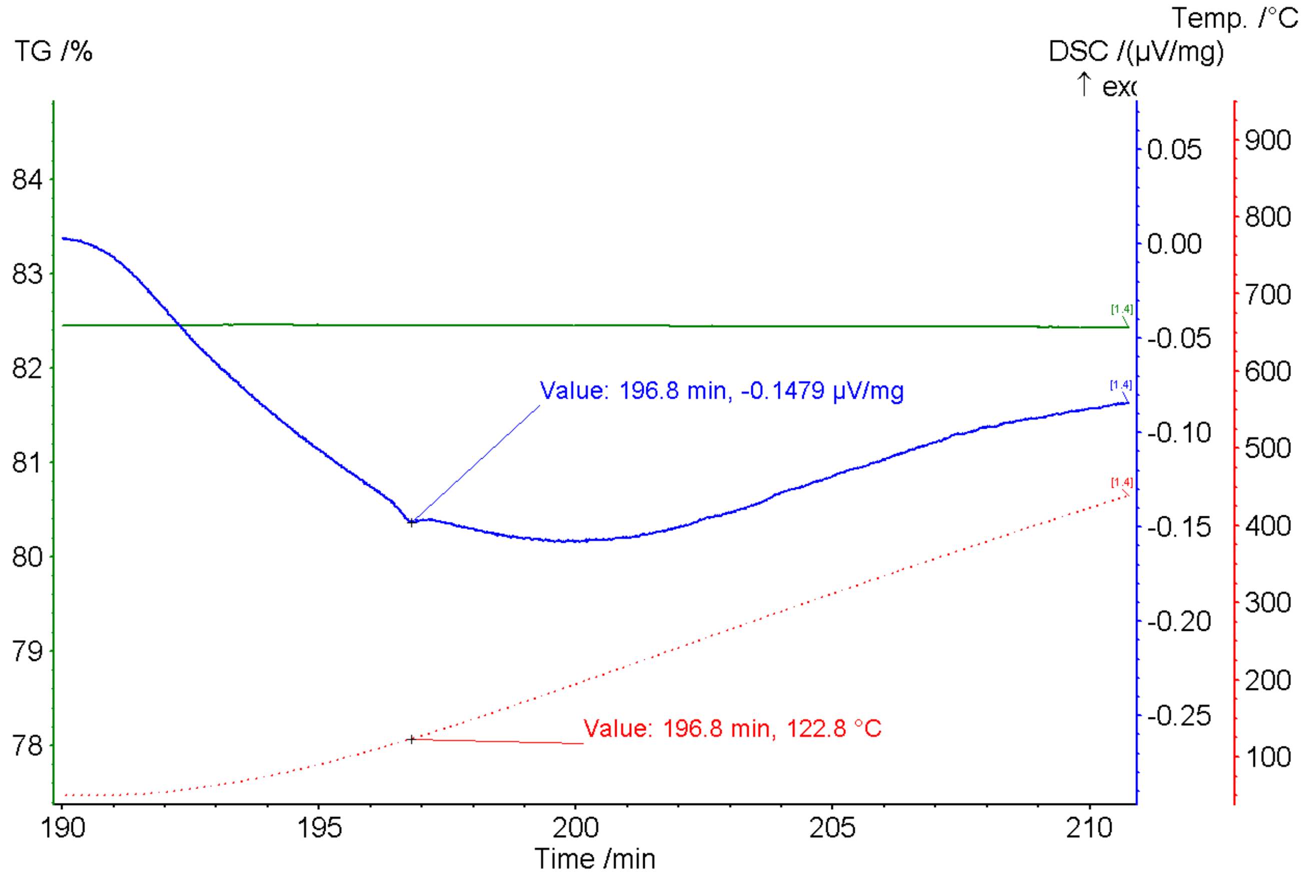
$BaTiO_3$ Nanoparticle Synthesis, $Ba(OH)_2 \cdot 8H_2O$ Reagent



- **Reheated BTO particles after initial cycle to 1300 ˚C**
- **Endotherm at 122.8 ˚C consistent with BTO Curie temp. (tetragonal → cubic phase transition)**

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Conclusions & Future Work

- **Benefits of Glass/Ceramic Nanocomposite Clear**
- **Facilitating first commercialized glass/ceramic nanocomposite**
- **Room temperature, aqueous, scalable syntheses for both PLZT & BTO developed**

Future Work:

- **Device fabrication and electrical testing**
- **Co-precipitate grain growth inhibitors and/or sintering aids on nanoparticle surface (i.e., “core/shell” structure)**
- **Use novel densification approaches (2-step sintering, liquid phase sintering, etc…)**

Acknowledgements

Jean Leger **Don Overmyer**

This work is supported in part by JMP DOE/DoD Technical Coordination Group X

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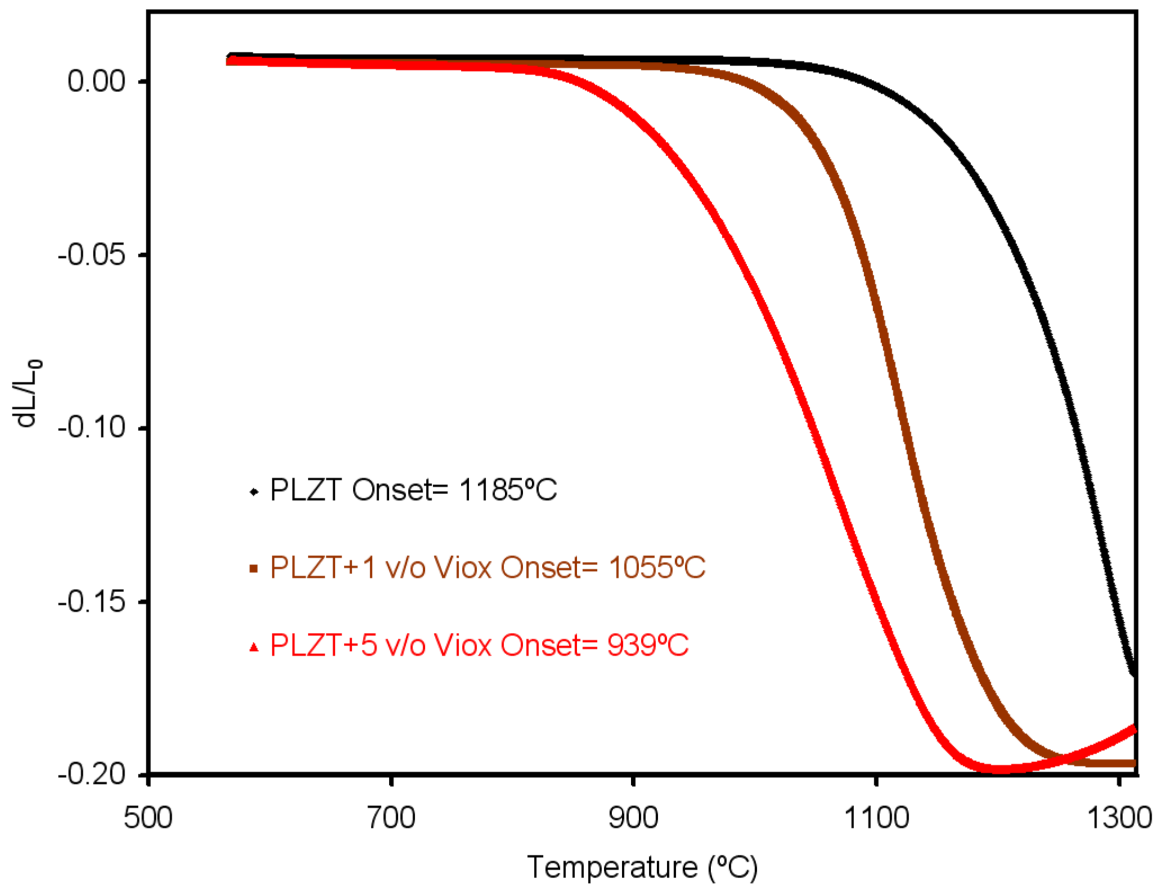
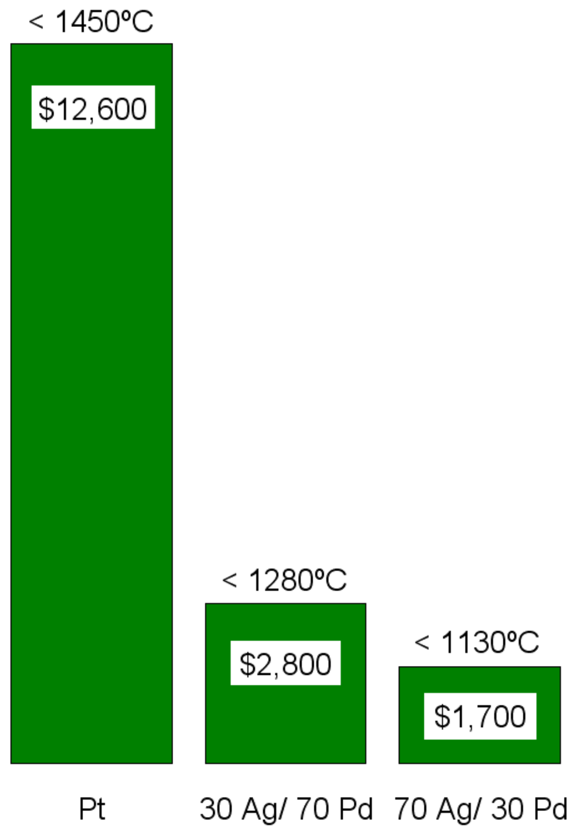
Extra Slides

Glass addition allows the use of a less expensive electrode and reduced lead volatility





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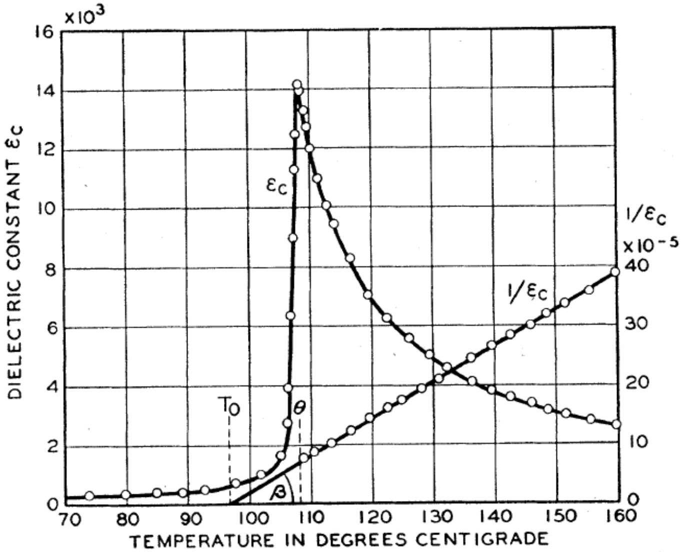
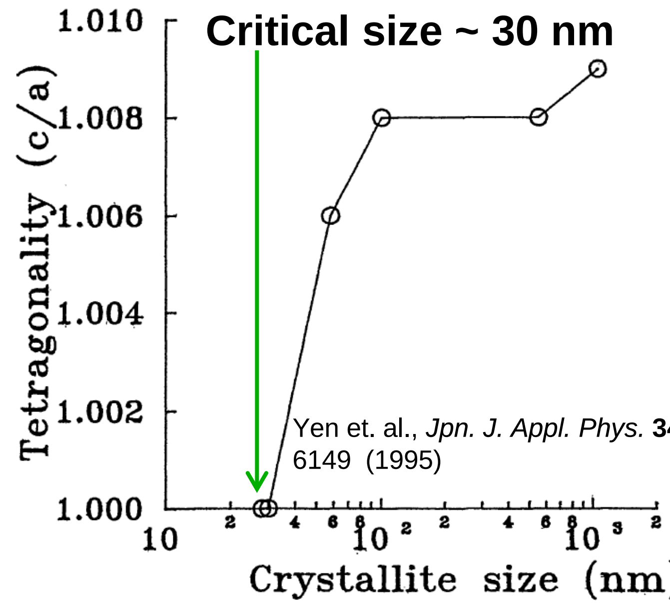
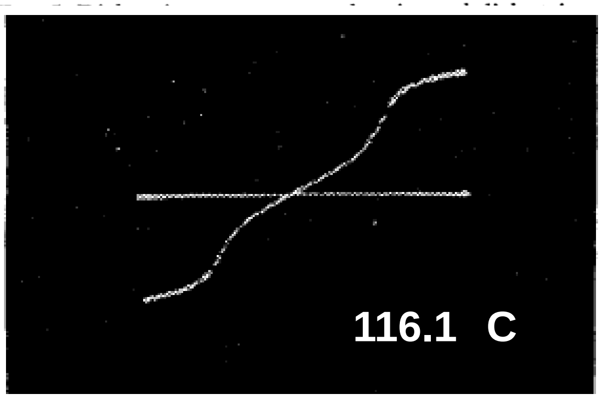
Exploiting Size Effects for High Energy Density Dielectrics

Paraelectric➔Ferroelectric (cubic➔tetragonal) phase transformations can be induced in ferroelectric materials that have lost their spontaneous polarization

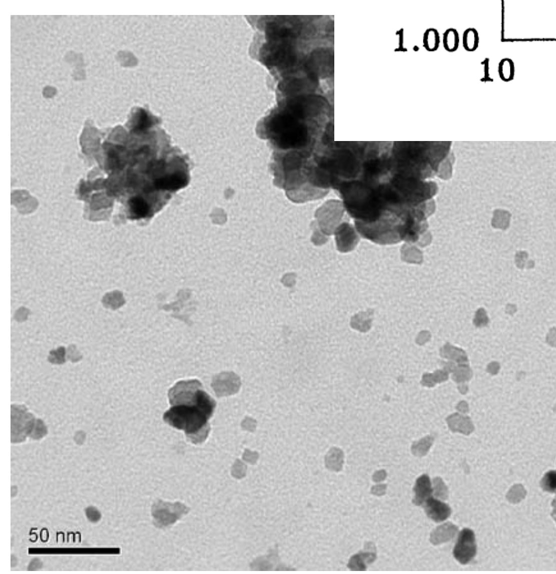


$$KV \approx k_B T$$





Merz, W. J., "Double hysteresis loop of $BaTiO_3$ at the Curie Point", *Phys Rev* **91** 513 (1953)



SNL BTO nanoparticles prepared from chemical synthesis route

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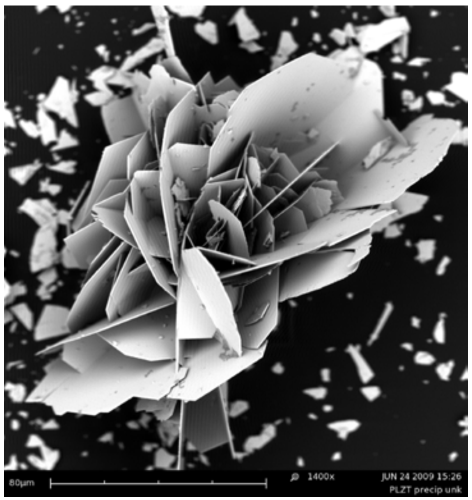
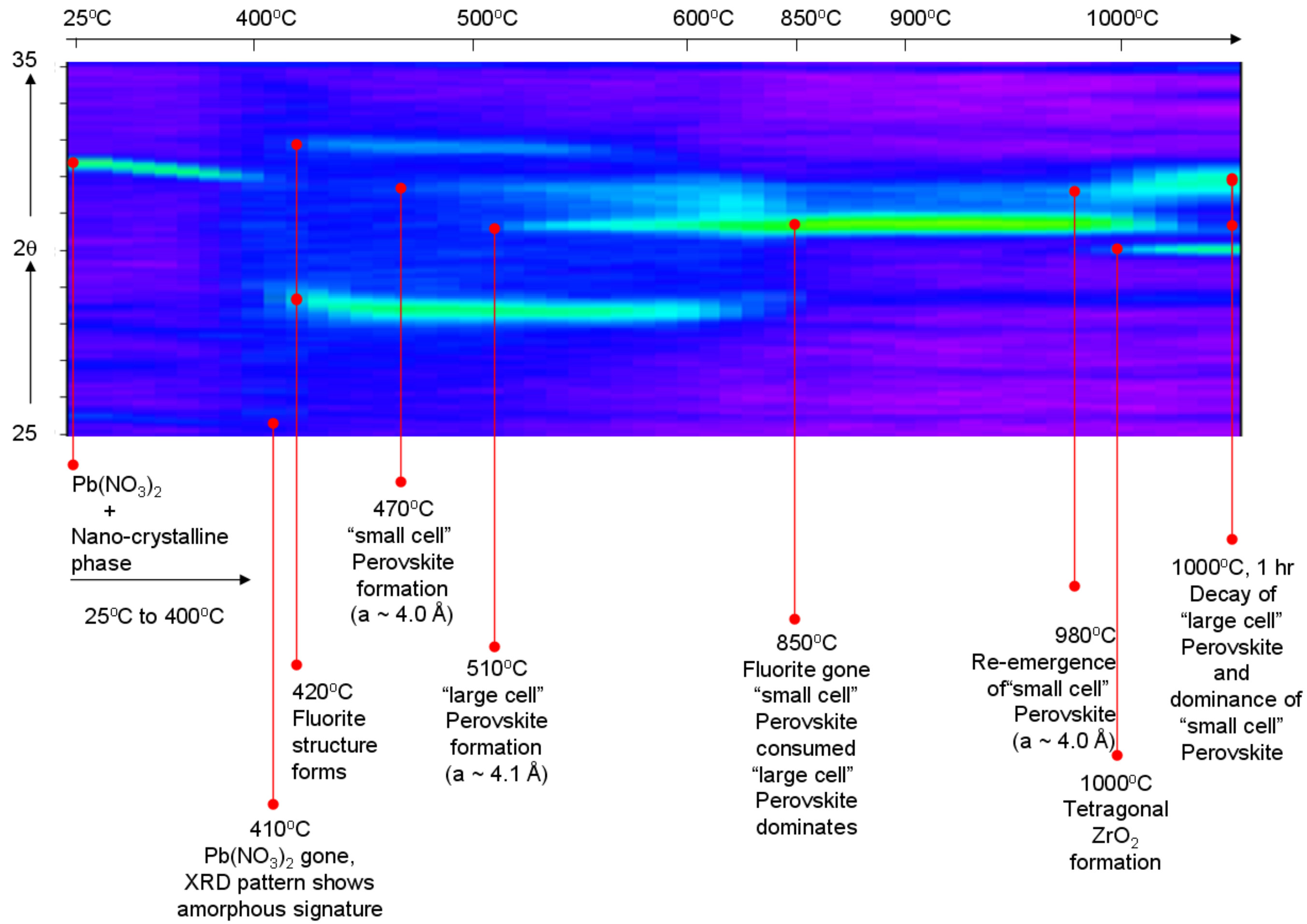
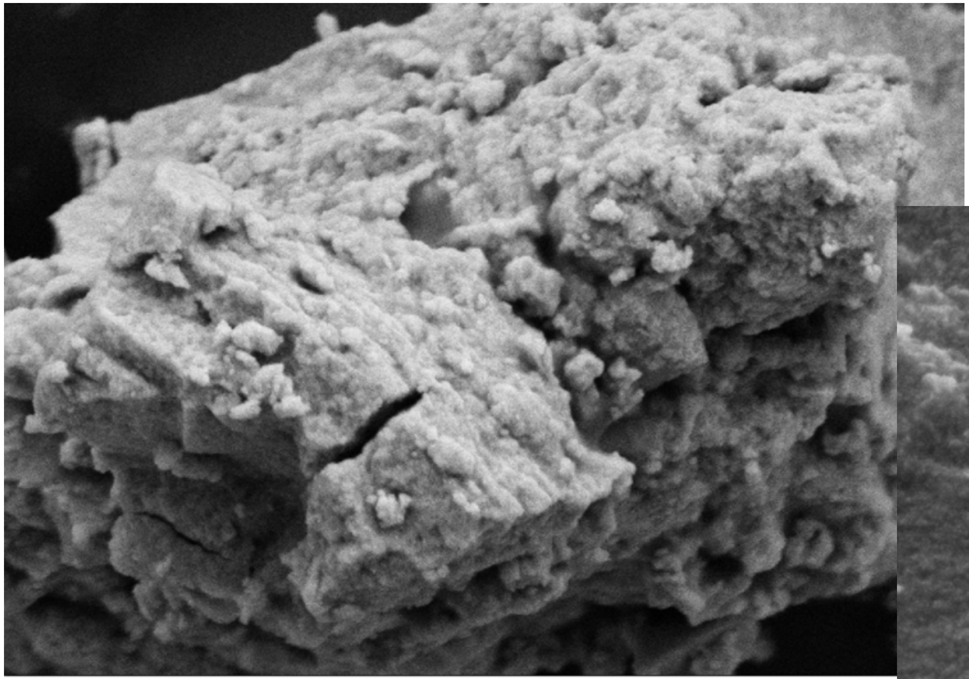
Previous synthesis: variety of phase evolution paths and several intermediate compositions



