Comparison of Shock Stimuli from Current Hazard Classification Testing and Potential Threats

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Outline

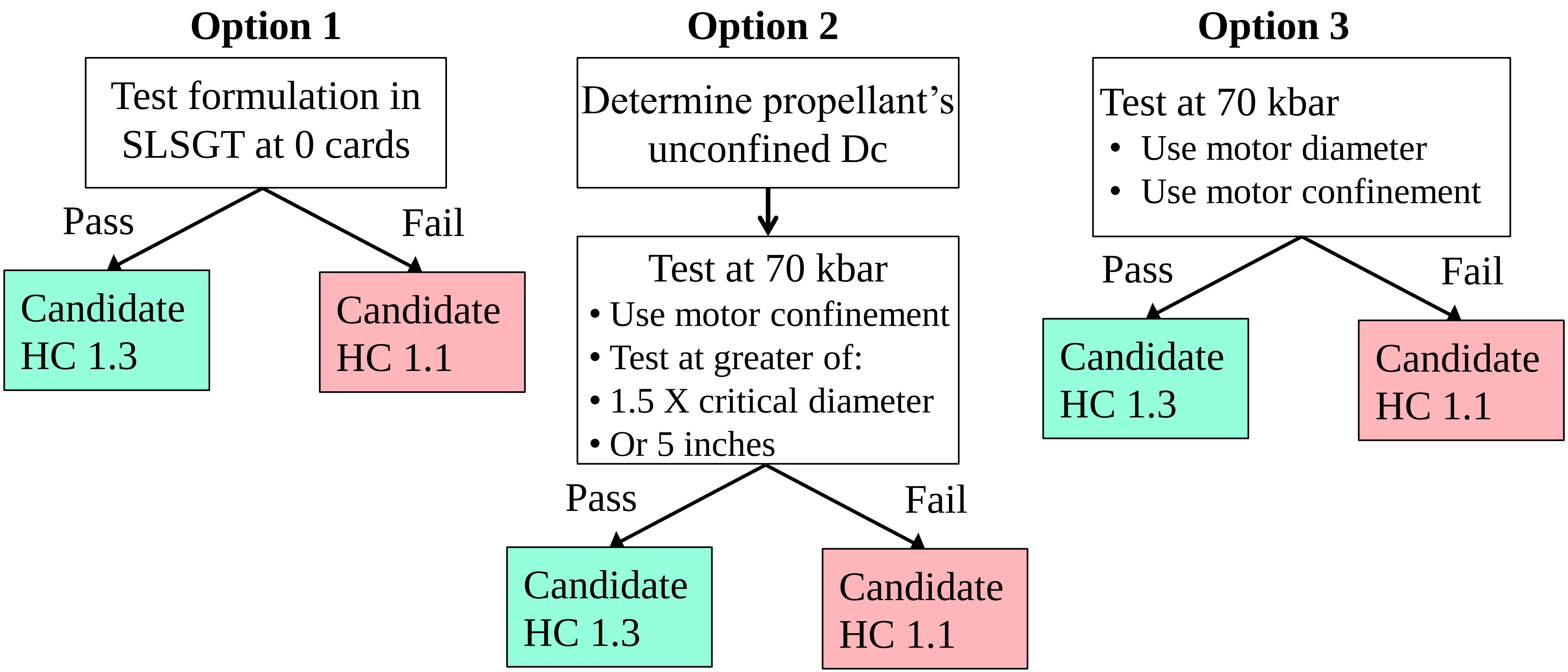
- Background
- Understanding the TB 700-2 Option 2 Shock Test
  - Impulse and Pressure Effects
  - Modeling Potential Accident Scenarios
- Pathfinder Experimental Studies
  - Booster Selection to Approach Constant Impulse Testing
  - Critical Diameter Determination
  - Go/No-Go Testing Using Different Booster Geometries
- Evaluation of Experimental Data
  - Comparison with Project SOPHY Data
  - Influence of Booster Configuration
- Summary
- Recommendations

Background and Current Protocol Requirements

- United States hazard classification of energetic materials and devices is governed by a Joint Technical Bulletin (TB 700-2, NAVSEAINST 8020.8C and TO 11A-1-47) titled: "Department of Defense Ammunition and Explosives Hazard Classification Procedures"
- Rocket motors are typically given one of the following hazard classifications:
  - HC 1.1 (mass explosion hazard)
  - HC 1.3 (mass fire hazard)
- It is highly desirable that large solid rocket motors have a HC 1.3 designation
  - HC 1.1 items have much larger quantity distance requirements, which adds a substantial logistic and facility burden
- A major, and often challenging, requirement in TB 700-2 is associated with shock sensitivity testing

Shock Testing – Current Protocol

- The TB 700-2 shock testing protocol is summarized below:



Option 2 is often the only viable path to a HC 1.3 for high performance rocket propellants used in large motors

