

50th Annual Fuze Conference

"50 Years of Support Freedom"

9 - 11 May 2006

Norfolk, Virginia

Session I & II: OPENING REMARKS AND KEYNOTE & GENERAL SESSION

- Keynote: Mr. Rene Kiebler, Deputy Project Manager Combat Ammunition Systems, PEO Ammunition
- OSD Perspecctive, Mr. Peter A. Morrison, Staff Specialist OUSD/DDR&E(S&T) Weapons Technology
- PEO Ammo Perspective, Mr. Rene Kiebler, Deputy Project Manager Combat Ammunition Systems, PEO Ammunition
- US Army RDECOM ARDEC Perspective, Dr. Joseph Lannon, US Army RDECOM ARDEC
- Navy Overview, Mr. Steve Mitchell, Ordnance Project Area Director, NAVSEA
- Air Force S & T Strategy, Mr. Timothy Tobik, Air Force Research Laboratory, Eglin
- Air Force Acquisition Strategy, Mr. J. Rick Holder, Sr., Director Fuze Squadron USAF, Eglin
- Fuze IPT Perspective, Mr. Lawrence Fan, Fuze and Microsystem Project Manager, NSWC

Session IIIA: OPEN SESSION

- PGMM, New Application for an Existing Fuze, Mr. Al DeSantis, Picatinny Arsenal, NJ
- Proximity Sensor for the Guided Multiple Launch Rocket System (GMLRS), Mr. Robert P. Hertlein, L3 Communications KDI Precision Products
- Portable Excalibur Fire Control System, Mr Gregory Schneck, US Army RDECOM ARDEC
- Enhanced Portable Inductive Artillery Fuze Setter (EPIAFS), Mr. Tom Walker, US Army RDECOM ARDEC Adelphi Fuze Division
- The Evolution of the DSU-33 C/B Proximity Sensor, A Success in Customer-Contractor Partnership, Mr. Michael J. Balk, ATK Ordnance Systems
- A New Fuze for an Electromagnetic Gun, Mr, Barry Schwartz, US Army RDECOM ARDEC
- Introduction of the Multi Option Fuze Artillery (MOFA) DM84 on 120mm Rifled Mortar, Mr. Jochen Wagner, JUNGHANS Feinwerktechnik

Session IVA: OPEN SESSION

- Challenges Associated with Development of the Affordable Weapon System Fuzing System, Mr. John Hubert, L-3/KDI Precision Products, Inc.
- FMU-139C/B. Electronic Bomb Fuze Design Update, Mr. David Liberatore, ATK
- Shipboard Submunition Fuze Safety and Realiability Enhancements, Mr. John Kunstmann, Indian Head Division, NSWC
- Thermal Battery Development Reduced Product Variability Through 6-Sigma, Automation and Material, Mr. Paul F. Schisselbauer and Mr. John Bostwick, ATK
- Performance Testing of Lead-Free Stab Detonators, Mr. Neha Mehta, US Army RDECOM ARDEC
- TNO Research on EFI's in Relation to Insensitive Munitions, Mr. Wim Prinse, TNO Defence, Security and Safety

Session VA: OPEN SESSION

- Hight-G Mortar Electronic S&A Development and Flight Test, Mr. Cuong Nguyen, US Army RDECOM ARDEC
- Safe Separation Study for MK 437 Mult-Option Fuze for Navy (MOFN), Mr. Brian Will, NSWC, Dalhgren
- Navy Proximity Fuze Simulation with Embedded Tactical Software, Mr. John Langan, NSWC WD
- Inadequacy of Traditional Test Methods for Detection of Non-Hermetic Energetic Components, Mr. Karl Rink, University of Idaho
- Weapons Reliability How Modern Warfare has Changed the Requirement, CDR Tom Hole, USN, US Navy PMA-201
- MAFIS a Proven Hard Target Fuze, Mr. Laurie Turner, Thales Missile Electronics
- Aurora a Proven Hard Target Fuze, Mr. Richard Clutterbuck, Thales Missile Electronics

50th Annual Fuze Conference



Thursday, May 11

- Session V-A (Chair: Leonard Friedman)
 - 1:00 Miniature ISD Design for GMLRS
 - 1:20 <u>High-G Mortar Elec. S&A Develop. And Testing</u>
 - 1:40 Safe Sep. Study for MK 437 Multi-Option Fuze
 - 2:00 Navy Proximity Fuze Simulation w/embedded...
 - 2:20 <u>Inadequacy of Traditional Test Methods....</u>
 - 2:40 Weapons Reliability-How Modern Warfare...
 - 3:00 BREAK
 - 3:20 MAFIS a Proven Hard Target Fuze
 - 3:40 <u>Aurora a Proven Hard Target Fuze</u>
 - 4:00 A Rapid Prototyping Process for Fuze Development
 - 4:20 Solid Foundations and White Hair: A Fuzing Per...
 - 4:40 Wrap-up / Conference Adjournment





Aurora Fuze for PGB PWIV R C D'A Clutterbuck NDIA Fuze Conference 11 May 2006

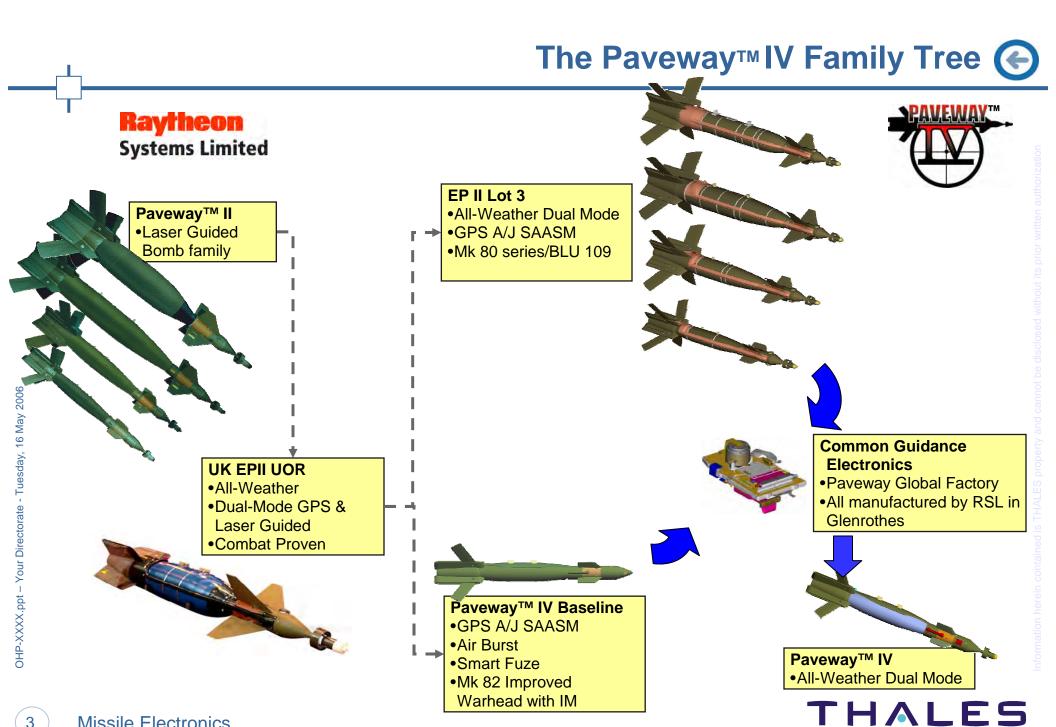
THALES



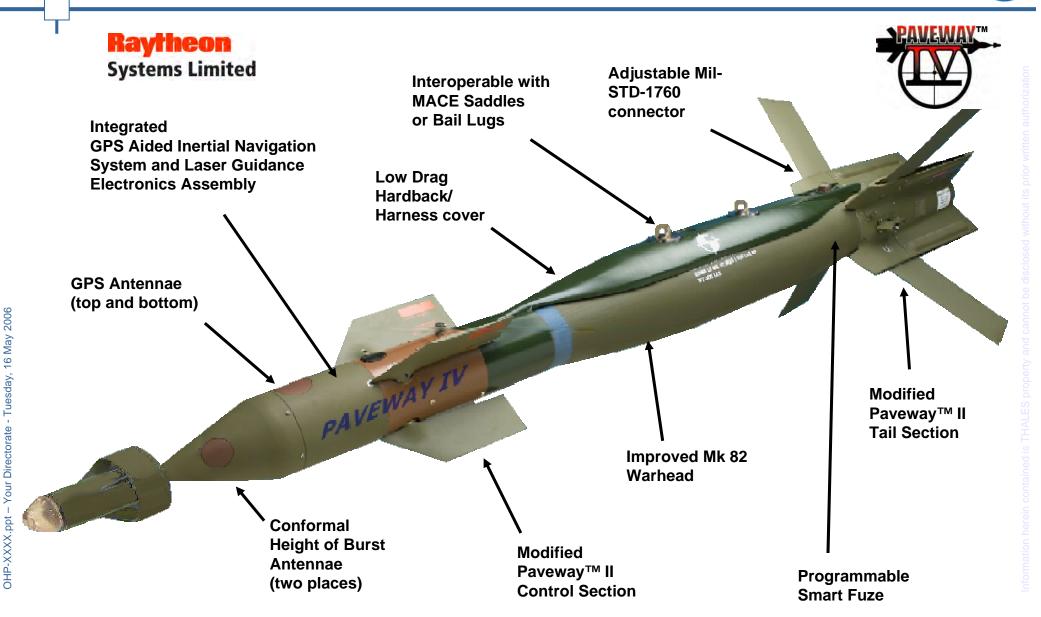
Hard Target Fuzing Perspective

- Weapon Background and Capability
 - → PavewayTM IV
- Fuze Background
 - → MEHTF-PSFT
- Fuze Second Environment Sensing
- Programme Status





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OHP-XXXX.ppt – Your Directorate - Tuesday, 16 May 2006

Company Background (

TME is a Fuzing Company
Building hardened fuzes since 1914
World's first In service Proximity Fuze (710 Electro Optical Pistol) ('42)

- 27,500 MFBF built
- Successful FCT trial at Eglin 1992
- Used by RAF, RSAF and USAF in Desert Storm
- Kosovo data indicates >99% reliability for MFBF in 400+ releases

World's first hardened and electronic multifunction bomb fuze (MFBF) - 1981

Pioneer in modern fuze hardened electronics

1918 - Shell Fuzing

1940's - Airborne Radar, Shell Fuzing, Proximity Fuzing (Rockets)

Bomb Fuze for "Bouncing Bomb" etc.

1950's - Naval Proximity Shell Fuzing

1960's - No.907 RF Proximity Fuze for Bombs.

1970's - No.952 RF Proximity Fuze for Bombs.

Multi Role programmable Shell Fuze (MRF)

1980's - SG357 Runway Cratering Weapon

MFBF (No.960) Multi-Function Bomb Fuze

1990's - Intelligent Hard Target Fuzing Research

EPIFS

2000's - Intelligent Hard Target Fuzing.

MAFIS, HTSF, MEHTF

PGB/ABF

BDI/BDA

Fuzing in High Speed Impacts

Paveway IV





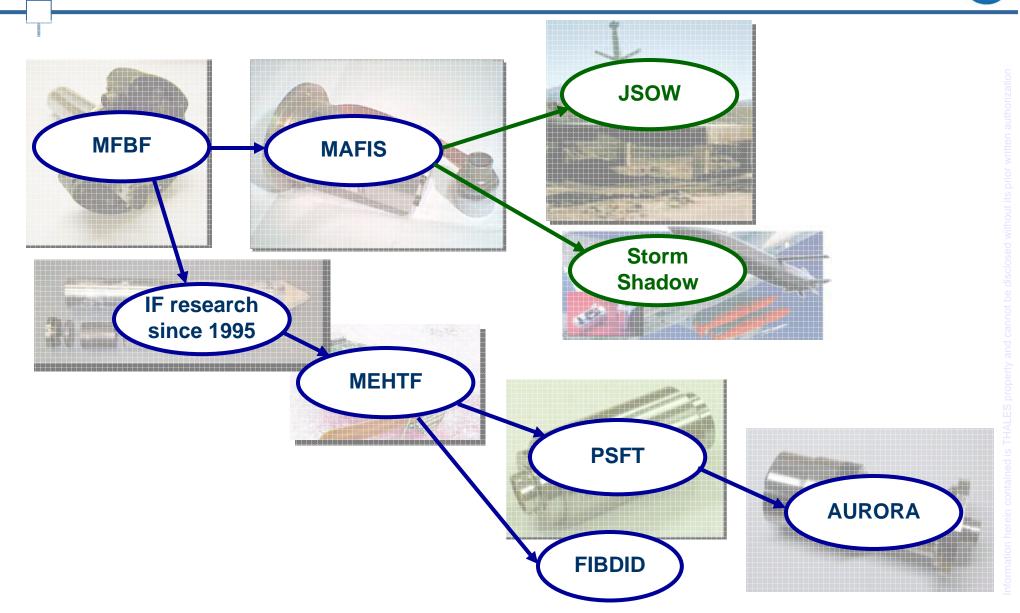






TME Bomb Fuzing Family Tree (







Missile Electronics

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Fuze Second Environment Sensing



Summary of Requirements for Safety Sensors:

- 1: Sense the Intentional Release from the launch platform
- 2: Confirm Weapon has been released into the expected environment

(Operation of at least one of the independent safety features shall depend on sensing an environment after first motion in the launch cycle or on sensing a post launch environment.) STANAG 4187 6b3





Typical Sensors used in past

Air speed,

Can provide power sources

(Bigger Area :- More Power {& Drag!})

But: Senses an environment that is not totally unique to "release" (mainly is "lanyard pulled") Also issues with high altitude, thin air,

Damage, drag etc.







Fuze Second Environment Sensing (



Typical Sensors used in past

Air pressure:

Pitot (air speed)

Motor operating





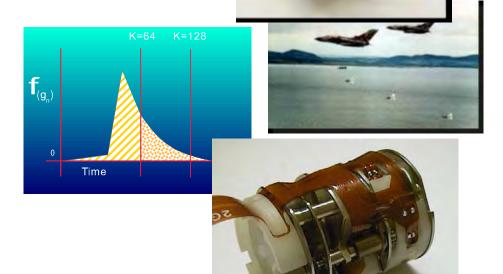
Fuze Second Environment Sensing (



Typical Sensors used in past **Acceleration sensing:** Parachute operation detection

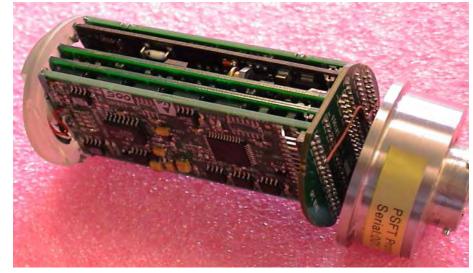
(Both Mechanically and Electrically)







PSFT Phase II Research added Improvements on MEHTF



- **Improved Safety Architecture**
 - → Late Arm
 - → Potential for different Arming sensor suites
 - Release Environment Observation



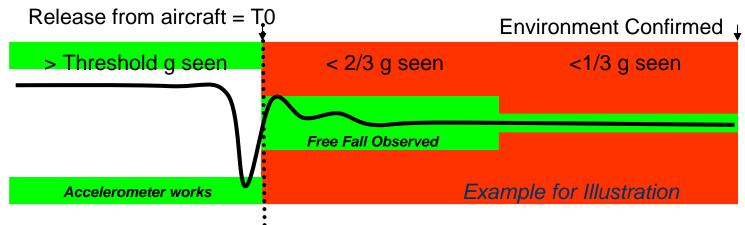
PSFT Fuze Internal "Second" Environment Sensing



■ PSFT introduced crossed axis MEMS Accelerometers and Processor to sense Post Release <u>Environment</u>







EXAMPLE: Internal Fuze Accelerometers monitor unique post launch zero g environment to confirm post launch environment.