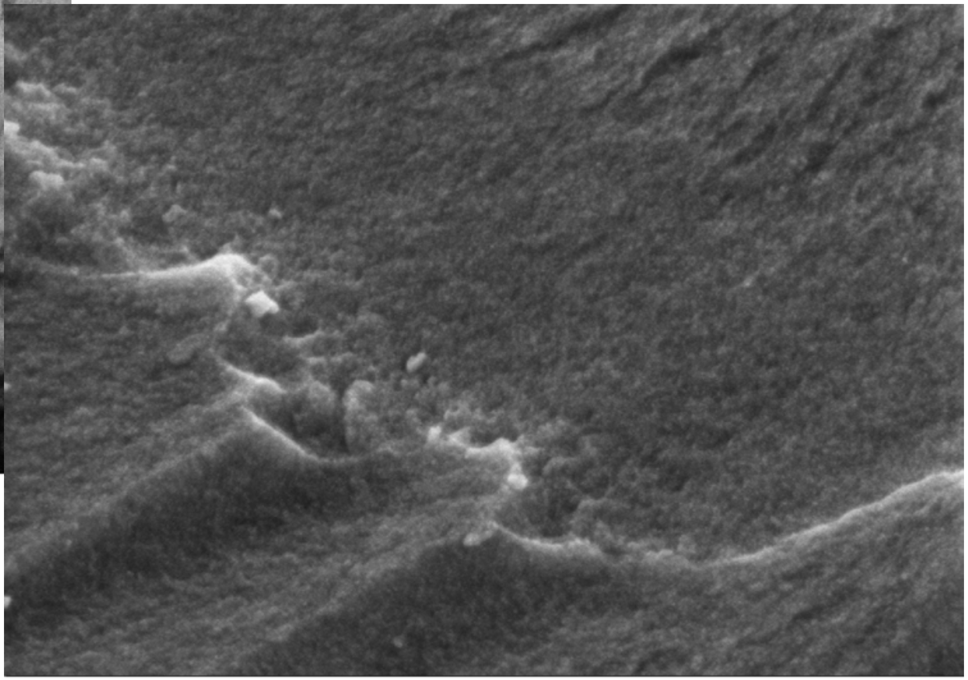


Full understanding of raw materials and better chemistry control allows simplification of the synthesis route

As-dried precipitate shows uniform morphology and no elemental segregation



400 nm



400 nm

Atomic homogeneity is key to achieving a phase-pure PLZT at low calcining temperatures

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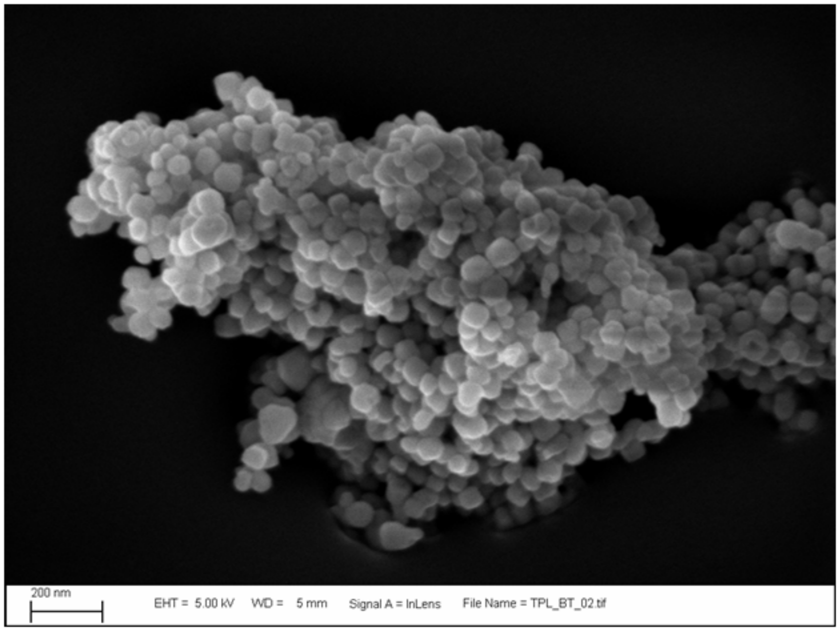
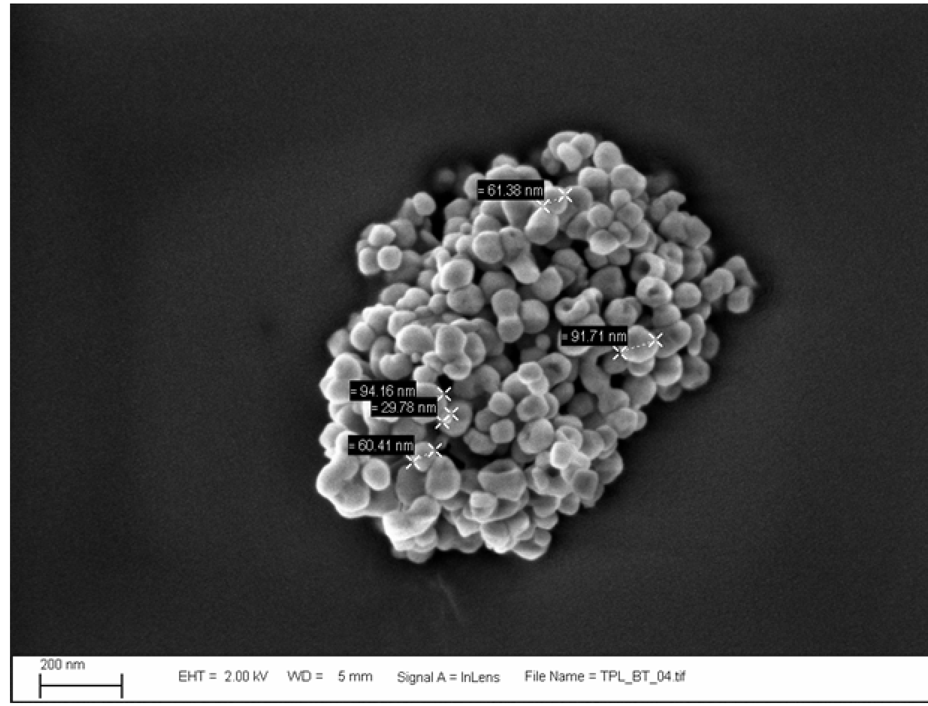
$BaTiO_3$ from TPL





- **NanOxide HPB-1000 from TPL**
- **BET surface area of 16.26±0.0669m^2/g**
- **Attrited to BET surface area of 18.65±0.0459m^2/g**

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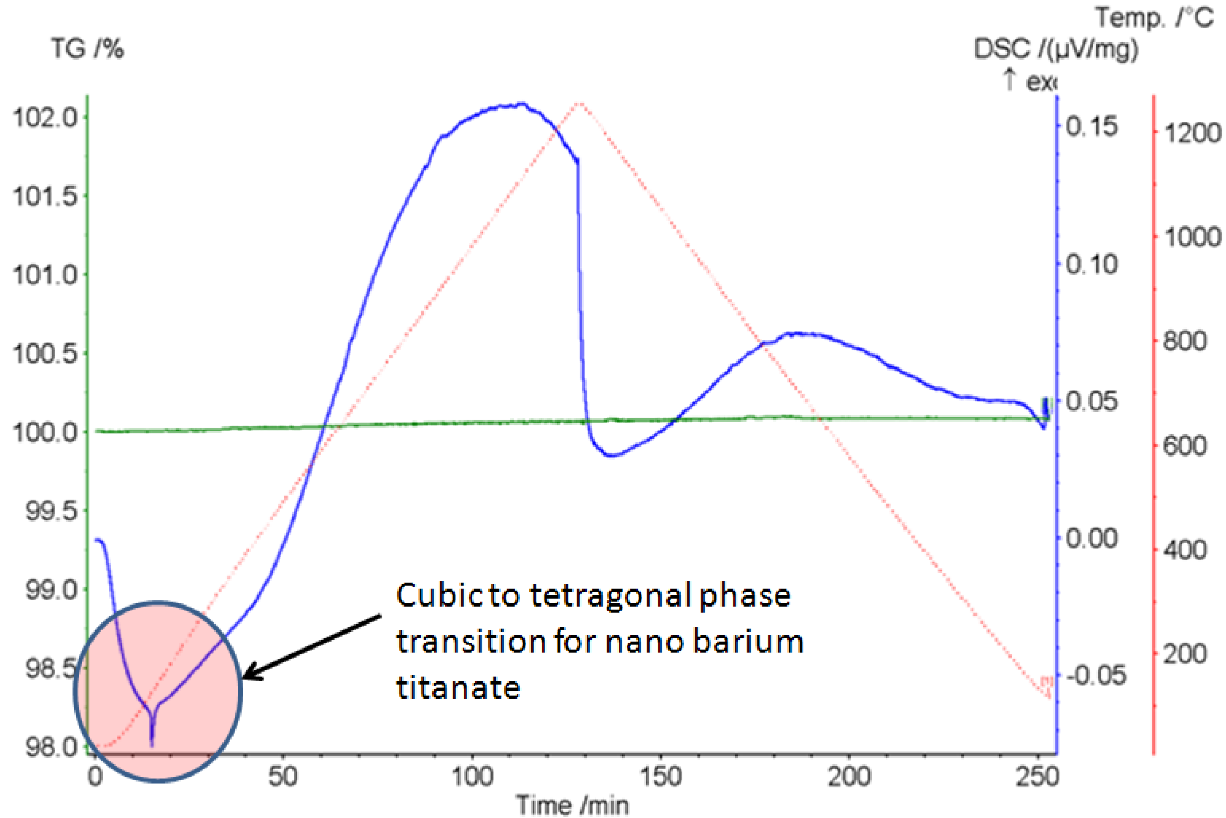
$BaTiO_3$ from TPL



- **Simultaneous thermal analysis (STA)**
- **Cubic to tetragonal phase transition is apparent for calorimetric results (DSC or differential scanning calorimetry)**
  - **Phase transition only visible after heating to 1300°C**

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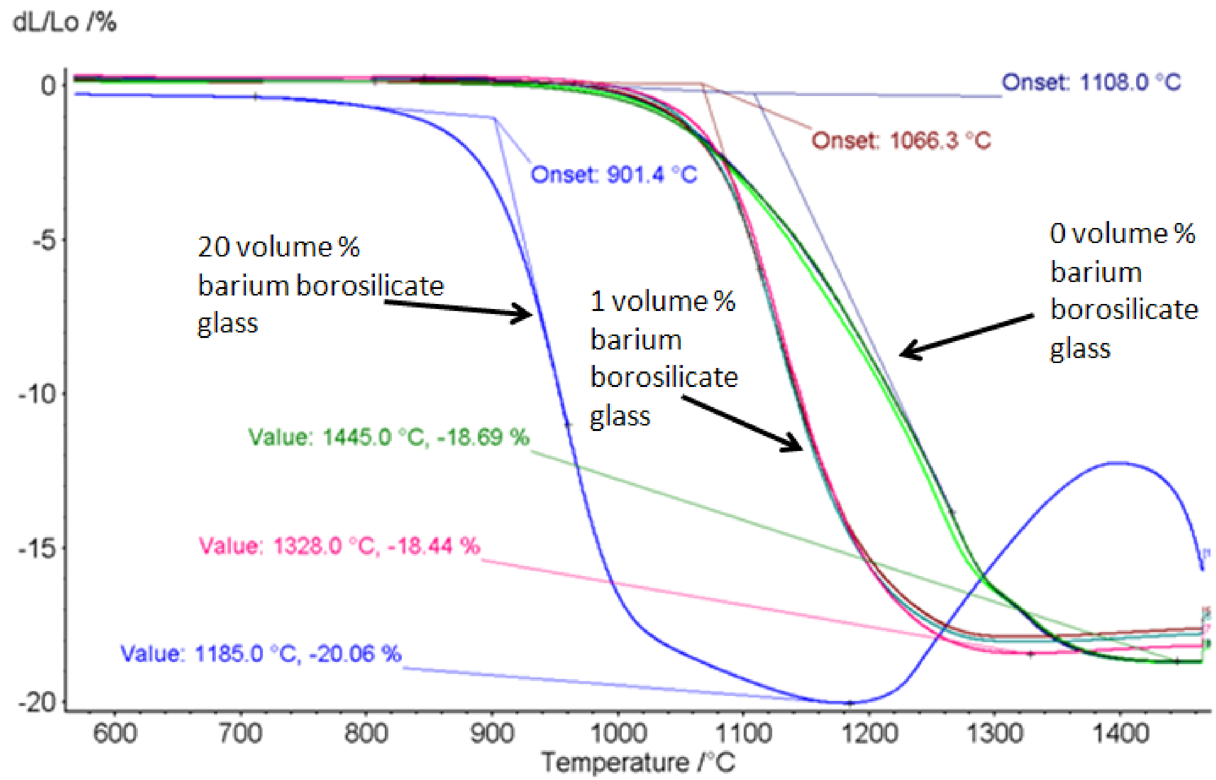
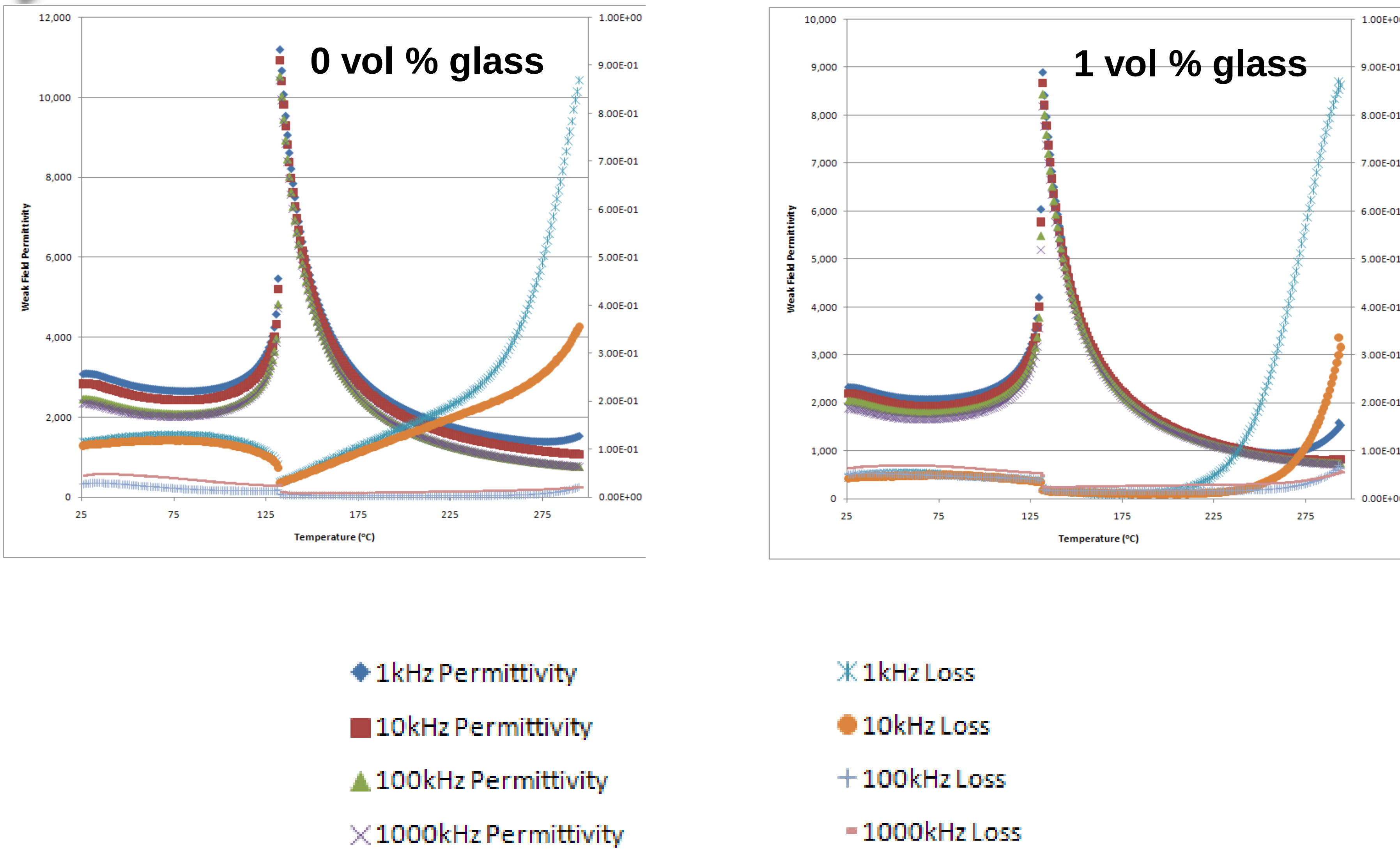
$BaTiO_3$ Nanocomposite Devices

Dilatometer sintering results



- **Sintered TPL nano-BTO pellets from 0 - 20 vol% borosilicate glass loading**
  - **Sintering temp. reduced by almost 300°C through glass addition**
  - **Sample porosity also appears to decrease**

$BaTiO_3$ Nanocomposite Weak-Field Analysis



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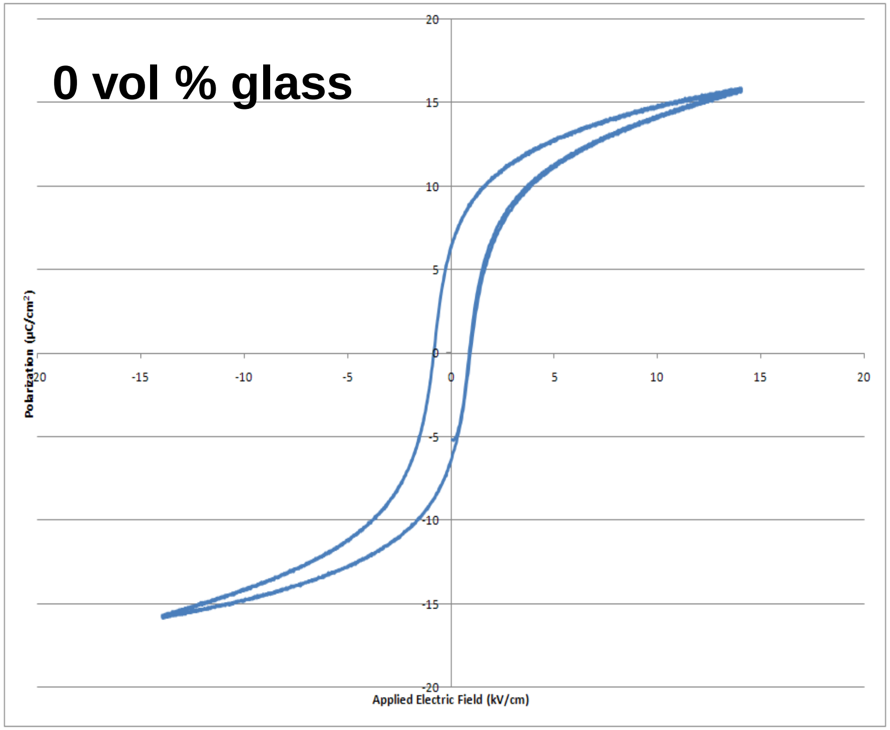
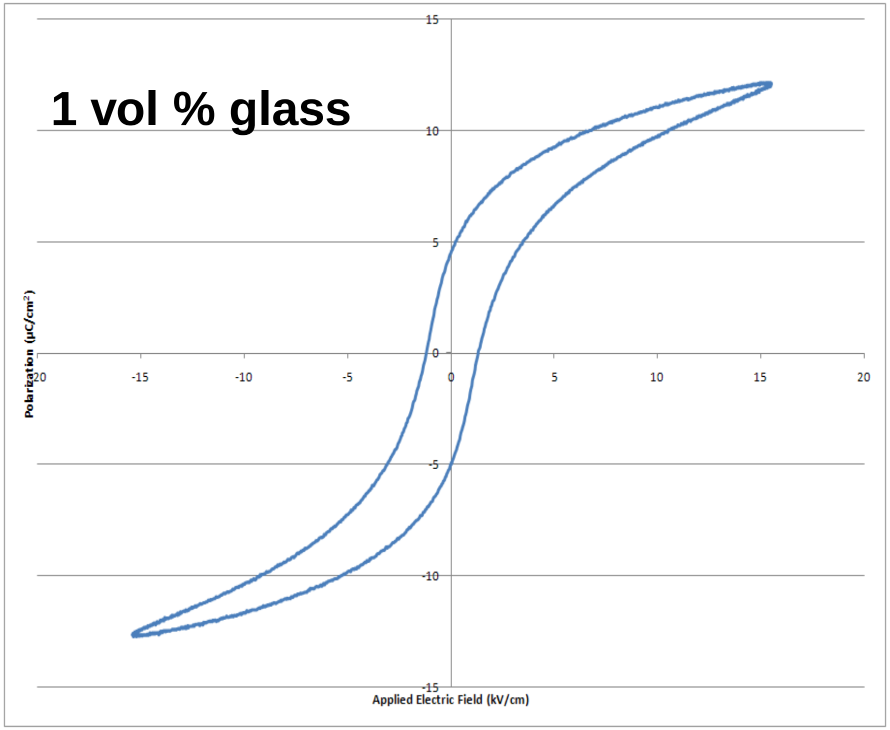
$BaTiO_3$ Nanocomposite High Field Hysteresis