Shock Testing – Unintended Consequences

- Observation: Current Option 2 shock testing protocol penalizes formulations with larger critical diameters
- The following example illustrates this problem:
  - Formulation A has a 3.33-inch critical diameter while Formulation B has an 8-inch Dc
    - With a larger Dc, *Formulation B would be assessed to be less shock sensitive* and should have a better chance of passing shock testing needed for a 1.3 HC
- To pass Option 2, Formulation B must utilize:
  - A larger test article
  - A larger booster

Larger boosters and test articles drive impulse higher at constant pressure

Critical Diameter Case Study		
Parameter	**Formulation A (Dc = 3.33 in.)**	**Formulation B (Dc = 8.0 in.)**
Nominal Article Wt (lb.)	25.5	353
TB 700-2 Compliant Booster Wt (lb.)	4.7	44.2
Impulse @ 70 kbar (kbar-μ sec)	440	1122

Understanding Impulse – Lessons from Project SOPHY

- Curves shown were drawn from test data for propellants containing RDX
- Minimum shock to drive sustained detonation of a zero percent AP propellant *was estimated as 8-10 kbar*
- Results did not agree with recent work and caused us to carefully analyze relevant literature on this topic

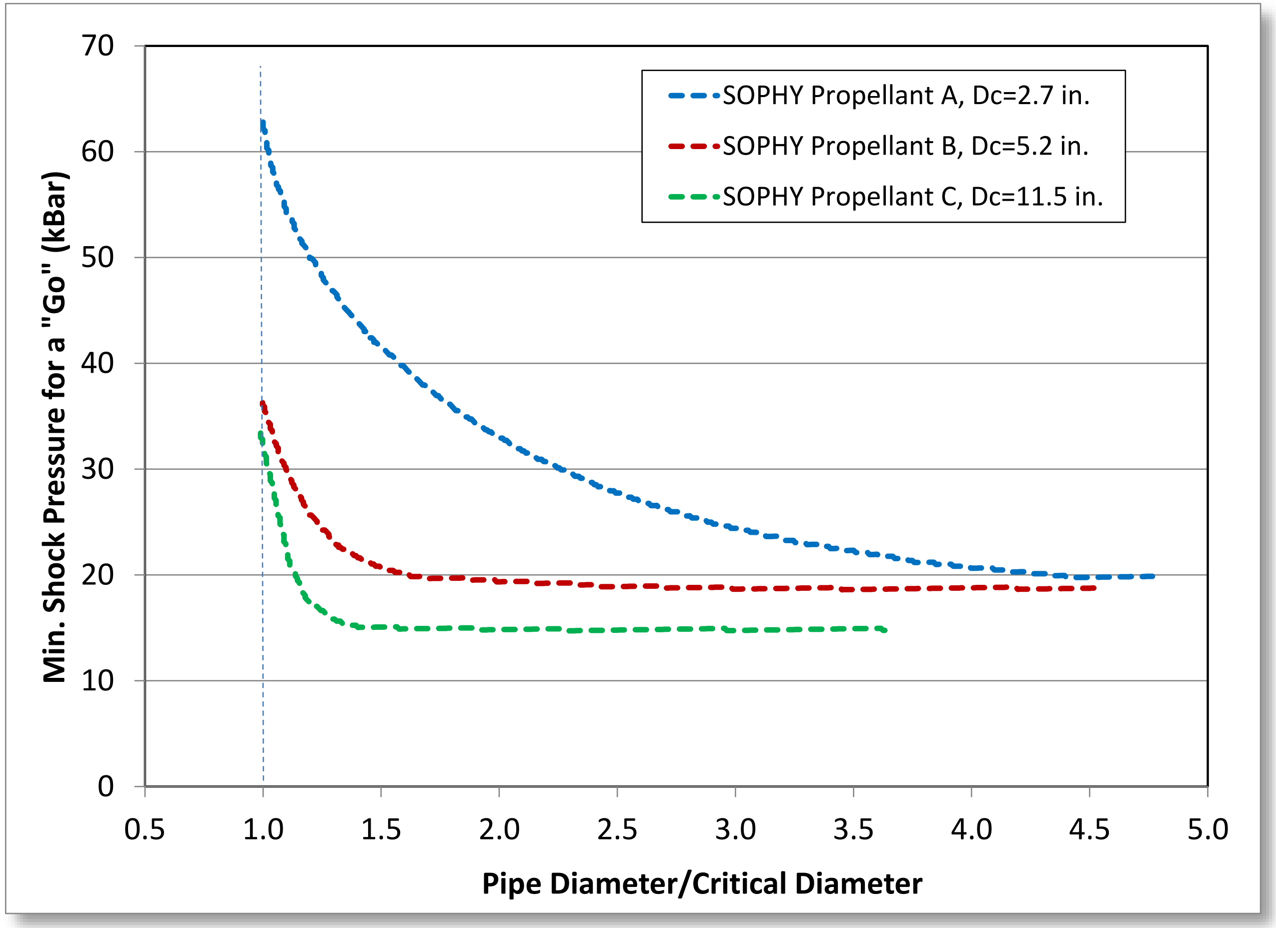
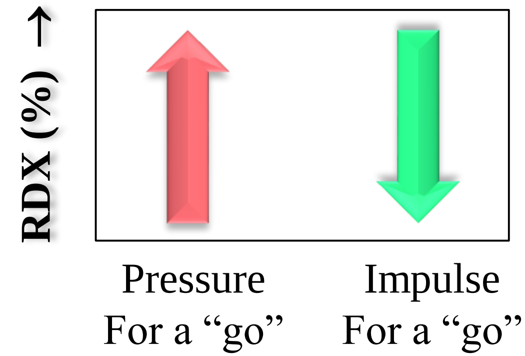
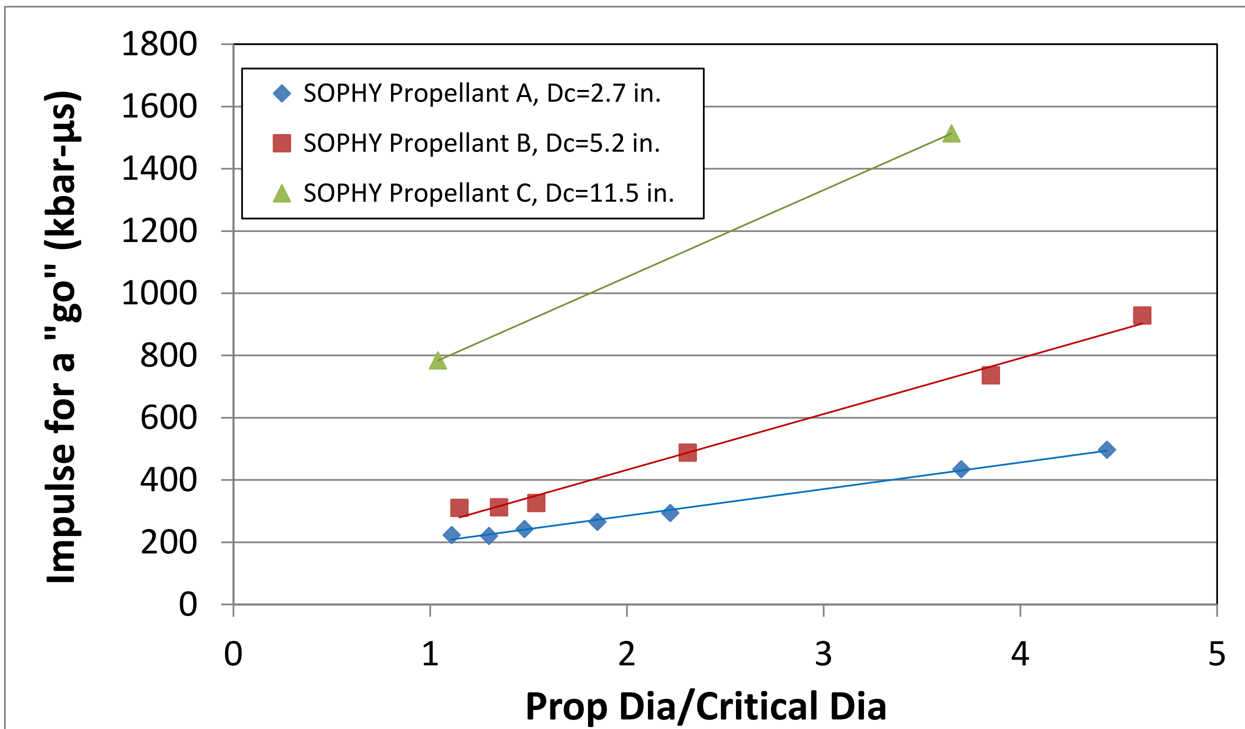


