Lightweight IM Impact Protection System for Reducing Reaction of Solid Rocket Motors

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Overview:

- Problem Statement / Solution
- Program Overview
- Projectile Defeat Mechanisms
- Rocket Motor IM Protection Systems
- Ballistic Modeling and Simulation
- Motor Reactive Modeling and Simulation
- Testing and Validation
- Conclusions

Problem Statement / Solution:

Problem Statement:

- As seen in recent global conflicts, Insensitive Munition (IM) technologies provide key tactical and strategic value for protecting personnel and materiel assets in the battlefield.
- Protection of tactical munitions while in storage, in transit, and in the battlefield is critical to mission success.
- Use of insensitive energetics (high explosives and propellants) may not be feasible to achieve performance requirements for existing and future weapon systems.

Solution:

- Novel, lightweight appliques/barriers for mobile missile launchers and transportation protection systems can be used to protect against bullet and fragment impacts in order to lower reactive response to Type V or better.
- Use of lightweight barrier systems as appliques or cannister inserts allow missile systems to use high performance energetics while retaining IM capabilities.

Program Overview:

ATC Materials, Inc. (ATC) successfully completed a Phase II SBIR program under the Army Research Laboratory (ARL). Team members: Shearwater Technology, Inc. and WA Gooch Consulting, Inc.

ATC has a long history of protection system development and production and has produced the Transportation Protection System (TPS) for the Missile Defense Agency (MDA) for in-transit protection of full-up missile rounds.

Program Achievements:

- Development of a modeling and simulation toolset for modeling ballistic performance of applique designs and reactive response of rocket motor.
- Development of a lightweight applique design capable of protecting AP-HTPB motors to Type V response level from **0.50-cal APM2 and FSP impacts at requirement velocities**.
- Development of novel manufacturing techniques to produce applique perforated strike plate.
- Validated applique design performance by conducting two live-fire FSP impact test events that produced Type V or better responses.
- Developed applique is a barrier system for reducing energetic response level and is not full-stop armor. Applique was designed to meet IM requirements of MIL-STD-2105D and associated STANAGs 4496 and 4241.

Phase II Program Resulted in the Development of Design & Manufacturing Methodologies that Can be Used Produce Lightweight, High-Performance Applique & Barrier Systems for IM Protection for a Wide Array of Weapon Systems.

Rocket Motor IM Protection Systems:

Lightweight protection barriers are not meant to perform as armor that completely arrests the threat projectile.

Instead, the primary design philosophy of the barrier is to:

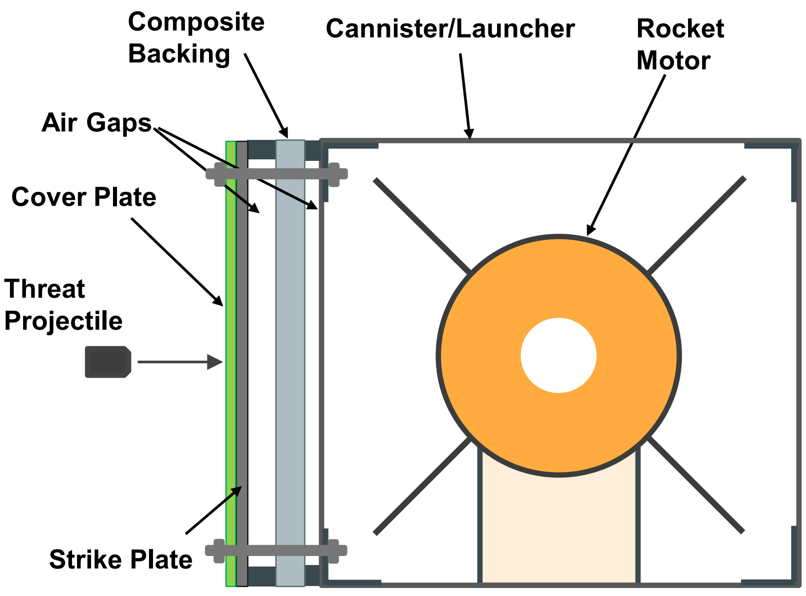
- **Fracture** the incoming threat
- **Spread** and divert debris
- **Capture** energy and momentum prior to motor impact.

Barrier system components & purposes:

- Strike plate – key driver of projectile fracture
- Air gap – allows debris to disperse
- Composite backing – capture debris momentum and strip APM2 jacket

Benefits of Perforated Strike Plate/Composite Backing Architecture:

- Multi-hit performance
- Armor can function as integrated structural component

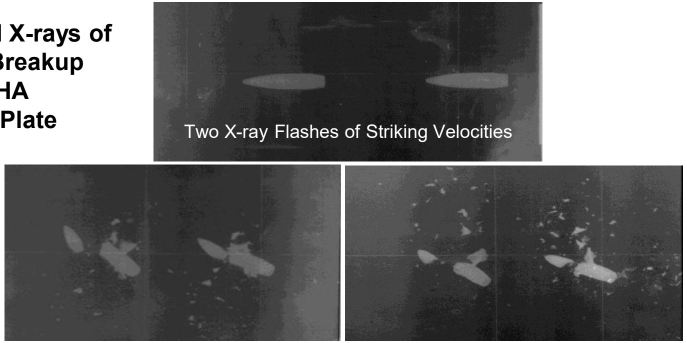


ATC Materials, Inc. Holds US Patent No. 14/661,860, "Lightweight Enhanced Ballistic Armor System" on this Enabling SBIR Developed Technology.