Accelerometer confirmed OK by sensing release & or carriage loads



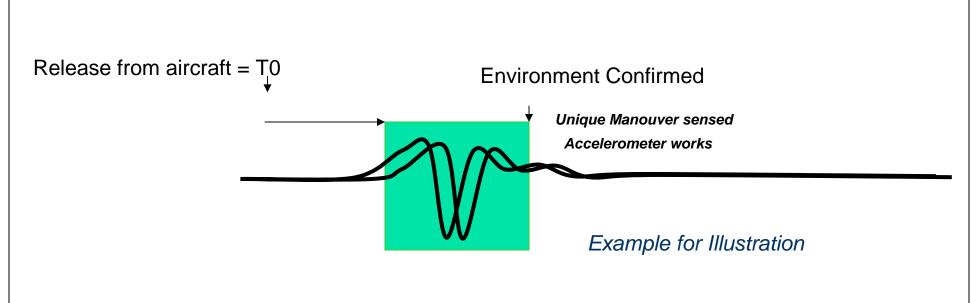
AURORA Fuze for PGB (Paveway IV)



Develop, qualify & manufacture, 2003 - 2006 Built on PSFT:

Decided to make system independent of release shocks:

Initially: use a Timed Manoeuvre

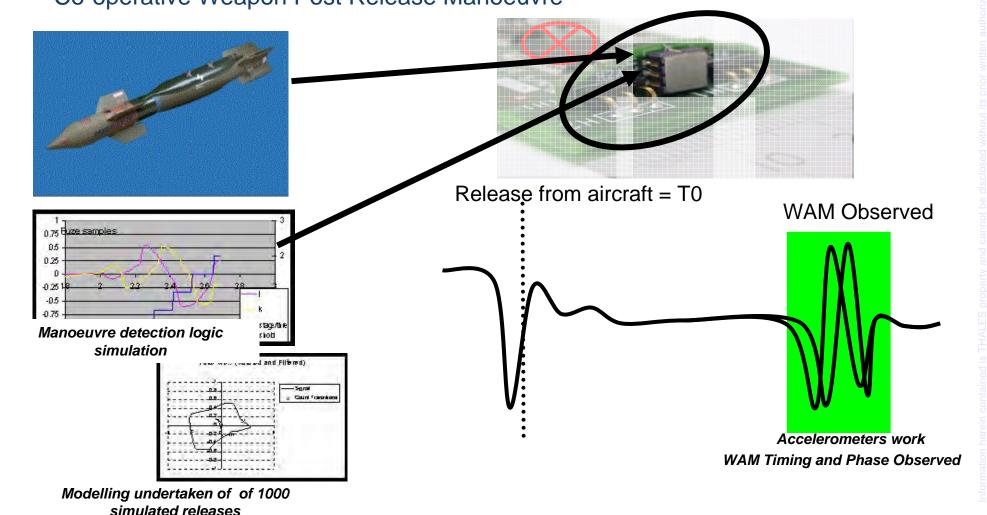




AURORA Fuze for PGB (Paveway IV)





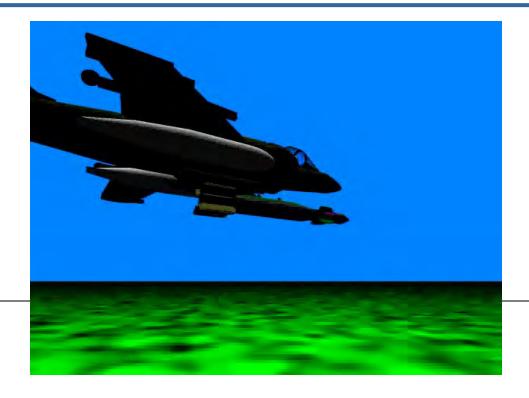


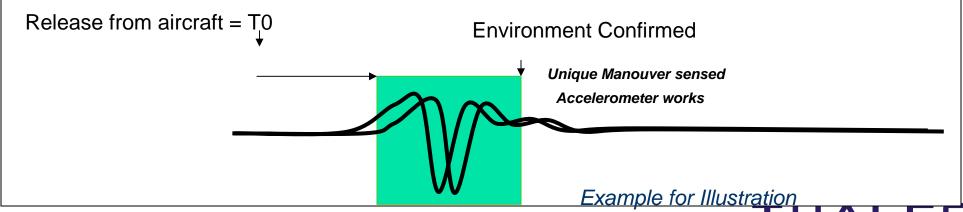


AURORA Fuze for PGB (Paveway IV)



WAM Option Initial Concept



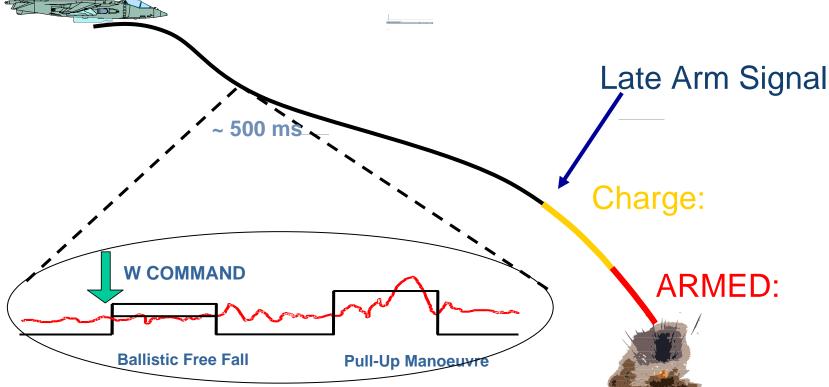


AURORA Fuze for PGB (Paveway IV) 'WAM' / 'WAD'



Further Improved concept:

- → Allow weapon to determine when to make manoeuvre:
- → Simplify Manoeuvre into 2 Stages:
- → Add Late ARM signal





AURORA Fuze for PGB (Paveway IV) 'WAM' / 'WAD'

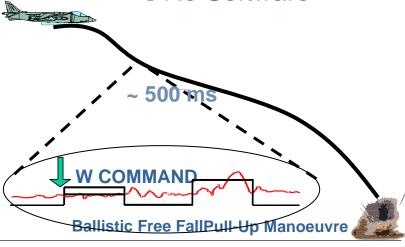


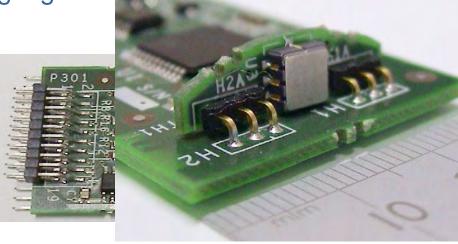
Advantages:

- Manoeuvre is at commanded time:
 - → Can be delayed to Lower Altitudes
 - → When convenient to Weapon
 - → Expands release envelope
- Is simpler to detect

→ All "Hardware" checking logic

→ No Software







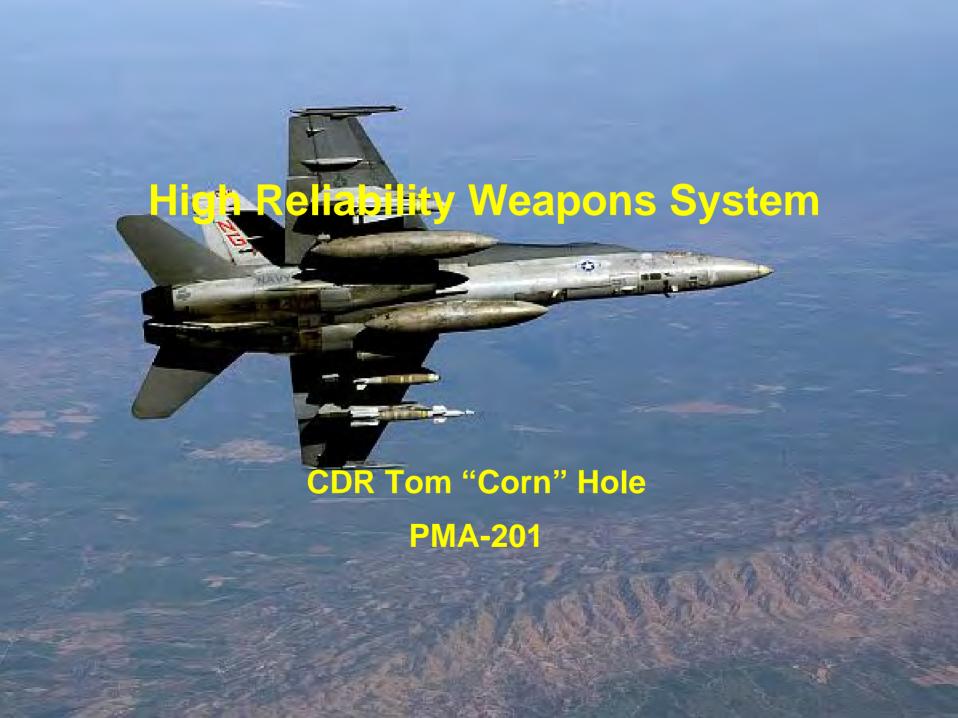


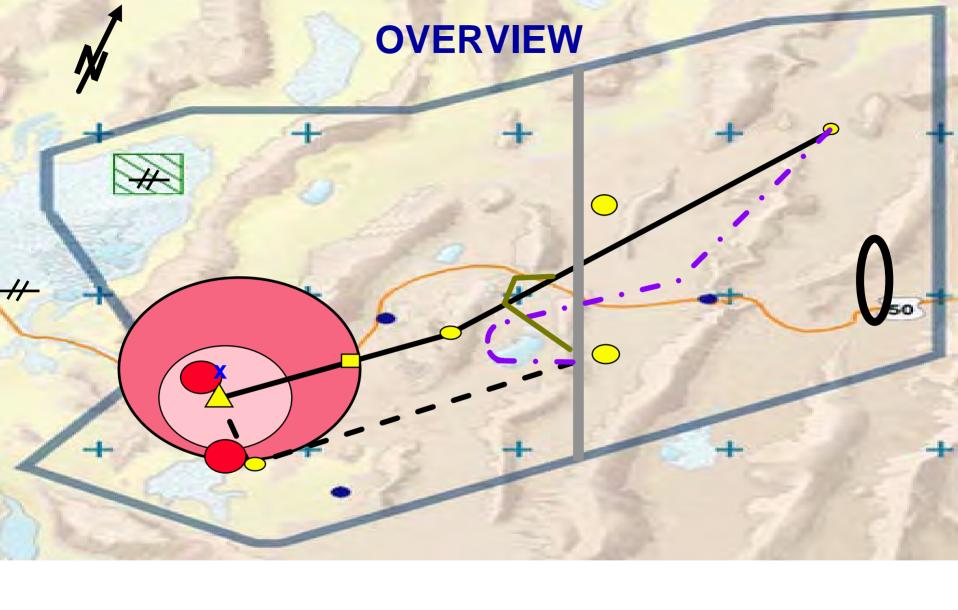


THALES MISSILE ELECTRONICS LIMITED



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STRIKE COMPOSITION

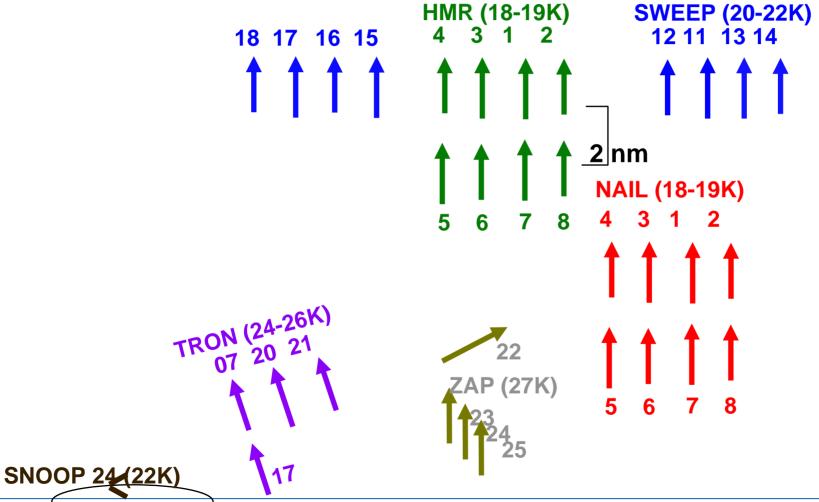
(Desert Storm)

THE AND USE CAL	L SIGN	AIRCRAFT	MISSION	ORDNANCE
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NAIL	41	FA-18	STK/FTR	u
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"	48	FA-18	"	tt
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"	17	FA-18	"	<u>*</u> 20 Support Aircraft
"	18	FA-18	"	36 Total Aircraft
TRON	07	EA-6B	JAM	1xAGM88 30 TOTAL AILCIAIL
"	17	EA-6B	"	"
TRON	20	FA-18	HVAAP	1/2/3
"	21	FA-18	"	1/2/3
ZAP	22	FA-18	HARM	3xAGM88
"	23	FA-18	**	"
"	24	FA-18	**	"
"	25	FA-18	**	"
SNOOP	26	S-3	ES	
RAVEN	27	ES-3	ES	
DOME	01	E-2	C2	
DOME	02	E-2	C2	NAVMAIR

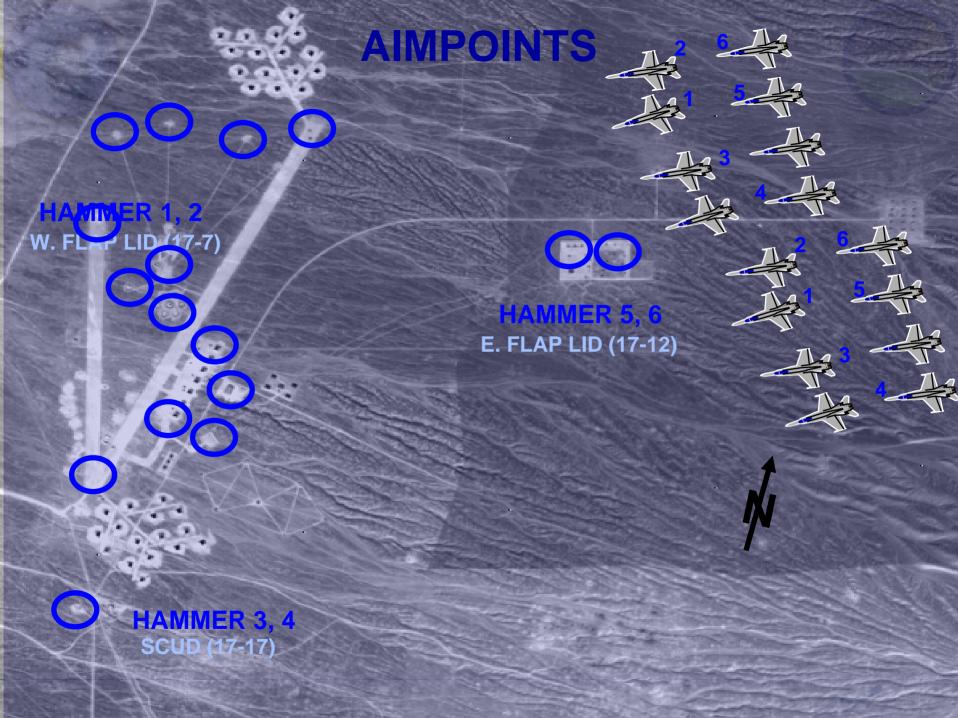


FORM SNAPSHOT



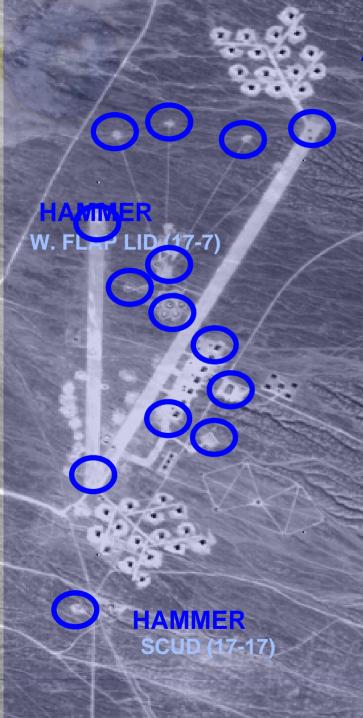


RAVEN 25 (23K)



STRIKE COMPOSITION

WE AND USAN CAL	L SIGN	AIRCRAFT	MISSION	ORDNANCE
HAMMER " " SWEEP " " TRON TRON " ZAP " RAVEN DOME	01 02 03 04 11 12 13 14 07 20 21 22 23 27 01	FA-18 FA-18 FA-18 FA-18 FA-18 F-14 F-14 EA-6B FA-18 FA-18 FA-18 FA-18 FA-18 ES-3 E-2	STK/FTR " " CL. ESCORT " " JAM HVAAP " HARM " ES C2	4 x JDAM " 1/2/3 2/2/2 " 1xAGM88 1/2/3 1/2/3 3xAGM88 " To prosecute 16 DMPIs requires: 16 PGMs 4 Strike Aircraft 11 Support Aircraft 15 Total Aircraft
				NAVAALI



AIMPOINTS



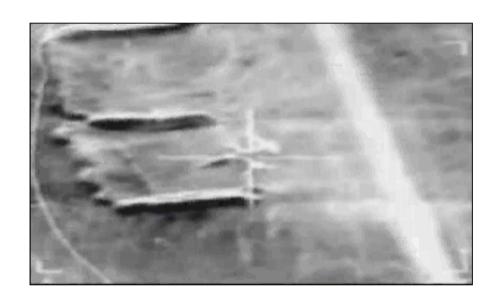
HAMMER E. FLAP LID (17-12)











Click box to run video.



Precision Revolution



Desert Storm

- Approximately 100,000 weapons delivered by TACAIR assets
- 93% were unguided
- 7% were precision guided

OEF / OIF

- Approximately 25,000 weapons delivered by TACAIR to date
- 85% were precision guided
- 15% were unguided

One bomb, One DMPI



How Does This Apply to Fuzes?



