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Pilot MSIAC

A System Approach to IM for Solid Rocket Motors

Composite Cases & Reduced Sensitivity Propellants

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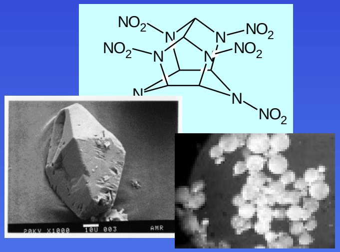
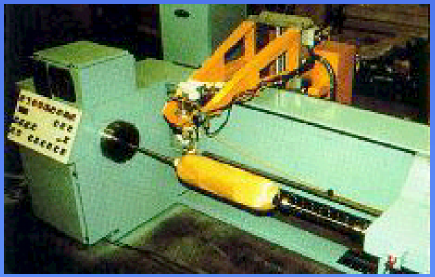
Introduction

Part 1: IM Rocket Motors

- Tradeoffs, “building in” IMness
- Reduced sensitivity propellants
  - Characteristics
  - Examples
- Composite Motor Cases
  - Benefits
  - Examples, IM test responses





Part 2: 21-inch Pulse Booster

- Example of motor with IMness built-in

An IM Rocket Motor

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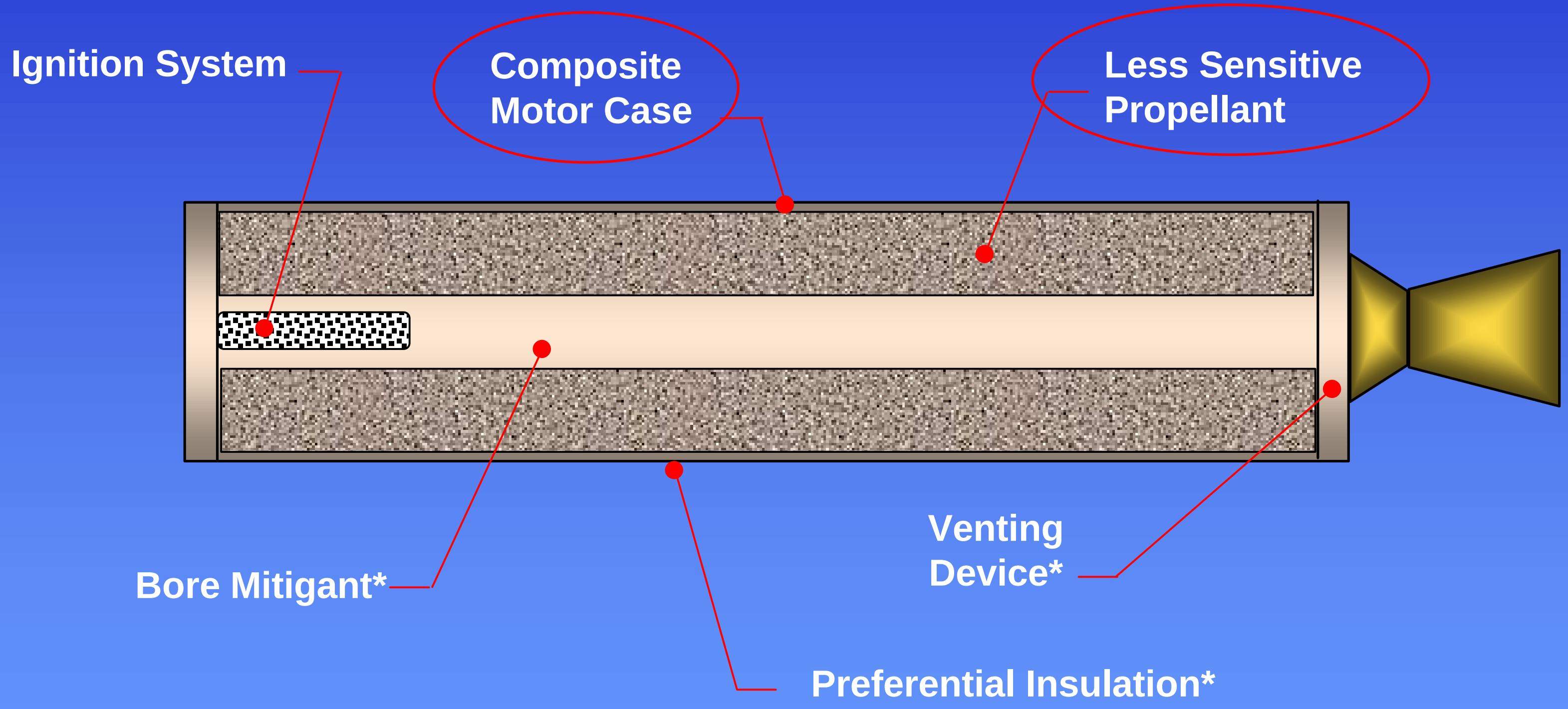