Projectile Defeat Mechanisms

- Primary defeat mechanism is an Ultra High Hard Armor (UHHA) perforated steel plate that induces projectile fracture.
- The strike plate perforations not only lower areal weight, but also, the angular cross-section imparts significant lateral forces on the projectile/fragment to induce further breakup, rotation, and off-axis disbursement of the residual debris.
- For jacketed AP threats the strike plate also strips the jacket from the core reducing the penetrator mass by 40%.

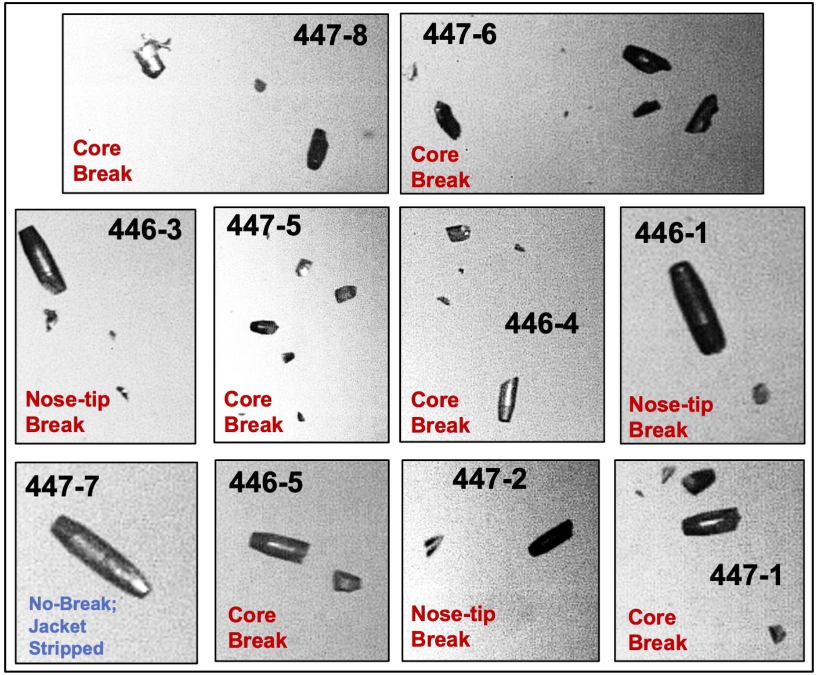
Orthogonal X-rays of Projectile Breakup Exiting UHHA Perforated Plate



Top View X-rays of Projectile

Side View X-rays of Projectile

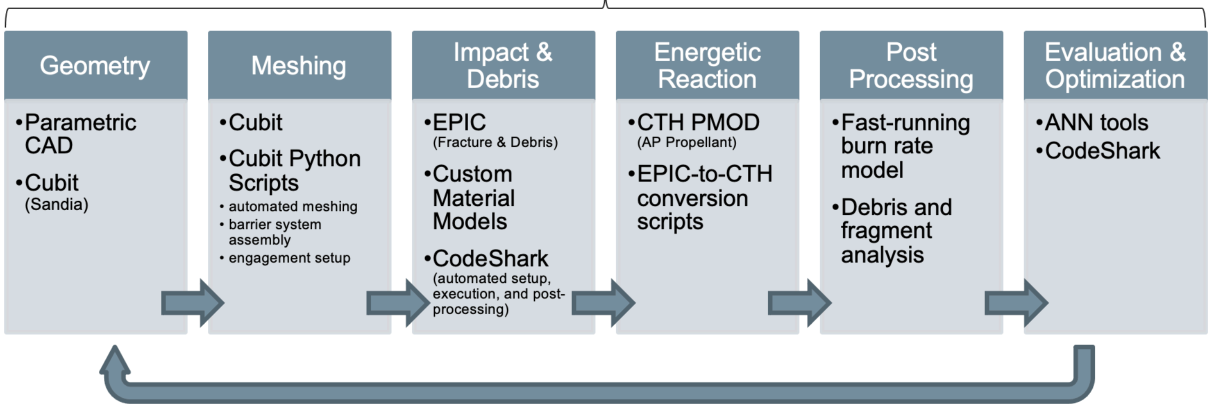
High Speed Images of Residual Debris From 0.50cal APM2 Ballistic Test Impacts Against ATC Barrier System



Modeling and Simulation Tool Suite:

- An end-to-end modeling and simulation tool suite was developed for evaluating the performance of protection system designs.
- EPIC18 was used for ballistic impact modeling; CTH was used for modeling reaction response of rocket motor.
- The tool suite allowed for rapid turnaround of design iterations and processed thousands of impact scenarios.