Figure 50 from the SOPHY II Final Report

Analysis of SOPHY Data – Finding a Path Forward

- Theoretical analysis of SOPHY data suggests impulse should be considered when determining relative shock sensitivity
  - Trend with impulse follows known sensitivity, go/no-go pressure does not





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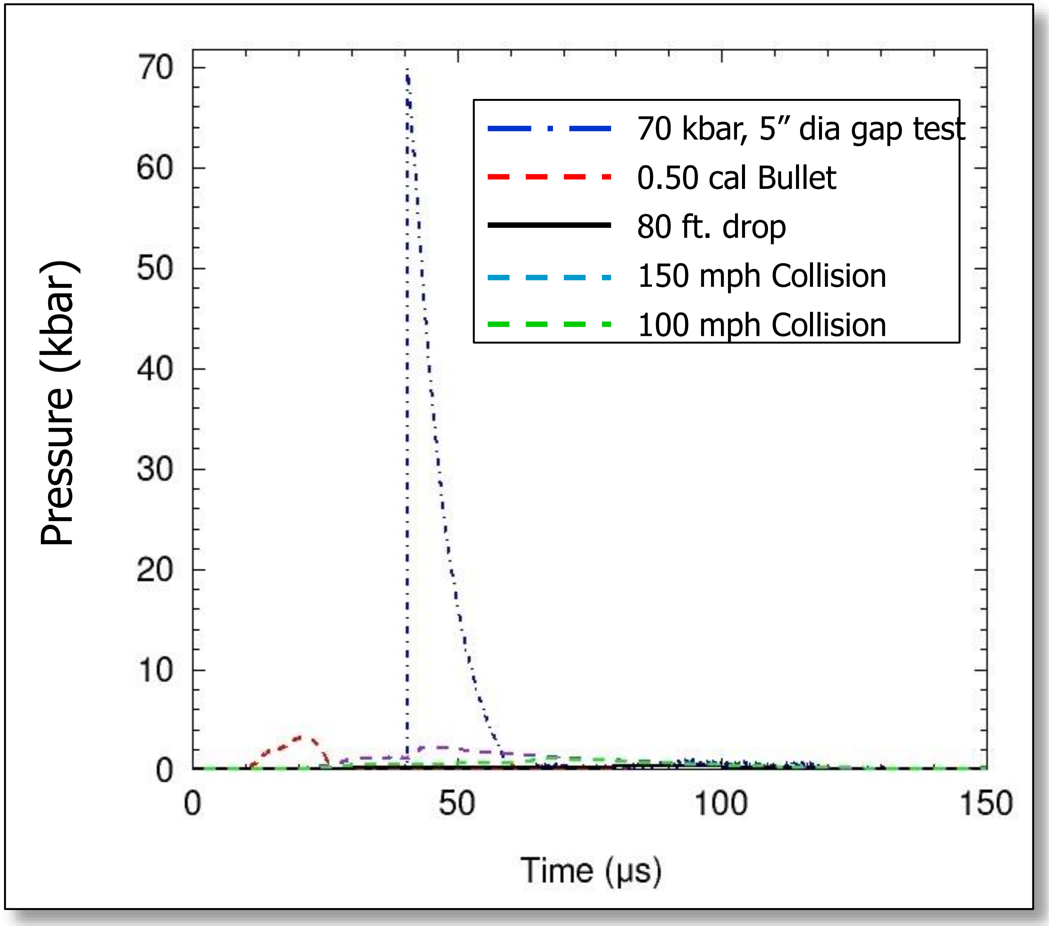
Another Important Piece to the Puzzle – Modeling Potential Unplanned Events

- Impulse experienced by a typical larger rocket was modeled for:
  - 0.50 cal bullet impact
  - 80-ft drop
  - 100 and 150 mph collision

- Impulse from potential events is far less violent than a 70-kbar test of a 5-inch diameter article
  - 5-inch diameter is the smallest size test article allowed for Option 2 shock testing



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Further Insight into Gap Testing – Decreasing Booster Height at 70 kbar Shock

- Interface impulse produced by full diameter boosters increases at constant pressure as article diameter grows
  - Full diameter boosters are required by TB 700-2 in Option 2 testing

- Reducing the booster height while maintaining diameter produces a relatively slow decrease in impulse
  - Large article with full diameter booster = high impulse
    - Even with reduced weight booster!
  - Small article with full diameter booster = lower impulse

Calculations with 70 kbar Peak Pressure at PMMA/Propellant Interface					
Propellant Acceptor	Comp B Booster		Attenuator	Pressure	Impulse @ 70 kbar
O.D. (in.)	Height (in)	Wt (g)	O.D. (in)	(kbar)	(kbar-μ sec)
6.00	6.25	2739	6.25	70	530
9.00	9.25	7553	9.26	70	788
9.00	2.00	1772	9.25	70	641

Freezing Booster Size Controls Impulse

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- Modeling was used to understand the relationship between booster size and geometry on impulse delivered at constant pressure
- Variations were based on practical options and included:
  - Changes to booster geometry
  - Attenuator shape/geometry (no significant influence on impulse)

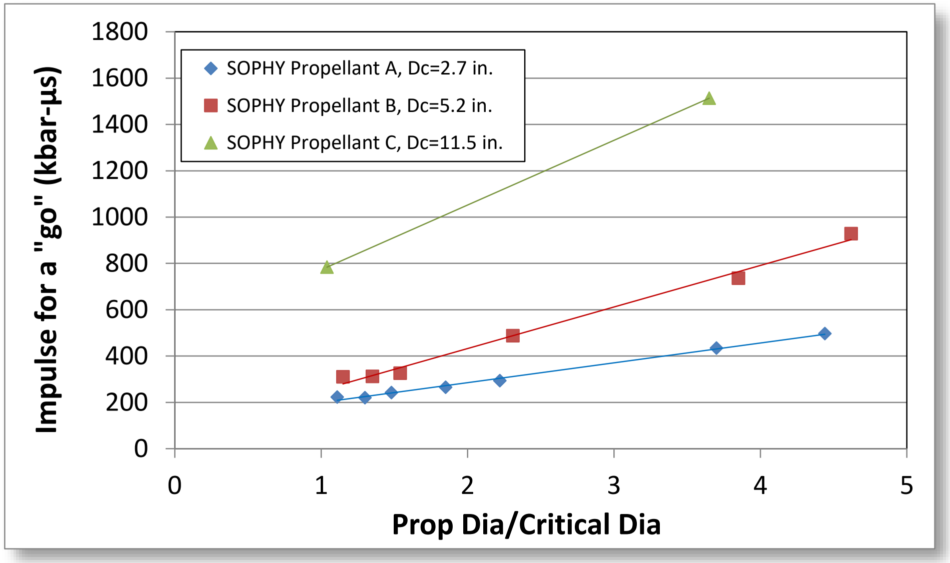
Calculations with 70 kbar Peak Pressure at PMMA/Propellant Interface						
Propellant Acceptor O.D. (in.)	Comp B Booster			PMMA Attenuator O.D. (in.)	Pressure (kbar)	Impulse (kbar-μ sec)
	Height (in.)	O.D. (in.)	Wt (g)			
5.0	5.25	5.25	1807	5.25	70	439
6.0	5.25	5.25	1807	6.25	70	459
8.0	5.25	5.25	1807	8.25	70	459
12.0	5.25	5.25	1807	12.25	70	459