Duds are bad

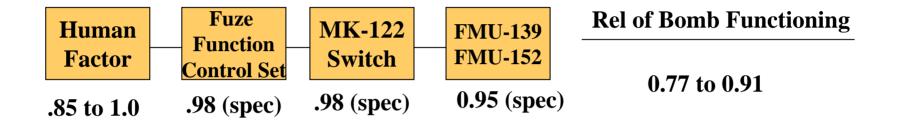
- Target not destroyed
- Troops in contact remain in contact (threat not destroyed)
- -Bad guys send the dud back to us as an IED
- –EOD must safe / remove dud

None of these results are good



Theoretical Fuze Reliability





- Current MATHMATICAL RELAIBILITY, according to spec, best case:
 - 93% reliable (FFCS mode)
 - 90% reliable (FZU mode)
 - FZU-48 spec reliability is 95% vs FFCS spec reliability of 98%

This is what DoN paid for: 93% best case reliability





Fuze Improvement Status



• FMU-139C/B

- Adds 4 minute life with FFCS
- Retains electro-mechanical safe arm device
- No improvement in reliability

• FMU-152 (JPF)

- Adds serial data interface to electro-mechanical safe arm device
 - Allows cockpit selectable arm/delay times
- No improvement in reliability vs FMU-139

• FMU-139D/B

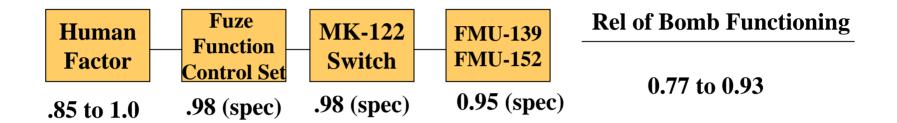
- Electronic Safe Arm Device
- Improves fuze reliability to near 100%
- Allows further improvement in overall system reliability not possible with current fuzes





Theoretical Fuze Reliability





- Current MATHMATICAL RELAIBILITY, according to spec, best case:
 - 93% reliable (FFCS mode)
 - 90% reliable (FZU mode)
 - FZU-48 spec reliability is 95% vs FFCS spec reliability of 98%

This is what DoN paid for: 93% best case reliability





Hi-Rel Program



- The first time you know if an FMU-139 or FMU-152 is going to work is when it hits the ground
- Goal of HiRel is to provide high reliability weapons SYSTEM
 - Computers talking to computers
 - Eliminates current electro-mechanical fuze designs
 - 1760 interface allows system to identify failures BEFORE the bomb is released
 - Improves / Eliminates points of failure
 - FZU
 - MK-122
 - Cables
 - Connectors
 - Greatly simplifies assembly and load process

Improve OVERALL Fuze System Reliability to near 100%





Hi-Rel Program



- DoD can't afford 100% inherent reliability
- BIT and status monitoring can be just as effective
- Example:
 - 100 bombs dropped, 5 duds = bad
 - 95 bombs dropped, 0 duds = good
- If we can achieve 85% reliability measured before the weapon is dropped but every weapon works 100% of the time when viewed by the bad guys, this is a good thing

Reliability is measured at the target



Words from the War



"My concern is that this war has reached a point where a tactical error can have strategic implications so everything in our arsenal needs to work first time, every time. We have also become the victim of our own success in that the ground troops "know" we can shack the target every time and pretty much control collateral damage. As such, we only drop one at a time so when one doesn't work as advertised it becomes obvious."

- Lt Gen Walter Buchanan Commander of 9th Air Force

Current Weapons Reliability Requirement = 100%





Summary



- One bomb, one target
- 100% is the requirement
- System of Systems approach





Abstract



Abstract: The FMU-139 and FMU-152 (JPF) are currently used in USN and USAF general purpose bomb based weapons to include JDAM, Laser Guided Bombs (LGB) and Dual Mode Laser Guided bombs (DMLGB). The demonstrated reliability of the FMU-139/152 in combat operations has been at or near 95%. The operational commanders have expressed that this is not acceptable and they require a weapons system that is 100% reliable. Any duds result in coalition forces being held at additional risk or the dud bomb being utilized as an IED by enemy forces. Just as the GPS weapon transformed our concept of one weapon, one kill, this same transformation has led to the requirement for 100% reliability. To be more precise, every weapon that is released must detonate. In order to achieve this level of performance, the current GP bomb fuzes must be transitioned to electronic safe arm devices. In addition, a system of systems approach to reliability and safety must be implemented. This is the approach that is being utilized in the High Reliability Weapons programs. This brief will cover the history. requirement and program the US Navy has implemented.

Power Sources Center



An advanced weapon and space systems company

50th Annual NDIA Fuze Conference Norfolk, VA 9-11 May 2006

Thermal Battery Development – Reduced Product Variability Through Six Sigma and Materials Finger-Printing

Authors:

Paul F. Schisselbauer
John Bostwick

215-773-5416 215-773-5428 **ATK OS Power Sources Center ATK OS Power Sources Center**













- Overview
 - Thermal Batteries and Applications
- Performance Comparison
 - Thermal Batteries Versus Ambient Temperature Batteries
- Process Definition Using Six-Sigma
- Thermal Battery Description
- Manufacturing Processes
 - Process & Materials Control
 - Materials Characterization
- Cost Reduction Initiatives
- Benefits of End-Product Consistency
- Summary



- Thermal Batteries are used on a variety of weapon systems, including:
 - Bombs
 - Projectiles
 - Missiles, etc.
- Proper battery function is often of critical importance in meeting a weapon system's mission requirements.



ERGM Projectile



CALCM

 Thermal batteries have a proven track record and are capable of meeting the most demanding requirements.



M830A1



- Correct battery function depends on its design and manufacture, both of which present some challenges.
 - Design subtleties affecting performance can be overcome using test verification
 - Manufacturing or materials subtleties, on the other hand, often cause issues even after they were thought to have been taken care of.
- This paper presents a thermal battery development effort where product variability is reduced through the use of six-sigma tools, materials characterization or "finger-printing", and automation.
- The battery developed by this effort can be used on several applications, including the DSU-33 Proximity Sensor and the Precision Guided Mortar Munition (PGMM).



PGMM



DSU-33 Proximity Sensor

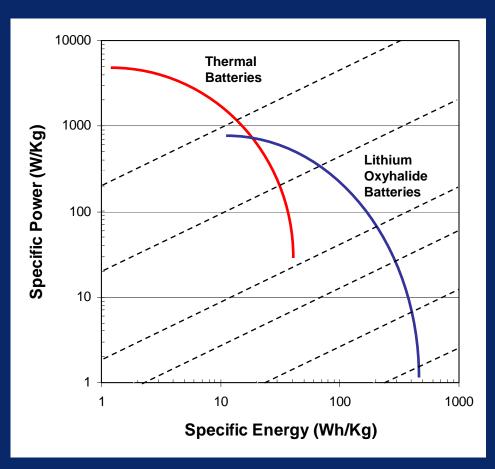
ACTIVE RESERVE

Performance Comparison



 Certain battery systems are ideally suited to military applications.

- Cold Operating Temp. (-45F)
- Long Shelf Life (>20 years)
- Lithium Oxyhalide Batteries are best suited to applications that require extended life.
 - Lithium/Thionyl Chloride
 - Lithium/Sulfuryl Chloride
 - Lithium/Sulfur Dioxide
- Thermal Batteries are best suited to applications that require high power.
 - Lithium Silicon/Iron Disulfide
 - Lithium Silicon/Cobalt Disulfide



Ragone Plot Comparing Thermal Batteries to Lithium Oxyhalide Batteries.

(Approximate data - plot for illustration purposes only)

Performance Comparison – General Features



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Parameter	Thermal Batteries	Lithium/Oxyhalide Batteries	
Description	Self-contained, hermetic, electrochemical power source	Self-contained, hermetic, electrochemical power source	
Storage Life	20 years	20 years	
Storage Mechanism	They achieve dormancy by utilizing electrolytes which require elevated temperature to become ionically conductive.	They achieve dormancy by physically separating the active components, i.e., the lithium foil anode and the electrolyte (catholyte).	
Strength	Provide <u>high current</u> density for high power applications.	Provide high energy density for extended mission times	
Reliability	High	High	
Thermal Management	Important design consideration	Minimal issues	
Cost	Cost Moderate to high Low to Moderate – cost effective in high volume production		



Performance Comparison



	Ambient Temperature Batteries			Thermal Batteries	
	Lithium Metal / Thionyl Chloride (Li/SOCl ₂)	Lithium Metal / Sulfuryl Chloride (Li/SO ₂ Cl ₂)	Lithium Metal / Sulfur Dioxide (Li/SO ₂)		Lithium Silicon / Cobalt Disulfide (LiSi/CoS ₂)
	Reserve:	Reserve:	Reserve:	Reserve:	Reserve:
Energy Density (Wh/kg)	50 to 150	45 to 135	32 to 95	20 to 45	20 to 75
	Active:	Active:	Active:	Active:	Active:
	300 to 440	265 to 387	200 to 280	N/A	N/A
Power	Moderate to High	Moderate to High	Moderate	High	High
Working Voltage Per Cell (Volts)	3.0 to 3.9	3.0 to 4.2	2.7 to 2.9	1.6 to 2.1	1.6 to 2.1
Temperature	-45F to +160	-45F to +160	-45F to +160	-45F to +160	-45F to +160

Process Definition Using Six-Sigma



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Concept Development

- Project Management (milestone planning, risk evaluation
- Voice of Customer
- Concept & Development
- Product Mapping

Product & Process Design

- DFM & DFA
- Process Mapping
- Design FMEA
- Process Capability
- Design of Experiments (DOE)

Product & Process Optimization

- DFM & DFA
- Process Design

Product & Process Capability

• Capability Analysis

Product Maturity





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Concept Development

Product & Process
Design

Product & Process Optimization

Product & Process
Capability



Voltage (V): 22 to 32.0

Current (mA): 350

Rated Capacity (mAh): 20

Activation Time (ms): < 500

Initiation Approach: Electric Igniter

Operating Temp. Range (°F): -65 to

+221

Storage Temp. Range (°F): -65 to +221



G3190B1 Thermal Battery (DSU-33 Application)

Physical Characteristics

Chemistry: LiSi/FeS₂

Size: 1.50" Dia. by 2.38" Length

Weight (g): 210

Environmental

MIL-STD-331 Environments



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Concept Development

Product & Process
Design

Product & Process
Optimization

Product & Process
Capability

- The G3190B1 device is a reserve primary lithium silicon/iron disulfide thermal battery.
- It is a self-contained, hermetic unit, capable of being stored in excess of 20-years and then being activated on demand.
- The battery's electrochemistry is based on Sandia's proven LiSi/LiCl-KCl/FeS₂ system.
- Overall Cell Reaction:

$$\text{Li}_4\text{Si} + \text{FeS}_2 \rightarrow 2\text{Li}_2\text{S} + \text{Fe} + \text{Si}$$
 (1.6V to 2.1V)

 This system easily meets both power and energy requirements of the DSU-33 fuze application.





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Concept Development

Product & Process Design Product & Process
Optimization

Product & Process
Capability

LiSi/FeS₂ Battery for DSU-33

- Battery uses 15 cells in series
 - Voltage: 31.5V max.
 - Working voltage per cell: 1.8 V nom per cell
- Application requires a power of 7.7 Watts
 - Battery power significantly exceeds requirement due to the relatively high intrinsic electrode capabilities and battery size.
 - Initial battery projection approximately 150 watts.
- Application requires a capacity of 19.44 mAh
 - Battery capacity significantly exceeds requirement due to manufacturing limitations for minimum electrode thicknesses.
 - Initial battery projection 120 mAh capacity.





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Concept Development

Product & Process
Design

Product & Process Optimization

Product & Process
Capability

LiSi/FeS₂ Battery for DSU-33

- Design uses a lithiated cathode to compensate for electro-active impurities.
- Electrolyte uses a eutectic binary composition of lithium chloride-potassium chloride to achieve lower temperature operation.
- Center fire initiation using an igniter.
- Operating Temperature Range: 352°C to 550°C.





Manufacturing Processes



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Concept Development

Product & Process Design

Product & Process Optimization

Product & Process Capability



Heat Pellet



Anode Pellet

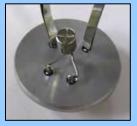


Separator Pellet



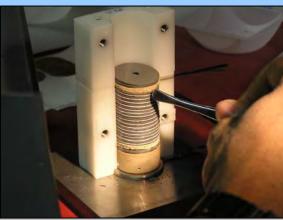
Cathode Pellet

Manufacture Subassemblies



TP/Igniter Assembly





Cell Stack Sub-assembly



Cut-away View of Thermal Battery

Final Battery Assembly





Process & Material Control



An advanced weapon and space systems company

Concept Development

Product & Process
Design

Product & Process
Optimization

Product & Process
Capability

Thiokol's "Fingerprinting" Program

 The diagnostic combination of analytical methods for detailed characterization of key materials

Value of a material fingerprint

- A fingerprint can be used to identify a material, to differentiate it from similar looking materials, or lead to its source
- Important for acceptance of materials, qualifying a change in a manufacturing process, location, or supplier

General Benefits of Fingerprinting

- Increases reliability and consistency of end product
- Fundamental understanding of critical materials
- Provides baseline chemical profile of materials in use
- Lot-to-lot consistency can be monitored and changes flagged
- Material changes can be traced to their source
- Acceptance testing for small supplier who cannot afford lab support
- Instills technical ownership for critical materials
- Enhance requalification of changes in vendor or production site
- Improved supplier relationship through data sharing
- Database available for failure analyses



Materials Characterization



An advanced weapon and space systems company

Concept Development

Product & Process
Design

Product & Process
Optimization

Product & Process
Capability

Analytical Tests

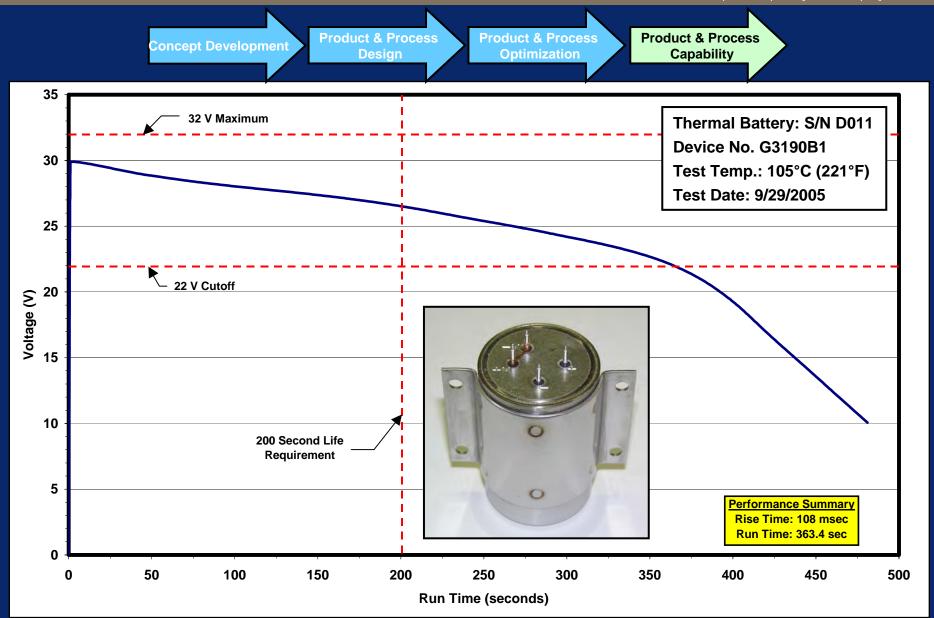
Test	Description	Use	
SEM	Scanning Electron Microscopy	Direct observation	
Raman	FT - Raman Vibrational Spectroscopy – Laser Excitation	Identifies molecules	
ICP/OES	Inductively Coupled Plasma with Optical Emission Spectroscopy Identification	Trace metal analysis	
EDS	X-ray Diffraction Spectroscopy	Elemental composition	
Metallurgical Analyses	Materials Analysis	Direct observation	
Other Tests	Pyrotechnic Burn Rates Pressure Generation Versus Time Electrolyte Leakage Tests Mechanical Properties		



Performance



An advanced weapon and space systems company





Cost Reduction Initiatives



An advanced weapon and space systems company

Concept Development

Product & Process
Design

Product & Process
Optimization

Product & Process
Capability

- Automated Mechanical Press
 - High Speed Pressing of pellets
 - Smaller Footprint
 - Good Modularity for Changes in Pellet Size
- FeS₂ Purification
 - Safe & Cost Effective
- Lithium Silicon
 - Manufacture Versus Buy
- Igniters
 - Make/Buy Analysis has Identified Low-Cost Solution that Meets Requirements



Benefits of End-Product Consistency



An advanced weapon and space systems company



- Increases product reliability
- Improves the consistency in performance, I.e., tighter groupings in performance
- Easier to identify technical issues



- A disciplined design and manufacturing approach using Six-Sigma tools has resulted in the success of this thermal battery project.
- Automated manufacturing of thermal batteries is long over due.
- Future power requirements appear to be headed toward higher energy and power densities:
 - Specific Energy: 35 Wh/kg → 70 Wh/kg
 - Specific Power: 750 W/Kg → 1500 W/Kg
- Technical innovations in both performance and manufacturing are required to meet the projected program demands.
- The *Power Sources Center* is poised and ready to take on these challenges.



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NDIA Presentation

<u>Preximity Euze Branck</u>

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Proximity Fuze Simulation with Embedded Tactical Software

Approved for public release; distribution is unlimited.





GenSim Fuze Simulation (1995 – present)

- GenSim runs missile endgame scenarios and outputs data in many formats. (Radar Proximity Fuze Simulation written in MS Visual C++). It is primarily written in "C".
- GenSim utilizes actual radar patterns / gains and implements Npoint target modeling and simulated radar clutter modeling.
- GenSim actually moves a missile reference and target reference along vectors toward Point-of-Closest-Approach (PCA) in its calculations. (This is called Time-Based processing).
- GenSim presently has about thirty target models and variations of target models. It has missile AAW targets, surface targets, and slow targets. It contains a low altitude clutter model.