*Examples of Mitigation Techniques

IM – A Systems Approach

Munition

- ✓ Motor Case
- ✓ Propellant
- ✓ Mitigation Devices
- ✓ Container/Storage
- ✓ Effect of Warhead

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Stimuli

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Environment

→ **Response**

Rocket Motor Design Tradeoffs

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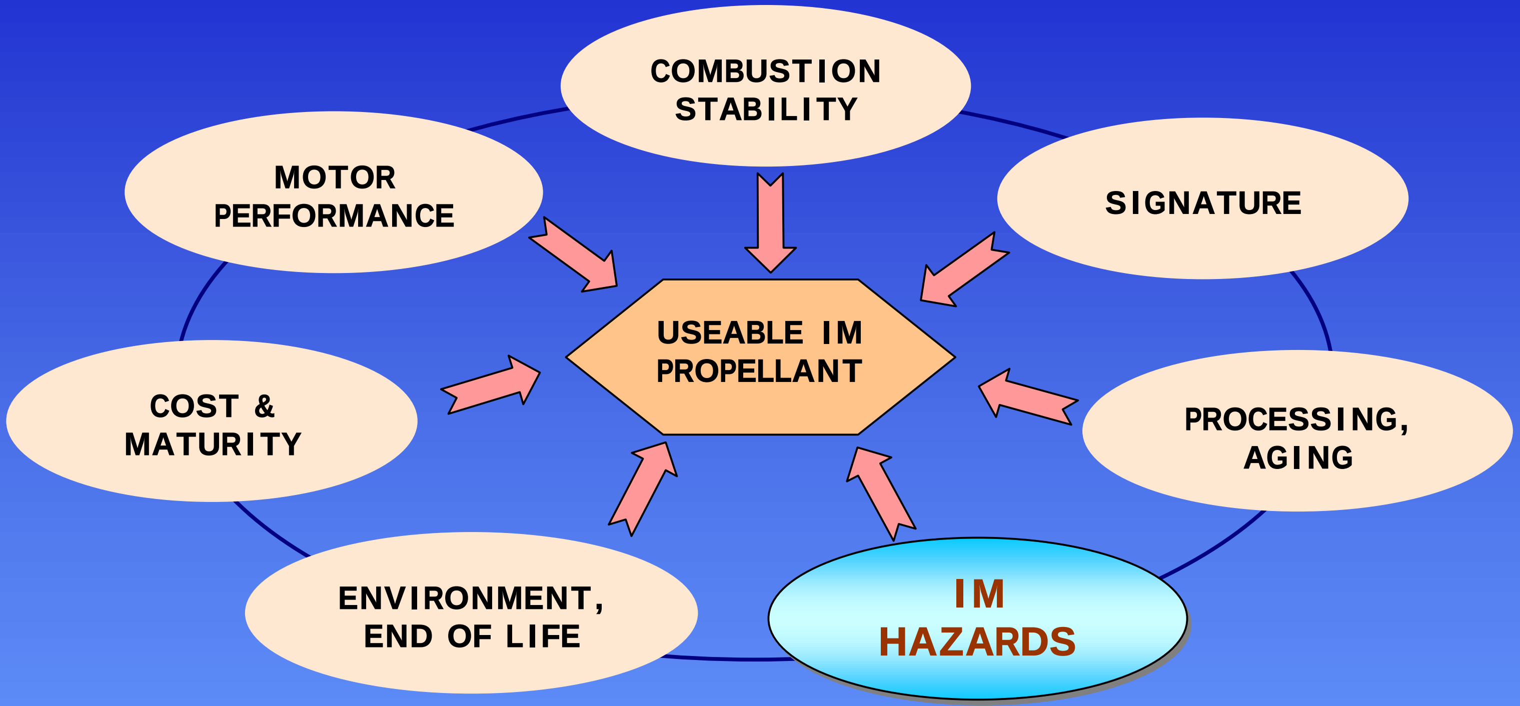

Can the designer increase propellant IM-ness without compromising other system requirements?

IM Propellant Characteristics

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- TOUGH – GOOD ELONGATION PROPERTIES → Absorb Energy, Deform with Minimum Damage
- ENERGY MANAGEMENT-PARTITIONING → Solids Loading, Particle Size, Sensitive Ingred., Binder Properties
- EXTINGUISHABLE → Difficult to Ignite: Smolder / Extinguish

?

IM Propellant Characteristics

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ENERGY MANAGEMENT- PARTITIONING

- Reduce Solids Loading
  - Develop new oxidizers
  - Use energetic binder system
  - Use high-density Additives

- Control particle size/ distribution

- Use low ignition temperature binders

- Use less-sensitive ingredients
  - Reduce nitramines, AP
  - Change ballistic modifiers

Not new concepts – How have we done in the past 10 years?

