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Naval Postgraduate School

Evaluation of Less Shock Sensitive Minimum Smoke Propellants in High Performance Composite Cases

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STRENGTH THROUGH TECHNOLOGY

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Presented by:

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ABSTRACT

This effort builds upon efforts to develop lower shock sensitivity minimum smoke propellants based on the ATK Cross-linked Double Base (XLDB) heritage. This family of propellants has been successfully subjected to processing development, limited aging, stabilizer depletion, mechanical property characterization, and sensitivity testing. A passive slow cookoff venting approach was implemented and prototype flightweight motors were tested under slow cookoff and bullet/fragment impact conditions.

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Background

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- **Fast Cookoff (FCO)**
  - Significant weakening of composite case due to direct exposure to fuel fire during IM test
    - Surface temp >> Tg
    - Little residual confinement for thin-walled composite cases
      - » Passive SCO venting devices may function in FCO scenario
      - » Apparent reduction in heating rate possible due to storage condition (e.g., containerized, round pallet config.) – *leads toward intermediate rate cookoff scenario*

- **Slow Cookoff (SCO)**
  - Some benefit from composite case alone (present design configurations)
    - Composite case generally provides less severe reaction due to slump and inherently lower dynamic yield strength
    - Conditions leading to increased thermal soak (i.e., slowest heating rates, packaging) can lead to more violent reactions
  - Mitigation device required
    - Motor-level built-in passive SCO mitigation device(s) desired from cost and ease of integration standpoint
    - End venting offers attractive solution
      - » Does not necessarily equal reduction in confinement (may be less effective for increasing length-to-diameter ratios)

Background

- **Bullet Impact (BI)**
  - Propellant shock sensitivity provides more dominant effect
  - Composite cases shown to reduce severity of reaction
    - Elimination of case fragment spall into propellant
  - Case design options for preferential fragmentation possible
    - Enhanced venting

- **Fragment Impact (FI)**
  - Propellant shock sensitivity provides more dominant effect
  - Composite cases shown to reduce severity of reaction
    - Reaction very dependant on fragment velocity (energy)
  - Energy dissipation approaches in packaging may be applied
    - Large volume penalties
    - Not practical for bare round configuration

Propellant Selection

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Ingredient/Property	Current Production	First Generation	Second Generation	
Category	Sensitive Class 1.1	Reduced Sensitivity MS Propellant Candidates		
DOB	1979	1992	2002	
Formulation type	XLDB binder with high nitramine	XLDB binder with AN and Casting Powder modifier	XLDB binder with AN and Co-oxidizers , Metal Salt modifiers	
Isp (% of baseline) Card Gap (cards) Critical Diameter (in)	100% 145 <0.5	95% 65 1.0	93-94% 65-80 0.5 – 0.75	
Mix Scale Manufactured (lbs)	2,000	1,000	100	100
Application	Fielded Tactical Motors	Development & Advanced Development Motors	Fixed Throat Advanced Development Motors	Controllable Thrust RDT&E Motors
Deficiencies	Sensitive	Limited ballistics & mechanicals	*Excellent mechanical properties, cold strain capability & processibility, higher operating pressure*	

Second Generation MS Propellant has Unsurpassed Strain Capability at Very Low Temperatures

Fourteen Different Formulations Evaluated and Show Strain Capabilities Approaching *90%* @ -54°C (do not become brittle)

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Propellant Comparison and Tested Configurations