Missile Proximity Fuzing

- Missile proximity fuzing is implemented in the last moments of missile flight as the missile and target converge to Point-Of-Closest-Approach (PCA). Proximity Fuzing is about detecting the target and timing the bursting of the warhead to optimize warhead fragment placement on the target.
- The design of missile proximity fuzes (Target Detecting Devices (TDDs)) requires analysis tools that simulate the fuzing system's operation and measures of effectiveness for the TDD as well as the missile itself.







Legacy Fuze Simulations (1970 –1980's)

- Simple Geometric models: Event based, this means that the encounter did not actually move but detection was calculated geometrically.
- Slow: The computers these were run on were mainframes or mini-computers and took a long time to run encounter scenarios. Administration issues.
- Target and Clutter models were geometric models (or utilized tables of data, not actual sensor models)





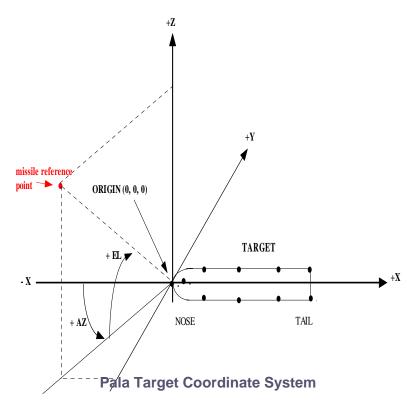
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Missile and Target Coordinates



Proximity Euze Branch

GenSim fuze Detection is done in a Missile-Body Coordinate System. The fuze detection point is defined by a spherical coordinate R, α , ϕ



The Npoint Target is loaded into GenSim in Pala Coords.



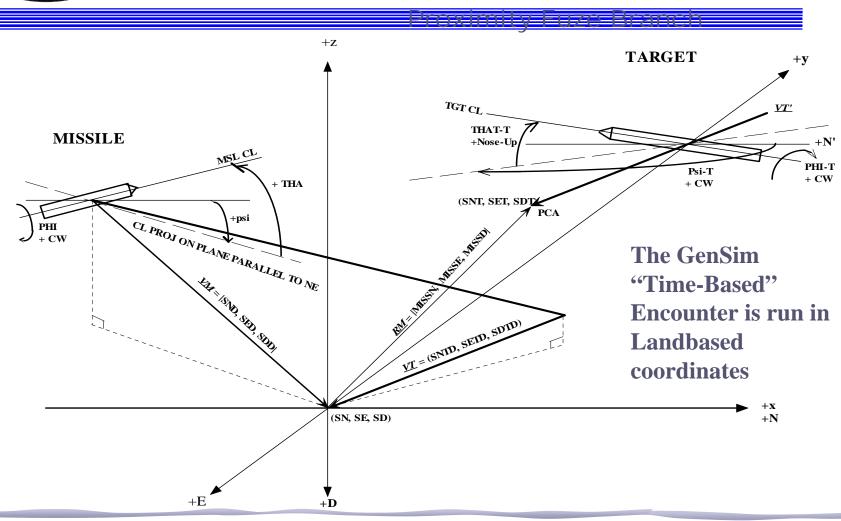


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Inertial Coordinates



(Landbased)





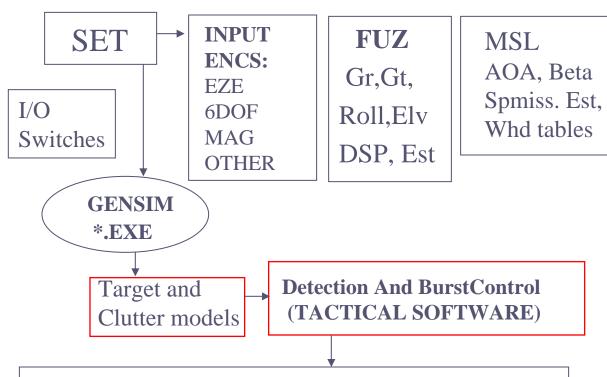






GenSim Input / Output Files

Proximity Euze Branch



The output files include: Detect, No Detect, Guidance Reject, DR/XR, VM/X, Graph, Lethal Burst Interval, Banana, Mesa, Warhead Enc Format

Target xyz

Clutter Mean, σ

The SET file is run with GenSim and calls the files it needs to run

Switches include:
Output / Analysis folder.
Repeat Encounter, Clutter
Rejection, Mirror,
Resp Est,
Detection Burst Cntl









Npoint Target Models

Proximity Euze Branch

- An N-point model accounts for target RCS as well as radar characteristics, The "N" is the number of radar reflector points. N-point modeling is based on the theory that radar data tends to pool in specific areas on the target.
- Locations are specified relative to target nose (*.xyz file).

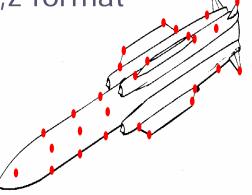
The xyz file contains "N" points in x,y,z format

The RCS specified in angle increments.

Az: -180 to +180.

EI: -90 to +90.

At present there are over thirty N-point
Targets developed for GenSim including
Missiles, aircraft, slow targets and surface targets.









Clutter Modeling

Proximity Fuze Branch

- The GenSim Clutter Model loads an input file that contains the (Mean, σ) for Clutter Radar Cross Section (RCS) tabulated for various conditions and incidence angle of the beam.
- GenSim uses encounter geometry in looking up the (Mean, σ) value.
- The Threshold is calculated as:

RCS = Mean + K * σ + Offset:

where: Mean, σ are lookup table values.

Mean, σ , and Offset are in dBSm.

K and Offset are the clutter sigma multiplication factor.





Early GenSim / Fuze Algorithms

- GenSim was designed to do analysis "trade studies" for missile proximity fuze development.
- Early GenSim contained its own fuze detection and Burst Control. Burst Control contains time-delay algorithms.
- This simulation was used to make fuze design decisions in sensory development, signal processing complexity, and missile / fuze interface limits based on missile encounter conditions (to name a few).
- With the burst control software (guidance / fuzing / warhead combined effectiveness "PK" could be estimated).





Early GenSim / Common Header

- In early GenSim planning, it was intended that this simulation be implemented together with actual missile fuze tactical software to aid in improved tactical software development as well as provide "accurate" fuze effectiveness under varying missile endgame scenarios. GenSim would create the missile / target environment and would call the tactical software.
- To prepare for tactical software implementation a common header file "*.h" was created where both GenSim could place program definitions as well as the tactical software. This created a "common placeholder" where GenSim could pass and receive info from tactical S/W. Detection and BurstControl functions were defined with the prefix: "Common_" to prepare for Tactical implementation. The function"Common_DetTdLogic" contained GenSim detection and BurstControl algorithms.







GenSim, Early Tactical S/W

- For the first Tactical S/W interface, the "Common_DetTdLogic" function was replaced with a Tactical Interface (TI) function called "TI_TerminalExecutive()". This file contains (GenSim/ Tactical) interface (TI) files.
- Other Tactical file definitions: "TI" was tactical interface, "LM" lightly modified tactical files, "SAL" were "Simulation Abstraction Layer" as opposed to the tactical "HAL" Hardware Abstraction Layer.
- The GenSim Side had to perform a lot of Tactical S/W initialization in the first implementation since the tactical software was not operating as it was designed. The tactical software was designed to run once. GenSim with embedded tactical must run multiple scenarios.







Early Tactical S/W (continued)

- GenSim is setup to run only the endgame portion of the encounter (last tenth of a second or so). The Tactical software is written to handle missile flight from intercept arm (last half second or so). GenSim has to properly handle the Tactical software for this part of the flight.
- GenSim would run the encounter and pass information to the Tactical S/W every frame while doing this pre-encounter initialization.
- In this early development our understanding of the Tactical S/W was poor and therefore our initialization methods were crude. The Tactical software was designed with microprocessors in mind and our embedded tactical simulation was not. The Dynamic-Linked-Library concept changed that.



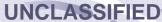




Preximity Euze Branch

- In the Dynamic-Linked-Library approach, the Tactical Software becomes an Executable (*.exe) called by the GenSim Executable program. The Simulation becomes multiple nested executable programs that pass information through a mailbox (DLL).
- GenSim initializations can be done on the GenSim side, Tactical initializations can be done on the Tactical side and pertinent information can be passed between the processes through the DLL. The DLL approach simplified Tactical "drop-in" to GenSim.
- Before the DLL was utilized, GenSim would have to be run once for each processor in the system. (working with each processor independently). With the DLL concept, each processor is now an executable called by the GenSim executable each frame.

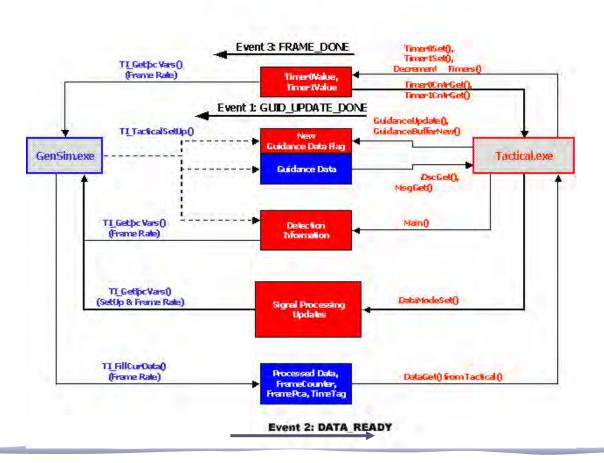








Proximity Fuze Branch



This figure shows a single processor, single executable DLL approach.

Red and Blue denote events where the DLL passes information between processors.



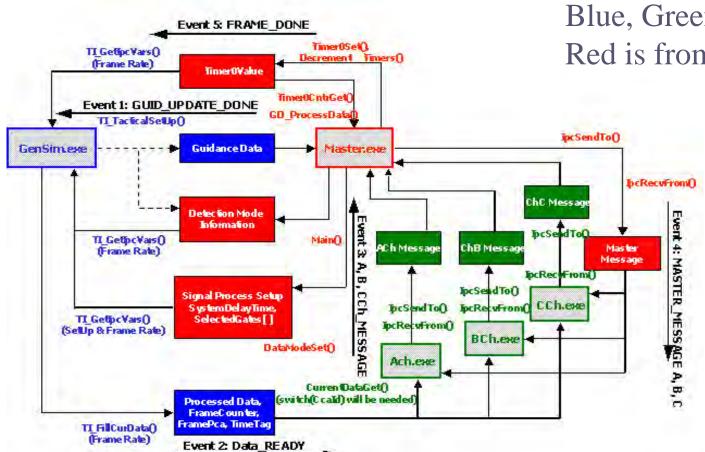








Proximity Euze Branch



Blue, Green is To Master Red is from Master

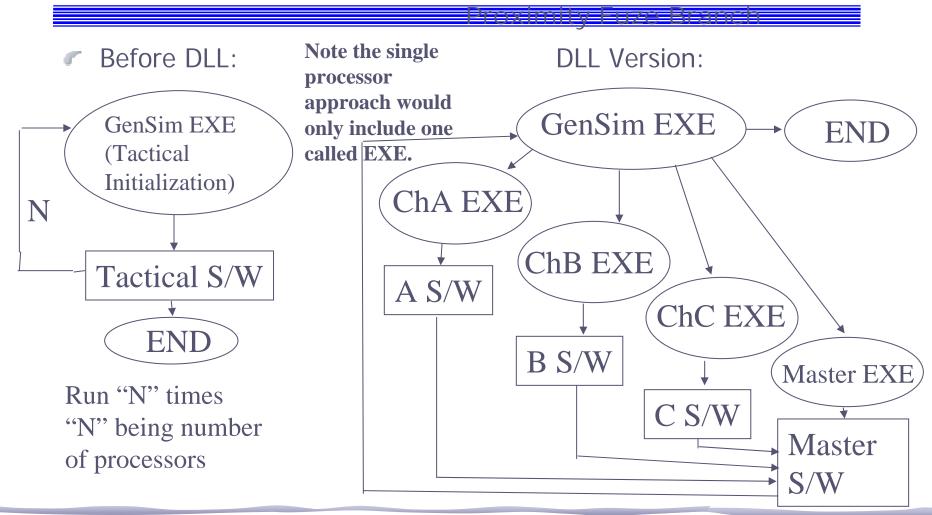
This figure shows a three processor, three executable DLL approach.

Red, Blue and Green denote events where the DLL passes information between processors.









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GenSim Used for Flight Testing

Proximity Euze Branch

- GenSim can interface with missile six-degree-of-freedom (6DOF) files (two different file formats).
- 6DOF's can be run to simulate flight test conditions and the files run with GenSim to see how the fuze tactical software will respond to the flight test encounters.
- With this approach, we have been able to diagnose errors in the tactical software that have been fed back to the contractor for fixes. The new tactical software can then be put in the simulation and the process repeated. Flight Test TM data can be compared to simulation output data for post-flight analysis.
- This approach led to the improved DLL tactical software interface.







Notes and Comments

Proximity Euze Branch

- By modeling Sensor TXT/RCV and Target reflectivity in the GenSim simulation we have a much improved simulation for doing missile fuze design verification and validation.
- Having the ability to "drop-in" a version of proximity fuze tactical software and run numerous tactical missile scenarios gives us an ability to find defects in the tactical software as well as predict tactical operation before any actual flight tests are performed. Post-Analysis with flight test TM can be compared.
- The Dynamic-Linked-Library (DLL) approach to interfacing the tactical software to the GenSim simulation simplified the interface, and improved the information handshake between GenSim and Tactical.





High-G Mortar Electronic S&A Demonstration





Presented by:
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ARDEC
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Co-authors
Stewart Genberg
Calvin Cheung





Outline



- High-G ESAD Systems overview
- Project Team
- Technical Approach
- Design Details
- Testing and Results
- Current Status





Project Overview



- ARDEC ATO project to demonstrate high-g survivability of a potential low-cost electronic safety and arming device (ESAD) suitable for mortar and/or artillery fuzing.
- Both in-house and Kansas City Plant fireset designs to be evaluated as part of effort.
- Initial project to focus on demonstrating survivability for worst case mortar launch environment.
- Project to conclude with ballistic demonstration test at Yuma Proving Grounds on 81mm ammunition at Charge 4.





Project Team



Team Members

Stewart Genberg – Team Leader ARDEC Fuze Division

Brian Mary – Lead Engineer ARDEC Fuze Division

James Hartranft – Mechanical Engineer ARDEC Fuze Division

Cuong Nguyen/ Calvin Cheung – Electronics Engineer ARDEC Fuze Division



Technical Approach



- Microcontroller based Control Logic
- Standard ESAD architecture with two static arming switches and one dynamic arming switch.
- Custom zig-zag setback switch to sense first launch environment and act as one static arming switch.
- Second launch signature simulated with independent time-out circuit.
- Independent low energy fireset board assembly two designs to be evaluated.



Technical Approach

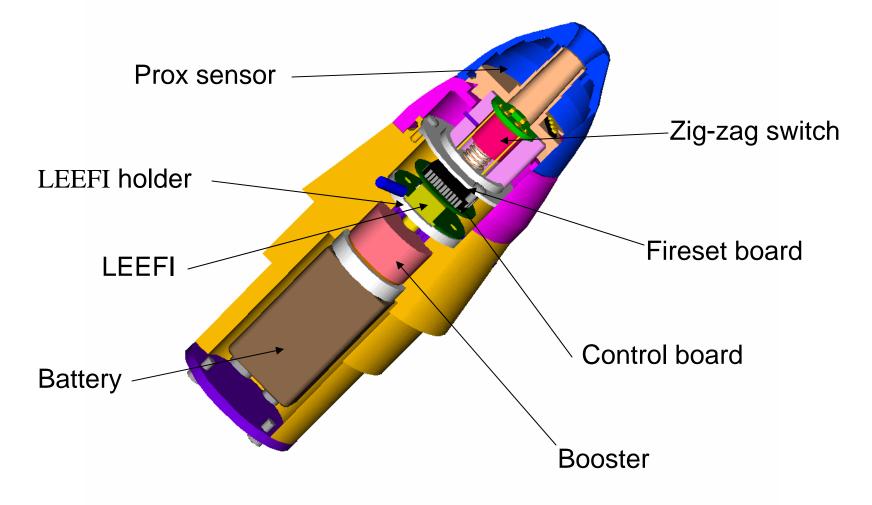


- Modified M734A1 mortar fuze prox electronics for target detection.
- Standard LEEFI slapper detonator with RSI-007 output.
- M734A1 PBXN-5 Booster to be used in ballistic demonstration test for function signature.
- Repackaged off-the-shelf alkaline battery power supply



Device Drawing

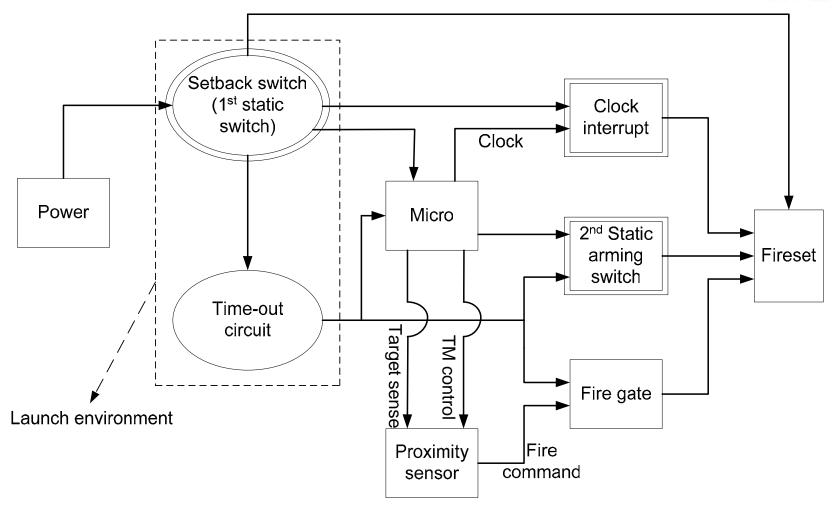






Control Logic Block Diagram







Control Algorithm



Pre-flight

- Screw inserted in custom power switch to connect battery power
- The micro will initialize and run a self-test to verify safe startup conditions
- If all safety conditions are satisfied, the prox sensor transmits a code to indicate fuze is safe to fire.
- If all safety conditions are not satisfied, the prox sensor will transmit fault codes signaling the error condition



Control Algorithm



Launch and Flight

- The micro remains in waiting state until zig-zag setback switch closes at gun launch
- During flight, the fuze transmits self telemetry data
 - zig-zag closure
 - Time out delay completion
 - High voltage charge detection on fire capacitor
- Self Telemetry data is transmitted on the down-leg of flight
- Prox sensor provides fire command to fireset electronics at proper burst height.