Insensitive XLDB, "Nitramites"

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SNPE & CELERG (France)

Energetic low-signature, cross-linked DB propellants

- ✓ Reduced Nitramine Level
  - AN Used to Replace a Portion of Nitramines
- ✓ Less-Sensitive Plasticizers
  - TMETN/BTTN

In reduced-smoke version

Nitramites: High level of shock sensitive ingredients

XDT or "bore effect" seen by developers as the main IM issue

Formulated to prevent XDT reactions to Bullet Impact

Bullet Impact: No Reaction

Remain Susceptible to SD

Fast Cookoff – Type V

IM Tests in Composite Case (hypervelocity demo)

HTPE

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Alliant Techsystems, NAWC, NAMMO Raufoss

Family of propellants based on hydroxy-terminated polyether binder

IM Approach

- ✓ **Reduced Solids Loading**
  - Energetic Plasticizer
- ✓ **Reduced Level of AP**
  - Energy Partitioned Using 2nd Oxidizer (AN)
- ✓ **Good Elongation**

Permits lower % solids at equivalent Isp of comparable HTPB propellant

10% Ammonium Nitrate

Reduced Smoke & Aluminized Formulations

HTPE

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What about the design tradeoffs?

Characteristic	HTPB	HTPE
Isp * ? (lb-s/in^3) reduced smoke	≥ 15	≥ 15
Burn Rate @ 1000 psi (in/s)	0.3 – 1.5	0.3 – 1.2
Pressure Exponent	~ 0.5	~ 0.5
Failure Stress @ 77ºF (psi)	120	170
Failure Strain @ 77ºF (%)	40	50
Modulus @ 77ºF (psi)	600	500
Pot Life (hours)	10	20
Shock Sensitivity (NOL Card Gap)	0 cards	0 cards

IM TEST	Configuration (10-inch Analog Motors w/Graphite Composite Cases)	
	HTPB	HTPE
Slow Cookoff	Explosion	Burn
Fast Cookoff	Burn	Burn
Bullet Impact	Deflagration	Burn
Fragment Impact	Explosion	Extinguish

IM Advantage

Evolved SeaSparrow (ESSM)

IM Performance Not as Impressive
Expect Significant Improvement with Composite Case

HTCE

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Pratt & Whitney (CSD) & NAWCWPNS China Lake

Family of propellants based on HTCE – block copolymer of polyTHF & polycaprolactone

- ✓ **Reduced Solids Loading**
  - Energetic Plasticizer
- ✓ **Reduced Level of AP**
  - Energy Partitioned by Using 2nd Oxidizer (AN)
- ✓ **Good Elongation**
- ✓ **Reduced AP Solubility in Binder**

China Lake's IMAD-116

CSD achieved BURN (Type V) responses to FCO, SCO, FI, BI with UTP-32,070

Similar properties to HTPE propellants; binder is lower cost, commercially available

Reduced Smoke & Aluminized Versions

Other Examples?

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Additional Examples, for various propellant types, in RTO paper (NIMIC O-74)

Includes discussion of new ingredients

Next version of NIMIC's EMC to include rocket propellant update

Input sought from IM community

Why Composite Cases?

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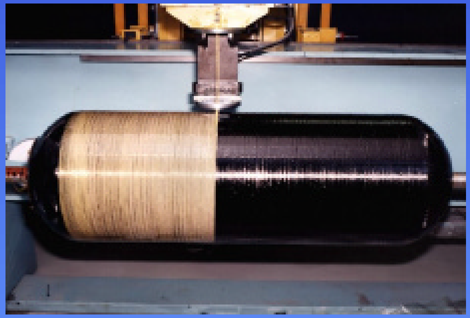
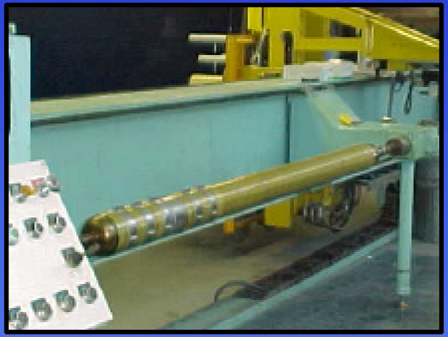
To reduce motor response to fuel fire: reduce confinement

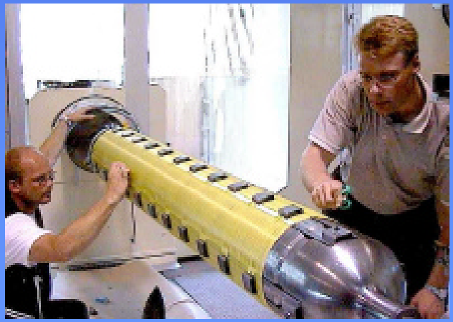


Weaken during FCO ➡ Burn, or low pressure burst

Improvements in FI & BI response (For some propellants)