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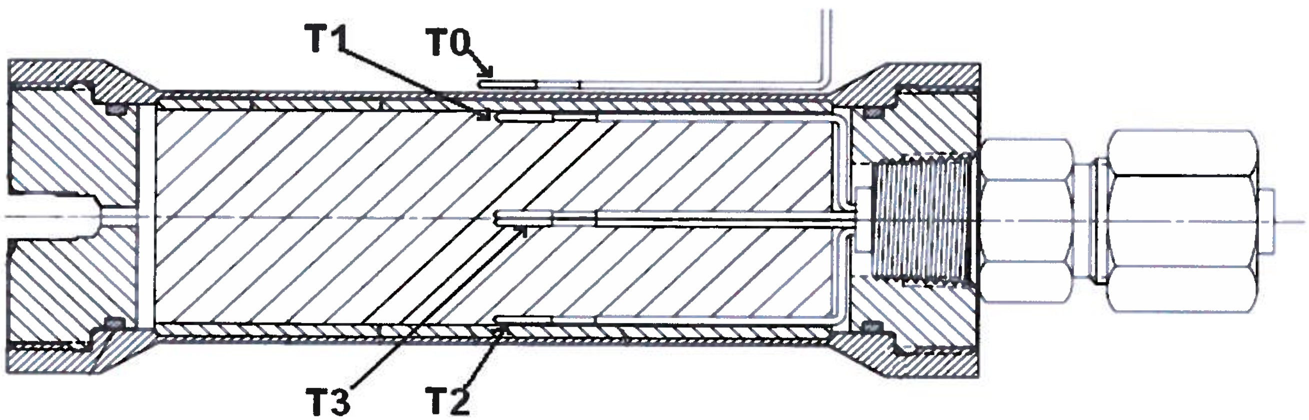
Formulation/Properties	XLDB			
NOL Card Gap (cards)	70	65	70	63
Co-oxidizer Type	RS-RDX		CL-20	- -
Full-scale IM Testing Performed	BI LVFI SCO	**Demonstrated production-readiness for drying and grinding operations**	BI HVFI SCJ	BI LVFI HVFI SCO
Case Materials	Composite	- -	Composite	Composite & Aluminum
Relative performance	92.8%		93.4%	92.0%

Developing a Design Approach for Slow Cookoff Mitigation

- **The initial focus of this effort was to implement an engineering solution for slow cookoff mitigation.**
  - Inherent to this task was to determine the autoignition response of the propellant under confinement.
- **An instrumented sub-scale cookoff chamber was designed and utilized to obtain thermal profiles at the surface, the propellant interface, and the center of the grain.**
  - Heating was applied via a fitted thermal heating jacket with electronic controller.
  - The XLDB propellant formulation containing RS-RDX was utilized.



Instrumented Sub-scale Cookoff Chamber
(propellant charge 45.7 mm diameter x 114.3 mm long)

Sub-scale SCO Characterization

Sub-scale Cookoff Chamber Test Data

S/N	Chamber Material	Wall Thickness (mm)	Heating Rate (°C/hr)	T0 (°C)	T1 (°C)	T2 (°C)	T3 (°C)
MS-5	Aluminum	2.54	25	144	143	142	128
MS-6	Aluminum	1.27	25	139	136	141	128
MS-7	Steel	1.27	25	141	138	133	124
MS-8	Steel	0.76	25	133	129	134	123
MS-17	Aluminum	2.54	3.3	127	123	123	144*
MS-18	Aluminum	1.27	3.3	119	117	117	118
MS-19	Steel	1.27	3.3	126	126	125	143*
MS-20	Steel	0.76	3.3	121	123	121	123

* *thermocouple data indicates reaction at or near thermocouple tip for MS-17 and MS-19*

Average Temperature Data

Heating Rate (°C/hr)	Surface Temp. (°C)	Interface Temp. (°C)	Center Temp. (°C)	DSC Initiation Temp. (°C)
25	139	137	126	-
3.3	123	122	121*	131

* *MS-17 and MS-19 center thermocouple excluded*

Effect of Heating Rate on Sub-scale SCO Reaction Violence

- The 3.3°C/hr tests exhibited significantly more violent reactions than did the 25°C/hr tests.
  - Significant amount of un-reacted propellant recovered from 25°C/hr tests
  - Post-test evidence from 3.3°C/hr chambers show increased distortion and heat-affected material

Post-test View of MS-7 (25°C/hr)

Post-test view of MS(3.3°C/hr)