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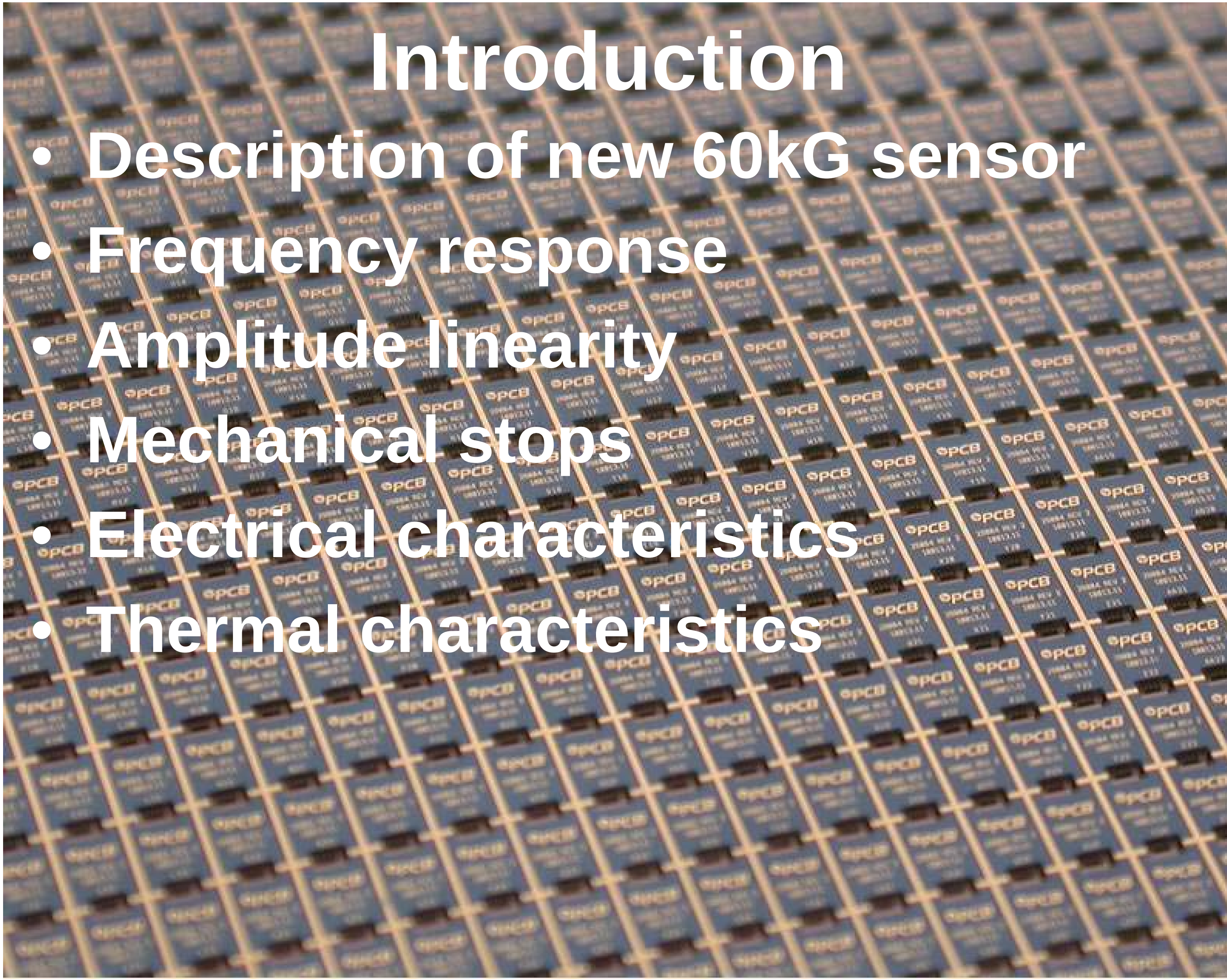
60kG MEMS Sensor

Robert D. Sill
Senior Scientist
PCB Piezotronics Inc.
951 Calle Negocio, Suite A
San Clemente CA, 92673
rsill@pcb.com (877) 679 0002 x2954

May 2010

PCB PIEZOTRONICS
A PCB GROUP COMPANY

Introduction



- Description of new 60kG sensor
- Frequency response
- Amplitude linearity
- Mechanical stops
- Electrical characteristics
- Thermal characteristics

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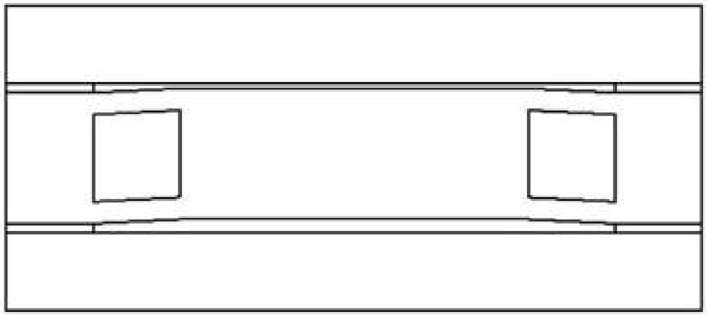
Proven Sensor Design



- Same body plan as proven 20kG sensor
  - Diced from a protective hermetic sandwich of three wafers
  - Air trapped in gap causes squeeze-film damping, reducing resonant amplification
  - Built-in mechanical stops prevent overrange failures
- Optimized features enhance survivability
  - Modified cantilevers for higher measurement range
  - Strain relief features reduce stress when stops are encountered
  - Improved ESD tolerance
  - (the last two features have also been applied to new 20kG)

Sensor Comparison

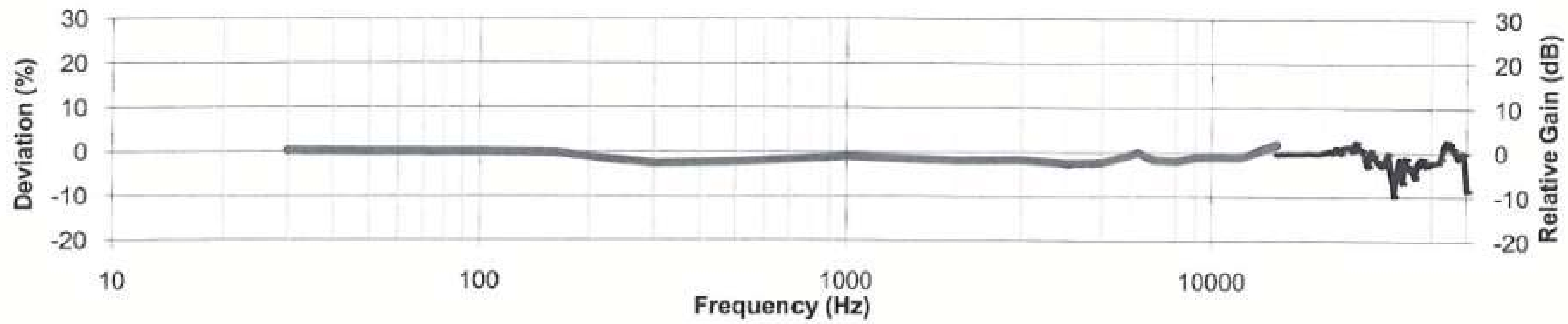
	20kG	**60kG**
Sensitivity	1uV/V/G	0.3uV/V/G
Full Scale (20mV/V)	20kG	60kG
Resonance	~65kHz	~150kHz
Mechanical stops	+/- 35kG	+/- 100kG
Resonant amplification “Q”	~10	~30 (estimated)

the following parameters are the same for both versions

Input Resistance	~5000 Ω
Bias (ZMO)	20%FS max (2% typical)
Dimensions	0.098” x 0.067” x 0.039” (2.5mm x 1.7mm x 1.0 mm)

Frequency Response

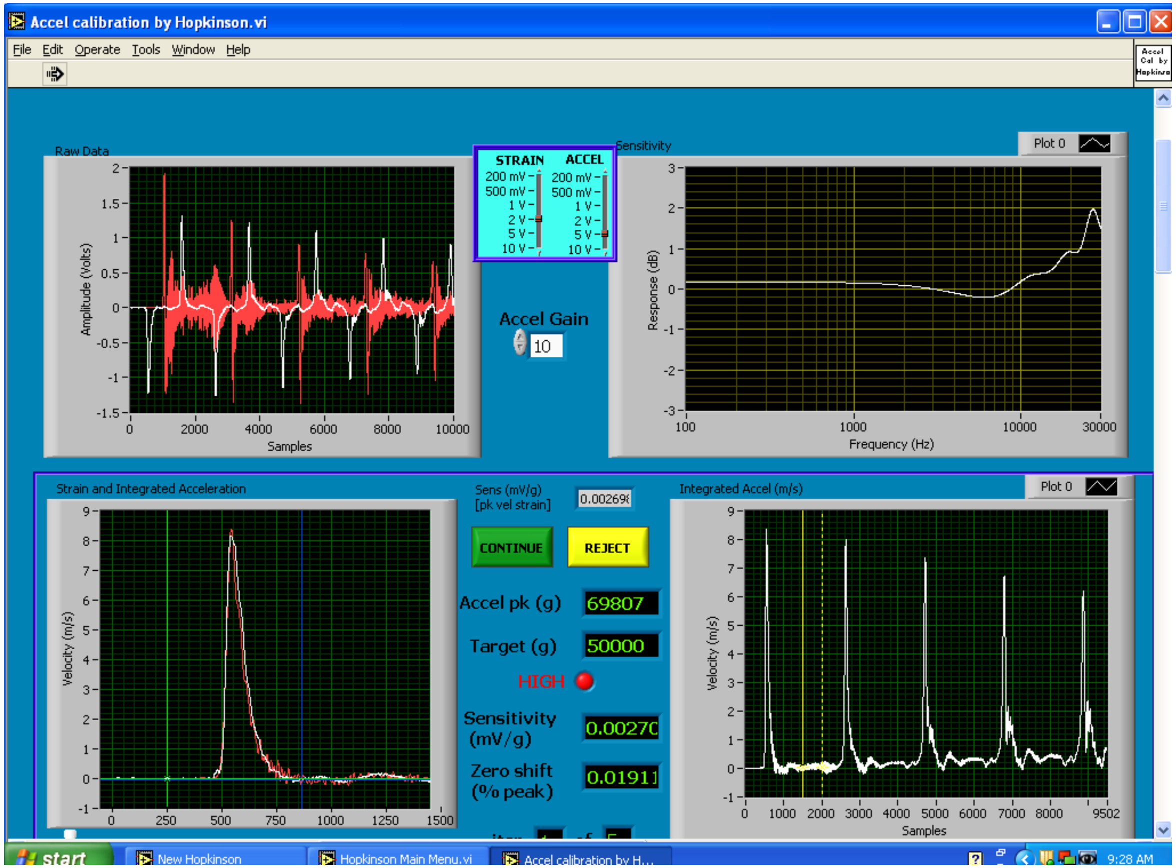
•From similarity, the response should be at least as flat as the 20kG sensor response, which has a lower resonance, shown here. It is difficult to measure the frequency response of 60kG sensor with a shaker due to force limitations of shakers.



•Classic SDOF of 150kHz resonance: <5% deviation to 30kHz.

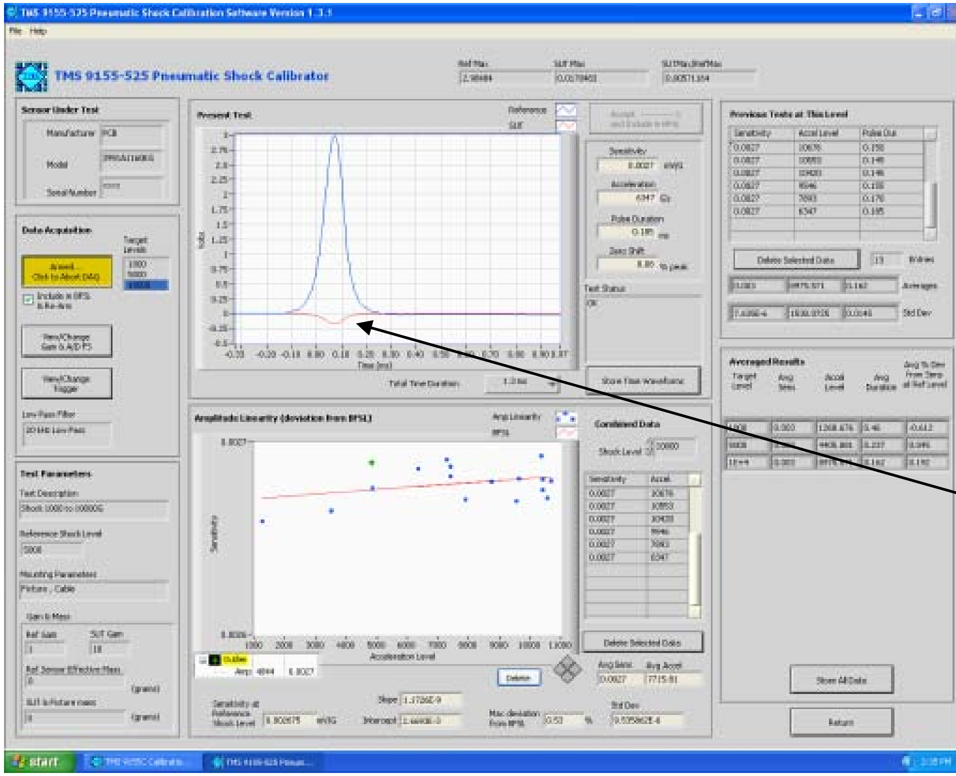
•It is possible to derive frequency response characteristics from shock data

Frequency Response (cont)



•Determined by this Hopkinson bar software, the frequency response on the upper right is <1dB to 20kHz. It is based on the ratio of FFT amplitudes of the integrated Unit-Under-Test to that of the velocity from the strain gages.

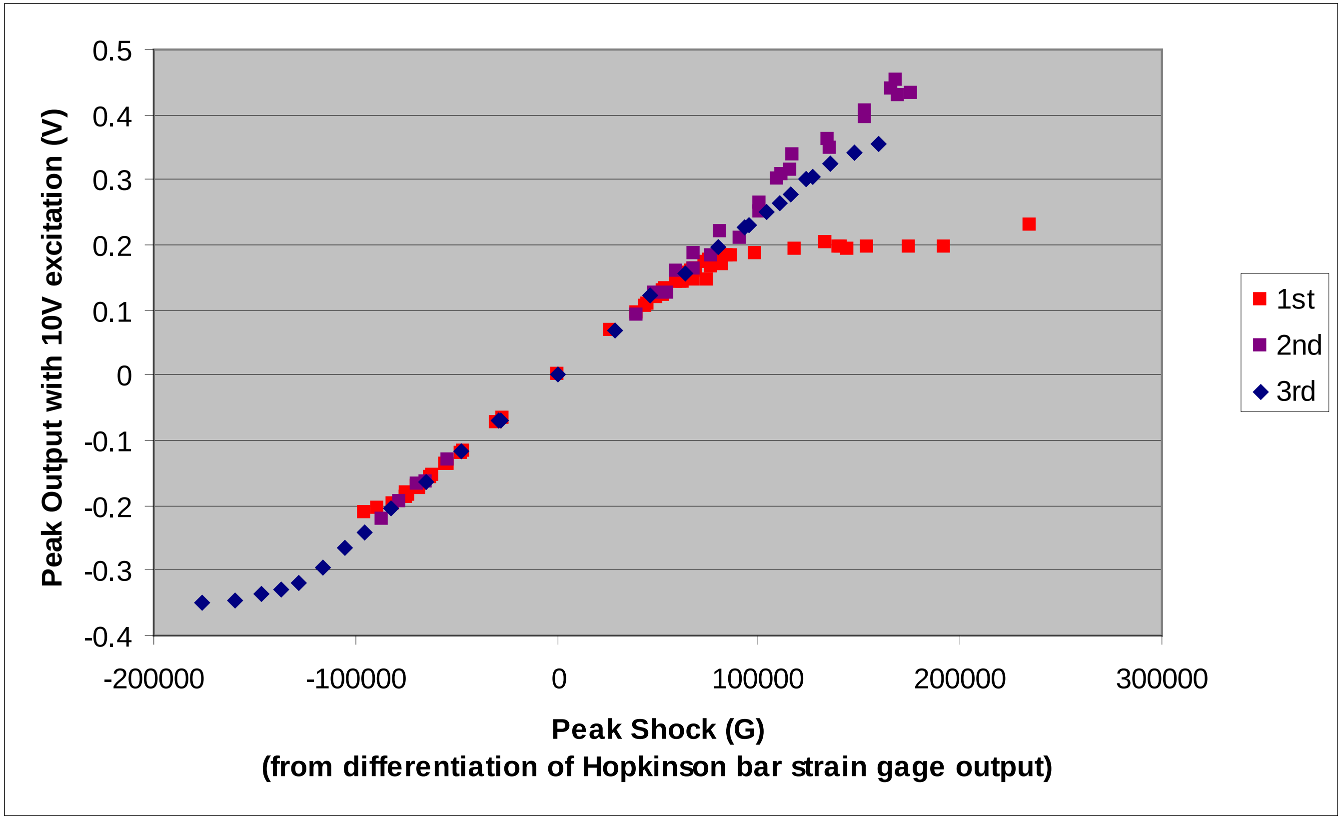
Amplitude Linearity



Negative-going output of unit-under-test when mounting upside down

- Sensitivity determined by comparison can only be done to ~10KG
- The package shown (but without welded cover) was mounted normally and upside down (don't try this at home)
- The lower plot is Sensitivity vs absolute G level, showing flat response in both positive and negative directions with deviations from BFSL of ~0.5%

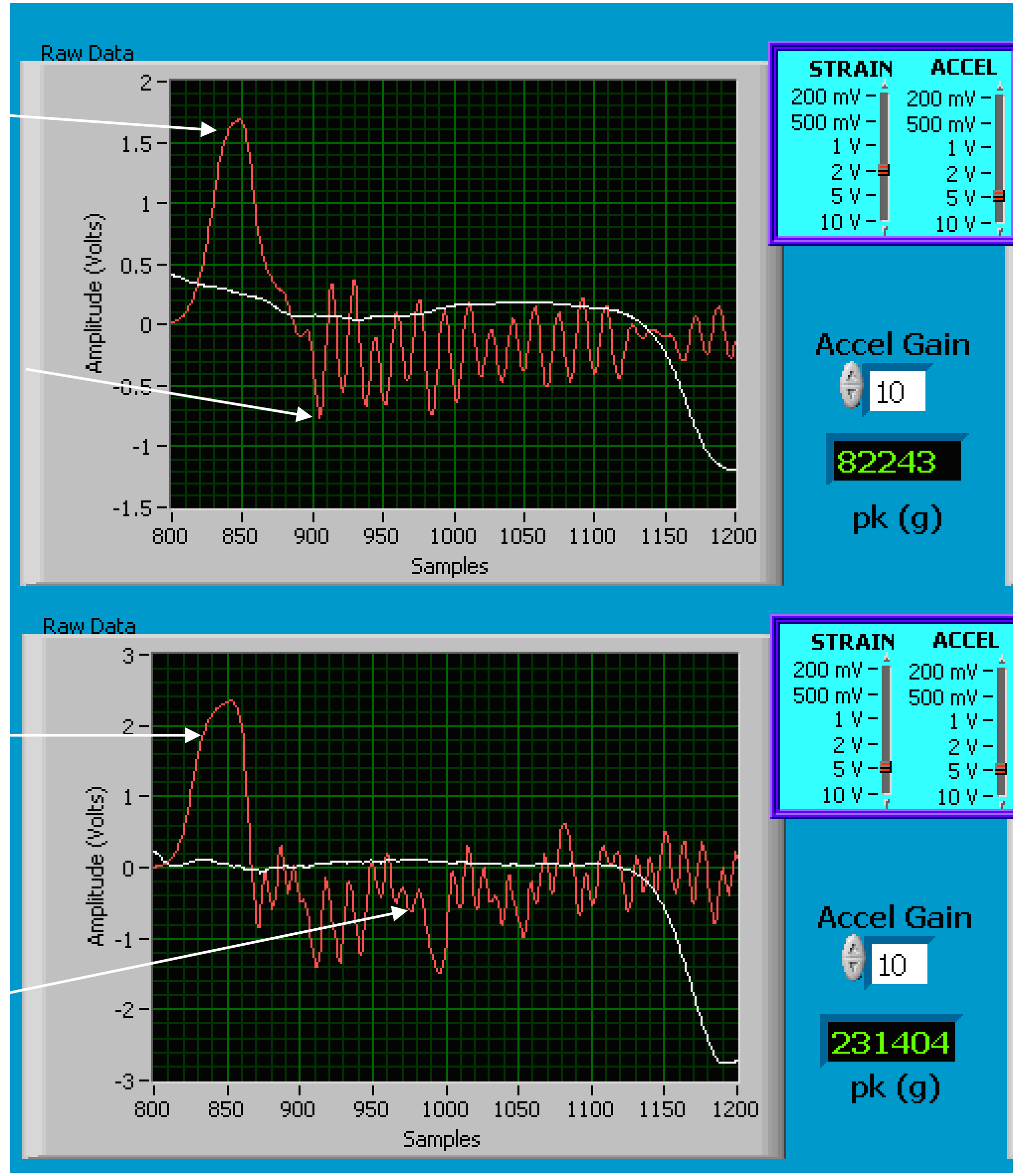
Finding the Mechanical Stop Level



- Three 60kG wafer assemblies were made with three intentionally different stop levels (in search of Goldilocks level)
- Hopkinson bar was used in these tests of linearity, again using sensor package that could also be mounted upside down