Reduce the "deadly" fragments in resultant debris



More effective when combined with less sensitive propellant

Composite Case IM Response

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Example: early (1980s) IMAD effort:

IM Test (per MIL-STD-2105)	Composite Case 6-in (15.2 cm) Ø	Monolithic Steel Case 6-in (15.2 cm) Ø
Fast Cookoff	**Burn (V)**	**Explosion (III)**
Slow Cookoff	**Explosion (III)**	**Explosion (III)**
Bullet Impact	**Burn (V)**	**Propulsion (IV)**
Fragment Impact	**Burn (V)**	**Deflagration (IV)**

What happens if we combine composites with IM propellant?

Using "garden variety" HTPB/AP propellant

Evolved Seasparrow

ESSM Composite Motor

Technology Program conducted by NAMMO Raufoss

Achieved significant improvements in IM response

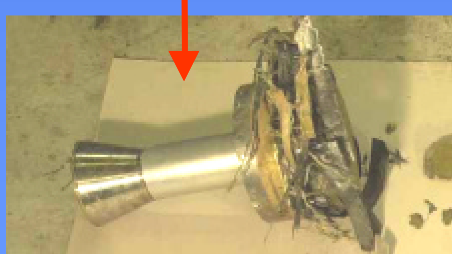
Photographs courtesy of NAMMO Raufoss AS

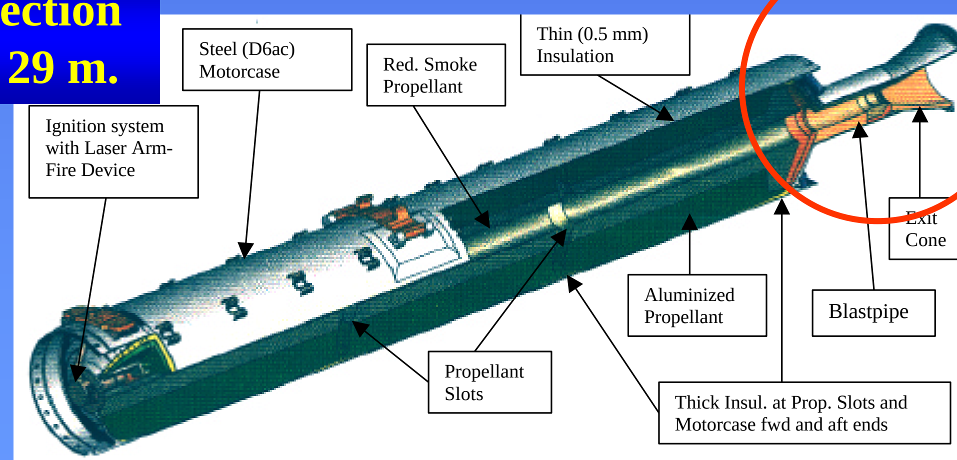
Evolved Seasparrow

Comparison of IM Responses – Baseline ESSM vs. ESSM Composite

IM TEST	ESSM Baseline (OHEB Evaluation)	ESSM Composite (NAMMO Evaluation)
Fast Cookoff	Explosion (III)	Burn (V)
Slow Cookoff	Explosion (III)	Deflagration (IV)
Bullet Impact	Burn (V)	Burn (V)
Fragment Impact	Deflagration (IV)	Burn (V)

Nozzle/blastpipe section (15.6 kg) expelled 29 m.





Summary – Part 1

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Propellant development primarily driven by performance

IM-ness is one of several competing requirements

Formulations, ingredients & techniques exist.
Designer can reduce sensitivity to IM hazards without compromising system requirements

Remember!

Propellant is only part of the equation – it must be integrated into a system approach for true IM-ness!

Composite Cases are another integral part of a system approach:

Is the technology mature?

21-inch IM Pulse Booster Project

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Background and Objectives

- MK-72 Largest VLS Compatible Booster
- Issues
  - All Up Round System Weight Limit 6500 lbs
  - MK-72 High Mass Flow Rise Rate
  - Limits System Growth Potential
- Design, Build and Test MK-72 Size IM Compliant Booster

Motor	SCO	FCO	BI	FI
MK-72 Bare	Detonated	Deflagrated	Exploded	Burned
MK-72 Encannistered	N/A	Exploded	Exploded	N/A
21" Pulse Bare	Exploded	Burned	Deflagrated	Deflagrated