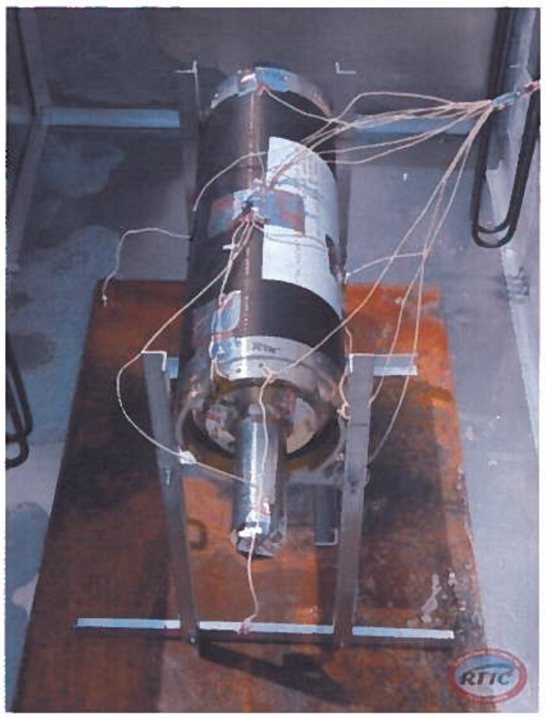
Sub-scale SCO Venting Test (3.3°C/hr)

- **The sub-scale chamber design was modified to incorporate a shape memory alloy (SMA) actuated closure release mechanism.**
  - The SMA is configured such that one of the chamber end closures is unlatched by the SMA reaching its activation temperature during the test
- **The temperature data correlates well with the 3.3°C/hr data from the previous tests**
  - the venting device allowed the closure to release from the chamber to prevent a violent reaction

S/N	T0 (°C)	T1 (°C)	T2 (°C)	T3 (°C)
MS-21	120	121	121	121
MS-22	122	122	123	121
MS-23	128	126	126	137
MS-24	120	124	119	119
MS-25	120	123	124	126
MS-26	126	-	-	-
MS-27	127	123	124	126
MS-28	122	-	119	112
Average	123	123	122	123
STDEV	3	2	3	8

Full-scale SCO Venting Test
(3.3°C/hr)

- **The SMA-based SCO venting approach was implemented in a 178 mm composite-cased test motor**
- **Expanding propellant grain gently pushed the aft closure away from the motor – air temperature was approx. 130°C.**
  - At some time prior to this event, the passive venting feature had released the nozzle closure from the rocket motor case as designed.
  - About 14 minutes later, the remaining propellant burned.



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Bullet & Fragment Impact Results

Propellant	XLDB MS Propellant (no co-oxidizer)	XLDB MS Propellant (no co-oxidizer)	XLDB MS Propellant w/ RS-RDX	XLDB MS Propellant w/ CL-20
NOL Card Gap	63	63	70	70
Case	178mm dia. Aluminum	178mm dia. Composite		
Grain type	CP	Boost-Sustain		
Shotline	Center	Center		
BI	No Reaction	No Reaction	No Reaction	--
FI (6000 fps / 1829 m/s)	> 85% of material recovered. Multiple fragments beyond 15 m	--	No Reaction Motor cut in half. All material within 15 m	--
FI (8300 fps / 2530 m/s)	Detonation	No Reaction	--	No Reaction

- **The bullet and fragment impact results begin to illustrate the incremental improvements available from composite case construction and less shock-sensitive propellants.**
  - IM compliance for a reasonably energetic propellant under high-velocity fragment conditions is unlikely in a metallic case.
  - There is a limit to the secondary benefits of the composite case.
- **The future challenge is to improve ballistic performance and tailorability while maintaining IM characteristics.**
  - Composite case technology is readily available and has been shown to improve IM performance for bullet and fragment impact when coupled with a less shock-sensitive propellant.

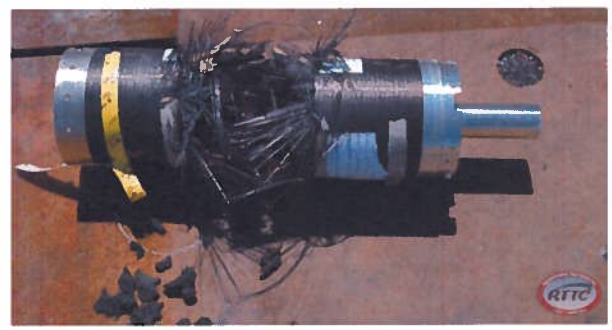
Comparison of Aluminum and Composite Cases with XLDB Propellants under BI & FI

BI – Aluminum Case (XLDB, no co-oxidizer)

BI – Composite Case (XLDB, w/ RS-RDX)