Mechanical Stop Dynamics

- From the 1st wafer, output slope just begins to smoothly "roll over" at 80kG
- Low-Q 150kHz resonance
- Recovers within a few microseconds from 230kG overload
- Output continues to increase after hitting the stop, the cantilevers continue bending from their own inertia
- Higher 250kHz mode is visible



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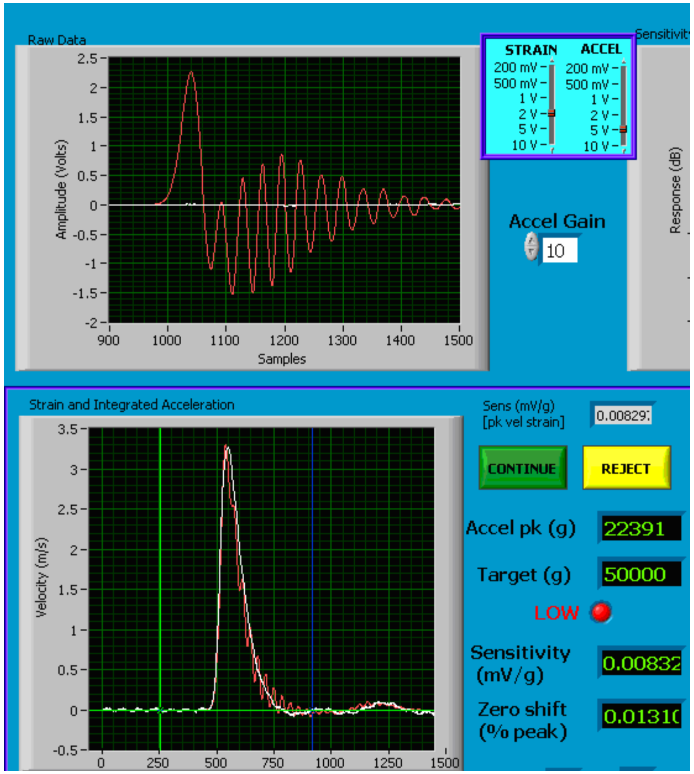
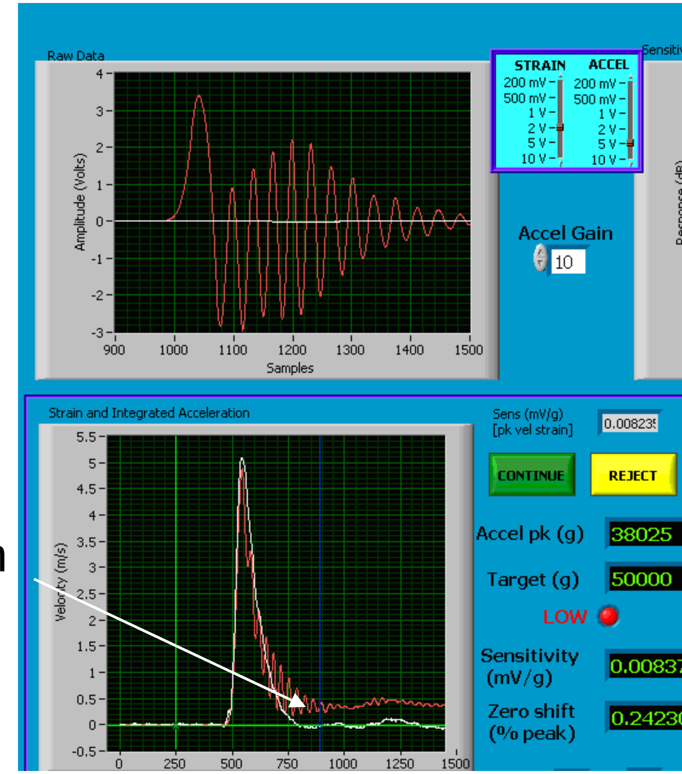
Errors Caused by Hitting Stops

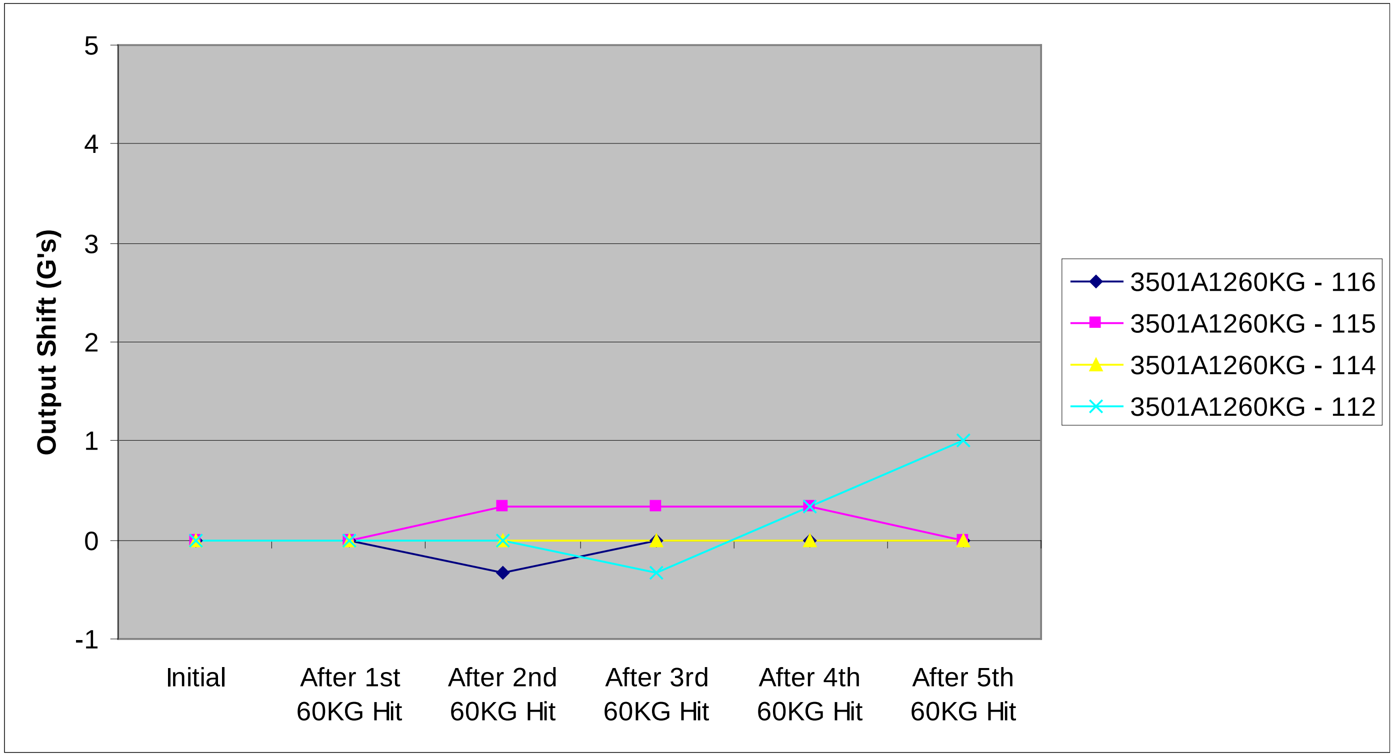


Integration error



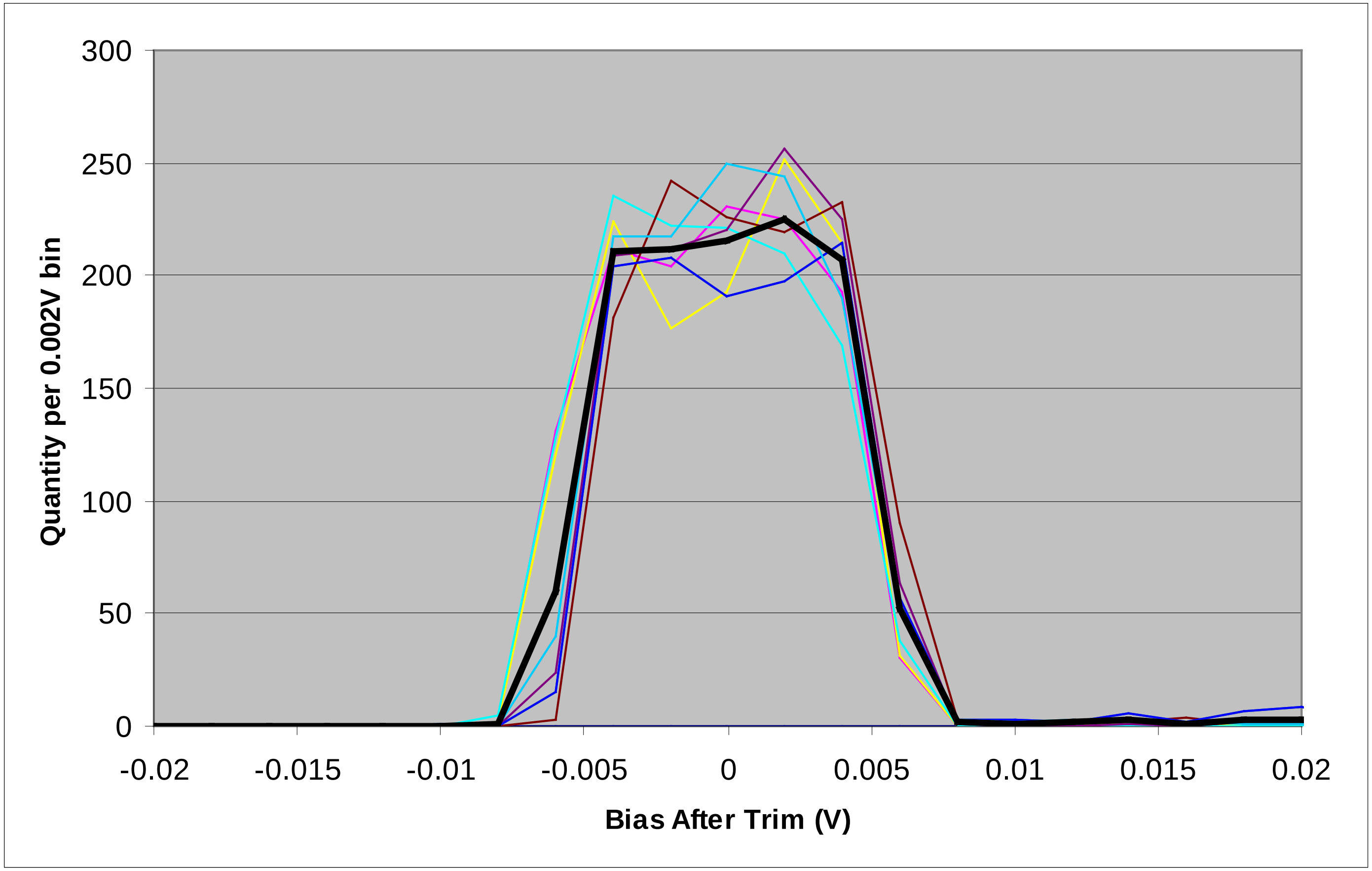
- The lower graph in each test is the integrated accelerometer output overlaid on the Hopkinson bar strain gage output. On the left is a 22kG test of a 20KG sensor; on the right is 38kG, at which the positive stops just touch. A microsecond delay of output explains the integration error on the right. (<u>This is NOT zero shift</u>.)
- The 60KG sensor allows much larger dynamic range to avoid hitting stops.

Zero Shifts due to Shock



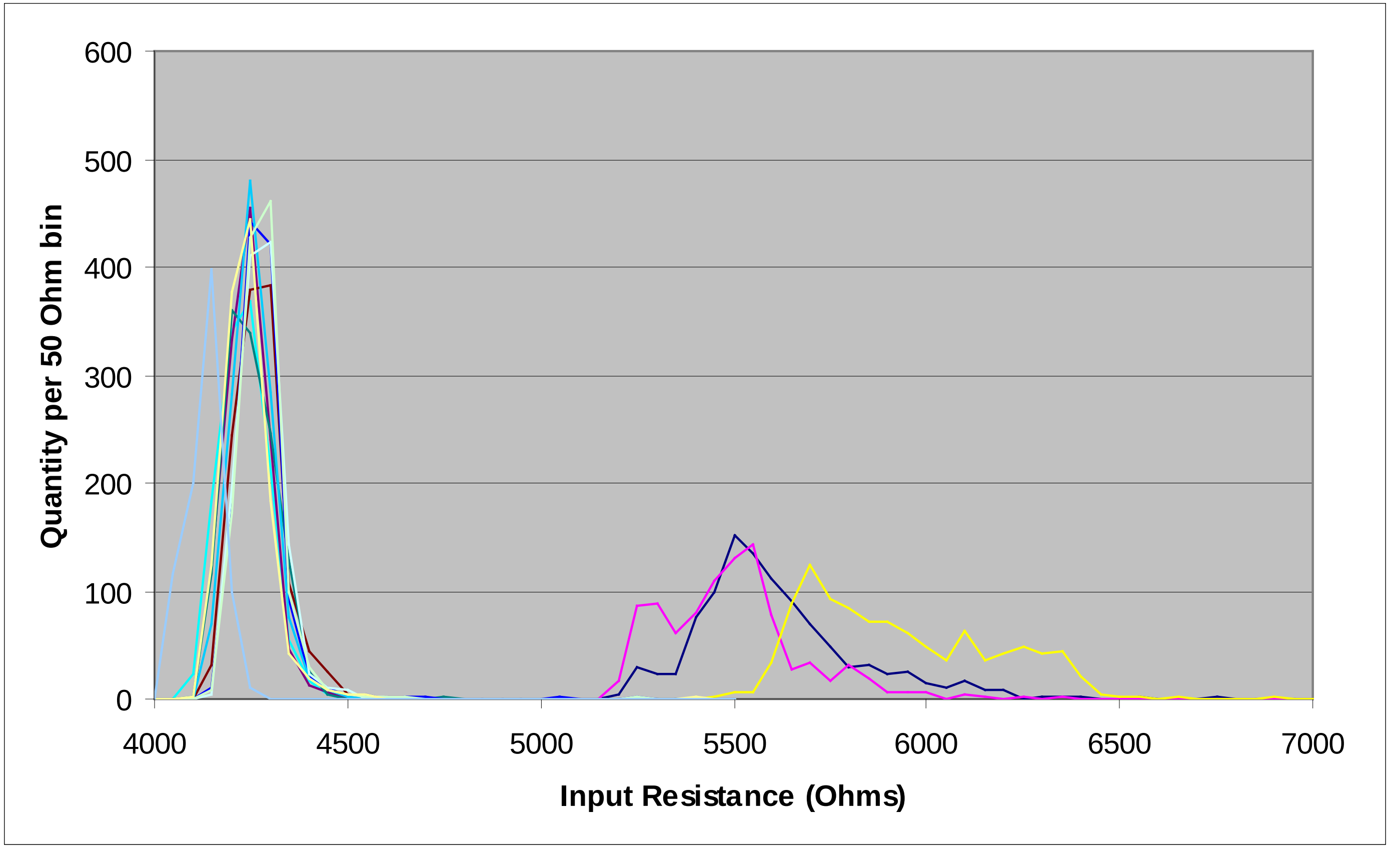
•These shifts represent a few microvolts total change in output over a sequence of 5 Hopkinson bar hits at 60KG on each of 4 sensors.

Bias Histograms



- The bias trim operation was performed on >10,000 sensors (each line represents a wafer, black line is the average)
- Typical bias after trim is 2% of Full Scale output (1 standard deviation = 1% Full Scale)

Resistance Histograms



- Resistance on 10 production process wafers on left shows extremely tight spread (standard deviation of <1.5%)
- This is an improvement over the 20KG prototype wafers on right, correlated with improved bias stability (see next graph)

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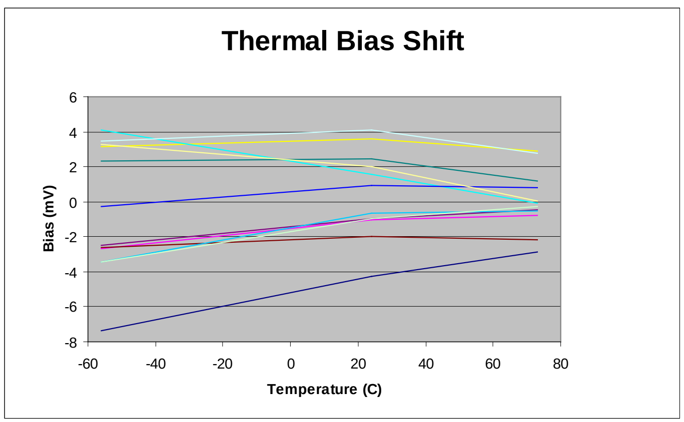
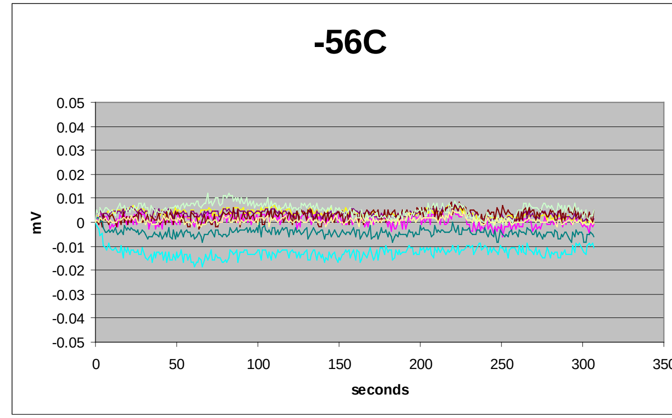
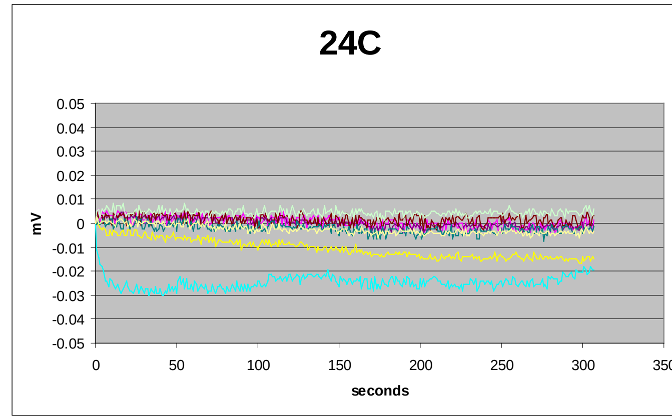
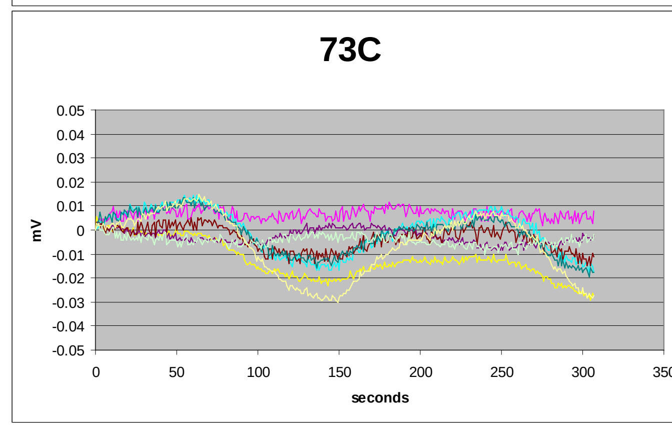
Power-on Warm-up Drift

- Excitation voltage is suddenly applied, then bias is monitored for 300 seconds. ~0.01% FS drift
- Self heating is minimal.
- Bias shift of <+/-4%FS/100C