Approach

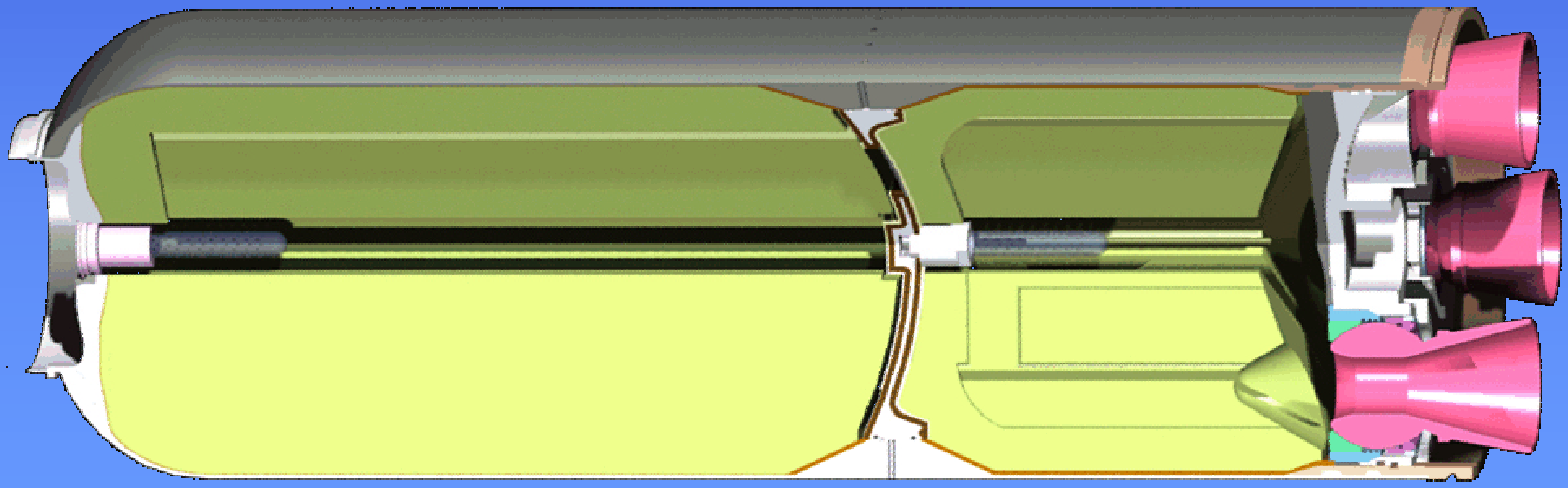
- Systems Engineering Approach
  - Included “building-in IMness”
- Energy Managed System - 2 Pulse Motor
- IM Aluminized AP/AN/HTPE Propellant
- Use Composite Case
  - Better IM performance in FCO, BI and FI
  - Reduction of collateral damage
  - Lighter weight
- Design to use Existing Aft Closure and TVA
  - 4 Moveable Nozzles

Maintain Similar System Performance

21" Pulse Booster

- **Pulse 2**
  - HTPE/Al/AP/AN propellant
  - BKNO3 igniter
  - Foam fins left in place

- **Pulse 1**
  - HTPE/Al/AP/AN propellant
  - $BKNO_3$ Igniter
  - Highly configured grain design



Propellant Grain Designs

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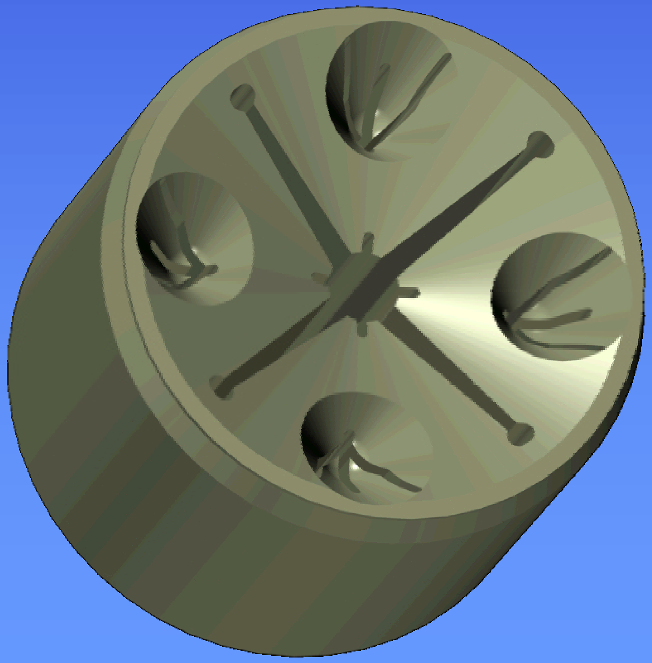
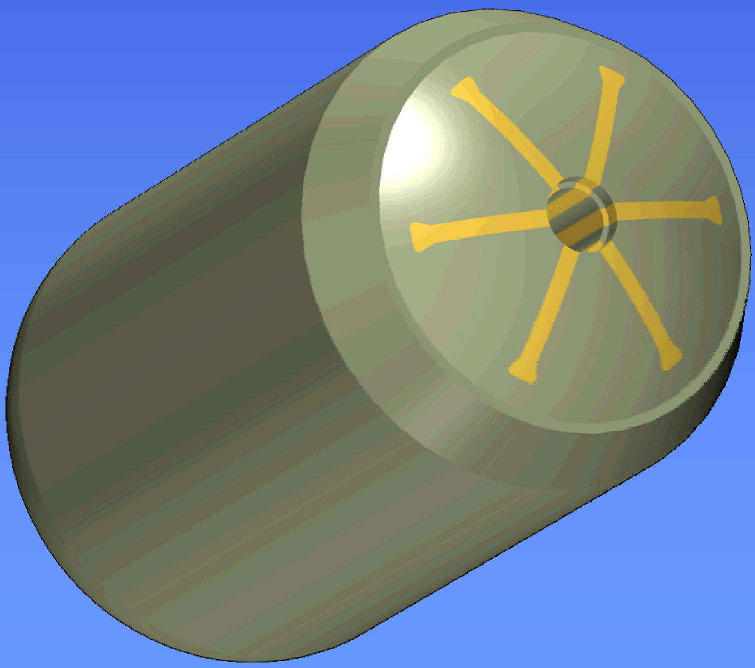
Pulse 1
High A_b
Target r_b = 0.7 ips @1000psia
Neutral Ballistics