Firesets



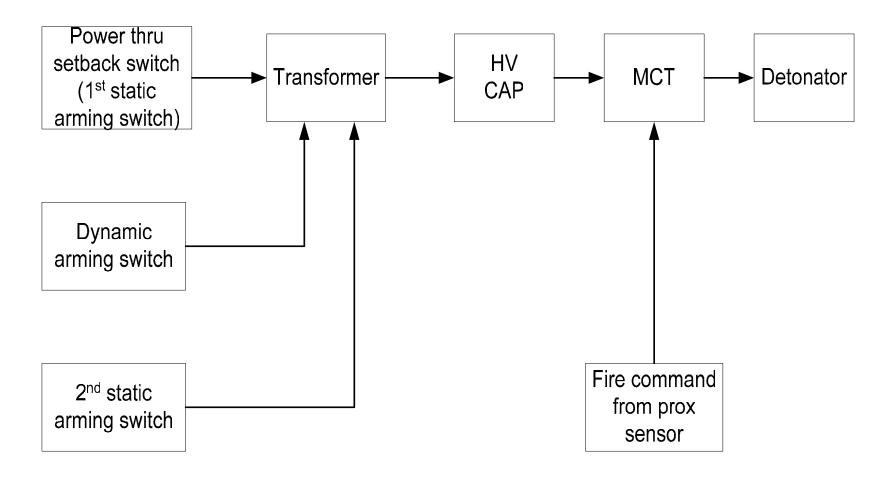
- In-house fireset
 - Freq: 50KHz, 25% duty cycle
 - Charges 0.1µF capacitor to 1000V
 - Custom transformer winding
- Kansas City Plant MIF
 - Freq: 30KHz, 50% duty cycle
 - Charges 0.2µF capacitor to 1000V
- Same interconnection configuration





Fireset Block Diagram



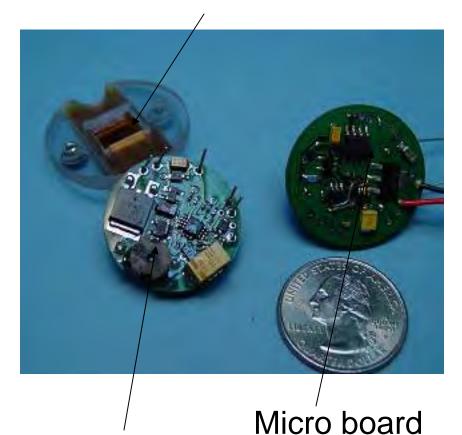




Electronics Hardware



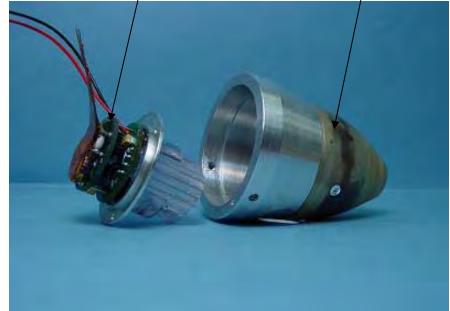
LEEFI holder



In-house fireset

Fireset board mated with Micro board

Prox sensor

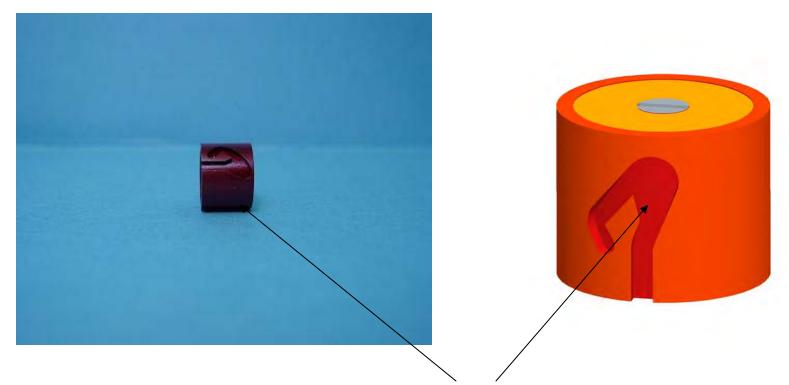






Electronic Hardware





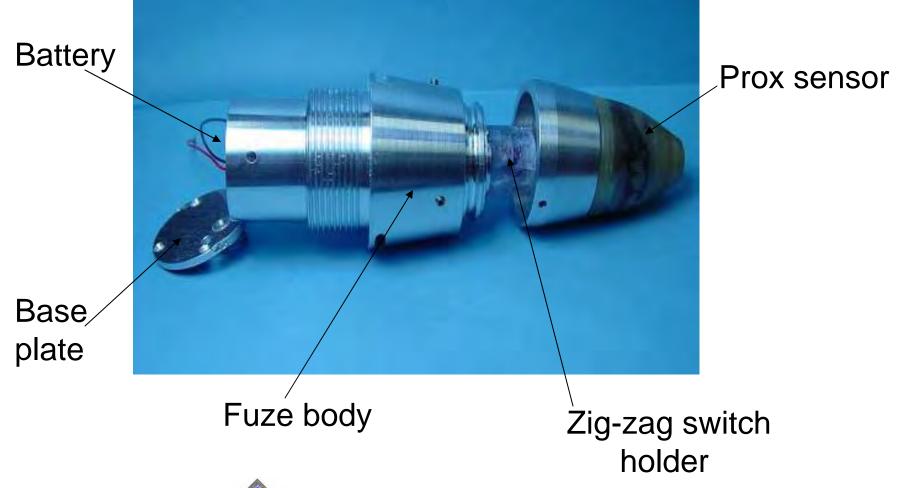
Zig-zag setback switch





High-G ESAD Hardware



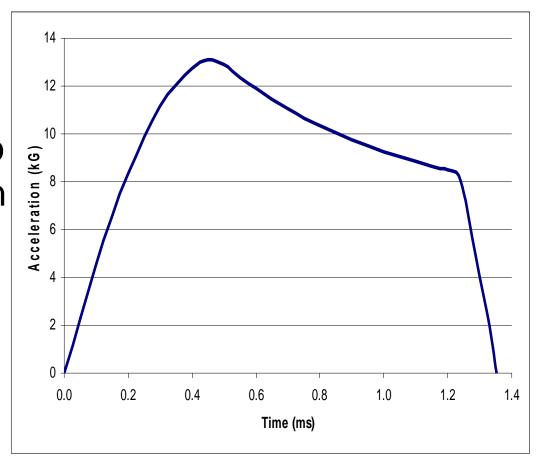




Air Gun Shock Pulse



All system components have been demonstrated to survive high-G air gun shock testing.





Current Status



- Initial design for mortar fuze application completed
- Fabricated 10 full-up assemblies.
- Explosive train reliability testing finished for fuze booster.
- Air gun shock testing completed on two units
- Ballistic test planned for remaining 8 units
 - 4 units with in house fireset
 - 4 units with Kansas City Plant fireset
- Awaiting field test Summer 2006

"Inadequacy of traditional test methods for detection of non-hermetic energetic components"

George R. Neff & Jimmie K. Neff IsoVac Engineering, Inc., Glendale, CA

Barry T. Neyer
PerkinElmer Optoelectronics, Miamisburg, OH

Karl K. Rink University of Idaho, Moscow, ID

The Authors Competency

- Many decades of experience in leak detection and failure analysis
- Manufacture of ordnance devices
- Fundamental research in ordnance device designs and performance
- Academic research in leak testing theory and application
- Preparation of Military Standards & Commercial Test Specifications

The Hermeticity Test Problem

- Poor understanding of leak test theory
- Misapplication of test methodologies
- Failure to understand device geometry
- Committing to traditional practices
- Ignoring MIL-STD limitations
- Lack of Field Feedback
- Inferior failure analysis
- Weak Statistical recordkeeping

The Hermeticity Callouts

Most Ordnance Devices have "Seal-Test" callouts of:

Visible to 5 x 10-6 std cm³/sec

(The "Gross-Leak Rate Range")

Many Ordnance Devices have Small & Zero-Cavities that are:

0.01 cm³ through 0.000001cm³

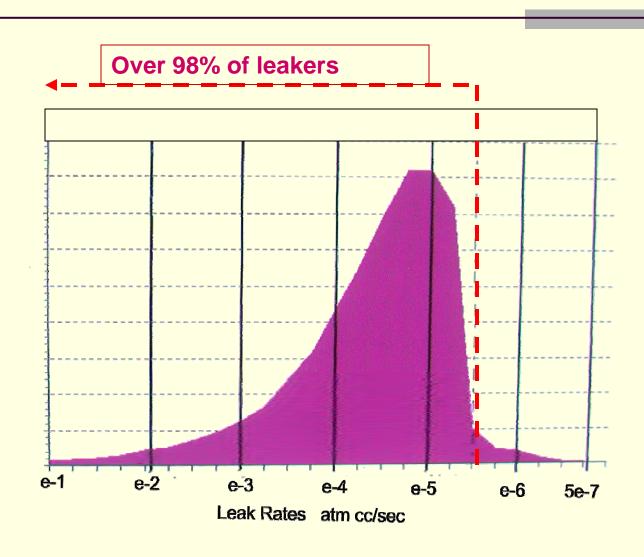
Test Methodology Reviewed

Helium Mass Spectrometry

Radioisotope Test Method

Red Dye Penetrant Failure Analysis

Typical Leak-Rate Distribution



Test Methods

Helium 'Mass-Spec' leak test method, (HMS)

- Being misapplied for "Gross-Leak" testing
- Requires "Caution" with small ordnance devices
- MIL-STDs limit HMS to Fine leak testing only, and not allowed for Gross leak testing.
- Unreliable to detect "gross leaks" in "Small & Zero-Cavity" devices

Helium Mass Spectrometry

"Back-Pressurization"

- Various bomb times and pressures
- Parts measured Individually
- Parts are evacuated prior to measurement
- Helium is lost during evacuation

Tracer-Gas loss During Evacuation:

- 0.0001cm³ cavity with 10⁻⁴ std cc/s leak
- 99.99% of Helium tracer gas in 10 sec.

Helium Mass Spectrometry

A "Leakage passage" Usually has short length and a 'passage' volume: < 10⁻⁵ cm³

Therefore: With a 10⁻⁴ cm³/s leak rate:

"Helium is gone in Less than 1 second".

Then: Detectable helium is only from:

"Interparticulate" cavities or "He Dissolved in Binders", very slowly released.

Result is an "Indicated-Leak" less than the spec, and an "escaped leaker".

Radioisotope (Kr85) leak testing

- Called out in MIL-STDs for Gross & Fine leak testing
- Testing small (0.02cm³) to large cavities.
- Testing "Small" & "Zero-cavities" with charcoal gettering.

Radioisotope Test Method

"Back-Pressurization"

0.01% Kr85 tracer-gas mixture

Measured "In-Place" (In Device Cavity)

Detectability: ~ 10¹¹ molecules Kr85

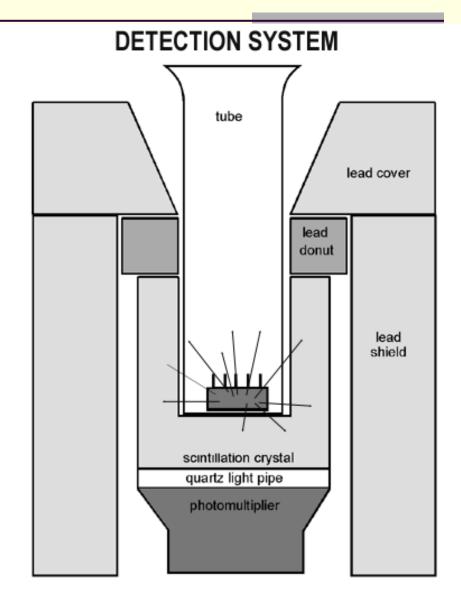
Bomb Times:

"Gross-Leaks" ~36 sec. (> 5 x 10-6)

"Fine-Leaks" ~6 min.

Technical theory of the test

The gamma rays from Kr85 gas trapped within a leaker, will penetrate the walls of normal devices, and are easily detected by the scintillation crystal at the counting stations.



Dye Penetrant Failure Analysis

Purpose"

- Verification of gross leakage
- Detectability to ~ 1 x 10⁻⁷ std cm³/s
- Isolation of leak sites

Glass header cracks

Glass-to-metal seals

Weld defects

Destructive test

Vacuum Decay Equation

$$P_t = P_o e^{-kt}$$

Where:

 P_t =Partial press Kr85 at time "t" Po =Original partial press Kr85 k= leak rate (std cm³/s) cavity vol. cm³ t = time in vacuum (sec)

The "Gettering" Technology

"Charcoal Gettering" of Kr85

- 1. Steam Activated Charcoal
- 2. High surface area: 500m²/gm
- 3. Mixed with ordnance
- One Particle of Charcoal:
 0.003" size, 0.243 μgm, vol. ~10⁻⁷ cm³

"Provides 133 mm² surface area".

"Gettering" of Kr85

"Steam-Activated Coconut-Shell Charcoal"

- 1. "Adsorbs" Kr85 tracer gas
- 2. Holds Kr85 by van der Waals forces
- 3. Does not effect ordnance materials
- 4. Adsorbs 27% by wt of water
- 5. Assures detection of 'wide open leak'
- 6. Used in 50+ million Ordnance parts/year

Leak Test Standards

MIL-STD-883

MIL-STD-750

MIL-STD-202

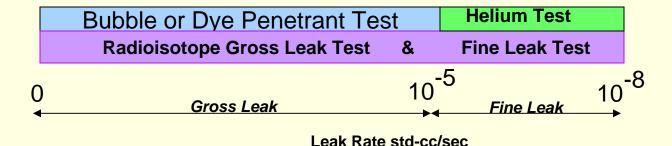
MIL-STD-S-19500

MIL-13474c-Squibs

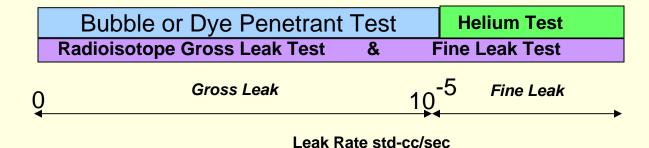
S-113 Ordnance

+ Others, (Military & Company Specs)
Mostly: based on MIL-STD 202

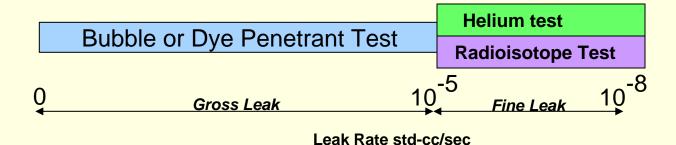
Mil Std. 883



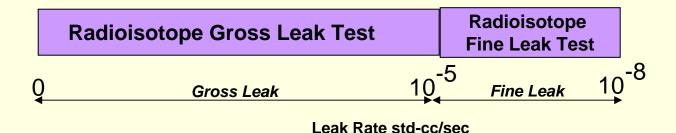
Mil Std. 750



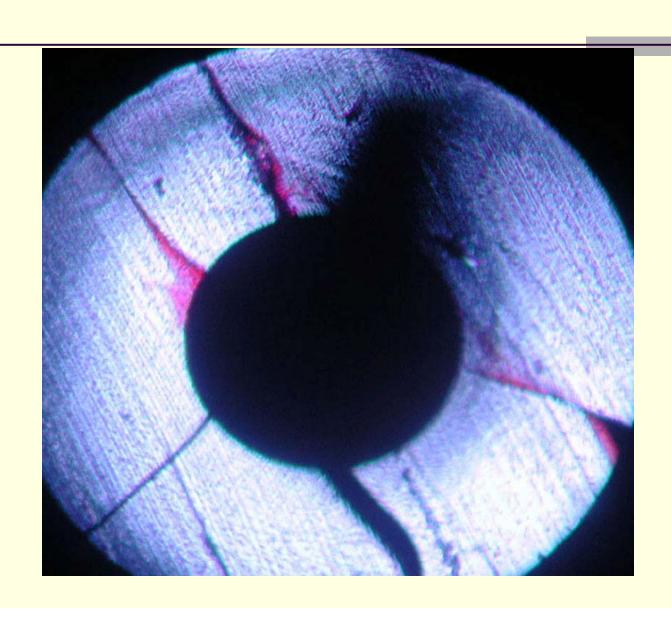
Mil Std. 202



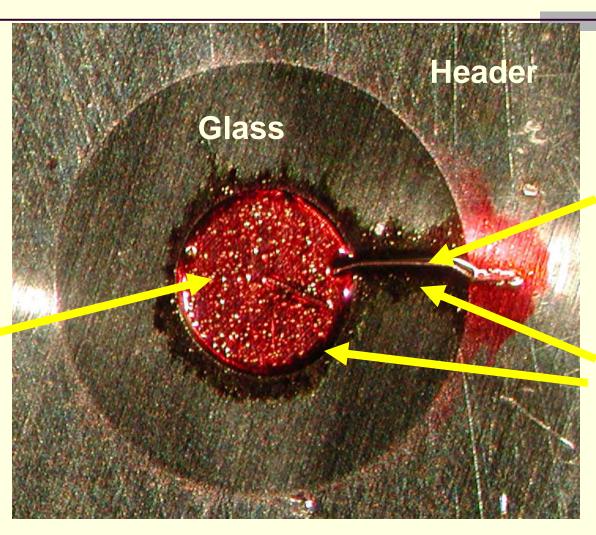
MIS-13474C (Missile Inspection Systems-Squibs)