Modeling indicates when the same booster is used for tests of increasing diameter, the larger articles see only a small increase in impulse!

Experimental Study

- A pathfinder experimental study complemented modeling efforts
- Goal was to learn whether the pressure and impulse trends observed in Project SOPHY would hold for modern propellants
- A new formulation was developed for this study
  - Composition incorporated lessons learned since the 1960s to achieve maximum performance with minimum sensitivity

- Targeted critical diameter was 2 to 3 inches
  - Allowed direct comparison with SOPHY Propellant A
    - Dc = 2.7 inches



Step 1: Critical Diameter Determination

- Propellant samples were cast in thin-walled plastic cylinders
  - Several tests were above and below Dc
  - Length to diameter was 4:1
  - Cylindrical Comp B boosters were used
- Measured Dc was between 2.0 and 2.25 in.
  - Assessed to be 2.125 in.

2.0 inch: no-go

2.25 inch: go

General Setup

Step 2: Go/No-Go Testing: Variation in Diameter and Booster

- Step two was to perform “SOPHY like” testing
  - Cast Composition B boosters were used for all tests
    - Initiation train used identical EBWs and Comp A pellets
  - Charge diameter ranged from 2.5 inches to 5 inches
    - Size of 5-inch article was compliant with TB 700-2 Option 2 requirements
    - Diameter to critical diameter varied from 1.18 to 2.35
  - Length to diameter was 4:1
- Small booster was above critical diameter
  - Known to deliver a shock which could initiate the propellant