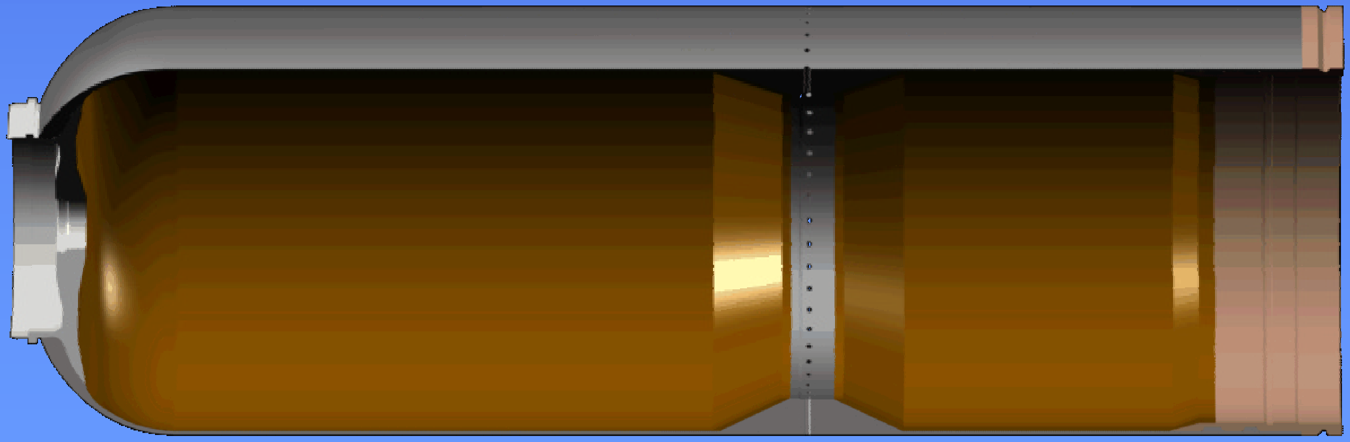


Pulse 2
6 fin design
Foam fins remain after casting



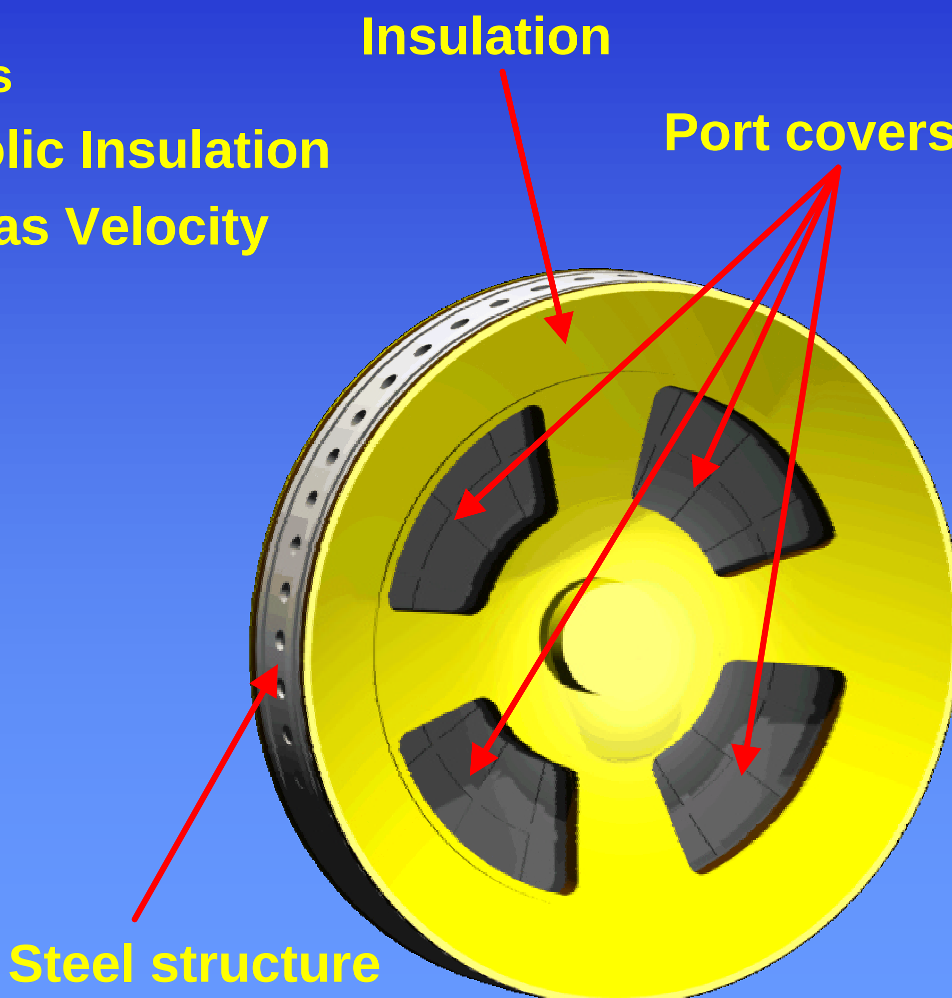
Case Design Overview

- Composite Structure: IM7 Fibers with Epoxy Resin
  - Kevlar Overwrap
- Wound in Forward and Aft Metal Sections
- Integral Bulkhead Boss
- Integral Insulation
- MEOP 2000-2300 psia
- Performance Parameters per WS25448



Bulkhead Design

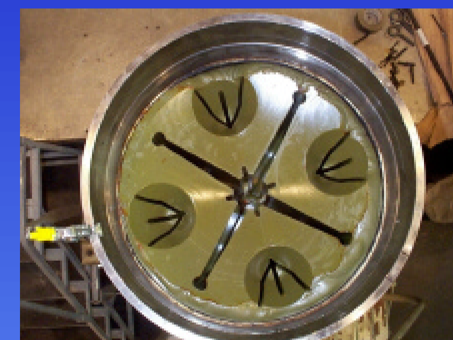
- 4130 Steel Structure
  - 48 Bolt holes; floating nuts
- Elastomerized Silica Phenolic Insulation