Red-Dye in "Header Gross-Leak"



Pin-Glass "Gross-Leak"

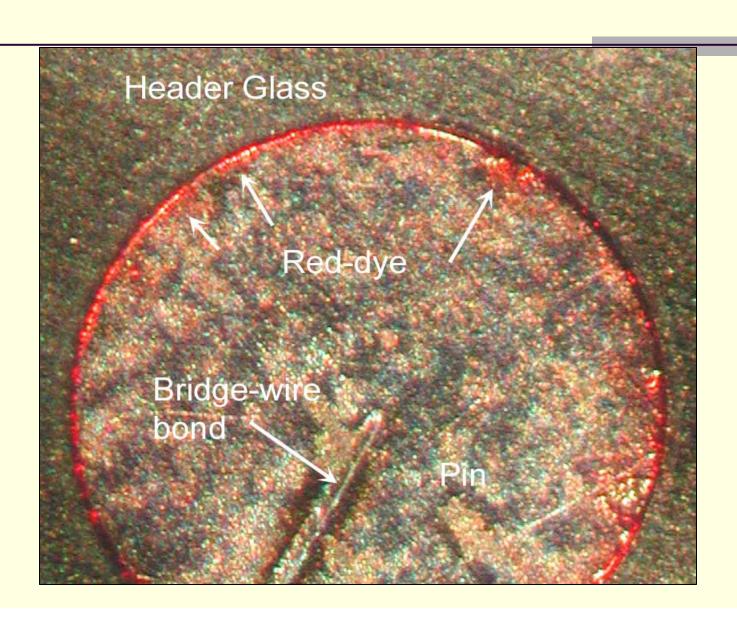


Bridgewire

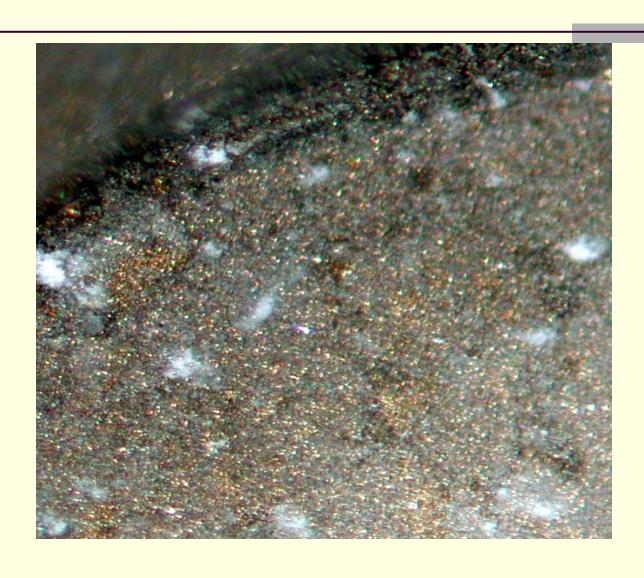
Red-Dye penetrant

Pin

"Pin-Glass Gross-leaks"

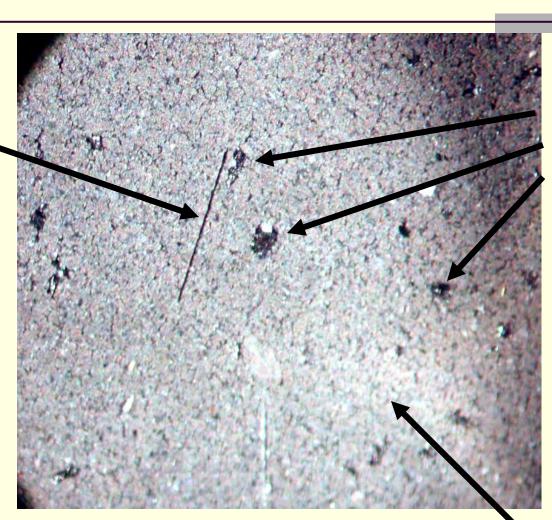


"Fungus-Growth" on Ordnance



Charcoal mixed in ordnance

Bridge-Wire Impression



Charcoal Particles

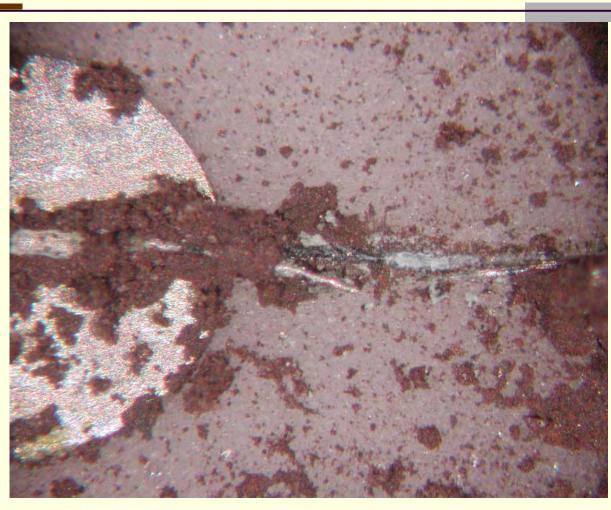
Compressed ZPP

Impulse Cartridge





Residue of corroded bridgewire



Need to Establish a Guaranteed Leak Test Method

- Leak testing of energetic products is inherently more complicated than a simple vacuum decay equation implies
- Need to <u>research known leakers</u> with proposed approach to ensure that the method works.
 - Investigate devices with known leaks in glass-to-metal seals and defective welds.
 - Verify that the method can detect such leaks

Use of Academia

University of Idaho has developed some <u>Unique Engineering Capabilities</u>

Fully equipped for "Fundamental Research"

- Skilled in Ordnance technologies
- Sophisticated Ballistic testing
- All leak testing methodologies
- Hermetic seal mechanics studies
- Gas and Moisture transfer through leaks
- Ordnance material behavior

The authors Thank You for Your Time

May we answer any Questions?

THALES NDIA Briefing (



Hard Target Reliability for MAFIS
L.J.Turner CEng MIMechE.
Ordnance Fuzing Group Manager



Company Background in Fuzing & Shock Hardening



1918 - Shell Fuzing

1940s - Airborne Radar, Shell Fuzing,
Proximity Fuzing (Rockets)
Bomb Fuze for "Bouncing Bomb" etc.

1950s - Naval Proximity Shell Fuzing

1960s - No.907 RF Proximity Fuze for Bombs.

1970s - No.952 RF Proximity Fuze for Bombs. Multi Role Shell Fuze (MRF)

1980s - SG357 Runway Cratering Weapon MFBF (No.960) Multi-Function Bomb Fuze

1990s - Intelligent Hard Target Fuzing Research

2000s - Intelligent Hard Target Fuzing Production and Research, MAFIS, HTSF & AURORA.





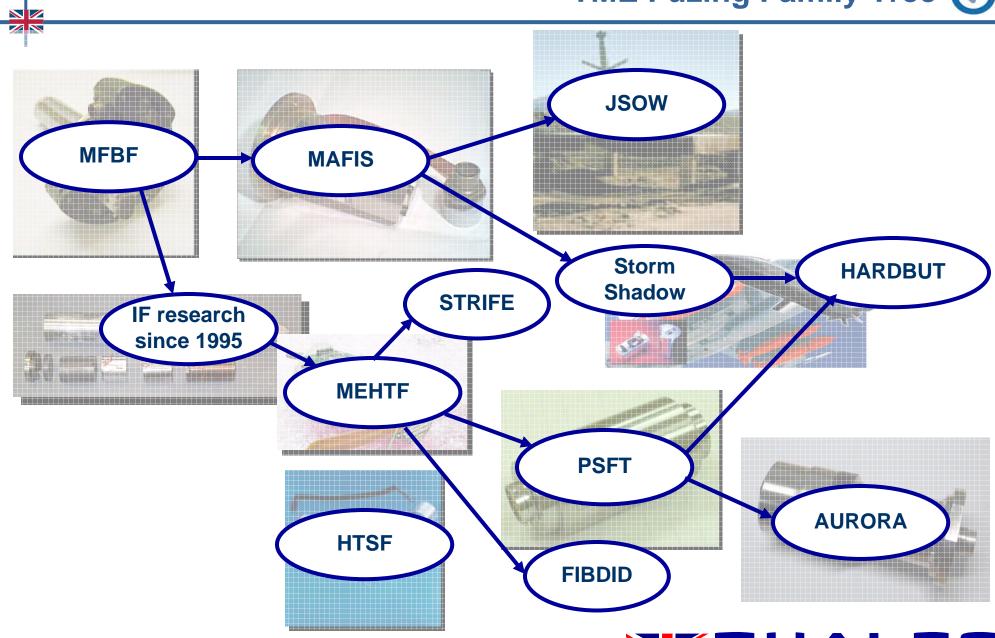






TME Fuzing Family Tree (





TME Hard Target Fuzing











MAFIS (Multi Application Fuze Initiation System) (



Modular 3" fuze

Shock hardened core electronics

Application specific interface module

High shock survivable for MWS

Out-of-Line arming system

Missile fuze (including reliability requirements)

Initially developed for Storm Shadow with BROACH warhead

Modularity permits ready adaptation to other applications

In full production for:

- Raytheon AGM-154C (JSOW)
- MBDA Storm Shadow



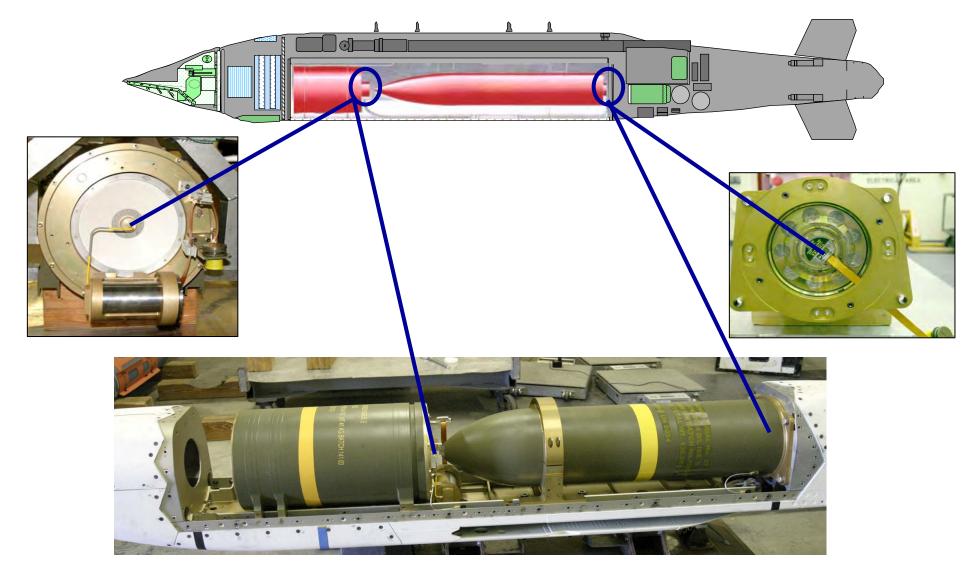






MAFIS (FSU-26/B) in JSOW (AGM-154C)





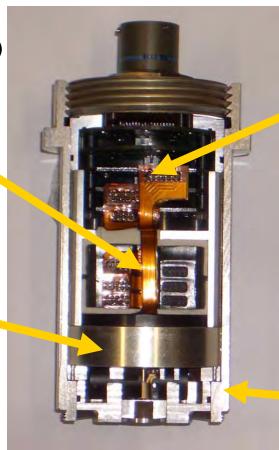






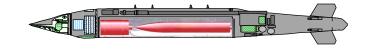
Core Electronics Module (CEM)

Detonator Alignment and Safety Module (DASM)



Application Specific Interface Module (ASIM)





Housing



Reliability in High "g" Domain (



- Severe Environment for survivable electro-mechanics
- Multiple shock effects
 - High "g" levels
 - **6**[™] Multiple Impulses
 - - Fuze x 3 Axis Longitudinal and Lateral
 - - **Excitation levels within fuze**
- Real impact data difficult to collect

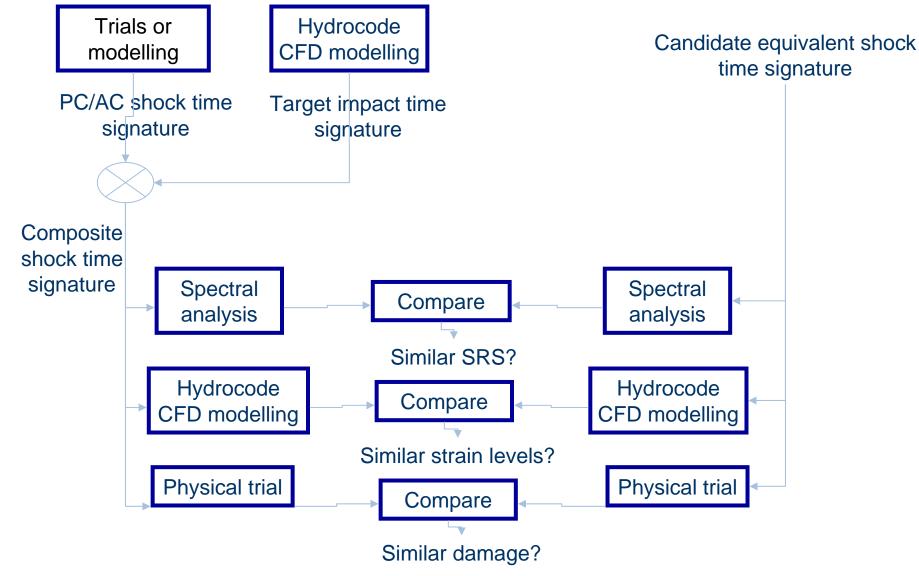






TME Shock Test Methodology







Trials / Evaluation Approach (





•	Computational Fluid Dynamics Simulation	Sled Trials	Catapult Trials
Advantages	•Inexpensive •Repeatable •Rapid	•All up round physical test •Closely replicate the tactical environment	•Inexpensive •Repeatable •Rapid •Adjustable shock environment •Temperature Extremes
Disadvantages	•Difficult to Validate •Easy to misinterpret the results	•Expensive •Non-Repeatable •Infrequent •Ambient Temp	•Requires Validation



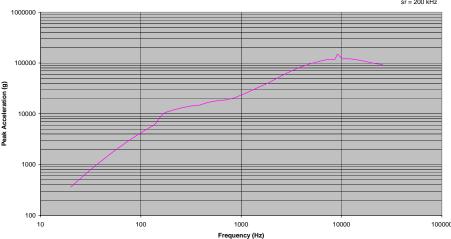
Basis for SRS Analysis and Test



SRS MAXI-MAX - Catapult, Longitudinal, 80 kg

Q = 10 fn[0] = 20 Hz





- **♠** Applicable for material transient responses with complicated waveforms
- **●***Enables the tailoring of shock exitations from actual data for the operational environment
- **●** Proven technique for shock simulation testing of complex waveforms
- **6**[™]Identified in UK (DEF STAN 00-35) and US standards (MIL-STD-810)
- Purpose of test to demonstrate the adequacy of material to resist degradation of functional / structural performance