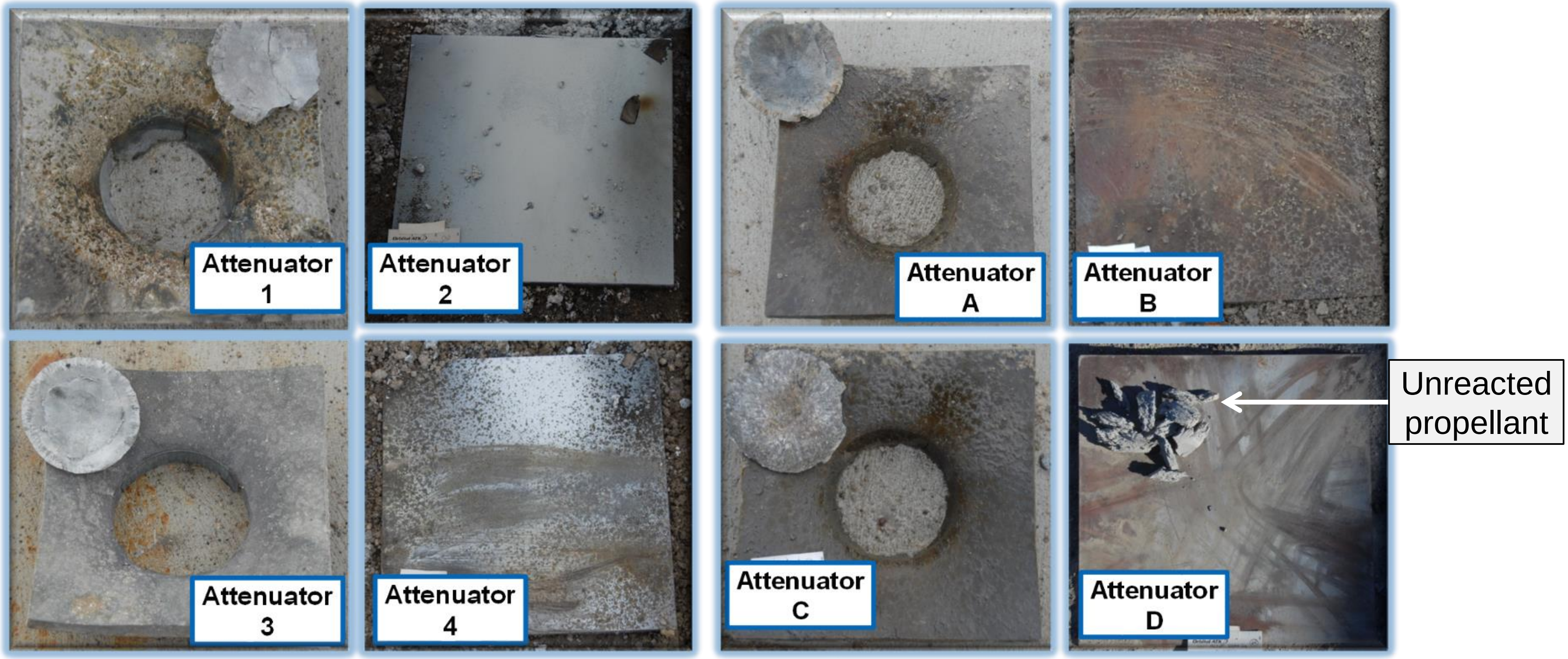
Small Booster Charge

Full Diameter Booster Charge

Test Summary

- Testing was divided into two different series
- Series 1
  - All tests used a full diameter cylindrical booster
  - Booster length to diameter was fixed at 1
  - Booster weight varied from ~400 g to ~2.5 kg
- Series 2
  - Matched Series 1 acceptor articles
  - Identical small boosters for all tests
- High-speed and real-time video on all tests
  - Go and no-go results were obtained

Representative Witness Plates

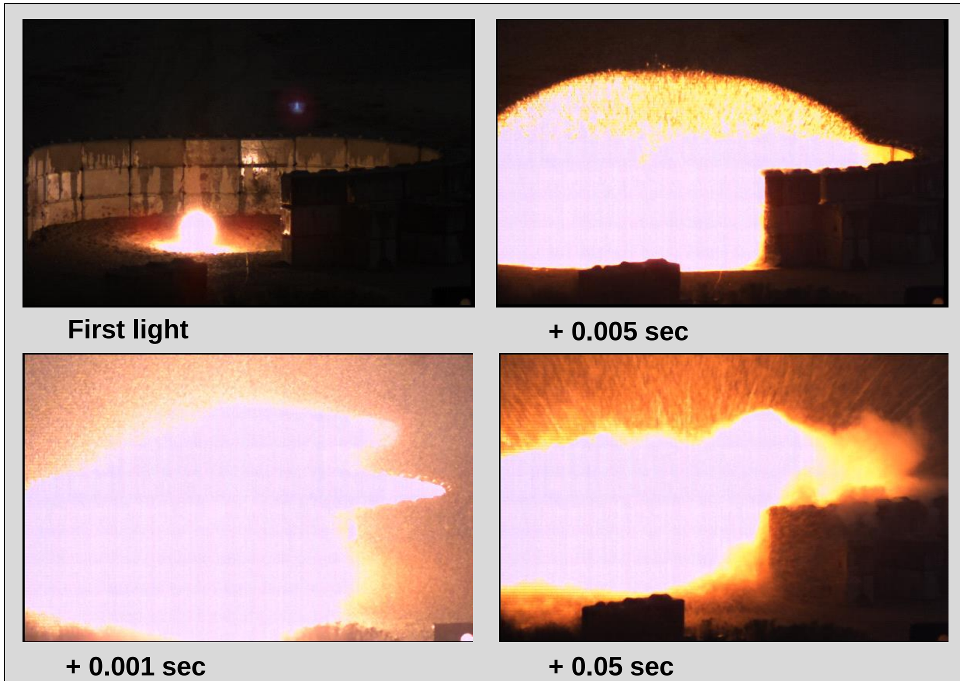


Witness Plates: Full Diameter Booster

Witness Plates: Small Booster

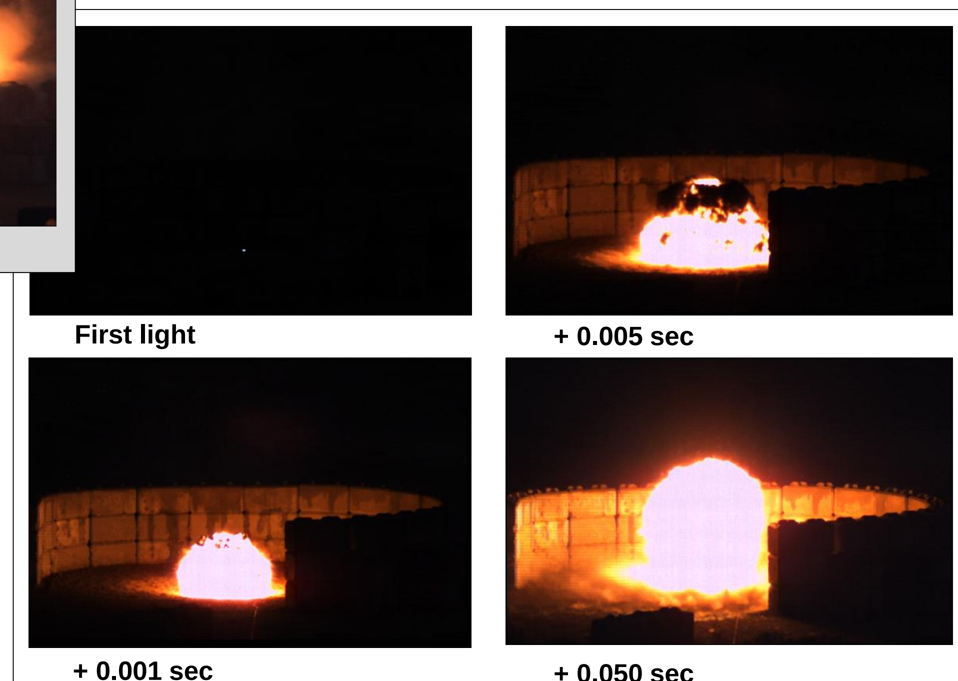
- Video analysis and witness plate examination were used to determine the acceptor detonated

