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

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OBJECTIVE

- 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

BACKGROUND

- 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

GAP TEST

- 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)

CONCERN

- 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

1998: TB 700-2

- 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

1998 TB 700-2: ISSUES

- 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

1998 TB 700-2: ISSUES

- 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

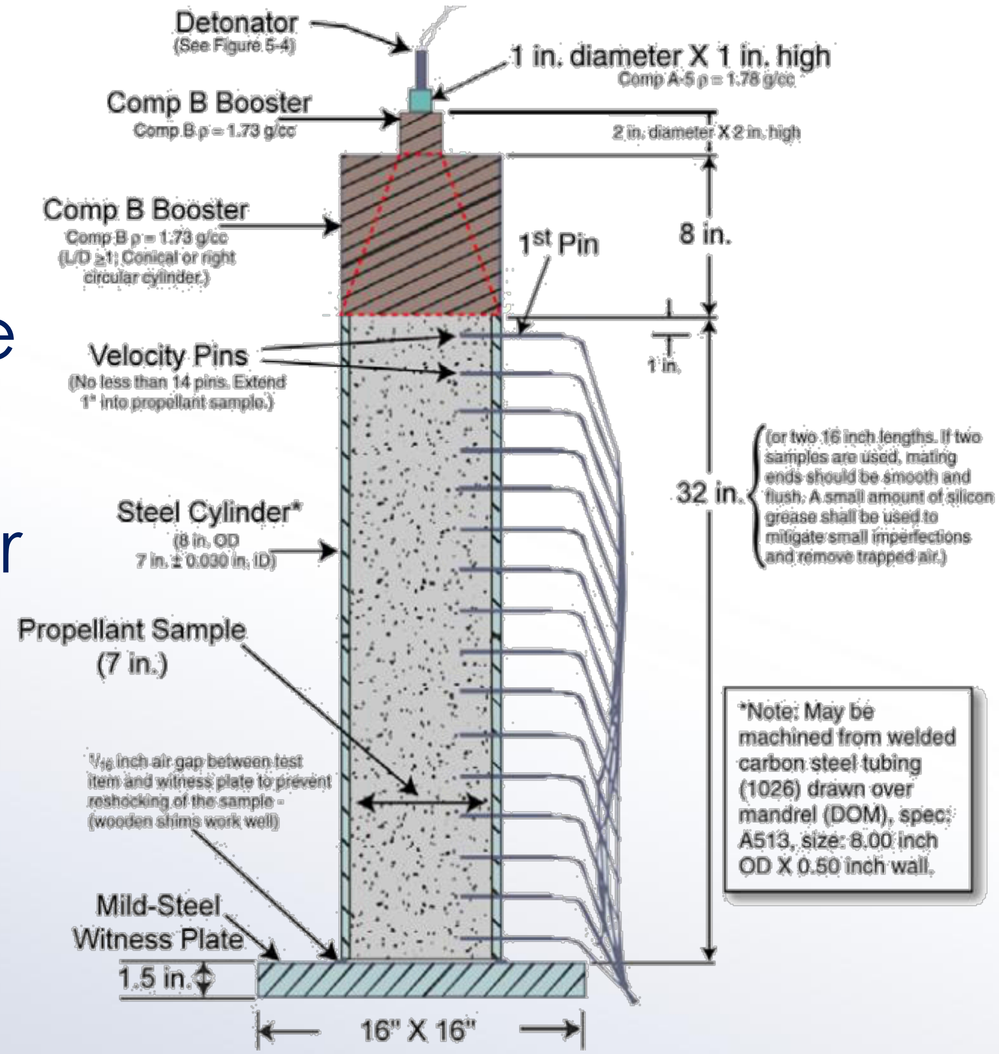
- Increase sample length
  - From 16-inch to 32-inch
  - Determine if detonation wave decayed
- Incorporate velocity pins
  - 14 pins, 1 inch away from donor
- Comp B conical booster
  - 8-inch by 8-inch cylindrical booster produced significant blast
- Adding an attenuator
  - Between donor and propellant
  - Provide a 70 kbar shock to sample