End-To-End Modeling and Simulation Tool Suite

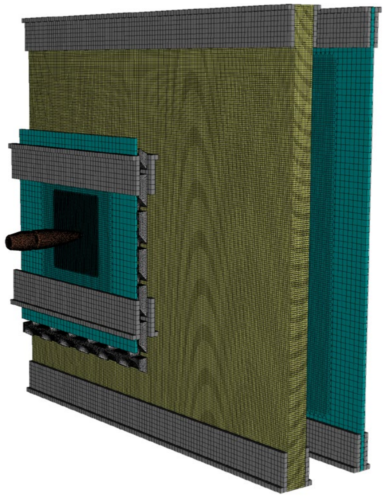


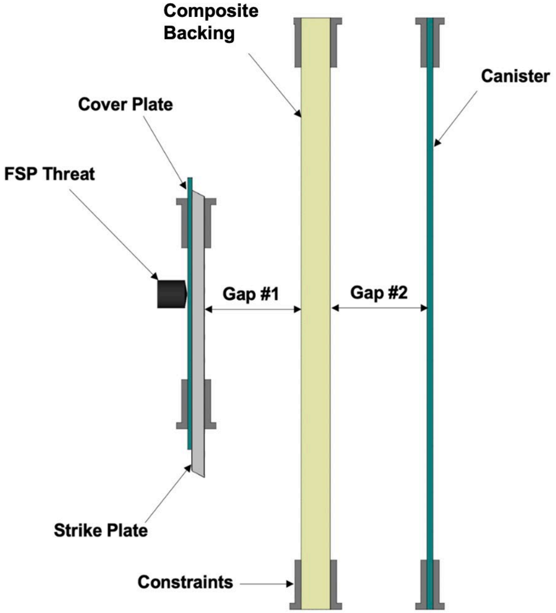
Criteria Driven M&S Optimization Loop

Ballistic Modeling and Simulation Setup:

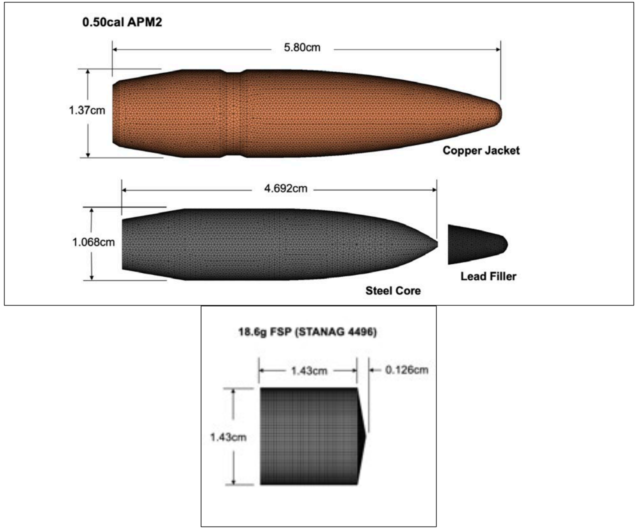
- The geometry/mesh model for the EPIC18 ballistic model for evaluating the barrier system performance is shown in images below. The Mesh was generated using the Cubit (Sandia) software.
- Material Models: Johnson-Cook Strength and Failure; Mie-Gruneisen EOS; Composite used hybrid method with bars for fiber and elements for epoxy matrix. Custom material model developed for UHHA steel strike plate.