Analysis of High-Speed Images Provided Valuable Insight into Reaction Type and Extent



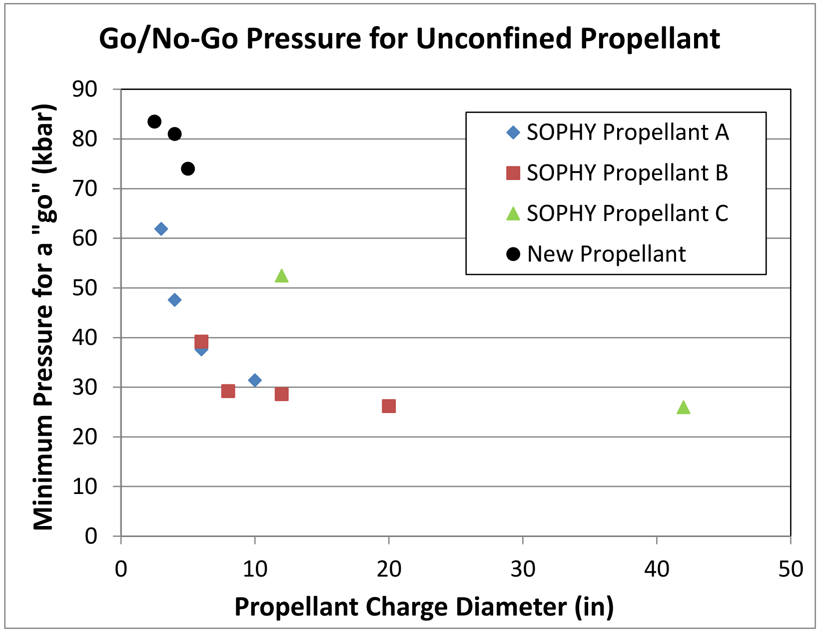
5-inch-diameter Test Article
Small Booster
Detonation Response

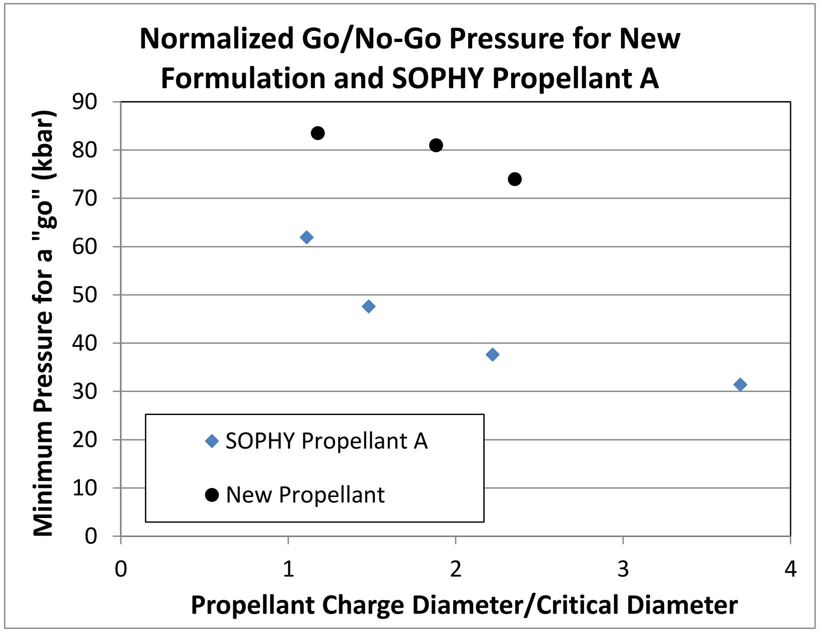
5-inch-diameter Test Article
Small Booster
Nondetonation



Comparison with Project SOPHY: Go/No-Go Pressure

- New propellant is more energetic and has a smaller critical diameter than SOPHY formulation
- New formulation requires higher pressure to cause a detonation
  - *Suggests progress has been made during the past 50 years!*