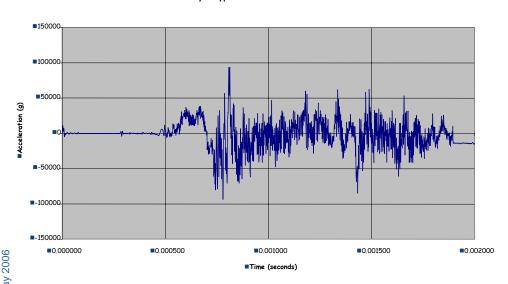




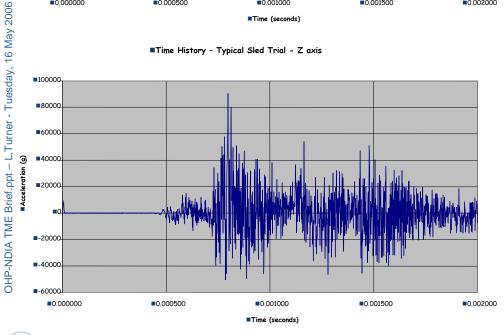
Typical Sled Trial Signatures (



■Time History - Typical Sled Trial - X axis



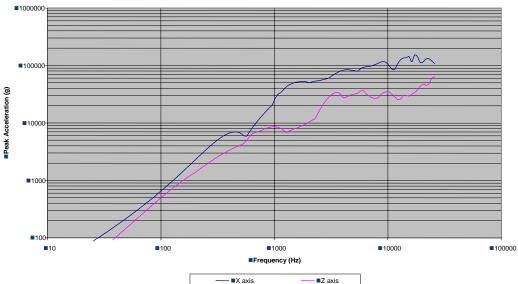
■Time History - Typical Sled Trial - Z axis





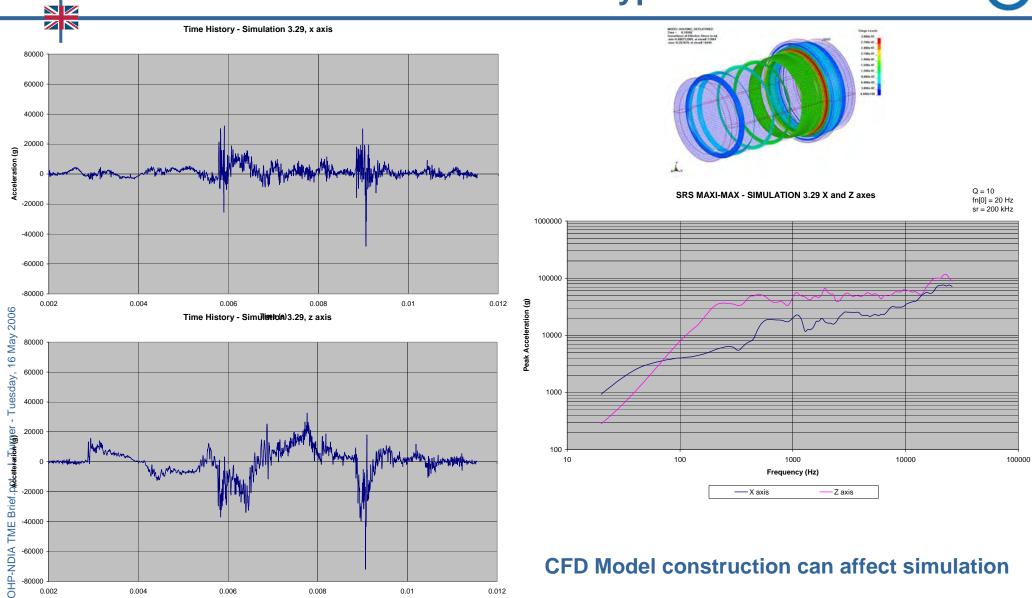
■SRS - Sled Trial





Typical CFD Simulations





0.012

0.01

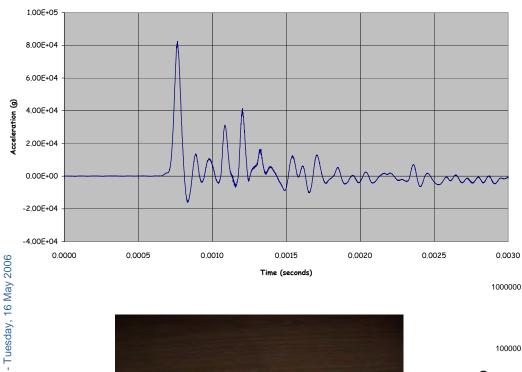


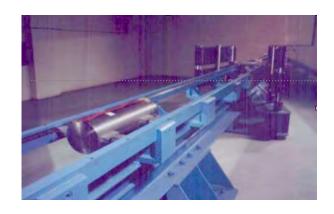
0.004

0.006

Time (s)

Time History - Catapult, Longitudinal, 80k g (nominal)

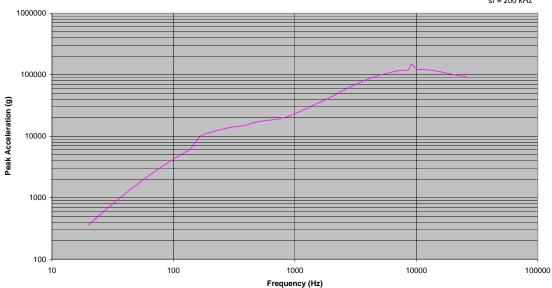




SRS MAXI-MAX - Catapult, Longitudinal, 80 k g







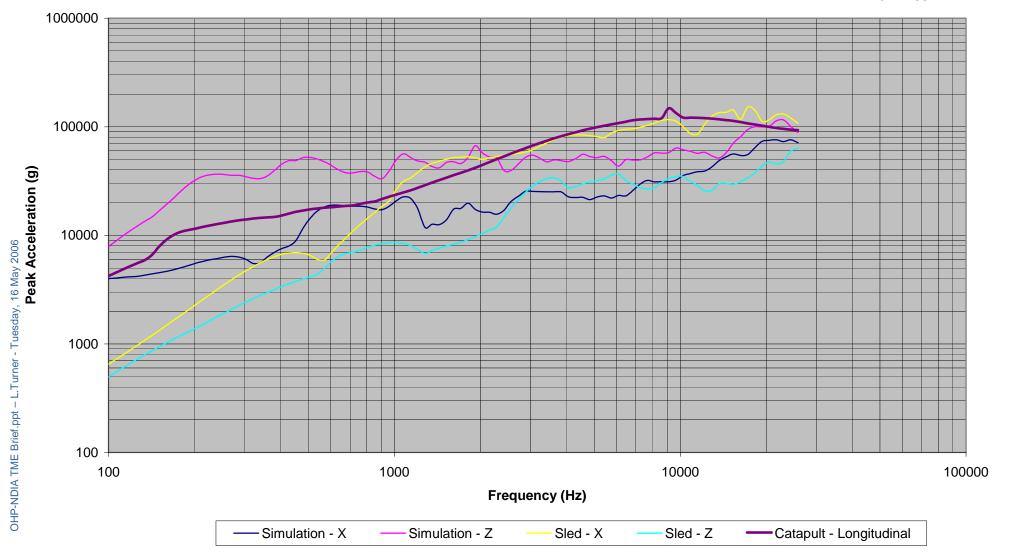
OHP-NDIA TME Brief.ppt - L.Turner

Sled / CFD / Catapult Comparison (



SRS MAXI-MAX - Composite Sled, Simulation & Catapult

Q = 10fn[0] = 20 Hzsr = 200 kHz

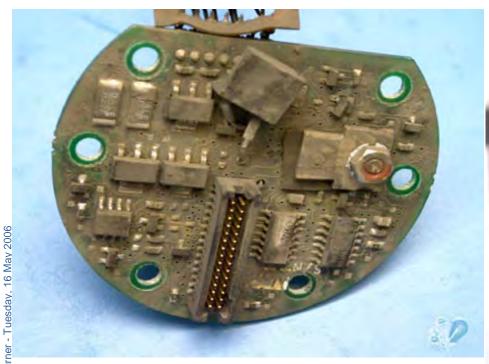


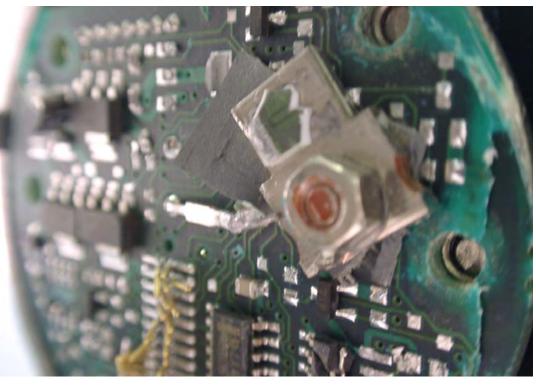


Achieving comparable damage (









Sled Trial Damage

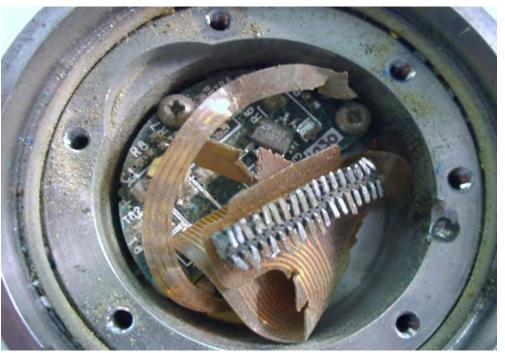
Catapult Test Damage



Achieving comparable damage (







Sled Trial Damage

Catapult Test Damage



Achieving comparable damage (



Damage to silicon component die





Sled Trial Damage

Catapult Test Damage



Catapult & Shock / Counter Shock Test Facilities



- Selected for capability to generate comparable SRS levels
- Creates 'equivalent damage'
- Quick testing turnaround
- Multiple Test configurations
- Longitudinal
 - Predominately axial shock application Multiple impacts
 - •Variable shock parameters "g" x Duration
 - Selectable Fuze roll orientation
 - Temperature extremes
- Lateral
 - As above plus simultaneous lateral and axial shock application – Multiple impacts



Testing for Survival and Function – Catapult (





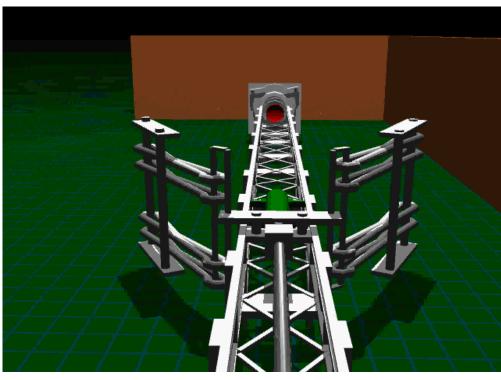


Test vehicle:

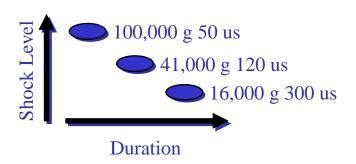
■ Mass: 22 kg max

■ Velocity: 50 m/s max

■ Shock: 100,000 g









Typical shock signature

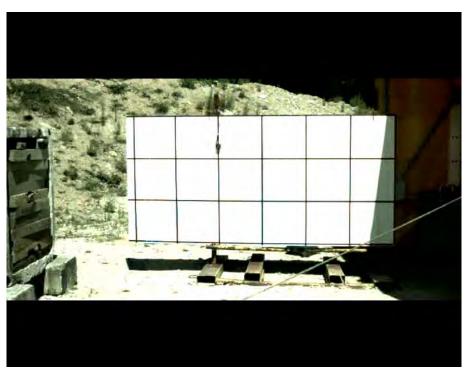


Testing for Survival and Function - Guns (

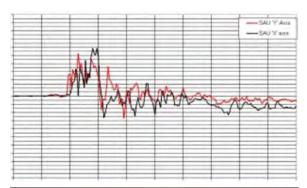


Shock counter shock (SCS) facility

- **●** High speed impacts
- **№** Multiple shocks
 - (typically +50kg for 700μs, -20kg for 600 μs)
- **●** High off-axis angles (Sub Modules)



Shock-Counter-Shock High Impact gun tests





Off axis test vehicle







™MAFIS Hard Target Fuze

- Successfully tested in excess of 50 K"g"
 - Multiple effects, 3 Axis, temperature extremes etc.
 - High reliability Missile levels
- ♠™ In service with RAF and USN
 - Storm Shadow & JSOW
- - **S**BDI/BDA
 - **In-Line Technology In-Line Technology**



MAFIS Proven Hard Target Fuze







THALES MISSILE ELECTRONICS LIMITED







Safe Separation Study for MK 437 MOFN (Multi-Option Fuze *for Navy*)

50th NDIA Fuze Conference May 9-11, 2006

Mr. Brian Will

Naval Surface Warfare Center, Dahlgren Division, Fuze Branch - Code G34 brian.will@navy.mil

(540) 653-5481 DSN: 249-5481



Introduction

- During the assessment of safe separation for MOFN there was much debate concerning methodology.
- This presentation is offered that other programs may benefit from the precedent set by MOFN which follows a safe separation assessment methodology of MIL-HDBK-504 *Guidance On Safety Criteria For Initiation Systems*.

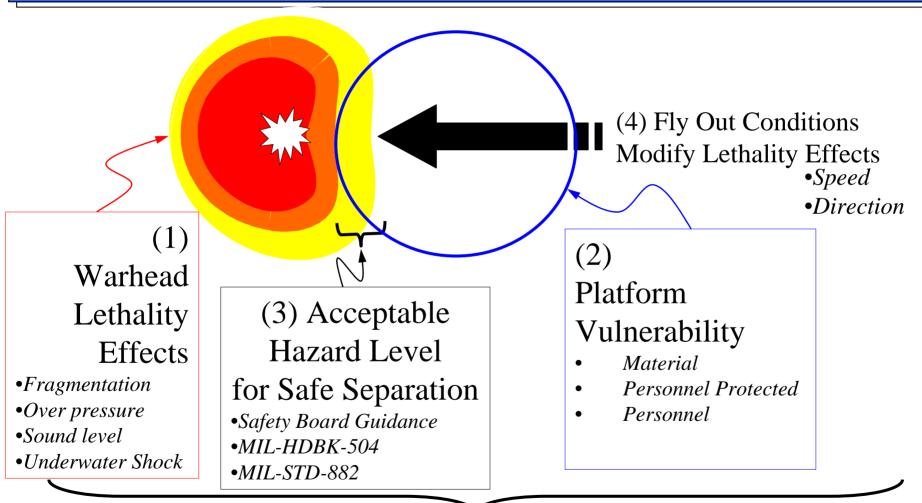


Background on Safe Separation

- The need to perform a separation analysis is codified in MIL-STD-1316.
- Para 4.2.2, Requirement
 - "A safety feature of the fuze shall provide an arming delay which assures that a safe separation distance can be achieved for all defined operational conditions."
- Para 3.29, Definition
 - "The minimum distance between the delivery system (or launcher) and the launched munition beyond which the hazards to the delivery system and its personnel resulting from the functioning of the munition are acceptable."



General Methodology for Safe Separation Assessment

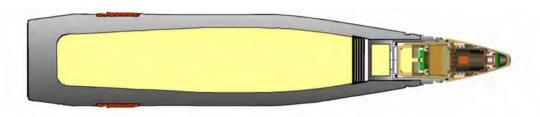


Analyzed at Worst Case Operational Condition



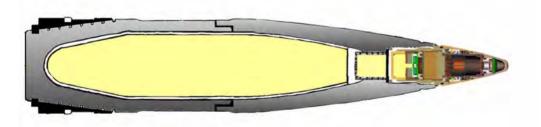
Warhead Lethality

MOFN has two potential warheads



EX 183 HE-MOFN

- •MK 64 PROJECTILE BODY
- •PBXN-106 EXPLOSIVE FILL



EX 184 HE-MOFN

- •HIFRAG PROJECTILE BODY
- •PBXN-106 EXPLOSIVE FILL

Warhead lethality effect is fragmentation



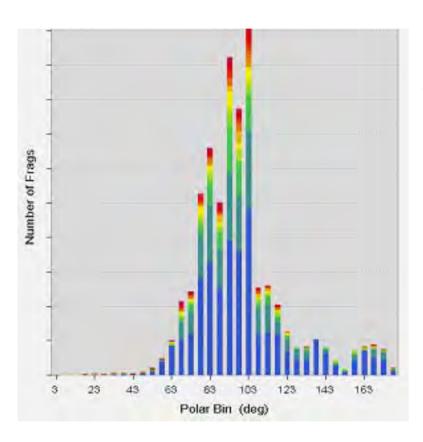
Warhead Lethality

- Warhead fragmentation characteristics determined with Arena Tests, min 3 tests of all-up munition (ref MIL-HDBK-504).
- Fragment size, location, and velocity captured.

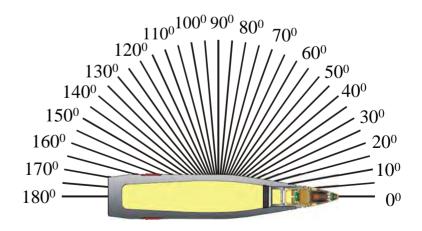




Warhead Lethality



- Data is put into JMEMs¹ format:
- For each 5° spherical arc
 - Fragment size quantized into bins & averaged
 - Fragment velocity averaged





Platform Vulnerability

- Two ships carry the 5" gun: Destroyers and Cruisers.
- Cruiser was selected for study because it is a longer ship with a larger deck area.

• Cruisers have two 5" guns. The forward gun was selected for study

because it has a greater range of motion.