- Large Port Area For Low Gas Velocity
- Graphite Fiber Port Covers



Motor Fabrication Photos

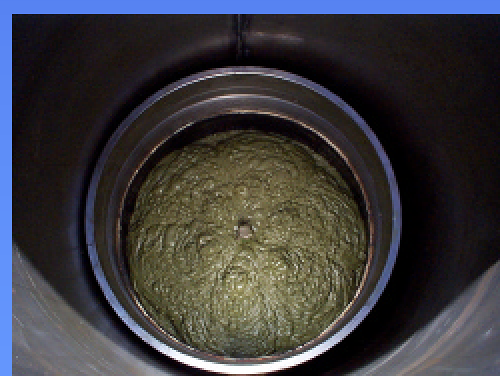
Installing pulse 2 mandrel in case

Positioning pulse 1 mandrel



Final pulse 1 grain

Pulse 2 grain former in place



Pulse 1 propellant

Mandrel plunge

Fast Cook Off Test

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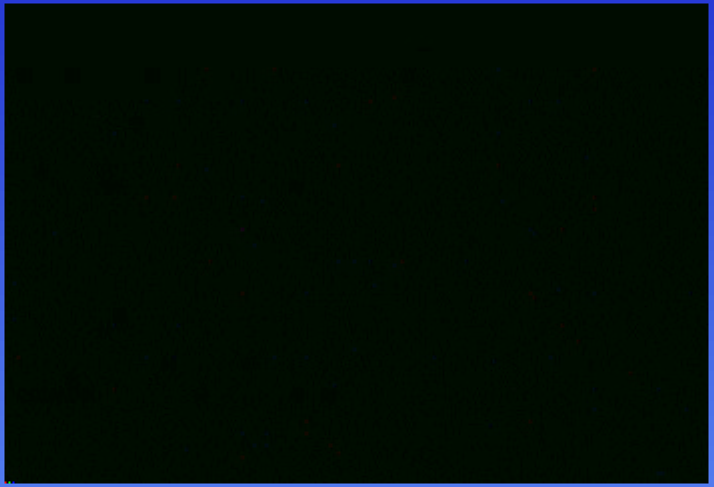
- Bikini Gauge Overpressures
  - 0 - 0.95 psi @ 50’
- No Pieces Outside of Pit
- Two Events
  - First at 6:30 probably pulse 2
  - Second at 12:30 probably pulse 1