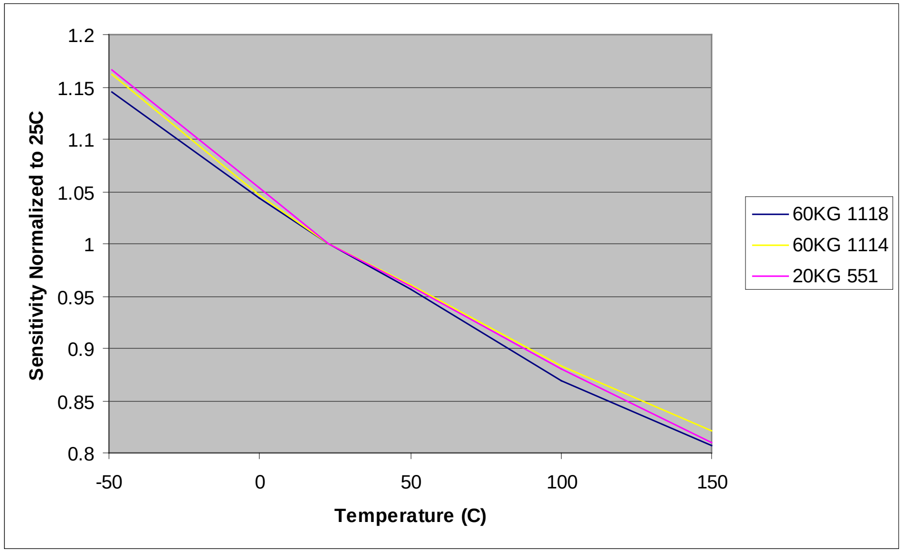




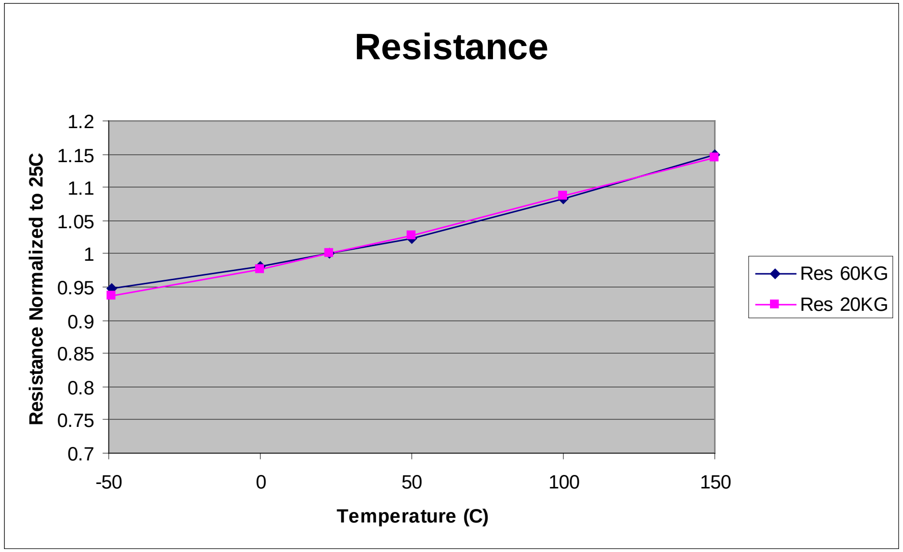


Thermal Characteristics

•Sensitivity: -17%/100C



•Resistance: +10%/100C



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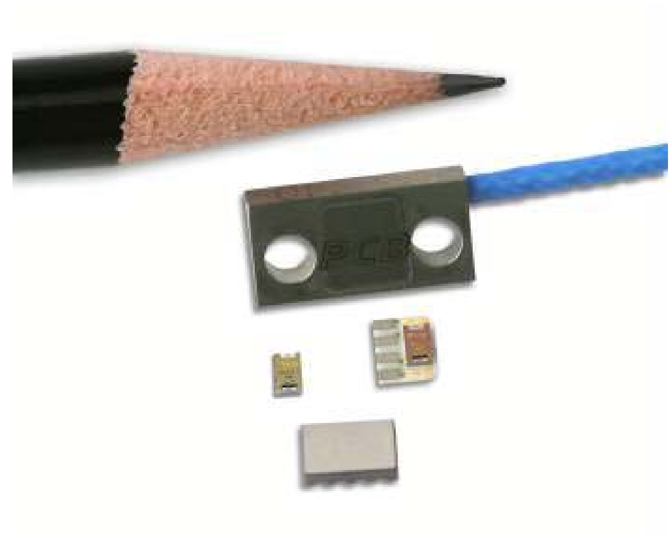
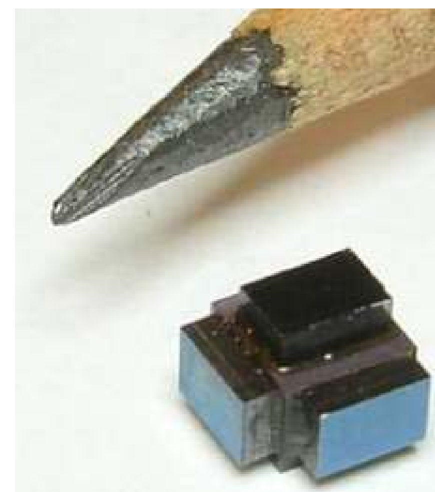
Conclusions



- New 60KG sensor:
    - Extremely rugged
    - Wide frequency response
    - Large dynamic range
    - Trimmed to low bias value
    - Low bias shift
    - Stable, low drift
- Manufacturing process is mature for 20kG and 60kG
- Both sensors fit in a large variety of packages



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Inkjet Printing of Nanocomposite High-Explosive Materials for Direct Write Fuzing

Andrew Ihnen and Woo Lee
Stevens Institute of Technology

Brian Fuchs, Anne Petrock, Phillip Samuels, Victor Stepanov, and Anthony Di Stasio
Picatinny Arsenal – ARDEC

54th Fuze Conference
13 May 2010
Kansas City, MO

Acknowledgements

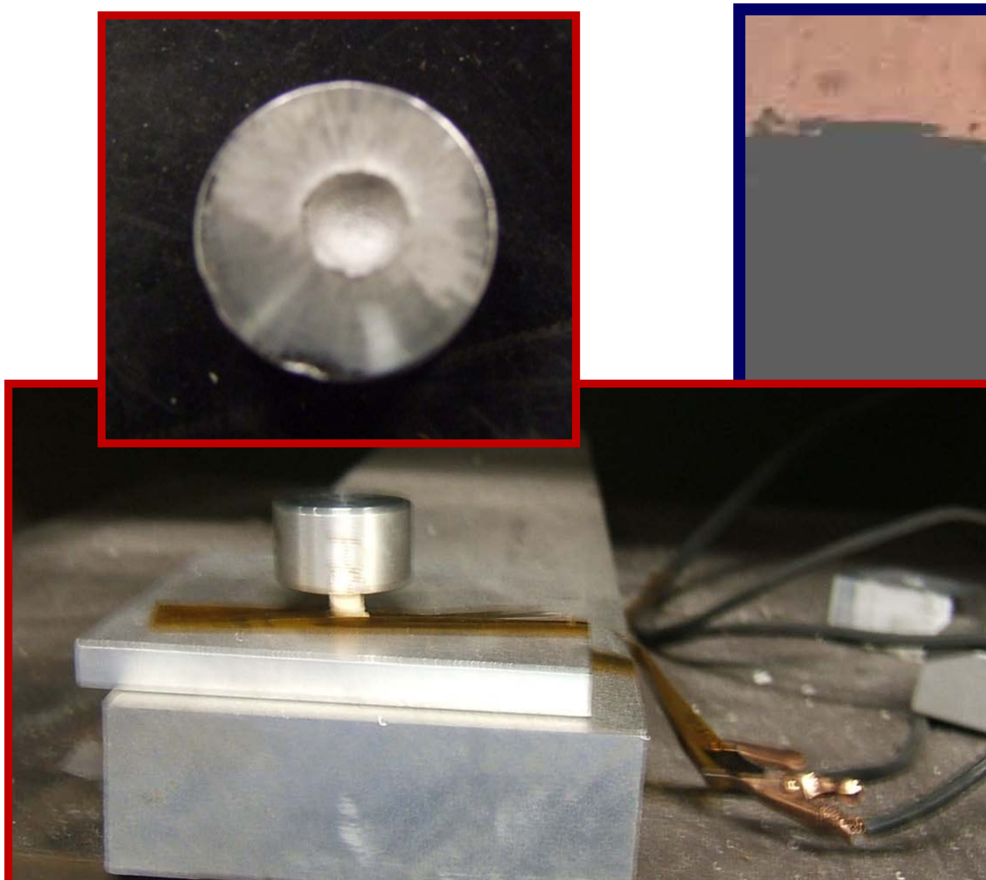
- Chris Morris, Luke Currano and Madan Dubey (ARL)
- Dennis Polla (DARPA)
- Carl Kime (Lodestar Strategies)
- Michael Bobrik (Systems Planning Corp.)
- James Zunino, III and Daniel Schmidt (ARDEC)
- Daniel Stec, III (SAIC)

Direct Write Technology

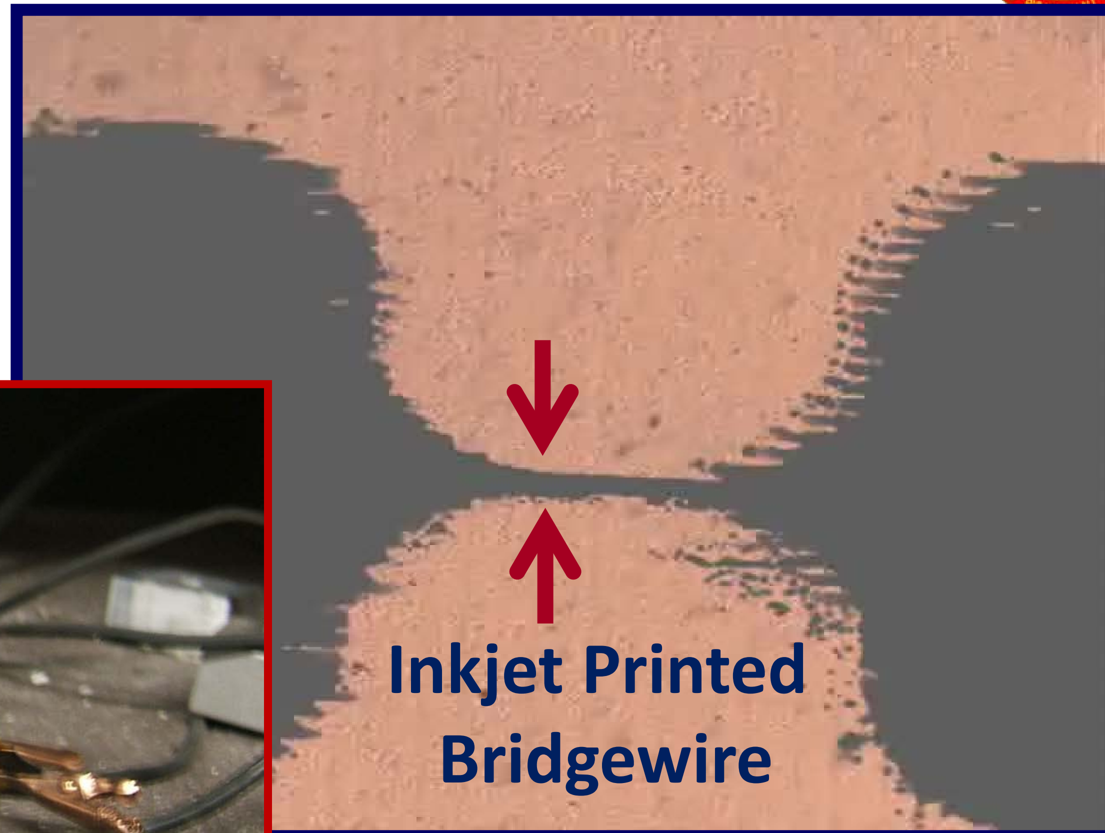
- The direct-write technology was developed for the rapid prototyping of electronic circuits, through a 1979 DARPA (Defense Advanced Research Projects Agency) program.[i]
- Syringe systems utilize direct displacement loading through a hollow pen point.
- Typical inks are conductive, such as those used for circuit boards or antennas. Ceramic and insulating inks have also been developed.
- The direct write techniques are advancing, with multiple companies making syringe type direct displacement machines. In 1999 DARPA invested $40 million dollars into direct write technologies[ii],[iii].
- EDF-11, a CL-20 based secondary explosive ink, has been developed for direct write loading of MEMS devices. It has been qualified by the US Army for use as a booster explosive.

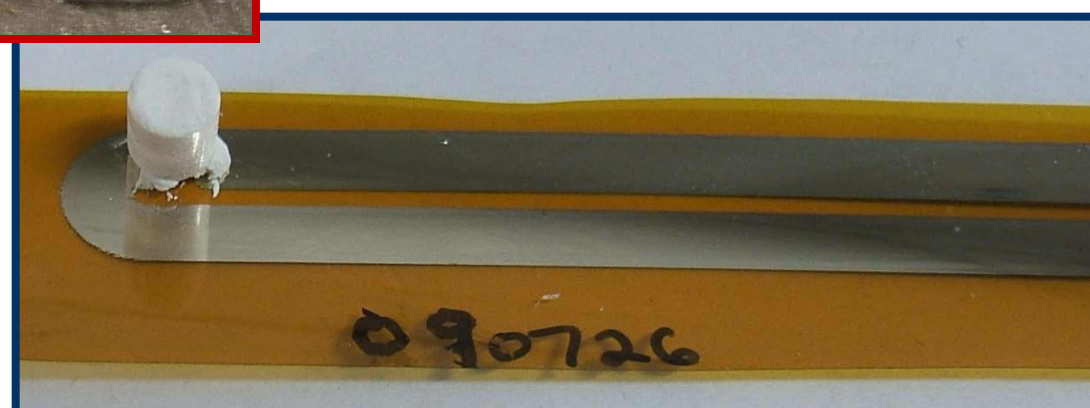
[i] Ohmcraft "Ohmcraft-A brief History" http://www.ohmcraft.com
- [ii] Pique, Alberto and Douglas B. Chriset "Direct-Write Technogies for Rapid Prototyping Applications" Academic Press San Diego Ca 2002.
- [iii] http://www.mesoscribe.com

What can the Army do Today?



Initiation to detonation with an explosive train





Integrated Flexible Energetics & Electronics (IFEE)

	Silicon Electronics	Flexible and Printed Electronics	Energetics
Feature Size	10^{-5} mm	10^{-2} mm	≤ 1 mm
Infrastructure Cost	$2-3 billion	$10-200 million	----

Can we shrink the size of energetic materials for integration with flexible electronics?

**Electronics statistics from the FlexTech Alliance

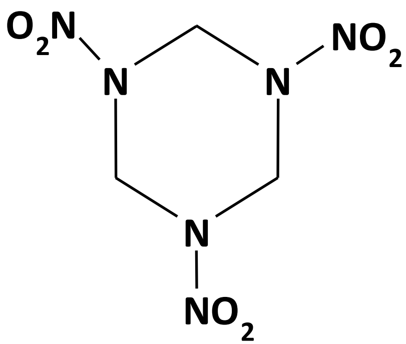
Goal of this Exploratory Study:

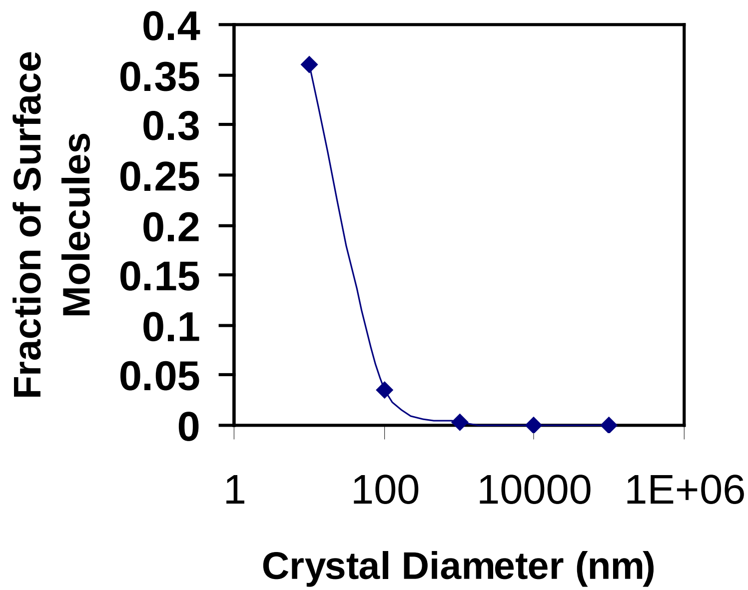
To inkjet print explosive materials with tailorable morphology for integrated flexible energetics and electronics.

Objectives:

1. Develop an ink to inkjet print and pattern explosive materials using a commercially available inkjet printer
2. Optimize ink for maximum spatial resolution
3. Characterize material to correlate printing variables to material structure and properties

Why Nano-Energetics?





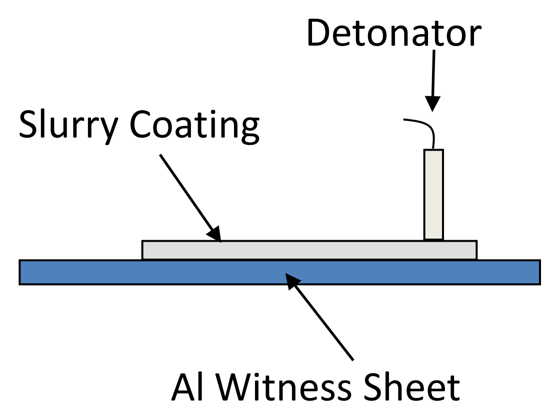
Higher Reactivity with Increased Surface Area:

- **$N\text{-}NO_2$ bond dissociation energy 8-15 kcal/mol lower for surface molecules vs. bulk (M. Kuklia, 2001)**
- **Distributed “hot spot” network**

Reduction in Critical Detonation Thickness

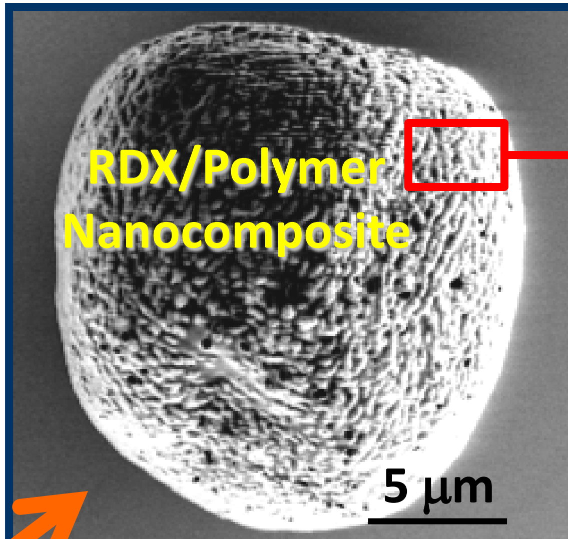
Material	Thickness (mm)			
	1.27	0.75	0.64	0.25
Class-5 RDX	No Fire.			
Type A nano RDX	Fire	Fire	No Fire	
Type B nano RDX	Fire	Fire	Fire	No Fire