2012: TB 700-2

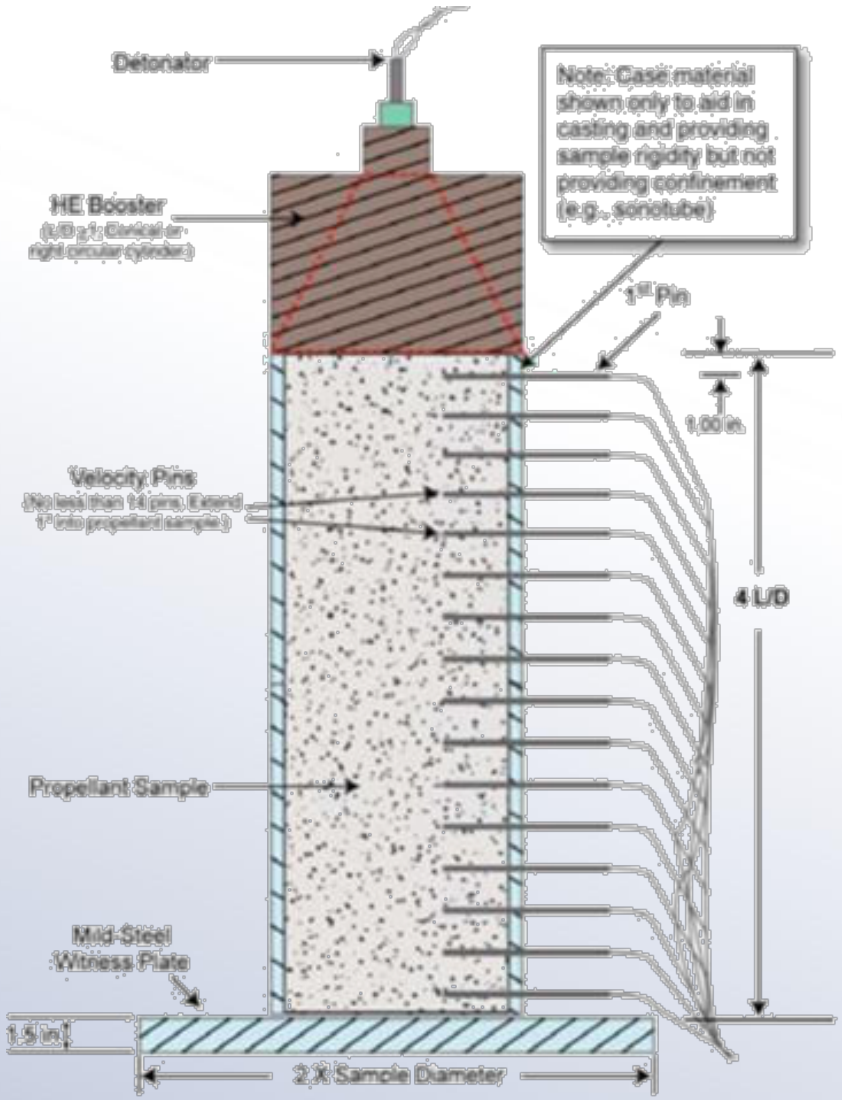
DDESB Memorandum

- 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



OPTION 2: D_{crit}