Barrier System Geometry/Mesh Model



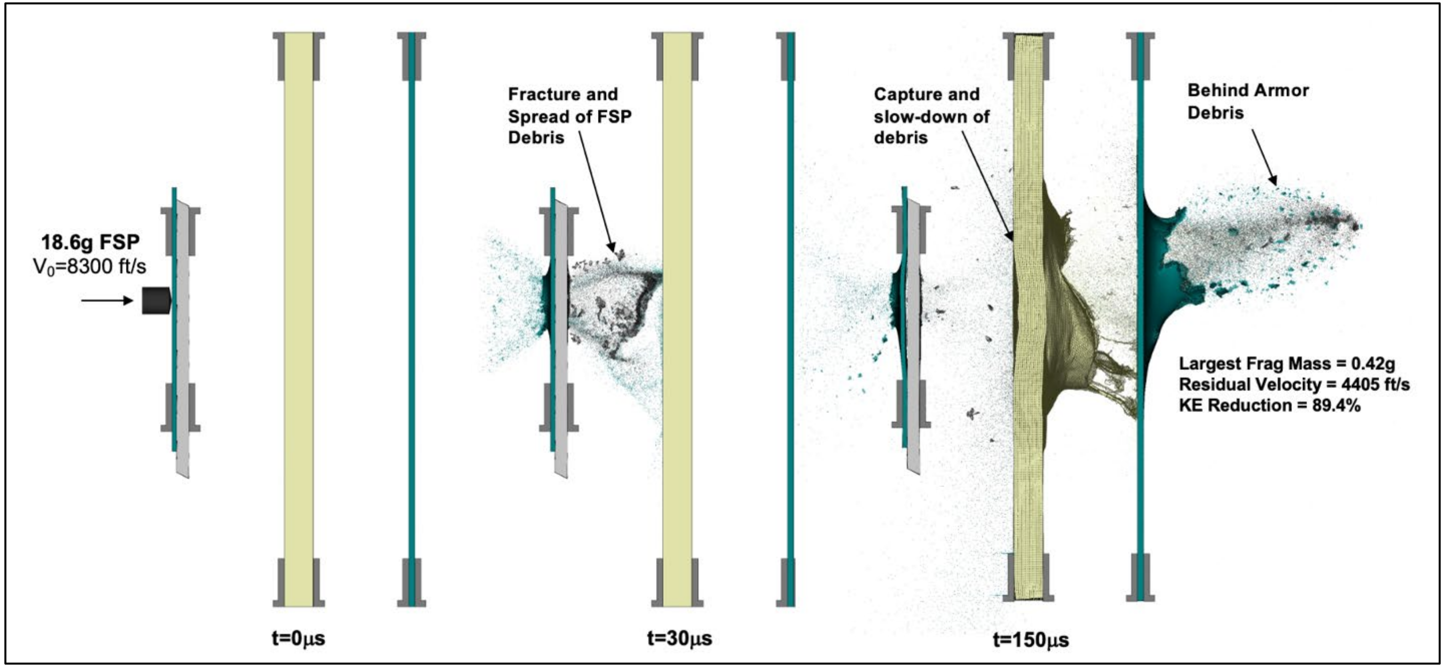


Threat Geometry/Mesh Model



Sample FSP Ballistic Simulation Results:

- EPIC18 was used to simulate an 18.6g FSP impacting the ATC barrier system at 8300 ft/s.
- The FSP is highly fractured by the strike plate and the debris cloud spreads prior to capture by the composite layer.
- In this case the fragment behind armor debris was slowed to 4405 ft/s and reduced KE by 89%.

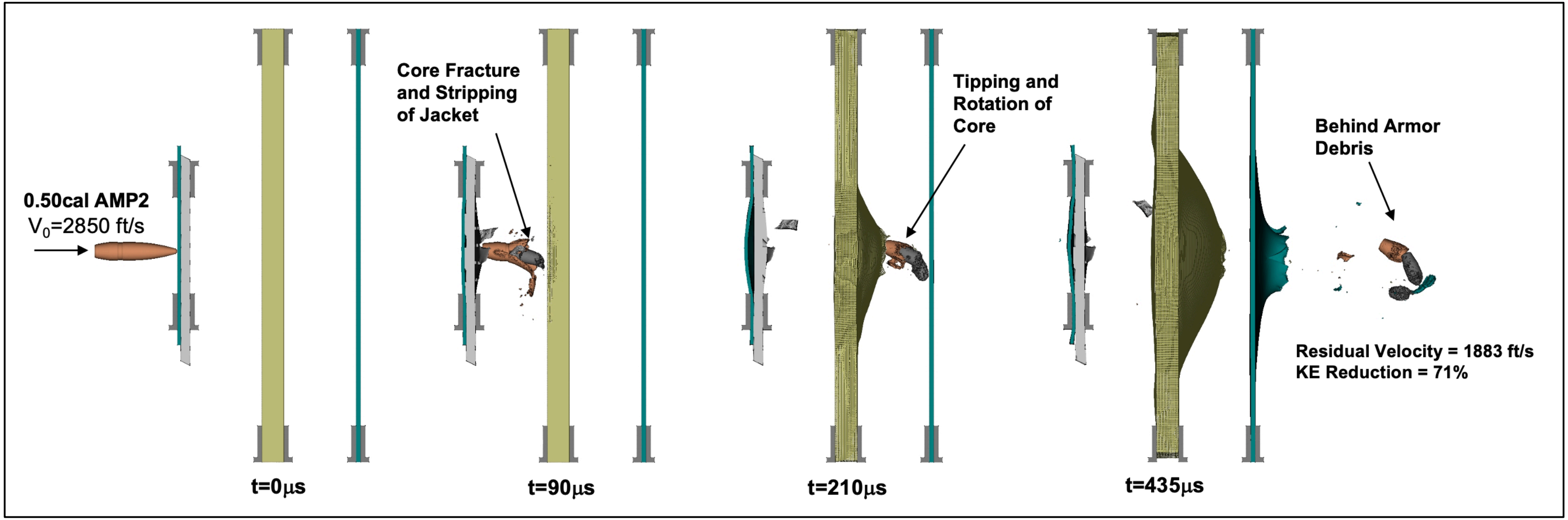


Sample Animation of FSP Impact Simulation:

18.6g FSP impacting the ATC barrier system at 8300 ft/s.

Sample 0.50cal APM2 Impact Simulation Results:

- EPIC18 was used to simulate a 0.50cal APM2 round impacting the ATC barrier system at 2850 ft/s.
- The AP core is fractured, and the jacket is stripped away from the core debris.
- In this case the fragment behind armor debris was slowed to 1883 ft/s and reduced KE by 71%.



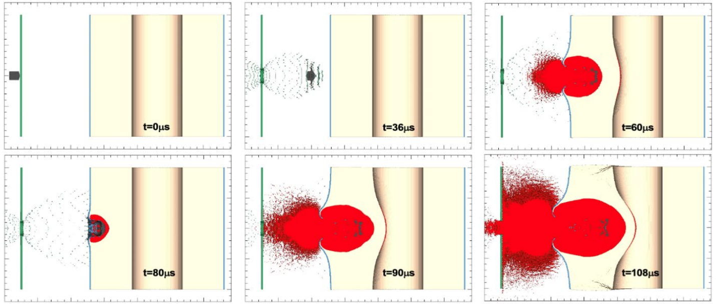
Sample Animation of 0.50cal APM2 Impact Simulation:

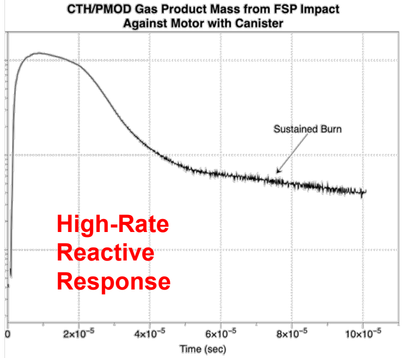
0.50cal APM2 projectile impacting the ATC barrier system at 2850 ft/s.

