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Design Synthesis Of Large Shaped Charges For Missiles: From Requirements To Qualification

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Design Synthesis Of Large Shaped Charges For Missiles: From Requirements To Qualification

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Miami, FL

Raytheon Missile Systems

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Aug 30, 2011

Agenda

- **Introduction to Large Shaped Charges**
- Missile Warhead Requirements
- Design & Analysis
- Shaped Charge Fabrication & Target Construction
- Testing of Missile Shaped Charges
- Summary

Each Component of a Shaped Charge Contributes to System Function

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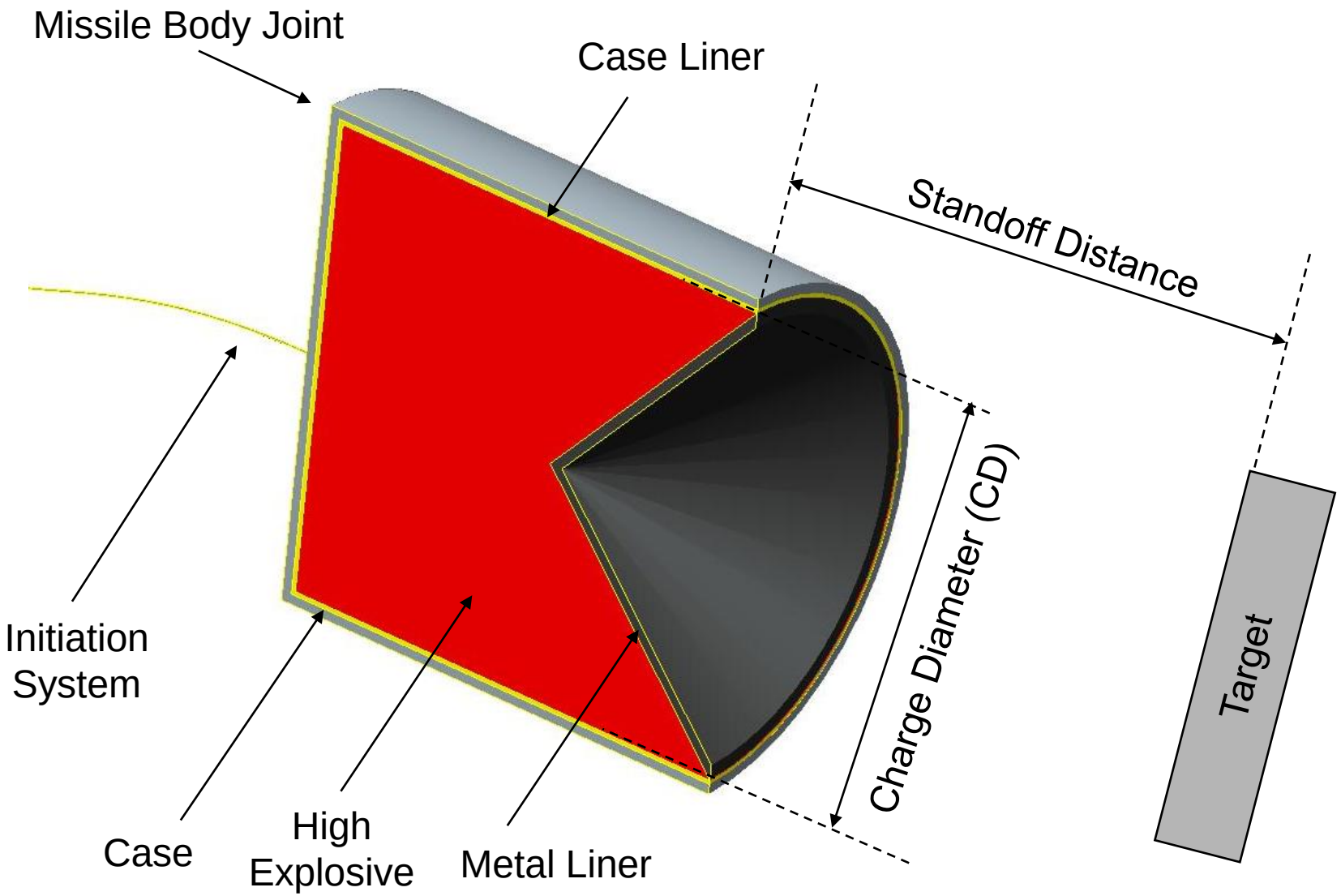

Shaped Charges Convert Chemical Energy to Focused Kinetic Energy

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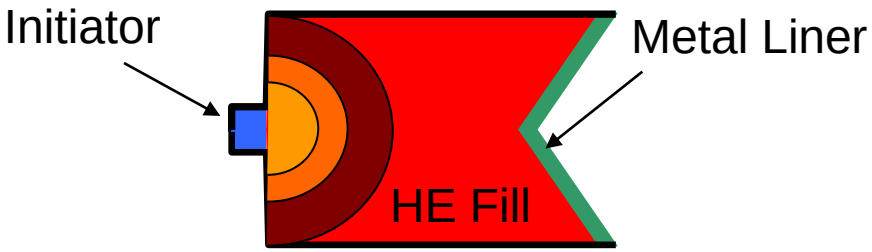
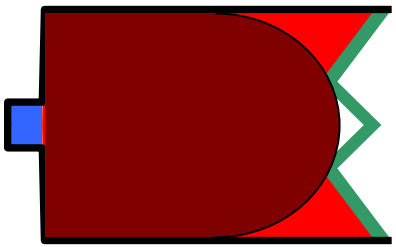
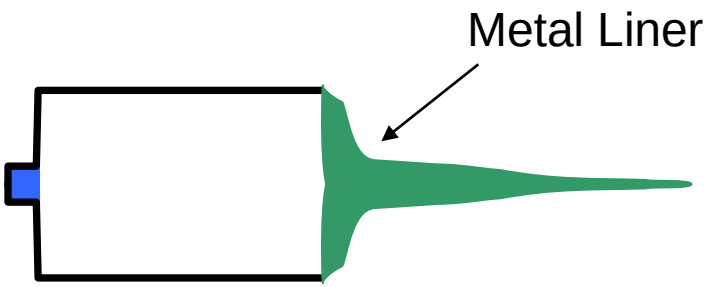