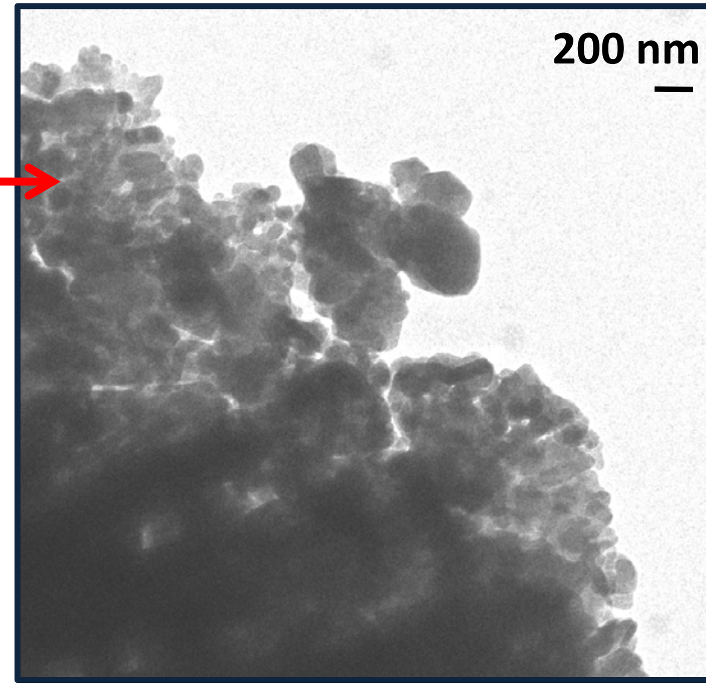
Coating Width: 5 cm

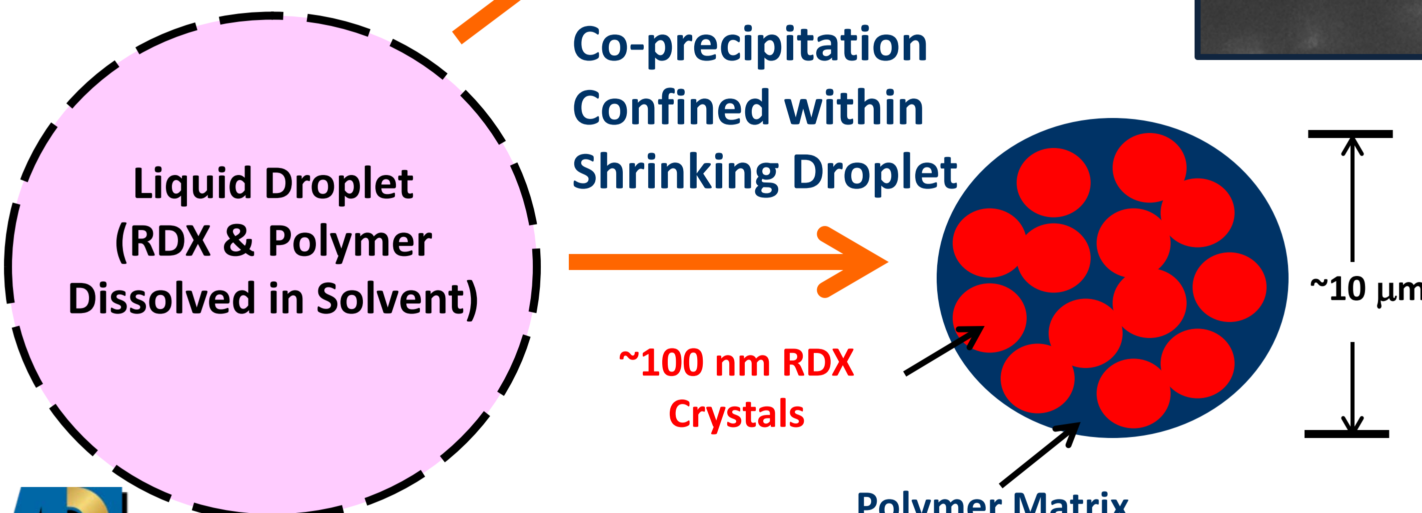


Confinement Effect in Nanocomposite RDX

STEVENS
Institute of Technology





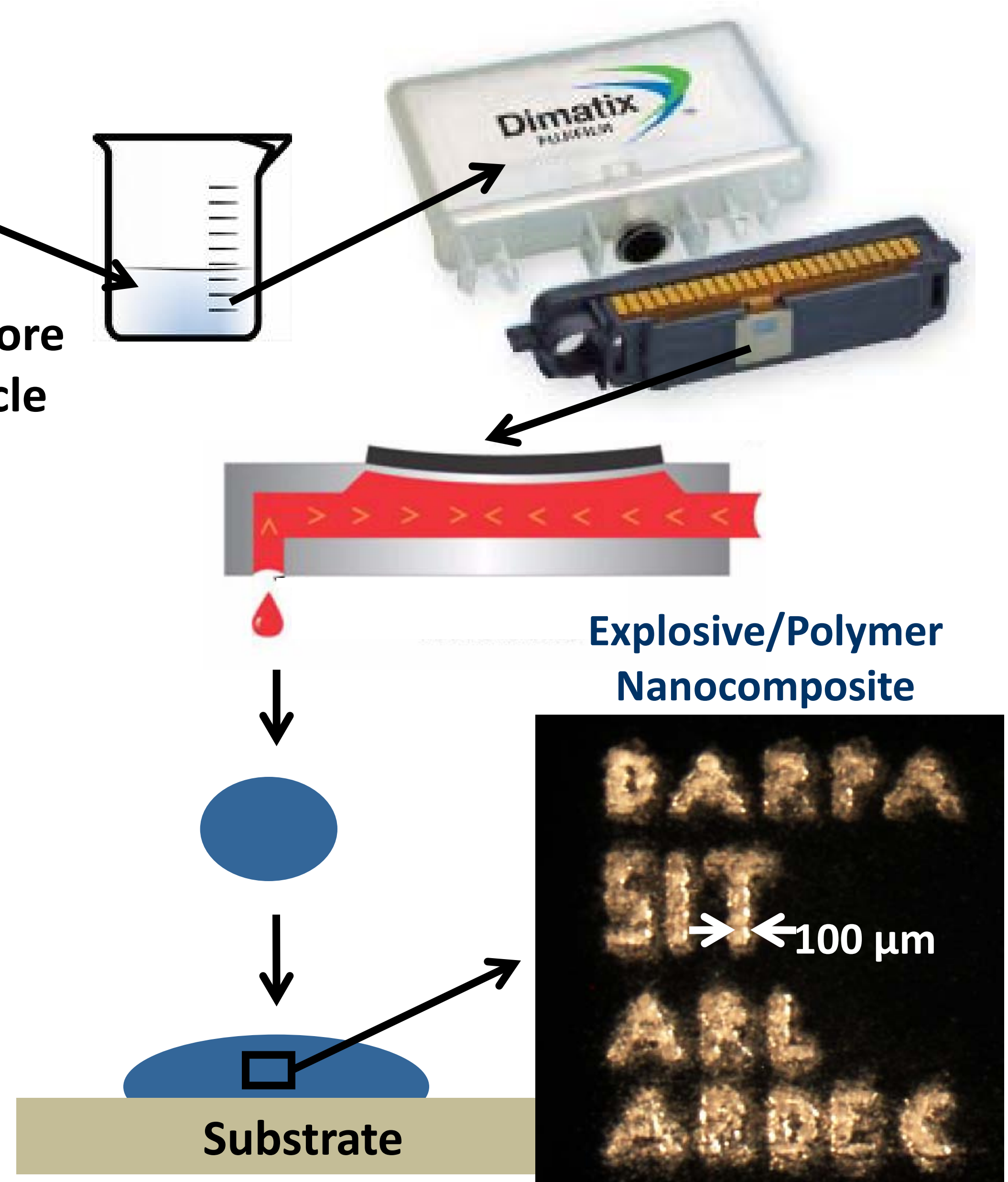


Patent I (Pending)

DARPA

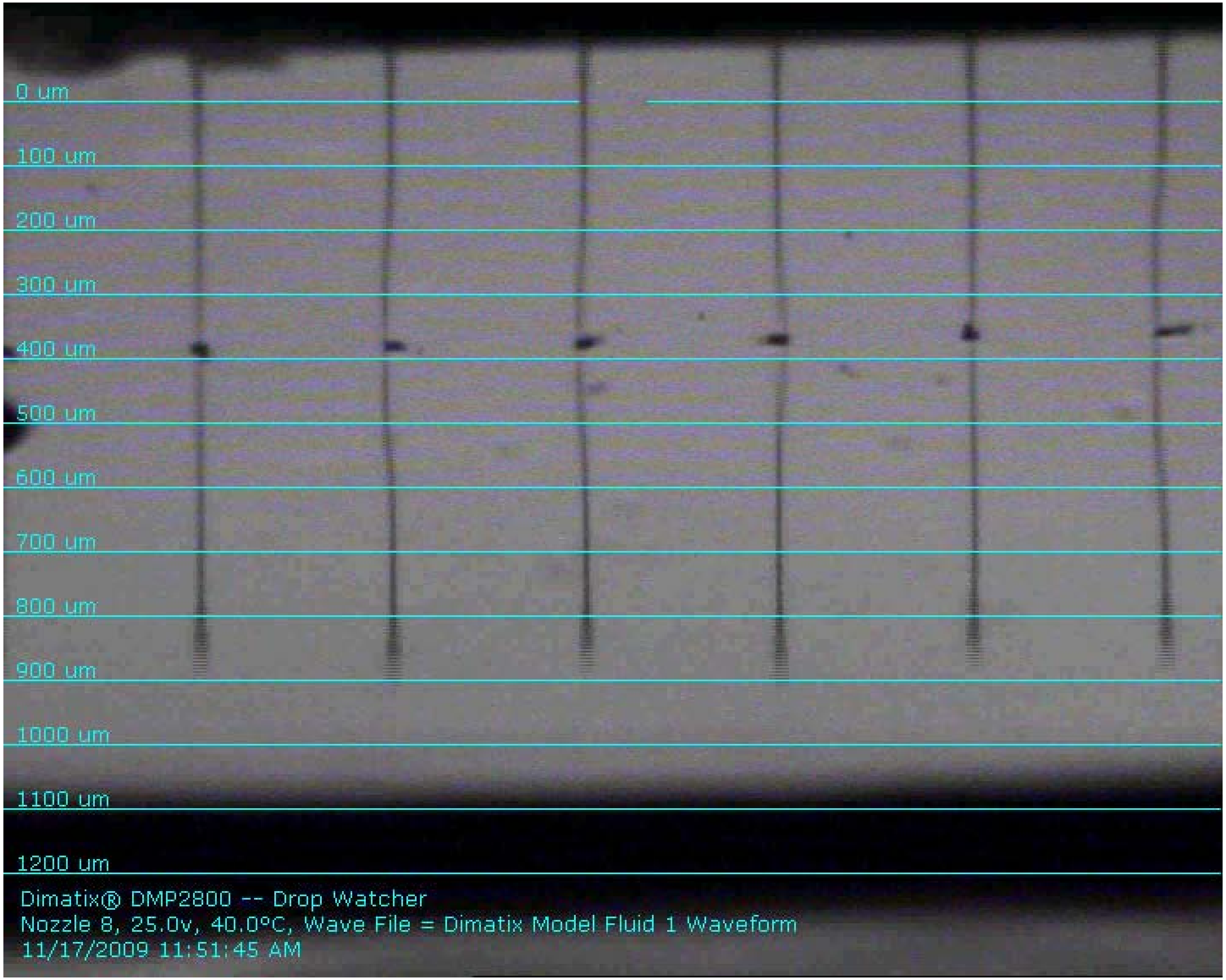
"One-Step" Printing Approach

- **All-liquid ink**
  - All desired ingredients are dissolved in an organic solvent
  - No colloidal suspension, therefore no issues associated with particle agglomeration, growth, dispersion, or clogging
- **One-step simplicity**
  - No issues associated with extra nanoparticle production and handling steps
  - Mitigated ESH concerns

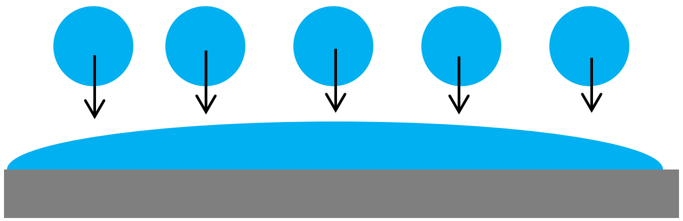


Patent II (Pending)

Jetting of One-Step Ink

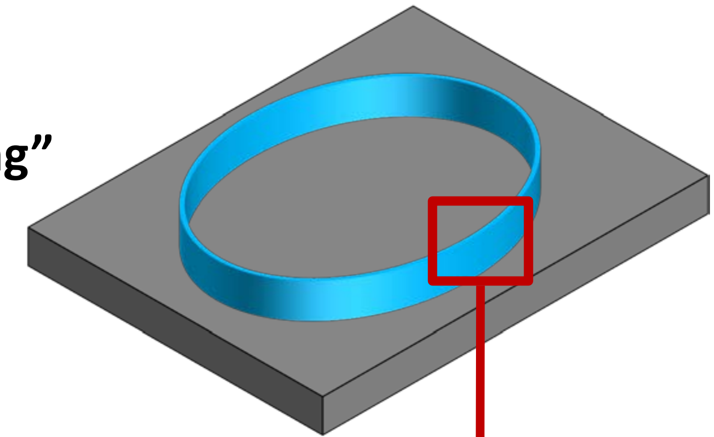


Pooling Effect in Inkjet Printing

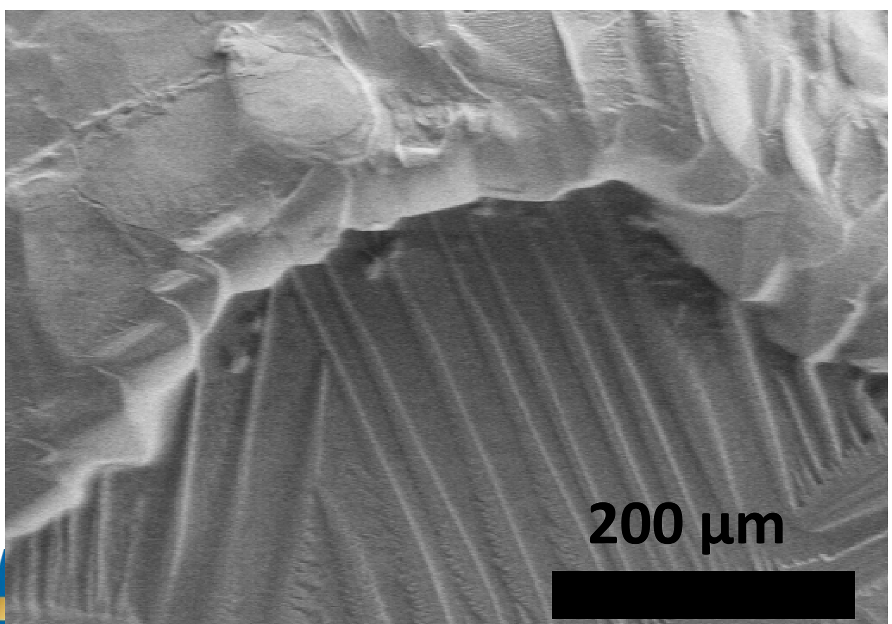


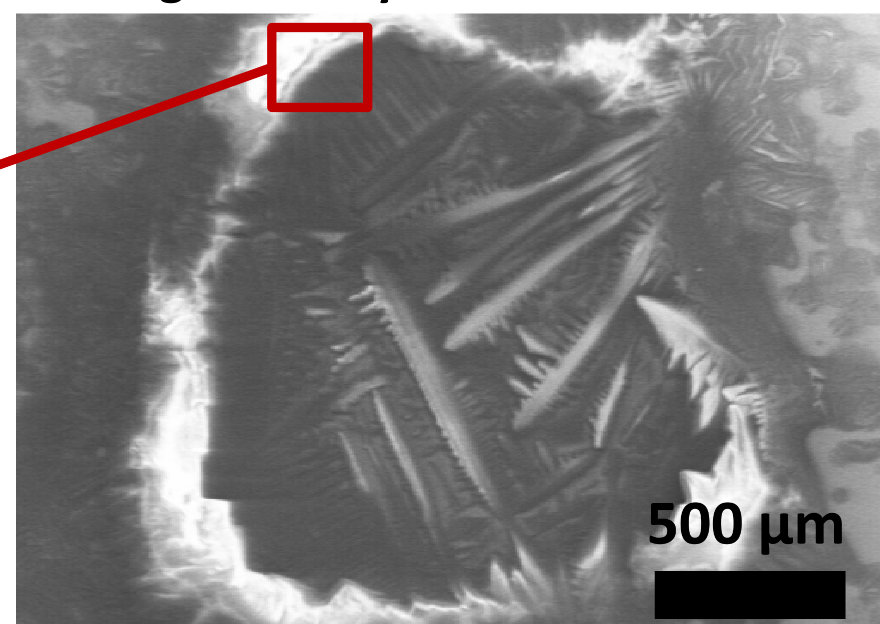
Pooling of Ink Droplets
with Fast Printing Conditions at
Ambient Temperature

Evaporates to
Form "Coffee Ring"

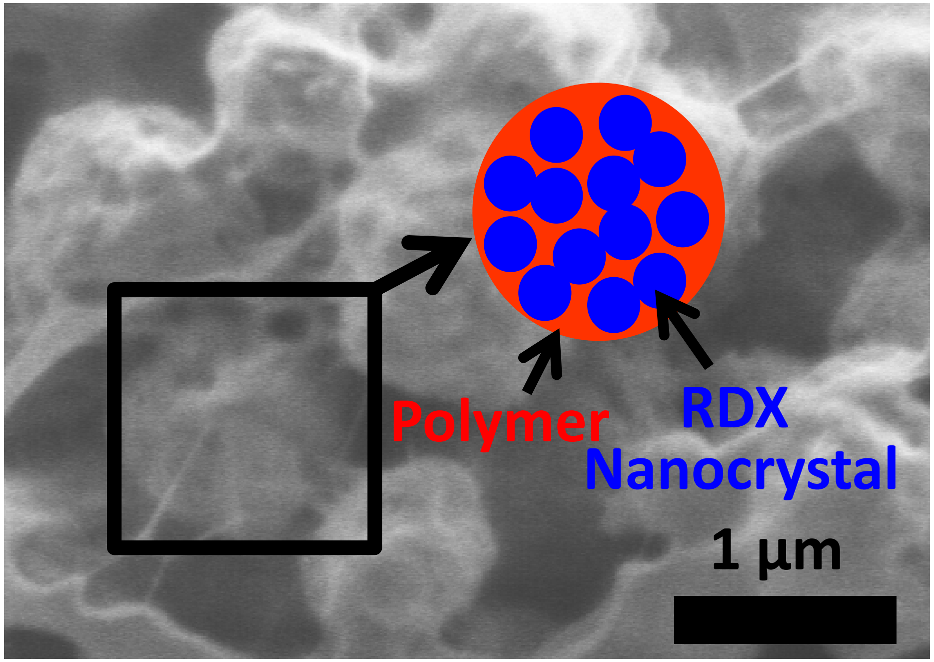


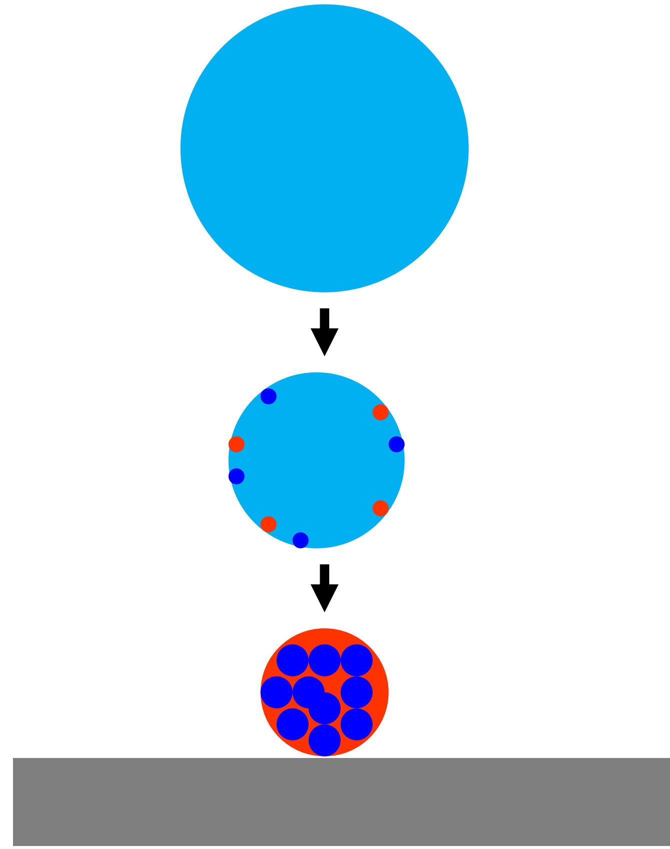
Uncontrolled Growth of
Large RDX Crystals





Confinement Effect in Inkjet Printing

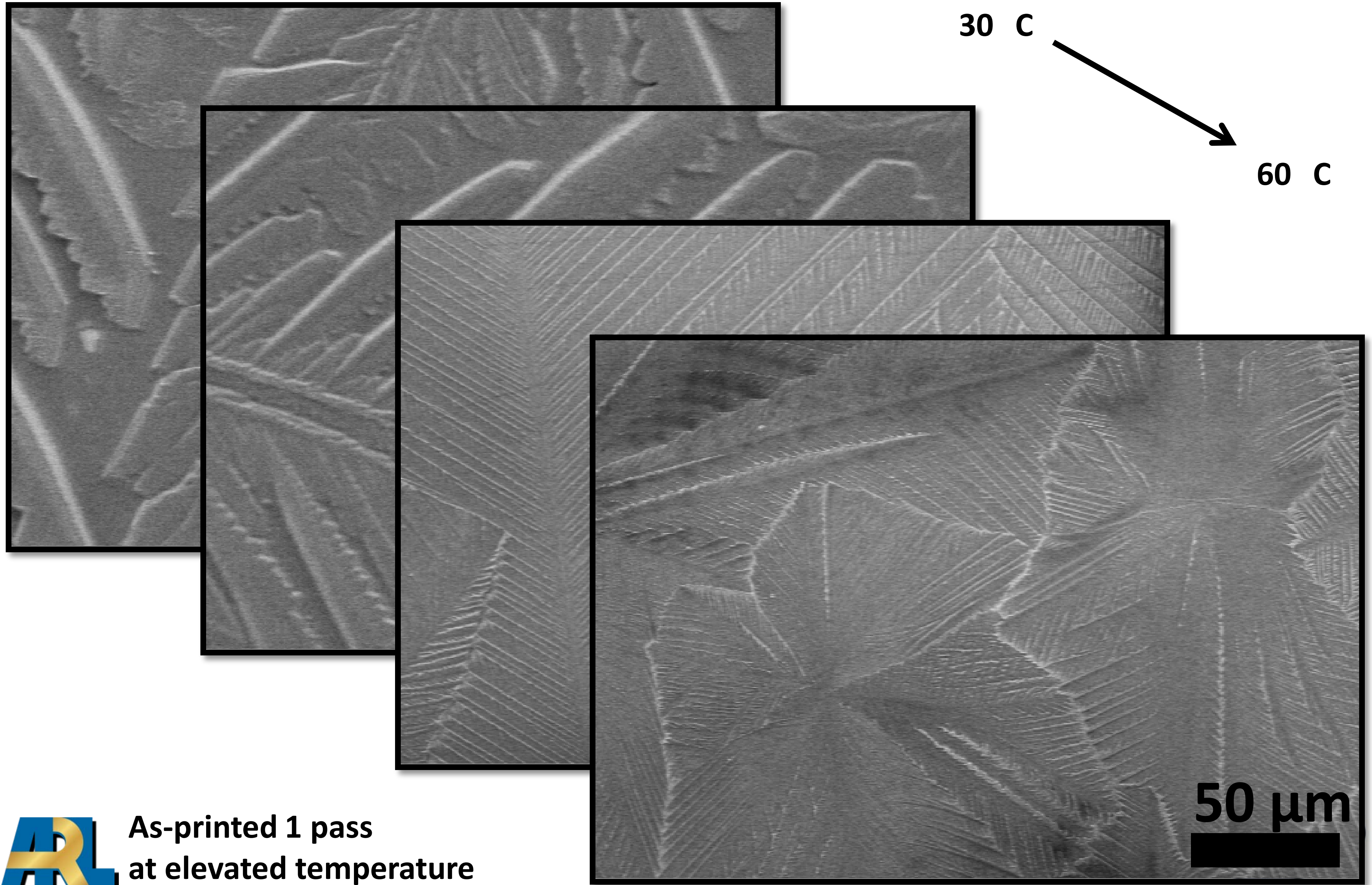




- Desired for nanocomposite structure formation

- In order to avoid “pooling” effect, (1) long wait between passes, (2) large distance between droplets to avoid droplet coalescence and (3) large distance between nozzle and substrate.