Rocket Motor Reaction Modeling:

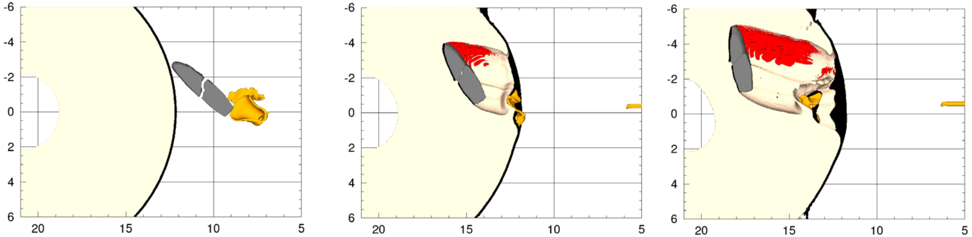
- CTH PMOD Reaction Model was used to model AP-HTPB rocket motor reactive response to impact stimulus.

FSP Impact at 8300 ft/s – Canister Only / No Protective Barrier





Single 50cal APM2 Impact – Post Armor Debris Converted from EPIC

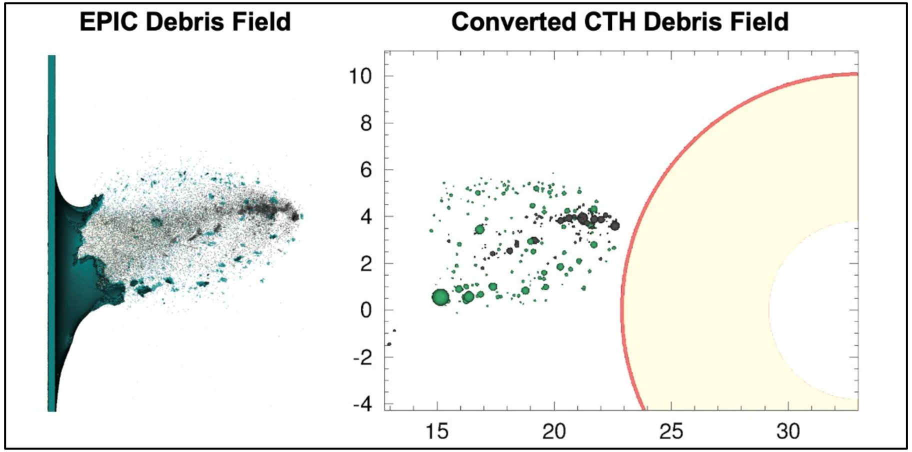


Low-Rate Reactive Response

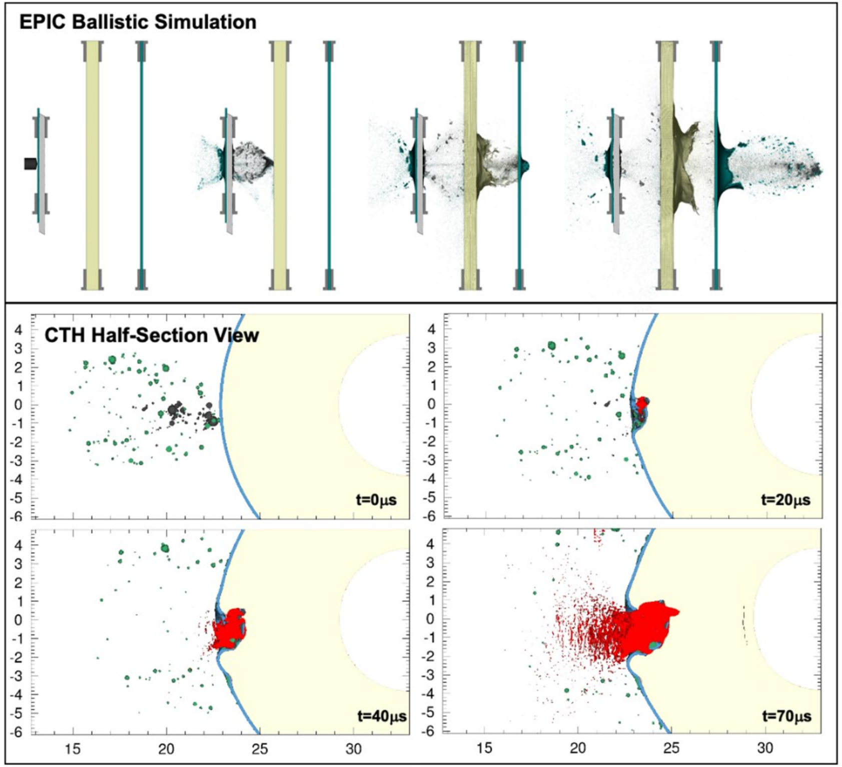
Debris Cloud Conversion to CTH:

EPIC debris fields predictions from FSP impacts were converted to CTH by inserting spherical fragments of equivalent material composition, mass, position, and velocity vectors into the CTH numerical domain.