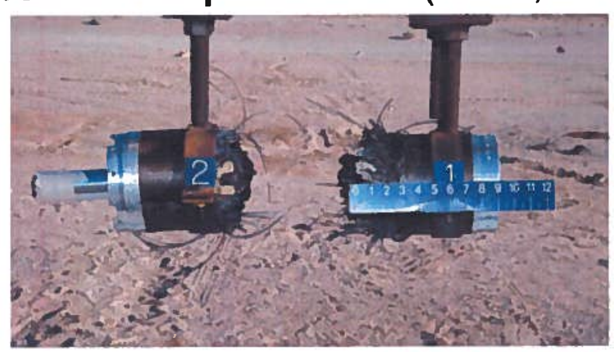
1829 m/s FI – Aluminum Case (XLDB, no co-oxidizer)

1829 m/s FI – Composite Case (XLDB, w/ RS-RDX)



2530 m/s FI – Aluminum Case (XLDB, no co-oxidizer)

2530 m/s FI – Composite Case (XLDB, no co-oxidizer)



1829 m/s FI to Aluminum Case with XLDB (no co-oxidizer)

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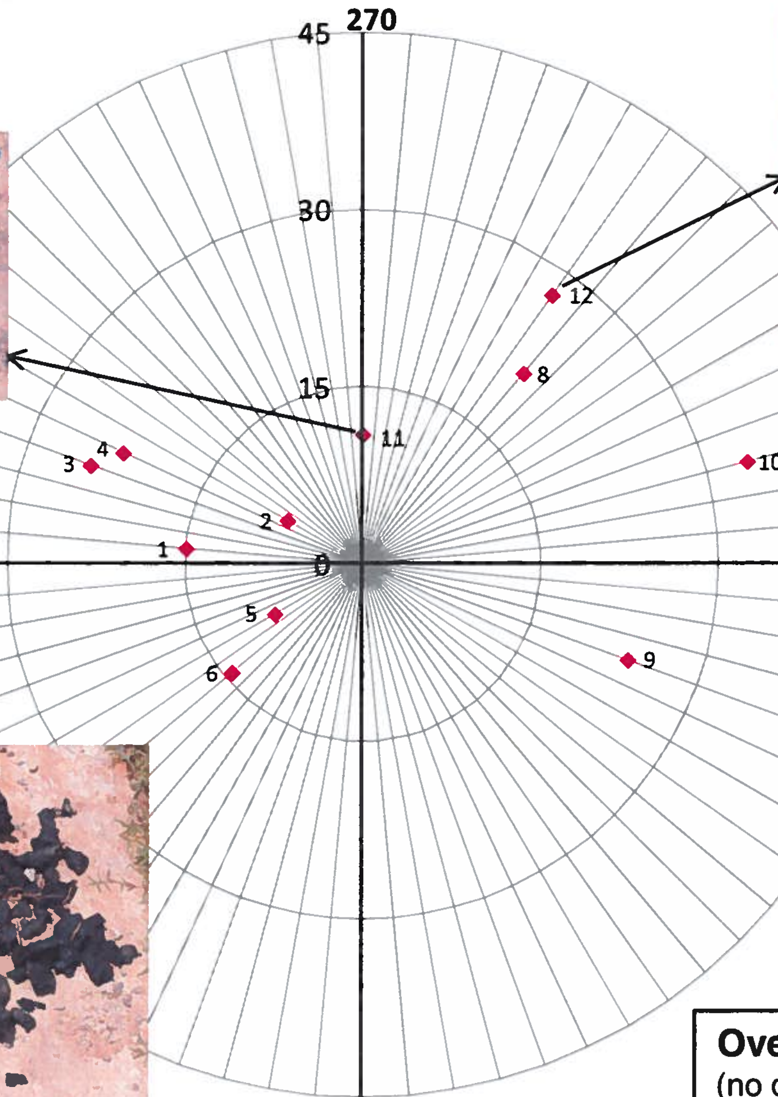
Case fragment with propellant