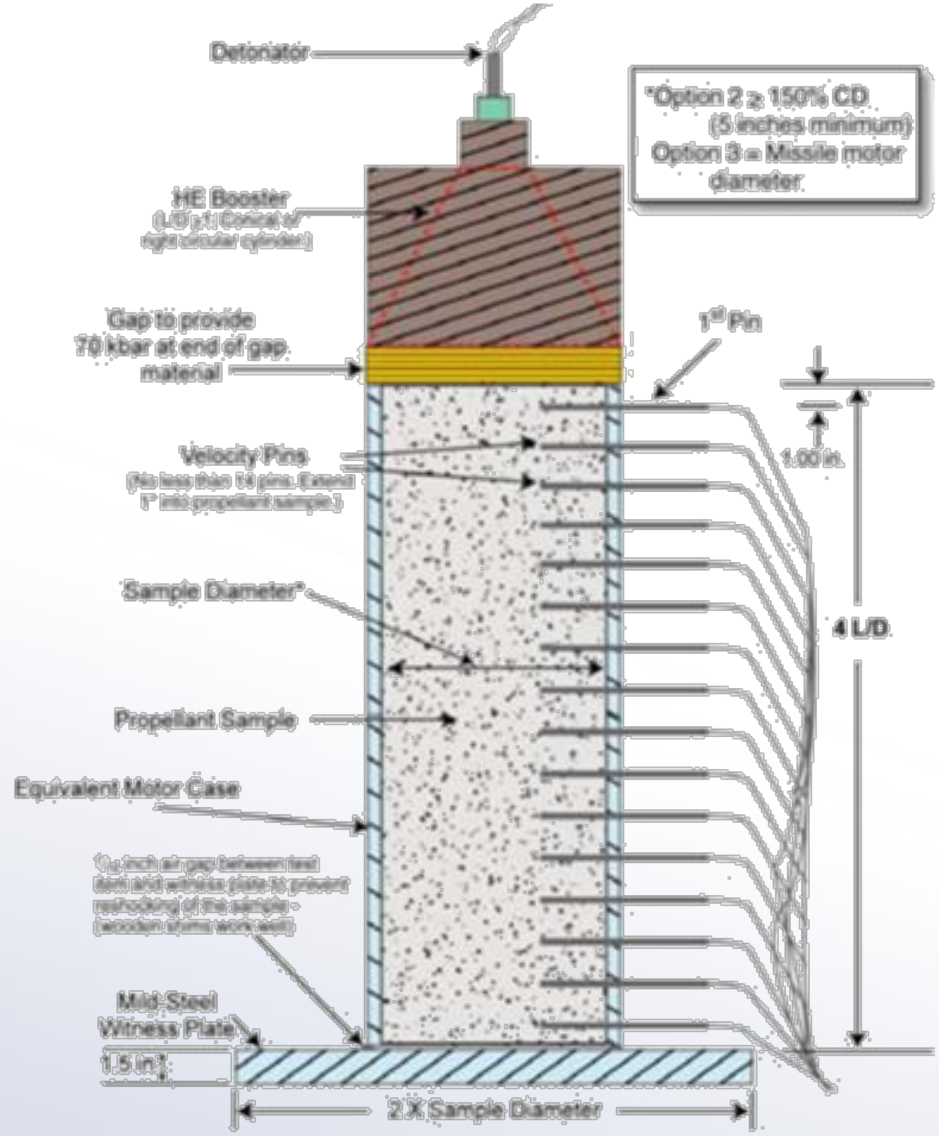
[A]

- Determine Critical Diameter [A]
- Address confinement thickness concern
  - Test in equivalent confinement to motor case