Comparison with Project SOPHY: Impulse

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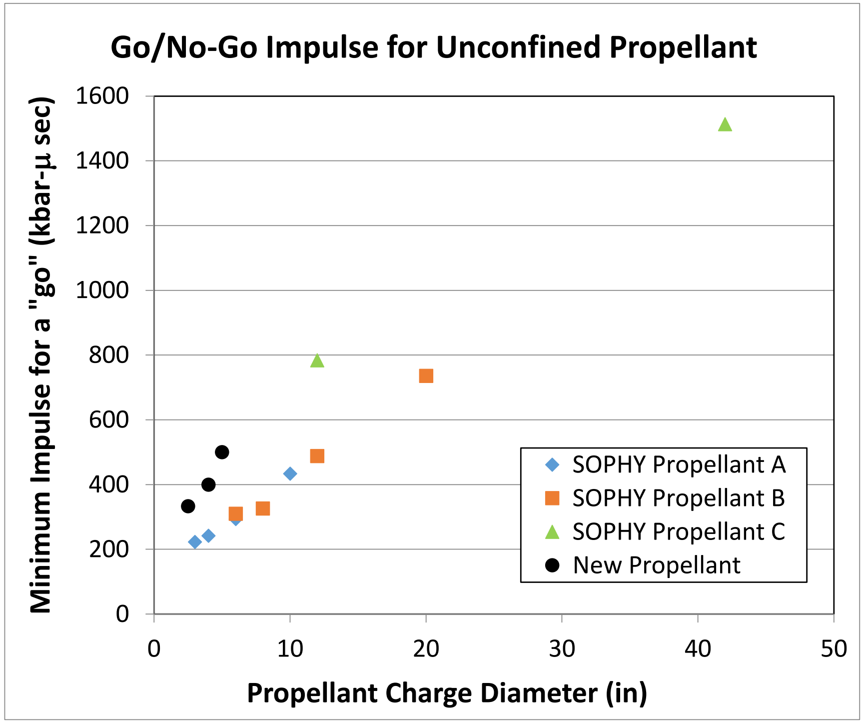
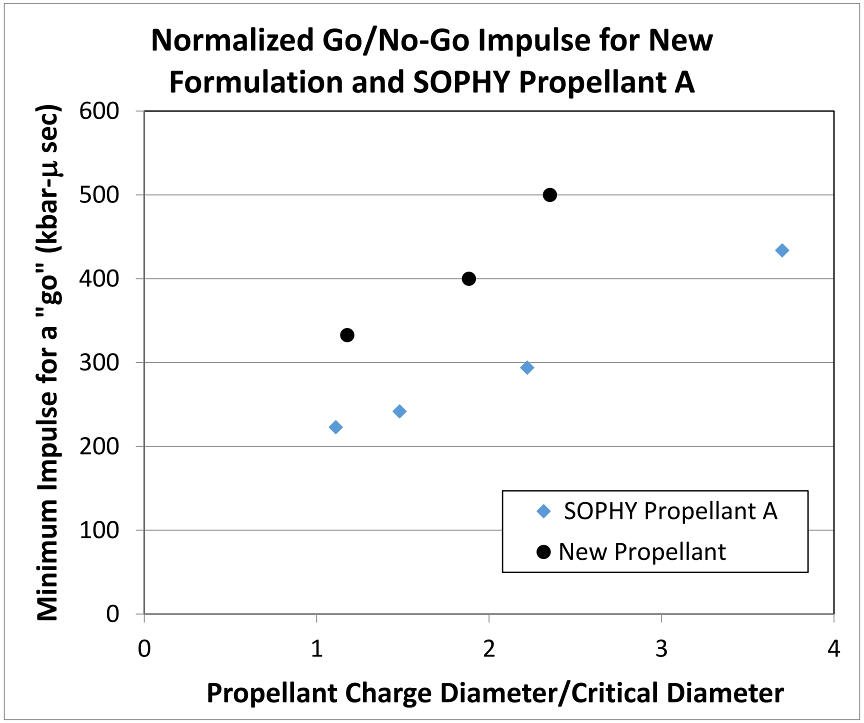
- New propellant follows Project SOPHY impulse-diameter trend
- New formulation requires a higher impulse level to cause a detonation





Summary

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- Theoretical studies support position forwarded by a large number of researchers who have previously studied this area, namely:
  - Current shock criteria are overly conservative with respect to the Class 1.1/Class 1.3 designation
    - Transportation, storage and handling events for large rocket motors generate a relatively low level of pressure and impulse
- Unintended consequence associated with current TB 700-2 Option 2 testing is a concern
  - May favor granting Class 1.3 designation to propellants with low critical diameter when compared with formulations that have moderate critical diameters
- Pathfinder experimental study indicates trends observed in Project SOPHY with respect to go/no-go impulse are valid for today’s formulations

Recommendations

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Near term:

- Incorporate an optional shock testing protocol into current standards
- Perform additional studies to better characterize the relationship between impulse and pressure

Conduct THA on specific system to identify hazards

Determine pressure and impulse of hazards using hydrocode modeling

Develop new propellant and motor design

Determine critical diameter of new propellant formulation

Recommend customized testing plan to board(s) that govern and designate hazard classification
Shock testing to include:

- Test articles @ 1.5 X Dc and motor confinement
- Shock testing which considers both pressure and impulse with a realistic margin of safety above expected hazards

Long term:

- Improve testing used in hazard classification process to better match energy levels and rates of delivery observed in potential handling, storage and transportation events