Case fragment with propellant

Post-test witness plate

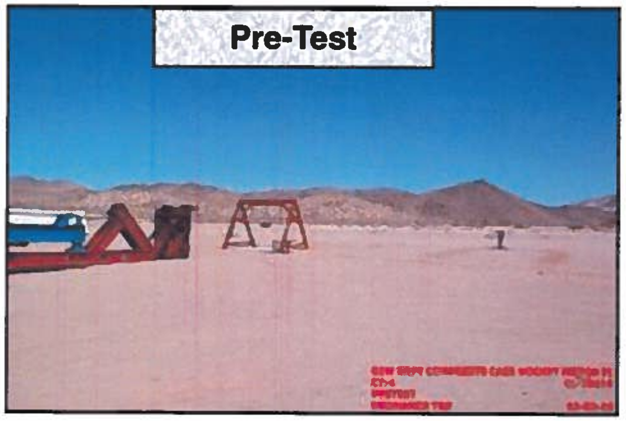
Recovered propellant

Shot line

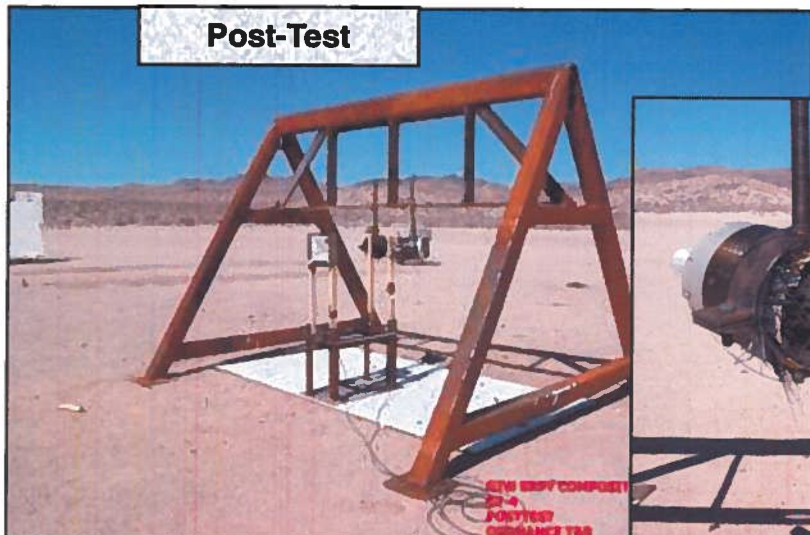
Overpressure < 3.4 kPa (0.5 psi)
(no greater than velocity calibration shot)

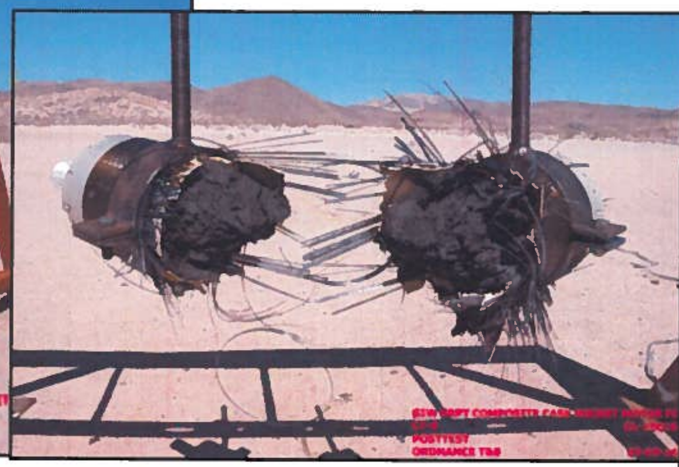
2530 m/s FI to Composite Case with XLDB (CL-20 co-oxidizer)

Pre-Test



Post-Test





Motor Did Not React!

~127 mm of center section produced all fragments. Four non-lethal fragments beyond 15 m.

Conclusion

- **This effort has focused on technology that is reaching the requisite level of maturity for transition to propulsion system development efforts**
  - Demonstration motors utilized flightweight hardware
  - Testing focused on developing a practical understanding of critical parameters

- **This effort represents the beginning of a larger effort to demonstrate an IM propulsion system in a relevant environment.**
  - There is a desire to improve the performance of less shock-sensitive propellants
  - The propellants investigated in this study represent the best compromise currently available between ballistic performance, IM, and mechanical properties

- **Technology development and demonstration efforts continue under the U.S. Department of Defense Joint Insensitive Munitions Technology Program (JIMTP)**