The position state of the debris cloud was scaled back in time to ensure that the cloud tip was positioned ahead of motor just prior to impact.

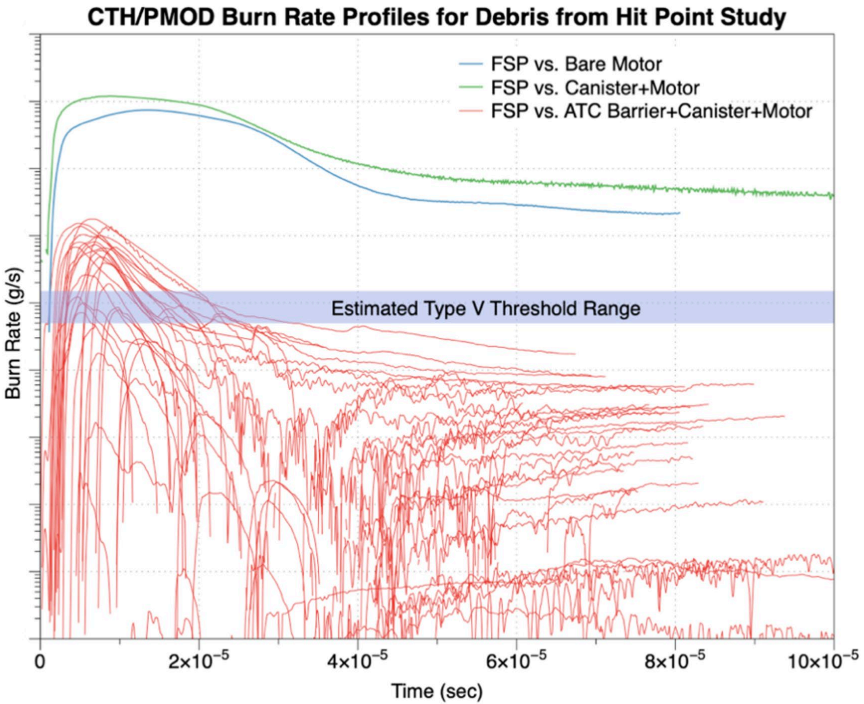


FSP Ballistic Impact Simulation Converted to CTH for Reactive Modeling



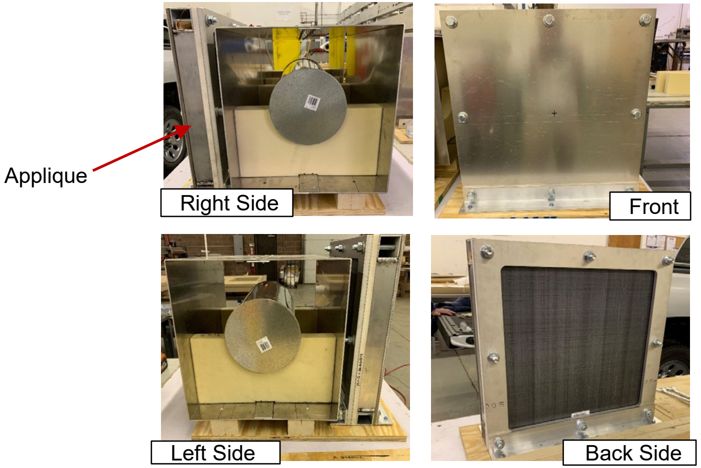
Reaction Rate Threshold Estimation:

- Consumption times of the live-fire surrogate rocket motor on the order of 10’s of seconds and were estimated to be Type V reaction outcomes.
- A numerical hit-point method was used to sample the barrier system strike plate perforation pattern to obtain a range of reaction rate data for the system. These simulations included the coupled EPIC18/CTH 3D modeling methodology.
- All hit locations measured for FSP at 8300 ft/s yielded sustained burn rates below the estimated Type V thresholds.



NTS Live Fire Test Series:

- Two full-scale live rocket motor tests were conducted at NTS Camden, AK
- The final IM design was an externally mounted IM applique designed to provide a Type V response from rocket motor under STANAG impact conditions.
- The live rocket motor testing was conducted with two IM fragment impact tests at 8300-fps as this threat exhibited the worst impact conditions and is a primary threat to missile system.



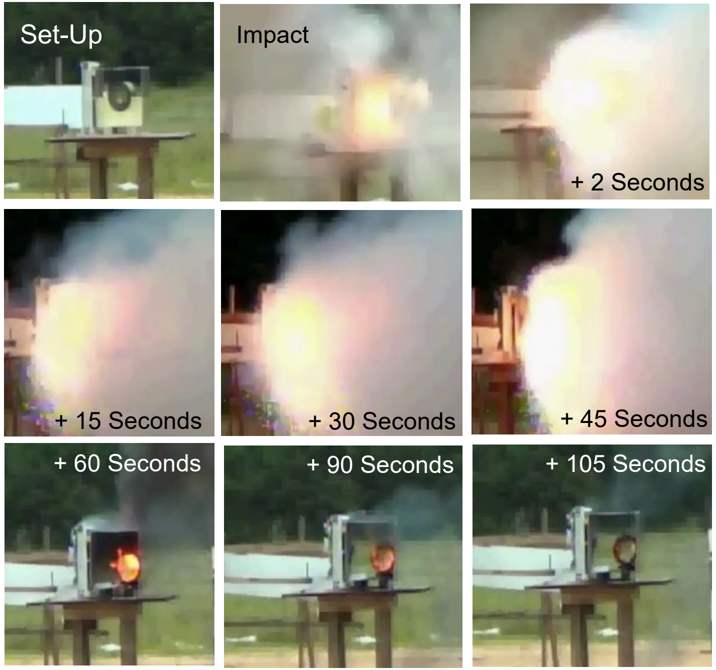
Fabrication of Test Array with Applique and Canister