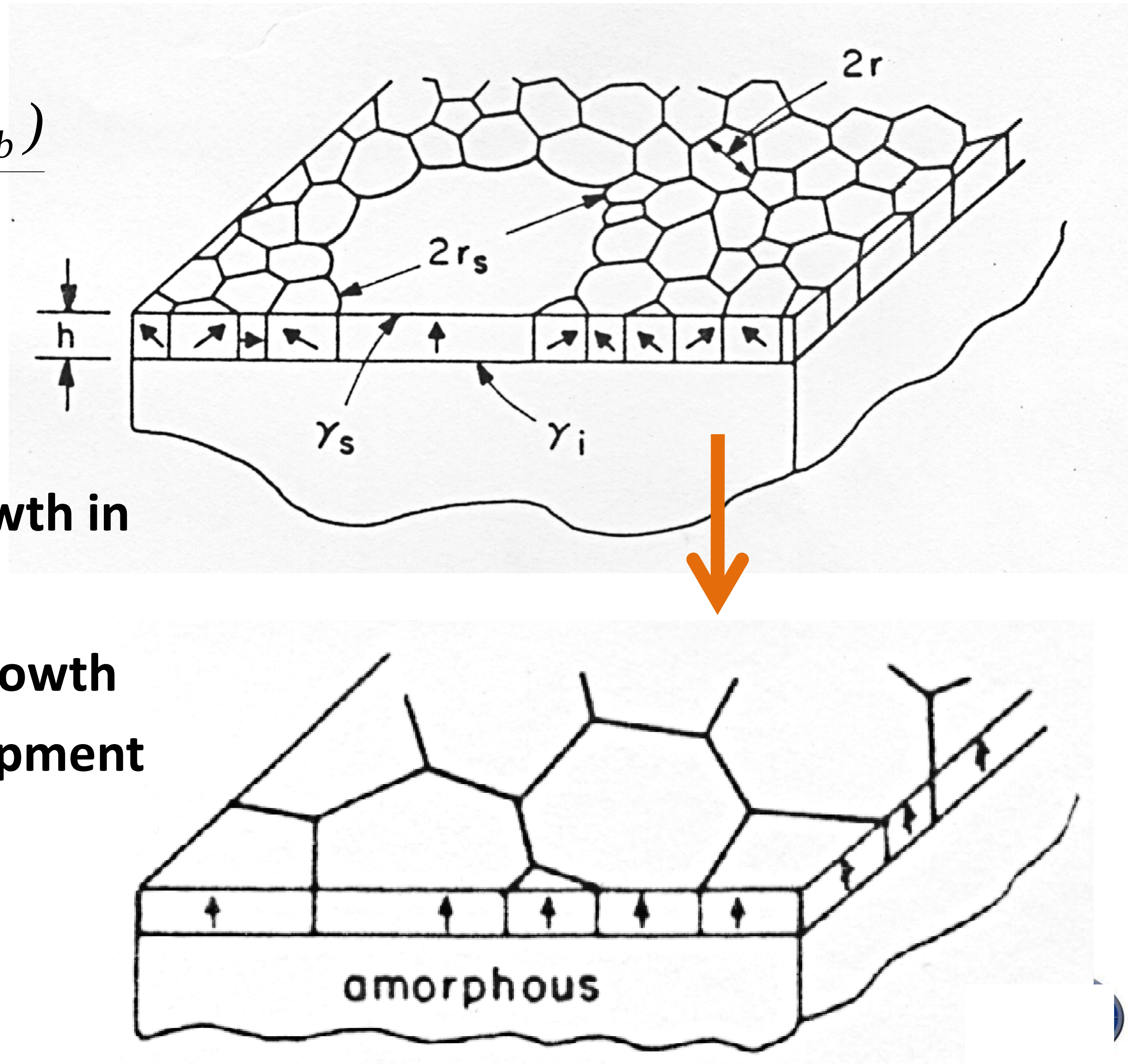
Temperature Effect on Grain Growth



As-printed 1 pass
at elevated temperature

Abnormal Grain Growth Mechanism

$$\frac{dr_s}{dt} \cong M\frac{(2\Delta\gamma+\gamma_{gb})}{h}$$

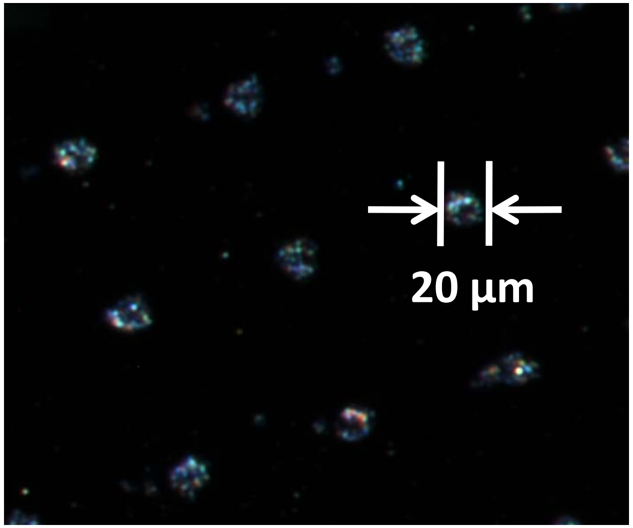


Abnormal grain growth in thin-films causes:

- **Lateral grain growth**
- **Texture development**

Thompson, 1990

Generation of Test Samples

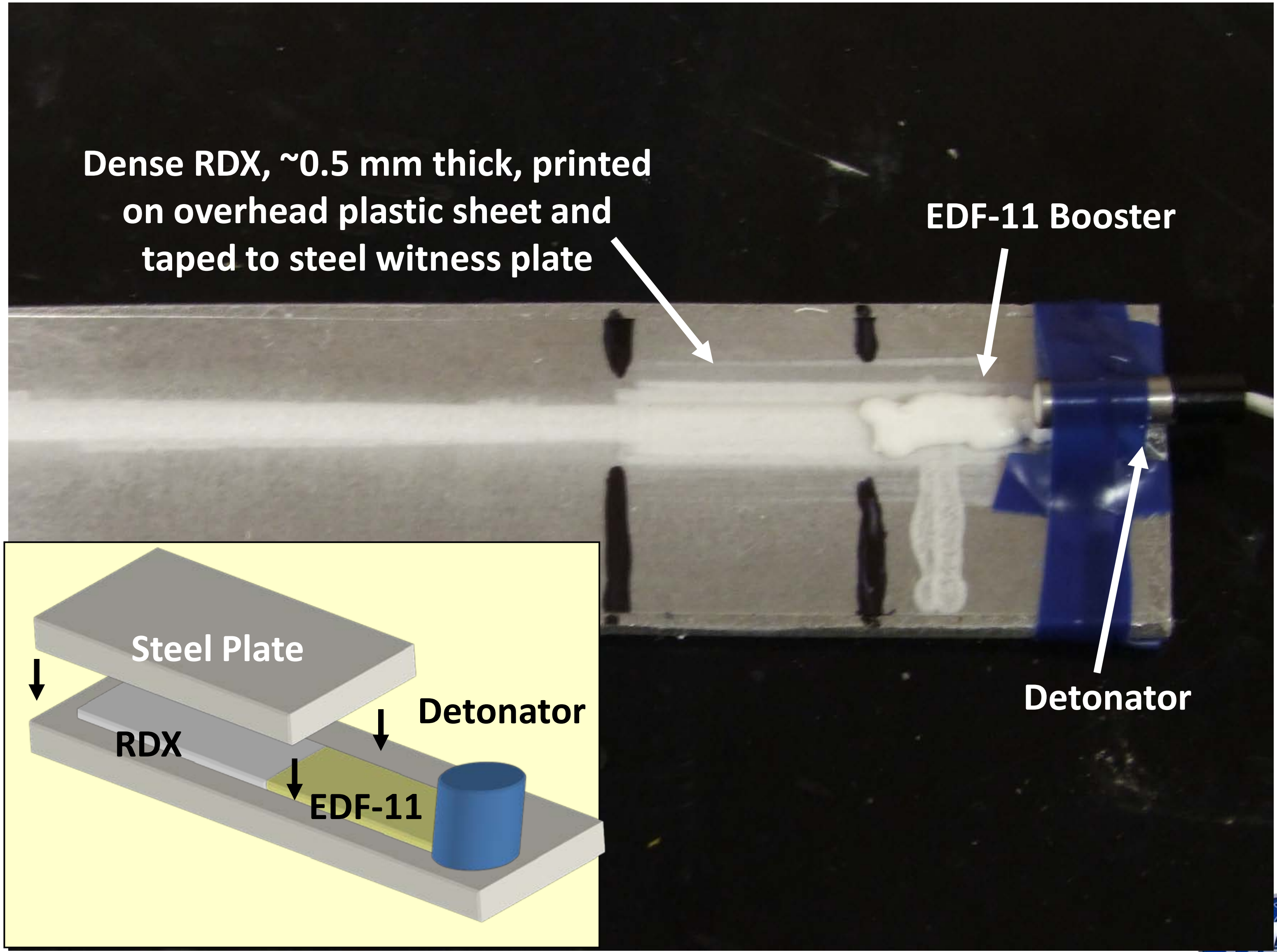


- **Ink and jetting parameters were optimized for maximum spatial resolution**

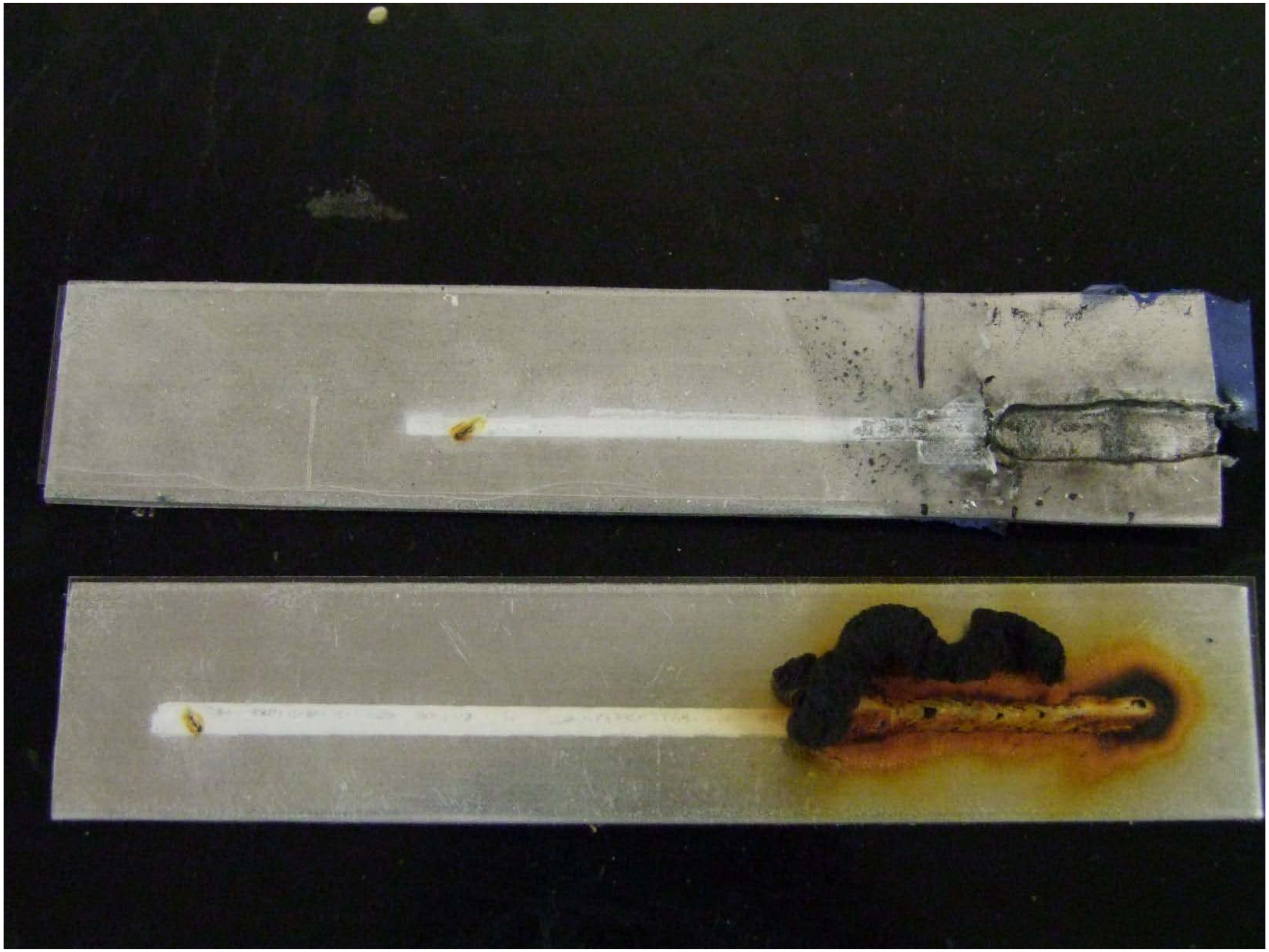
- **Process to produce RDX nanocomposite morphology was unreasonably slow**
  - Printing rate <100 µm/week
  - No samples generated for testing

- **Heating the substrate produced dense morphology with abnormally grown grains**
  - Printing rate ~30 µm/h

Example of Dense RDX Samples



Dense RDX Samples after Testing



Conclusions and Future Work

- Inkjet printing of explosive materials was demonstrated with:
  - Tailorable morphology
  - ~20 μm pattern resolution
- The nanocomposite RDX structure was produced, but was not tested due to unreasonably slow printing speed
- The dense RDX structure could be burned, but would not detonate at ~500 μm thickness
  - Without nanocrystalline RDX, sub-mm critical thickness to sustain detonation may not be achievable
- Current efforts aimed at printing alternative nanoenergetic materials for:
  - Critical thickness <100 μm
  - Printing speed >10 μm/h

54th Annual Fuze Conference
Session VA, 13 May 2010

Impact Switch Investigation

Naval Air Warfare Center
Weapons Division

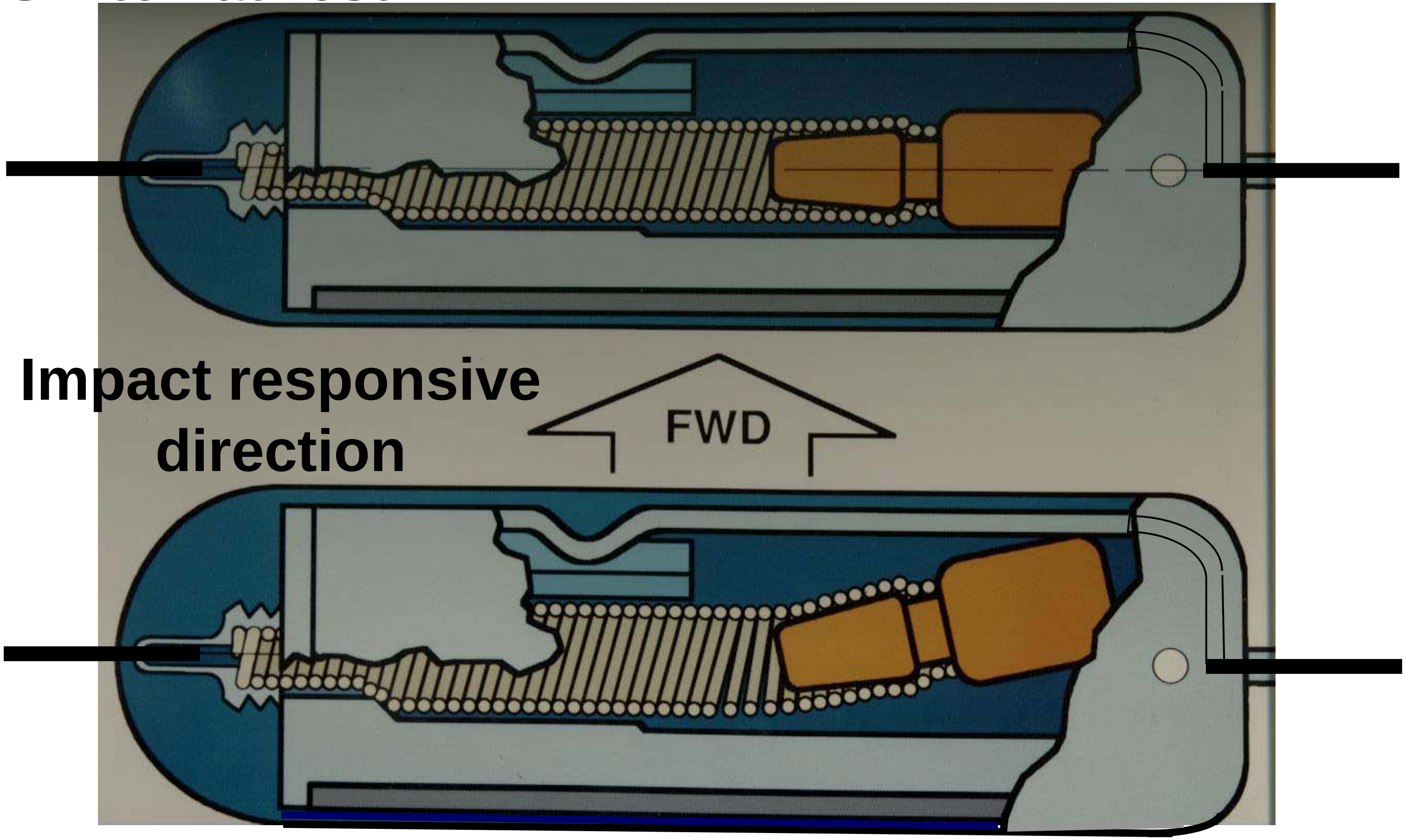
Sam Tuey
Code 478300D
COM (760) 939-2698, DSN 437-2698
sam.tuey@navy.mil

Impact Switch
Investigation

- Investigation objective is to characterize switch vibration response
  - Investigation is 40% complete
  - Vibration test level is based on estimated and actual flight test data
- Reporting on preliminary result
  - This data is not yet applicable to any system in use
  - Switch becoming more sensitive to vibration as exposure is accumulated
- Has plan to complete switch characterization with vibration levels from flight testing