Distribution Statement A: Public Release

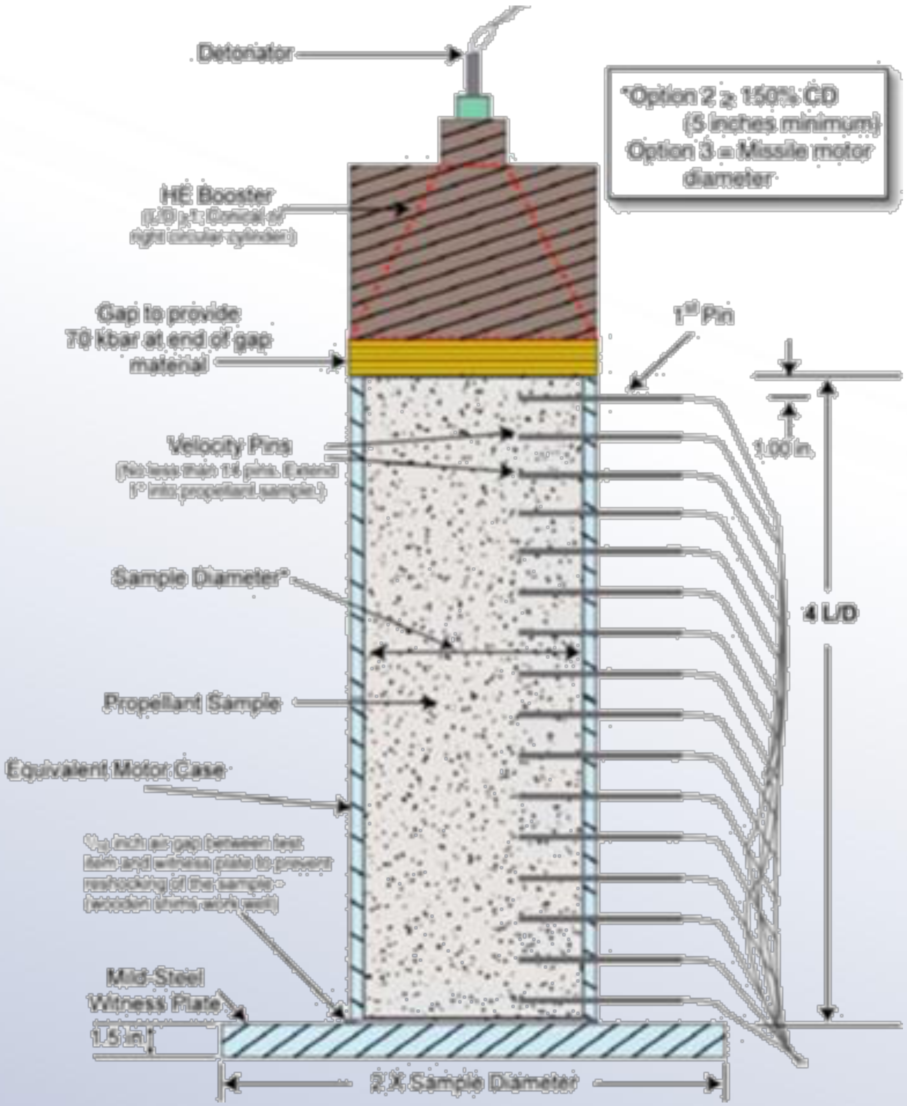
OPTION 2

- Minimum sample diameter [B]
  - 5-inches
  - 150 percent of unconfined critical diameter
- 14 velocity pins minimum
- Attenuation to allow 70-kbar shock



[B]

OPTION 3



- 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

CONFINEMENT - LINDFORS et al.

- 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

Time/ Case (μs)	Unconfined Propellant (ρ = 1.850)	12.75" x 0.5" Steel Case Rho = 7.90	Schedule 40 PVC Rho = 1.376	Schedule 80 PVC Rho = 1.376	12.75" x 0.375" Aluminum Rho = 2.703	12.75" x 0.687" Aluminum Rho = 2.703
100	103.2	103.4	98.5	99.4	99.3	100.1
125	111.2	139.4	109.2	109.32	110.3	119.0
150	118.1	186.8	115.0	115.4	124.6	141.3
175	137.4	**312.2**	133.4	132.4	162.9	194.5

- ½-inch steel case
  - Highest confinement
  - Highest pressure
    - Pressure at 175 μsec = 312.2 kbar
    - Original shock wave pressure = 280 kbar

MODEL - MILLER et al.

- 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

GENERAL FINDINGS

- 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

GENERAL FINDINGS, cont'd.

- 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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QUESTIONS

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