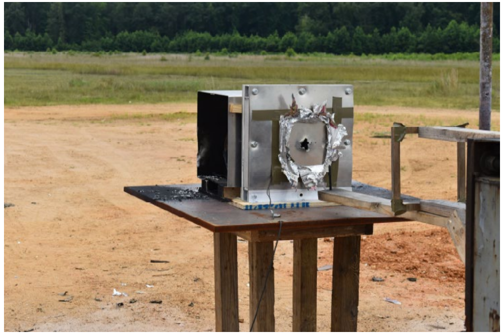
Aluminized HTPB Surrogate Rocket Motor Fabricated by R3 Aerospace

Live Fire Test TS-1: FSP Impact V_0=8515 ft/s

- TS-1 impact velocity was 8515 ft/s and propellant burn time was 57 sec.
- Test stand and canister stayed intact, and motor burned out in-place. Outcome was Type V response.

Test Outcome:
Slow Burn
(Type V Response)





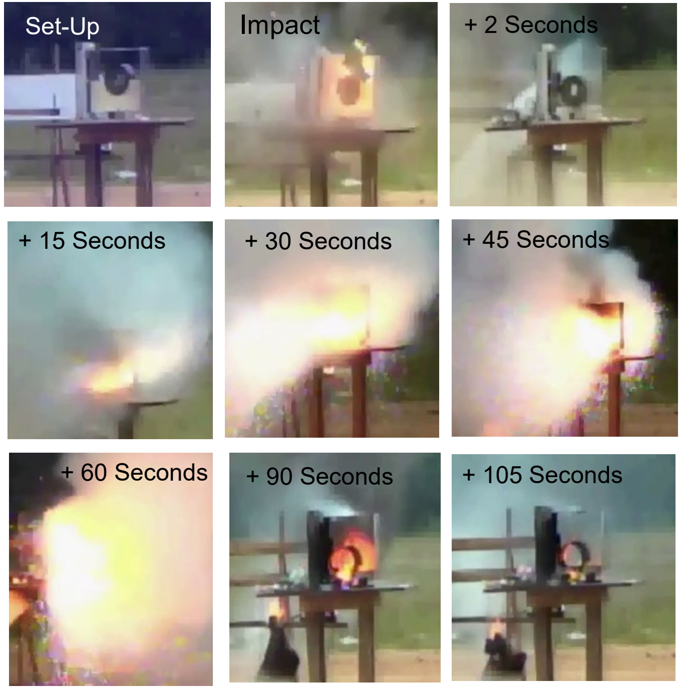
(U) Front side of barrier assembly

(U) Burnt out motor case still intact

Live Fire Test TS-2: FSP Impact V_0=8415 ft/s

- TS-1 impact velocity was 8415 ft/s and propellant burn time was 107 sec. with delayed ignition.
- Test stand and canister stayed intact, and motor burned out in-place. Outcome was Type V response.

Test Outcome:
Slow Burn
(Type V Response)



Front side of barrier assembly

Burnt out motor case still intact

SHEARWATER Technology Inc.