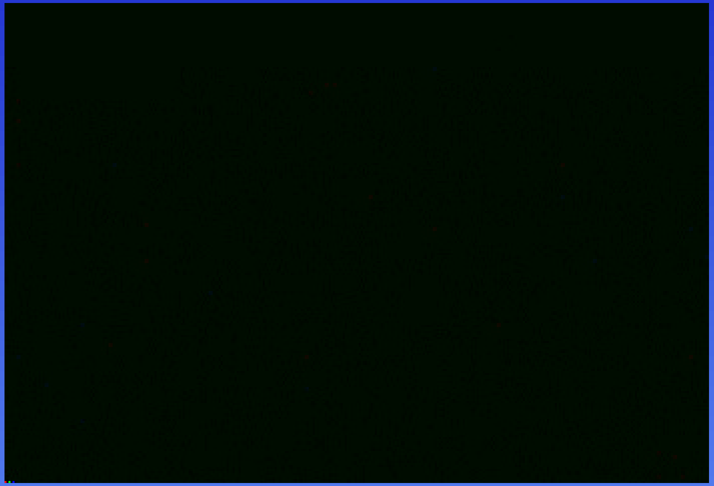
Aft closure

Bulkhead

BURN

Slow Cook Off Test

- **Bikini Gauge Overpressure**
  - **2.8 - 3.7 psi @ 50’**
- **Piece distribution**
  - **Pulse 2 case section and fwd polar boss 556’ from stand**
  - **Hypothesized pulse 2 went propulsive, broke on impact with burm. It burned where it came to rest.**



EXPLOSION

Bullet Impact Test

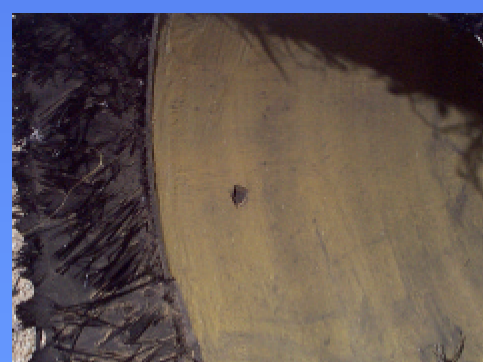
- Bikini Gauge Overpressures
  - 1.9 - 2.8 psi @ 50'
- One Bullet Hit Motor
- About half of the propellant recovered
- Poor liner/propellant bond

DEFLAGRATION

Bullet Impact Photos

Pulse 1 case section

Bulkhead build-up section



Inside of pulse 1 section

Fragment Impact Test

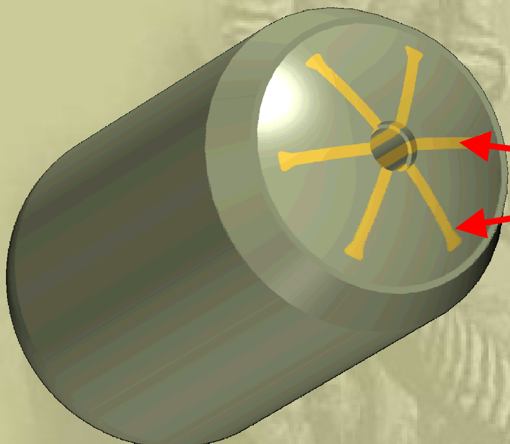
- Very few pieces went any distance
- Pulse 2 separated and burned 10' from stand
- Pulse 1 section of case shredded
- Some pulse 1 propellant pieces found

DEFLAGRATION

Post-test

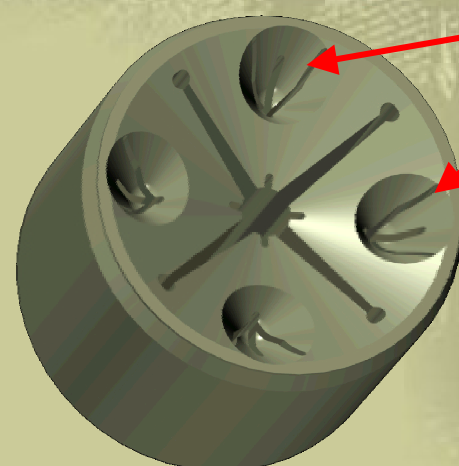
The End

Grain Designs



<u>Pulse 2</u>
6 fin design
Foam fins remain after casting
~650 lbs propellant

Chukar Feet



<u>Pulse 1</u>
High A_b
~310 lbs. Propellant
Target r_b = 0.7 ips @1000psia
Neutral Ballistics