DDG-51 Arleigh Burke class (Aegis) Destroyer



CG-47 Ticonderoga class Cruiser



Platform Vulnerability

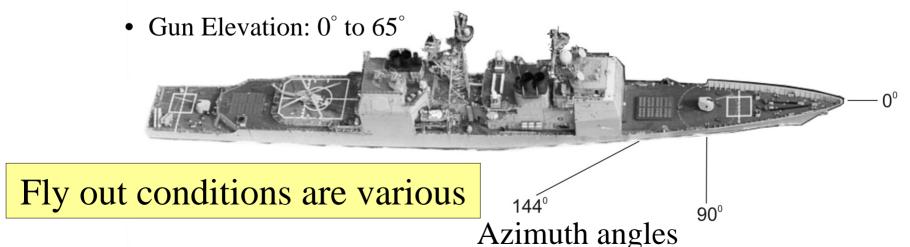
• Ship superstructure not as susceptible to damage as personnel who may be on deck.

Vulnerability based on personnel on deck using JMEM vulnerability models.



Fly Out Conditions

- Fly out defined by velocity and direction:
 - Velocity
 - MK 67 Mod 3 Standard Prop Charge: IV = 2650 fps
 - MK 68 Mod 2 Reduced Prop Charge: IV = 1500 fps
 - Direction
 - Gun Azimuth: 0° to 144°



NDIA Fuze Conf 2006



Acceptable Hazard Level for Safe Separation

- MIL-HDBK-504, *Appendix A**, guidance:
 - Safe Separation Distance is the shortest distance where probability of a hazardous fragment hit from functioning of the munition is no greater than one in ten thousand (.0001)
 - A hazardous fragment is one with velocity greater than V_{50} for skin penetration.

Acceptable hazard level based on MIL-HDBK-504

*Note: Appendix B is for Air Launched Munitions



Defined Operational Conditions

SAFE SEPARATION SCENARIOS										
Scenario #	1	2	3	4	5	6	7	8	9	10
Mission	AAW			NSFS		ASuW				
Elevation	+65°		+65°		+46°		0°		0°	
Azimuth	-144°		-144°		-90°		-144°		-144°	
Projectile	MK 64		HIFRAG		MK 64		MK 64		HIFRAG	
IV (ft/s) **	2,400	1,400	2,400	1,400	2,400	1,400	2,400	1,400	2,400	1,400

Ten scenarios correspond to 3 types of engagements:

- air targets (AAW),
- long range shore targets (NSFS), and
- close in surface targets (ASuW).

Worst case operational scenarios identified



MK 64 proj. 150 ft range Std Charge 90° Azimuth 60° Elev.

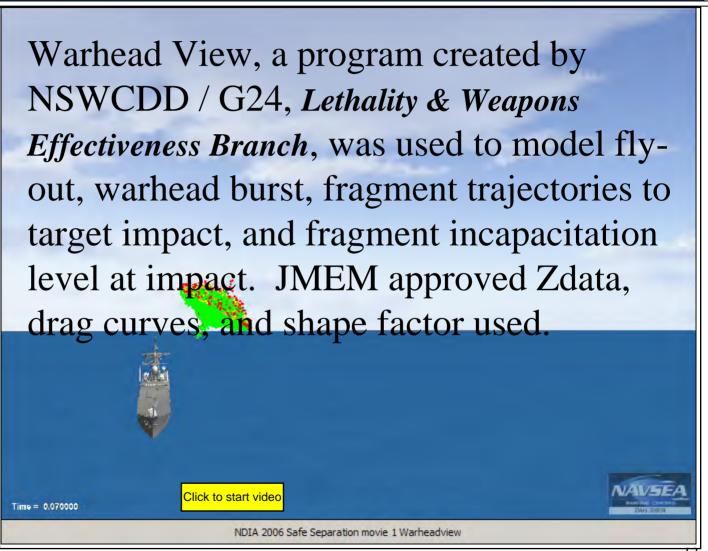
Frag Colors:

0 to 5 grams

5 to 10 grams

10 to 20 grams

Above 20 grams



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Probability of incapacitation of each fragment computed following JMEM methodology

$$P_{I/H} = 1 - e^{-a\left(mV^{\frac{2}{3}} - b\right)}$$

• Each summed to obtain total probability and normalized to the area of a person.

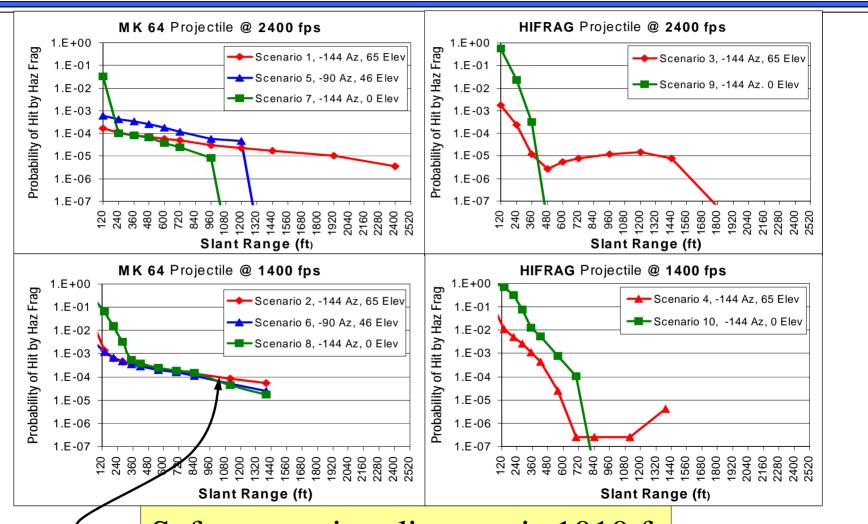
$$P_{Inc} = \left(rac{A_{pers}}{A_{Ship}}
ight) \sum_{N_{Hits-ship}} P_{I/H}$$



Sample data from Warhead View, 3 incapacitation levels computed

Scenario 1, -144° Azimuth, 65° Elevation				Probability of Incapacitation, 1 person			
Burst Time (s)	Slant Range (ft)	Average Number of Fragments Impacting ship	Average Fragment Mass (grains)	Lethal Wounding, Summer Clothing	Serious Wounding, Summer Clothing	Skin Penetration, Nude	
0.05	120	398.1	10.78	0.0000710	0.0001648	0.0001705	
0.10	240	446.9	8.73	0.0000413	0.0001060	0.0001105	
0.15	360	494.7	8.04	0.0000280	0.0000800	0.0000843	
0.20	480	459.5	8.95	0.0000205	0.0000648	0.0000693	
0.25	600	330.4	12	0.0000153	0.0000520	0.0000568	
0.30	720	216	17.8	0.0000120	0.0000443	0.0000490	
0.40	960	79.9	43.06	0.0000063	0.0000255	0.0000290	
0.50	1,200	35.2	83.67	0.0000045	0.0000195	0.0000225	
0.60	1,440	17.1	134.37	0.0000033	0.0000148	0.0000170	
0.80	1,920	4	387.64	0.0000020	0.0000085	0.0000100	
1.00	2,400	1.7	634.26	0.0000008	0.0000030	0.0000035	





Safe separation distance is 1010 ft



Operational Requirement for Close Engagement

- MOFN has a requirement for close-in engagement for ship self defense against small surface attack craft.
- MIL-HDBK-504 guidance is that a System Safety Risk Assessment (SSRA) be developed, per MIL-STD-882, and signed off by the Developer (PM) and User acknowledge and accepts the risk.
- 2 additional hazard assessments were performed.
 - Hazard of engaging target at min range.
 - Hazard of early burst at min arming.



Min Engagement Hazard

To determine hazard of Engaging Targets at Min Range:

- 1. Identify operational configuration.
- 2. Determine Incapacitation Probability due to warhead function.

$$P_{inc\,/\,Det}$$



Min Engagement Hazard

Worst Case Operational Configuration:

- Projectile = EX 184 HE-MOFN
 - MK 64 Projectile w PBXN-106 fill

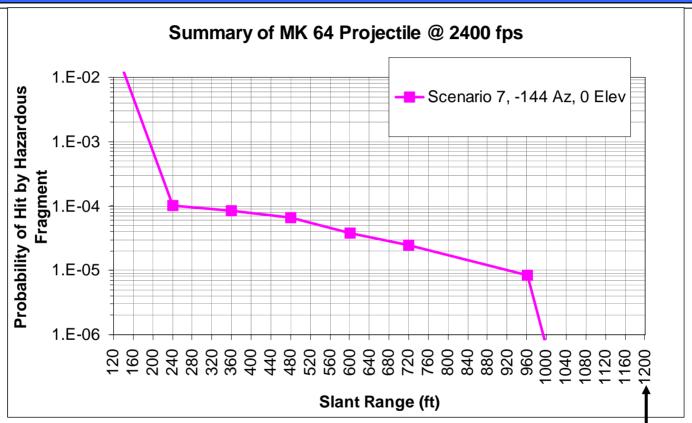


- Propelling Charge = MK 67 Mod 3 Std Prop Charge
 - IV = 2650 fps
- Platform = US Navy CG-47 Class Cruiser
 - Gun direction 144° azimuth, 0° elev
- Min Engagement Distance is 0.5s.
 - Firing Circuit disabled until 0.5s





Min Engagement Hazard



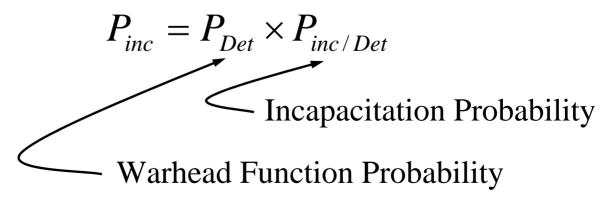
The hazard of engaging targets at minimum range is zero.

0.5s
Minimum
Engagement
distance



Early Burst Hazard

- Early burst hazard at min arming presents a hazard that must be identified per MIL-STD-882 and accepted by the program.
- To determine hazard:
 - 1. Identify operational configuration.
 - 2. Determine probability of incapacitation from warhead function.
 - 3. Determine probability of warhead function.



21



Early Burst Hazard

- Worst Case Operational Configuration:
 - Projectile = EX 184 HE-MOFN



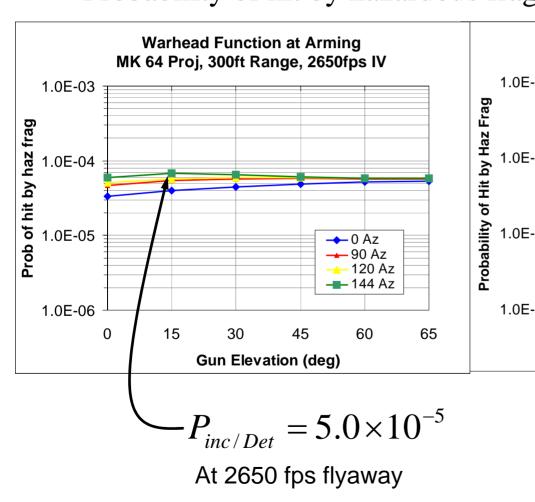
- MK 64 Projectile w PBXN-106 fill
- Propelling Charge = MK 68 Mod 2 Reduced Prop Charge
 - IV = 1500 fps
- Platform = US Navy CG-47 Class Cruiser
 - Gun direction survey of all
- Average arming at 290 ft
 - Std Dev 7.1 ft

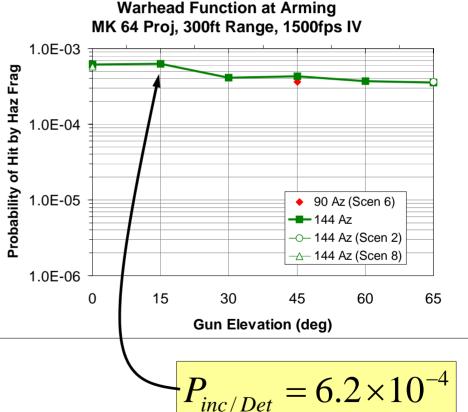




Incapacitation Probability

Probability of hit by hazardous fragment at arming distance





At 1500 fps flyaway



Warhead Function Probability

- Fuze is primary source of inadvertent warhead function.
- Quantity of test data is available from M782 MOFA production.
- Two failures (early bursts) out of 1,975 Lot Acceptance Test gun shots. Demonstrated failure rate of 1.0 x 10⁻³ (note that that these failures caused rejection of the lot and are not representative of the stockpile).
- MOFA will be less than this because



Warhead Function Probability

- Improvements to MOFN that will reduce safety failure rate.
 - Software rewritten following procedures for safety critical applications (IEEE/IEA 12207.1, 12207.2, and EIA/IEEE J-STD-016).
 - Over half a million software tests were performed with zero failures.
 - Cause of early bursts in MOFA tests has been identified and will be corrected in MOFN production. Army estimate of safety failure rate, between arming and safe separation distance, is 1x10⁻⁸.



Early Burst Hazard

Early burst hazard at min arming distance is:

$$P_{inc} = P_{Det} \times P_{inc/Det}$$

$$P_{inc} = (2.6 \times 10^{-8}) \times (2.6 \times 10^{-4})$$

$$P_{inc} = 2.6 \times 10^{-12}$$

- Probability of hit by a hazardous fragment is less than 1 in a million for the worst case condition.
- Severity of hit is skin penetration (50% probability) which corresponds to level III of MIL-STD-882 (injury resulting in one or more lost work days).



Early Burst Hazard

Hazard Risk Index of MIL-STD-882

	TIGEATA TRICK ITTACK OF THIS COL							
	Severity of Occurrence							
Frequency of Occurrence (over the life of an item)	CATASTROPHIC (I)	CRITICAL (II)	MARGINAL (III)	NEGLIGIBLE (IV)				
FREQUENT (A) P > 10 ⁻¹	I-A	II-A	III-A	IV-A				
PROBABLE (B) 10 ⁻¹ > P > 10 ⁻²	I-B	II-B	III-B	IV-B				
OCCASIONAL (C) 10 ⁻² > P> 10 ⁻³	I-C	II-C	III-C	IV-C				
REMOTE (D) 10 ⁻³ > P > 10 ⁻⁶	I-D	II-D	III-D	IV-D				
IMPROBABLE (E) 10 ⁻⁶ > P	I-E	II-E	III-E	IV-E				

Level of Risk Acceptance, Navy

> High ASN-RDA

> > Serious PEO

Medium PM

> Low PM

Hazard Risk Index per MIL-STD-882 is III-E. This hazard must be formally accepted by the Program Manager.



Real Life Example of why we do safe separation studies

- 2 Feb 2005, USS Lassen DDG-82, had a close aboard detonation at a <u>reported</u> distance of 150 feet.
- Weapon was a D350 5" High Explosive projectile:
 - M732 Fuze, MK 64 body, Comp A-3 fill
 - Standard Propelling charge
- The gun barrel was pointing 82° azimuth to port side, and 7.1° elevation.



 Model of USS Lassen incident

Color Code Fragment size

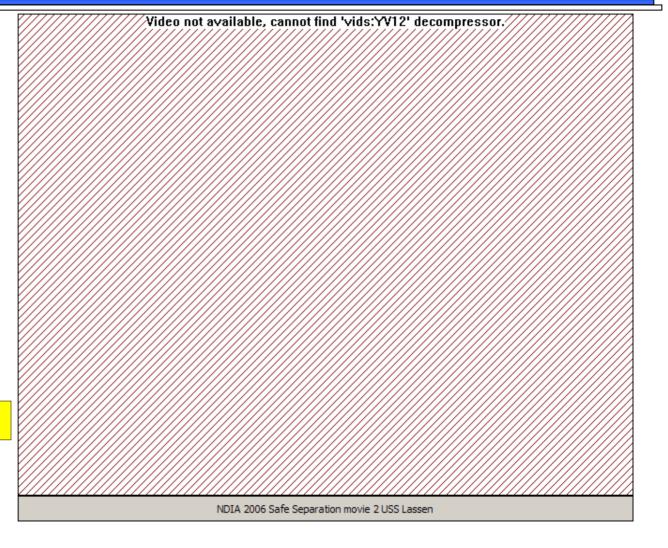
1000 grains

100 grains

30 grains (22 bullet)

10 grains (BB)

1 grain





- No injuries resulted from incident.
- Very little data was available for the incident; no IV, video, or audio to confirm estimated distance of detonation. Crew reported 2 "small" fragments on deck. Fragments were discarded.

The "small" fragments found on deck are not inconsistent with predictions.



- Malfunction was probably fuze function at arming due to a design weakness particular to the M732 fuze.
- Two independent assembly errors, occurring in the same fuze, will allow the fuze to detonate on arming. (Note that the M732A1 corrected this problem)
- Arming distance in 5" gun is about 295 ft.



- Historical research:
 - 2.4 million fuzes were fired by Army, USMC, & Navy
 - 4 incidents of detonation at arming reported by Army, 5 including Navy
 - No correlation to manufacturer or to lot number
 - No material or personnel injury
- Conclusion: Because screening is impractical, and probability of event is so low and probability of injury is so low, investigation was closed with only an advisory to ship captains.



Summary / Conclusions

- Determination of safe separation distance takes 4 factors, analyzed at worst case operational condition:
 - 1. Warhead lethality effects
 - 2. Platform vulnerability
 - 3. Fly-out conditions which may modify warhead lethality effects
 - 4. Acceptable hazard for safe separation
- If there is a requirement to engage targets within safe separation distance, a System Safety Risk Assessment (SSRA) is to be developed and signed off by the Developer (PM) and User acknowledge and accepts the risk.