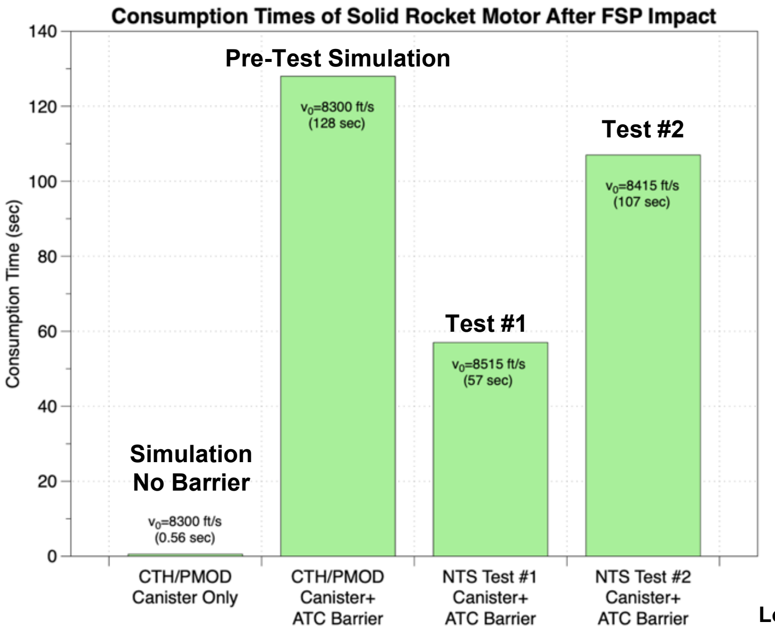
Atc materials

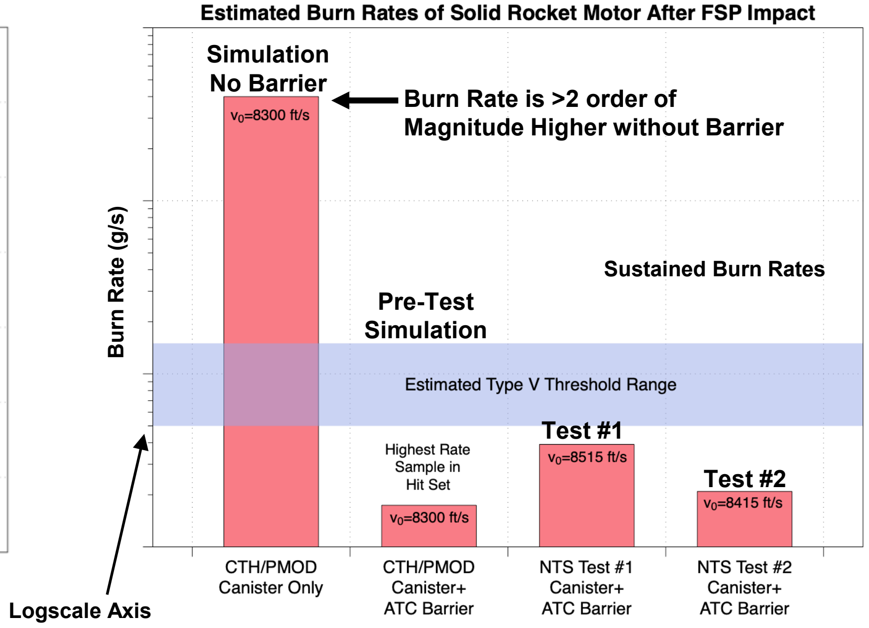
Live Fire Test TS-2 Video:

- 18.6g FSP impact against AP-HTPB rocket motor at 8415 ft/s.

Comparison of Simulation and Test Results:

- Pre-test simulation burn rate and consumption time predictions compared well with test, especially considering that burn rates can span several orders of magnitude.
- Low reaction rates correlate with Type V seen in both tests.





(U) Final Design Performance Predictions:

- The final design areal density is less than 12 lb/ft^2
- The table below lists performance predictions for the Phase II ATC barrier system base on test and simulation results.

18.6-g STANAG FSP at 8300-ft/s:
KE reduction = 80 - 90%
Probability of Type V outcome = 98%
0.50-Cal APM2 at 2850-ft/s:
KE reduction = 0.60 - 85%
Probability of AP core fracture = 50%
Probability of Type V outcome = 100%

ATC Barrier System Provides High Level of Protection Against AP and FSP Threats for AP-HTPB Propellant Based Rocket Motor

Follow-On Work:

- While the current Phase II effort has ended, additional funding would allow for further development of the ATC barrier system.

- Additional testing should be performed to:
  1. Identify baseline motor response without a barrier.
  2. Identify motor response with realistic confinement and nozzle aperture.
  3. Provide additional data for validating simulation reaction rate predictions.

- Development and implementation of damage sensitization models for AP-HTBP propellant to support evaluation of multi-hit 0.50cal APM2 scenarios (e.g. triple-fifty tests).

- Continued refinement of strike plate design and manufacturing to further optimize performance and reduced manufacturing costs.

- Investigation of additional of composite backing materials to further reduce system areal density.

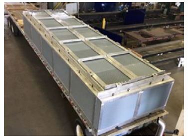
Barriers as an IM Solution

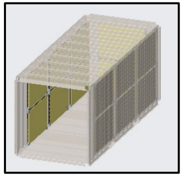
Ballistic barriers decouple performance and safety in energetics allowing for munition enhancement while maintaining IM compliance

Historic view

With barriers as an IM solution

IM compliance…	ATC barriers
…does not address common threats	Meets Type V for "triple-fifty," and fragment
…is energetic specific	>80% KE reduction likely provides Type V or better for all munitions
…reduces performance	Decouples IM compliance from performance allowing energetic enhancement while maintaining safety
…negatively impacts logistics	Minimal impact and may be integrated directly into future containers, canisters, and launchers





Summary:

Demonstrated IM Compliance via Ballistic Barriers
ATC Phase II effort successfully developed and demonstrated an armor to provide IM compliance for munitions, solving a major problem for the Army as many current programs are not in compliance with bullet (STANAG 4241) and fragment (STANAG 4496) IM requirements outlined in MIL-STD-2105.

Significant Reduction in Reaction
The Phase II prototype reduced reactions to Type V for a typical rocket motor with aluminized ammonium perchlorate (AP) solid propellant.

Development & Validation of Modeling and Simulation Tool Suite
The team further developed modeling and simulation tools that will allow additional optimization of ballistic barriers for IM compliance for other munitions and energetics.

Ballistic Barriers Enable Performance
ATC's barrier design provides a practical armor system which moves the safety burden from energetics to the ballistic barrier enabling pursuit of greater performance by decoupling energetics and safety.

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