Impact Switch
How It Works

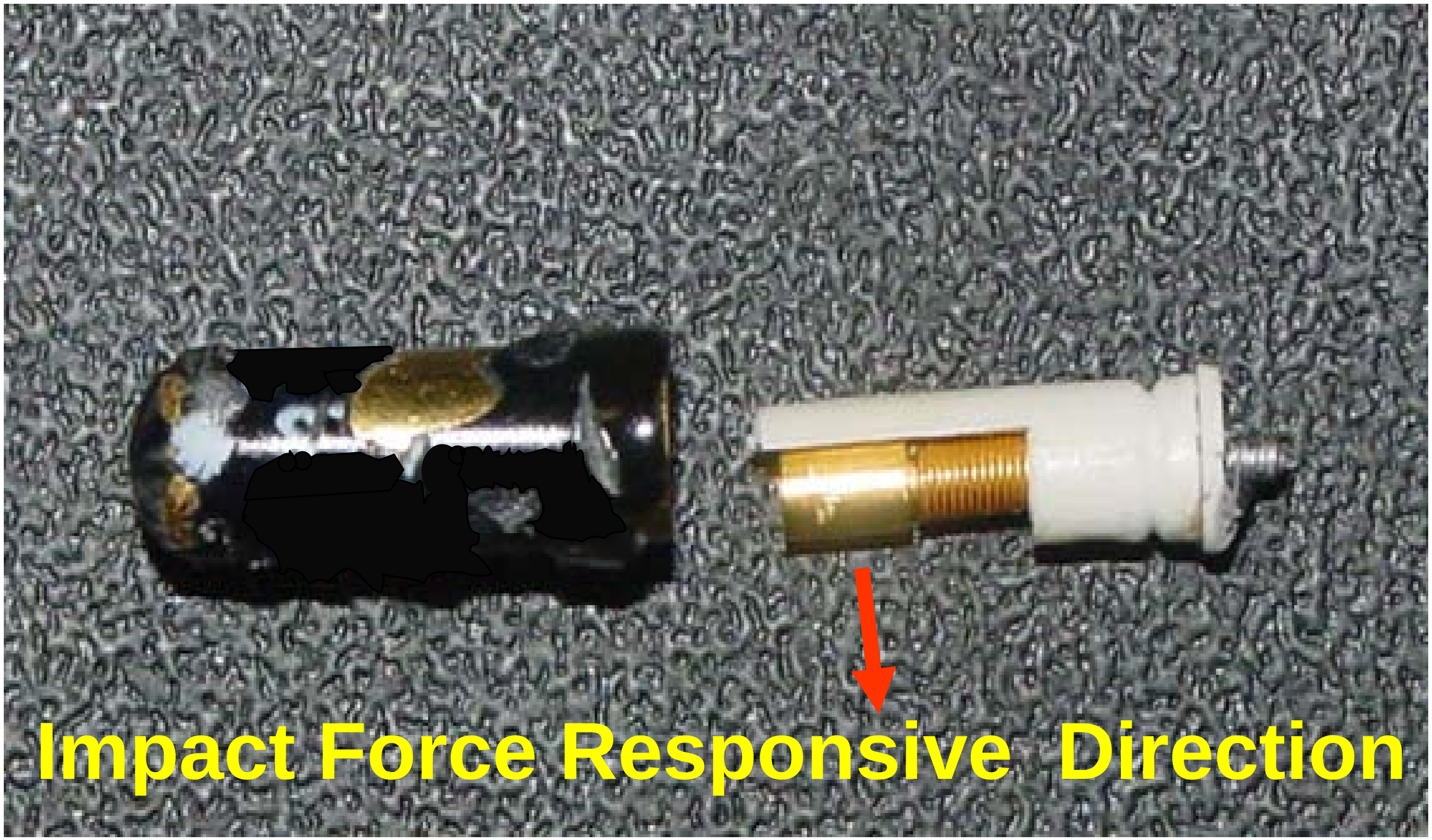
Switch at rest



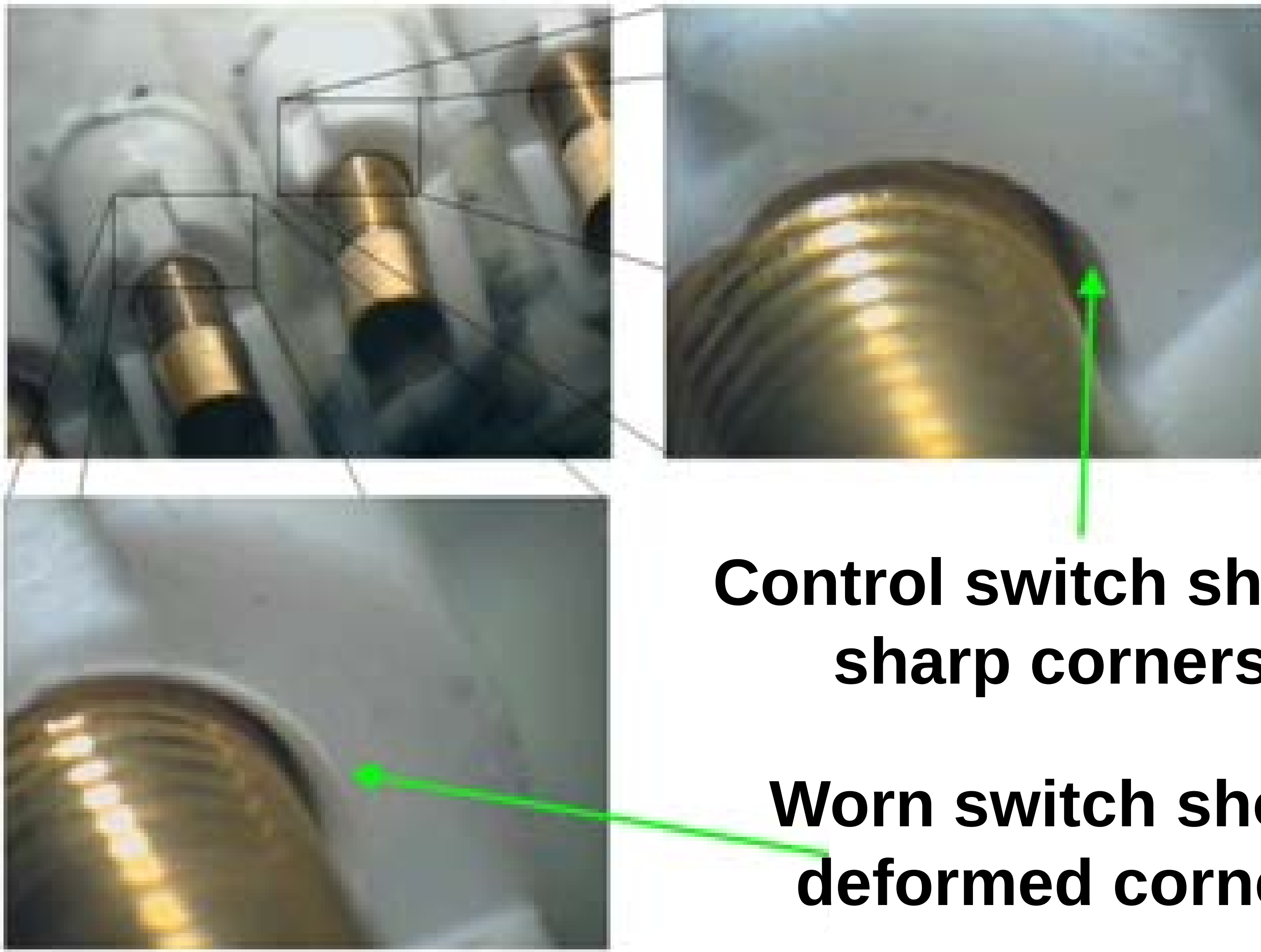
Impact responsive direction

Impact Switch Construction

Partially disassembled switch



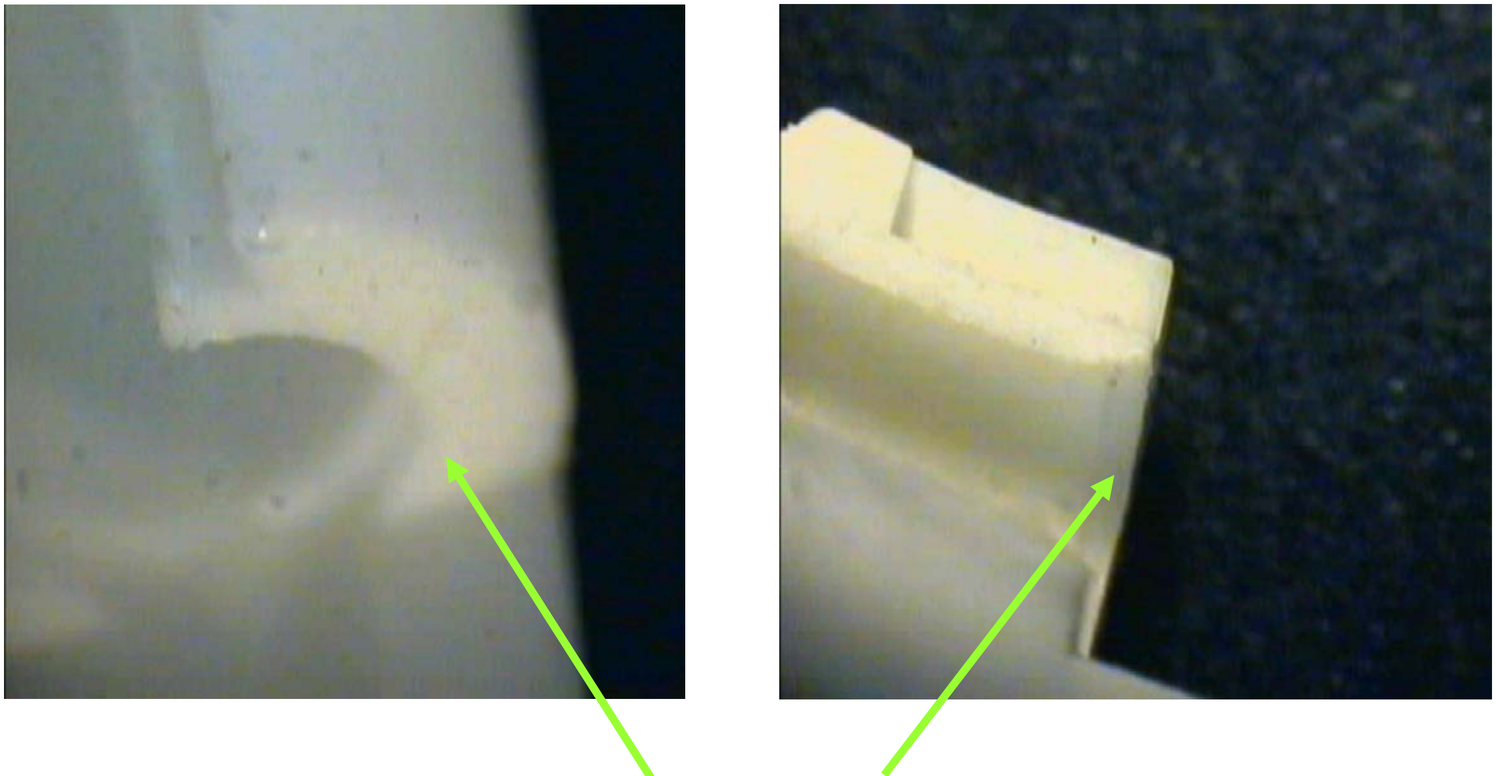
Impact Switch
New vs. Worn Out



Control switch shows sharp corners

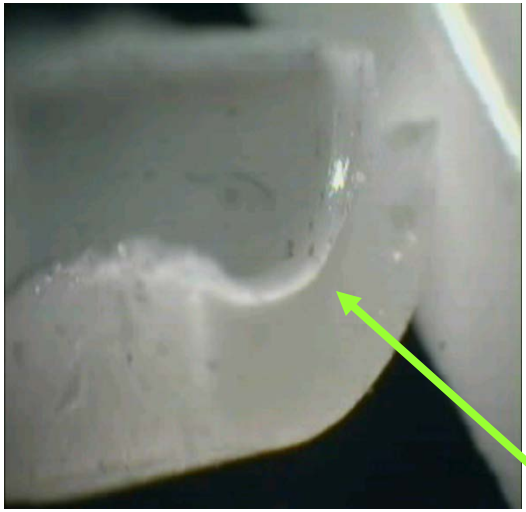
Worn switch shows deformed corners

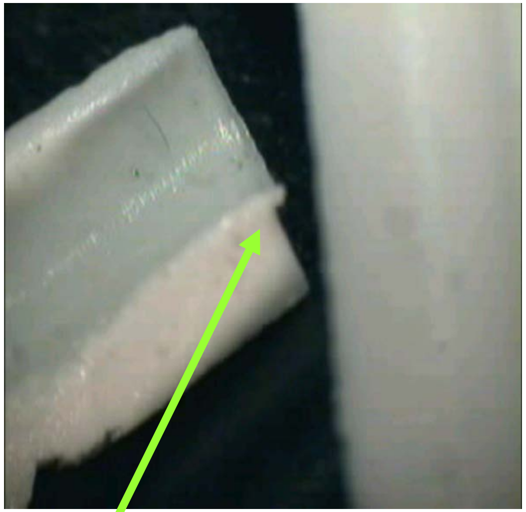
New Impact Switch

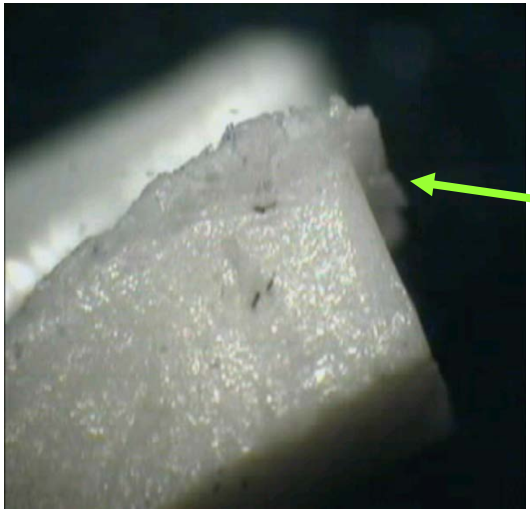


New Switch Plastic Body

Worn Impact Switch







Body Deformed

Impact Switch Production Test Spec

- **Pendulum Test**
  - **Switch remains open at velocity change = x ft/s**
  - **Switch closes at velocity change = y ft/s**

- **Centrifuge test**
  - **Switch closes at xx g**
  - **Switch remains open at yy g**

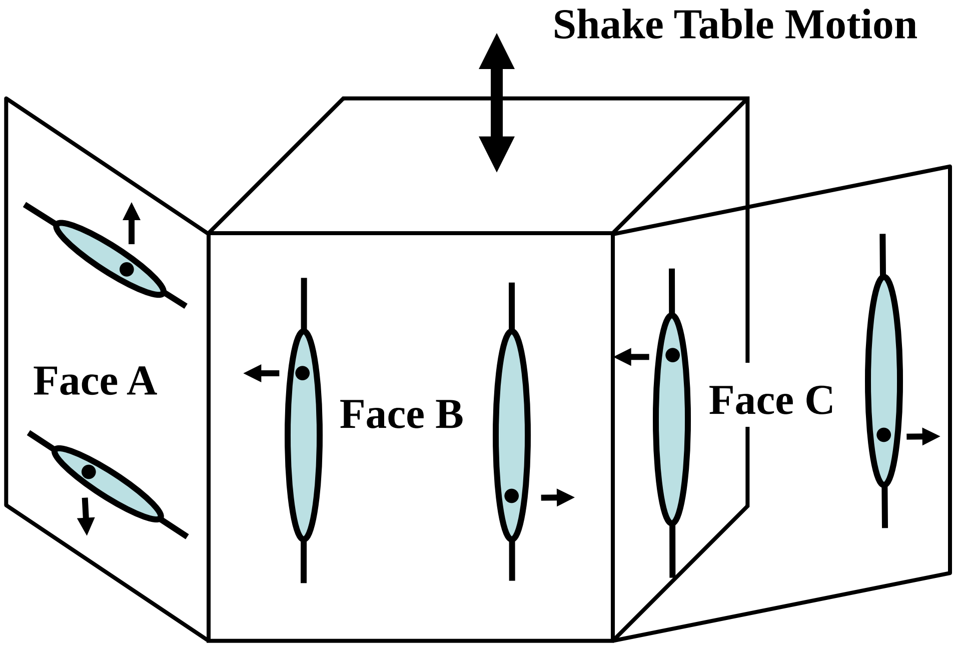
- **Sine vibration environmental conditioning**
  - **5 g for 30 minutes**
  - **Frequency sweep = 10 to 2k Hz**

Impact Switch

Vibration Characteristic Test Set Up

Vibration test fixture

(With up to 12 switches per side)

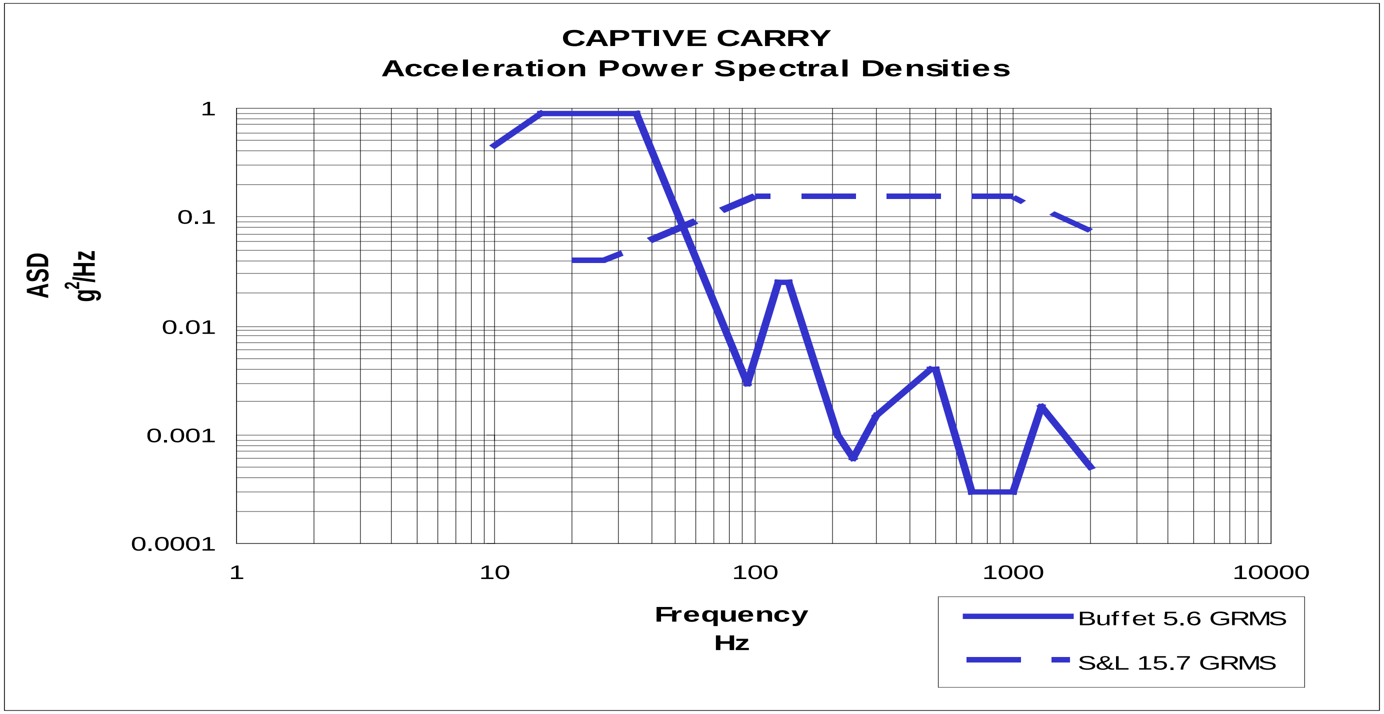


Impact Switch Placement on cube

Impact Force Responsive Direction

Impact Switch
Vibration Test Levels

- **Estimated captive carry vibration test level**



- **Free flight vibration test level was from flight test data**

Group1 Impact Switches Vibration Test Data

Looking for trigger threshold (12 Switches on Face A had response)

	Test 1	Test 2	Test 3	Test 4
Sine Sweep	Start from 5g, 50 - 2kHz 5g = trigger, 50-120Hz	From 5 g going down, 5-150 Hz 0.7g = trigger, 35-50 and 80-90 Hz		
Estimated Captive Carry			Start from 1x 1 x = trigger	
Free Flight				Start from 1x 1x = no trigger 1.26 x = trigger

Group1 Impact Switches Vibration Test Data

Face B and C Switches Moved to Face A (10 Switches)

	Test 1	Test 2	Test 3	Test 4
Sine Sweep		Start from 5g going down 3g = trigger		
Captive Carry				
Free Flight	Start from 1x 5x = trigger		Start from 1x 3.16x = trigger	Start from 1x 1.26x = trigger

Note the quick drop in free flight trigger threshold
Switches would still pass G trigger threshold test

Fresh Impact Switches Vibration Test Data

12 New Switches on Face A

	Test 1	Test 2
Sine Sweep		Start from 1g, 50–1kHz 4g = trigger, 50-120Hz
Captive Carry		
Free Flight	Start from 1x 1 to 10 x = no trigger	

Impact Switch

Preliminary Characteristic/Conclusion

- Based on limited test data
- Transition from fresh to worn switch is TBD
  - Transition is rapid at a TBD level
  - No change in impact g trigger level

- New switch vibration trigger threshold
  - Sine: 4g, 80-90 Hz
  - Captive carry: TBD
  - Free flight: ≥ 10x

- Worn switch vibration trigger threshold
  - Sine: 0.7 g, 40-50 Hz and 80-90 Hz
  - Captive carry: ≤ 1x
  - Free flight: 1.26x
  - No change in impact g trigger level

Impact Switch
To Complete Characterization

Plan is to get 3 D plot on switch:

Trigger Threshold = F(Vibration Level, Exposure Time)