STATUS - CRITICAL DIAMETER AND GAP TESTS FOR HAZARD CLASSIFICATION OF SOLID ROCKET MOTORS

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DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.
• Brief history of propellants
  – How formulations have changed with time
• Development of the gap test
  – Determine transportation and storage hazard classification
• Overview of current test procedures
• Options available to the system developer
  – Strengths and weaknesses of each option
• Facilitate dialogue on methods to improve gap testing
• World War II – Early 1950s: Double-base propellants
  – Small critical diameters
• 1950’s – 1960’s: Composite Propellants
  – AP/Al/binder replaced many NC/NG formulations
  – Critical diameter increased markedly
    • Proliferation of AP based systems
• 1970’s: Improving propellant compositions
  – Adding nitramines to increase specific impulse
    • Range, velocity, and payload
  – Burning rate modifiers
    • Decrease time to target
  – Increased performance – decreased critical diameter
• Shock initiation test (1950)
• Predict hazard from unintentional detonation
  – One explosive exposed to shock
  – Quantify the sensitivity of the material
• Los Alamos National Lab small-scale gap test
• Naval Ordnance Lab large-scale gap test (NOL LSGT)
• Super large-scale gap test (SLSGT)
• AP/Al/binder propellants
  – Critical diameter in multiple feet
    • Project SOPHY: \( d_{cr} \) greater than 62 inches
  – Industry stopped determining critical diameter
    • Hard to find large mechanical shock threat

• Reduce the hazard classification of a system propellant from HD 1.1 to HD1.3
  – Add nitramines until a “go” reaction, then decrease nitramine content until “no-go”

• Larger gap tests needed
• NOL LSGT and newer formulations
  – Could not help characterize large solid rocket motor hazard

• Modification of the Technical Bulletin 700-2
  – UN Test Series 6
    • Used for hazard classification HD1.1, 1.2, 1.3, and 1.4
    • Single package test – UN Test 6 (a)
    • Stack test – UN Test 6 (b)

  – Alternate tests
    • Performed on large solid propellant rocket motors – very expensive
• Shock input into propellant > 280 kbar
  – No attenuator between booster and donor
  – Storage and transportation hazards < 10 kbar
• 16-inch length sample
  – Did not allow shock to decrease to sonic velocity
• Test thick-wall steel-bomb-cased energetic materials
  – ½-inch-thick steel wall not representative of rocket motor cases
  – Greater pressures than shock wave from donor
• No velocity pins, no determination of shock wave velocity
  – Shock wave velocity could help determine “go or “no go”

• Maximum allowable sample diameter: 7 inches
  – Larger critical diameter propellants
  – Inadequate to determine sample’s hazard
1998 TB 700-2: SUGGESTED CHANGES

- Increase sample length
  - From 16-inch to 32-inch
  - Determine if detonation wave decayed

- Incorporate velocity pins
  - 14 pins, 1 inch away from donor

- Comp B conical booster
  - 8-inch by 8-inch cylindrical booster produced significant blast

- Adding an attenuator
  - Between donor and propellant
  - Provide a 70 kbar shock to sample
2012: TB 700-2
• SLSGT suggestions resulted in modifications
  – DDESB document signed by Capt. William Wright, Chairman
• Three options replace section 6-6(c) of 1998 TB 700-2
  – Option 1. Refined SLSGT
  – Option 2. Determine unconfined $d_{crit}$
  – Option 3. Missile motor diameter
- Refined version of SLSGT
- 32-inch-long sample
- 14 velocity pins
- Either a right circular cylinder or conical booster
- No PMMA attenuator
• Determine Critical Diameter \([\text{A}]\)
• Address confinement thickness concern
  – Test in equivalent confinement to motor case
• Minimum sample diameter [B]
  – 5-inches
  – 150 percent of unconfined critical diameter
• 14 velocity pins minimum
• Attenuation to allow 70-kbar shock
• Similar to Option 2
• Confinement = motor case
• Sample diameter = missile diameter
• Closely recreate original environment an item would be used in
• More applicable to smaller tactical missiles
• Much less cost effective for larger diameter solid rocket motors
• Gap research continued
• Role of confinement
  – Determine effects of different confinement
  – AP/Al/HTPB propellant 12-inch diameter sample
  – Different case materials
  – Different case wall thickness
    • No confinement
    • Schedule 40 PVC pipe
    • Schedule 80 PVC pipe
    • 0.37-inch aluminum wall thickness
    • 0.0687-inch aluminum wall thickness
    • ½-inch thick steel wall thickness
CONFINEMENT EFFECTS

Lindfors, et al. AP/Al/HTPB Propellant

<table>
<thead>
<tr>
<th>Time/Case (µs)</th>
<th>Unconfined Propellant (ρ = 1.850)</th>
<th>12.75” x 0.5” Steel Case Rho = 7.90</th>
<th>Schedule 40 PVC Rho = 1.376</th>
<th>Schedule 80 PVC Rho = 1.376</th>
<th>12.75” x 0.375” Aluminum Rho = 2.703</th>
<th>12.75” x 0.687” Aluminum Rho = 2.703</th>
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</tbody>
</table>

- ½-inch steel case
  - Highest confinement
  - Highest pressure
    - Pressure at 175 µsec = 312.2 kbar
    - Original shock wave pressure = 280 kbar
• Studies of four different propellants
• Modified DYNA-2D predictions vs experimental data
  – Zero cards vs 50 cards
    • HD 1.1 vs HD 1.3
• Reduce size of donor – no apparent effect on walls
• Confinement change
  – From ½-inch steel walls to PVC
    • PVC impedance < steel impedance
    • Rocket motor case confinement
  – Reproduce observed gap test results
  – Model could be a viable tool in designing alternate gap test configurations
• Gap test continues to evolve
  – Solid rocket propellants < shock sensitive
• Option 1 may not be the most appropriate test
  – Confinement can vary reaction levels
  – Duration of the input pulse can affect reaction of material
    • Longer duration, lower pressure pulse – sufficient to initiate sample
• Understanding properties of the system is important
  – Critical diameter
  – Casing influence on shock sensitivity of material
• Which test to use?
  – Understand the system
• Some problems are known
  – Solutions have yet to be found
• Additional work is needed
  – Experimental and analytical

It is important to consult the Service Hazard Classifier early in the process when determining which test standard to implement during any program development effort.
CURRENT WORK

• Extensive literature review
  – Use and evolution of critical diameter and gap tests through the years

• Papers are being reviewed and summarized
  – Hazard Classification
  – TB 700-2
  – Critical diameter
  – Gap tests
  – Alternate tests

*The authors are soliciting papers in these areas to include in the study*
Why Bother?

- Important to understand the different types of gap tests used
  - Assess shock sensitivity
- More comprehensive understanding of each test configuration
  - Help identify methods to correlate data between tests
  - Identifying origins, test setup, applications, and limitations
    - Determine what the results of each test reveal about the material's shock sensitivity
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