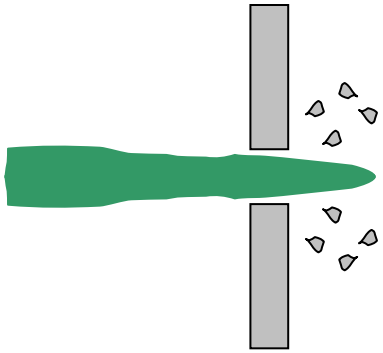
1. Initiator starts reaction and high explosive (HE) fill rapidly transforms to high pressure gas



2. HE reaction causes the liner to collapse toward a focal line in space.



3. The collapsed metal liner is squeezed into a focused fast moving jet



4. High velocity jet is target defeat mechanism

Chemical Energy Stored In An HE Fill Is Converted Into Kinetic Energy Of A High Speed Metal Jet

The Largest Shaped Charges Were Developed During the Second World War

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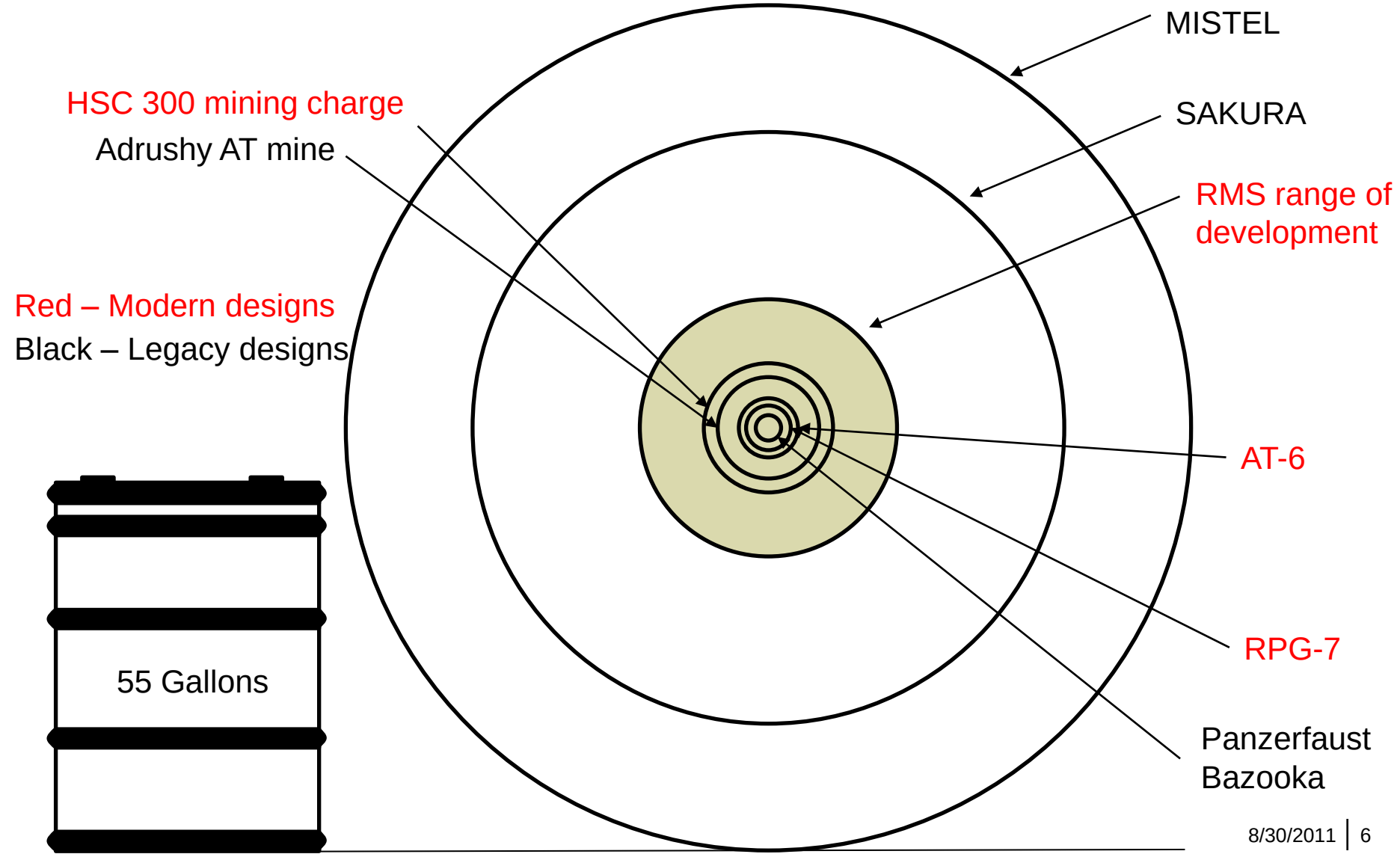
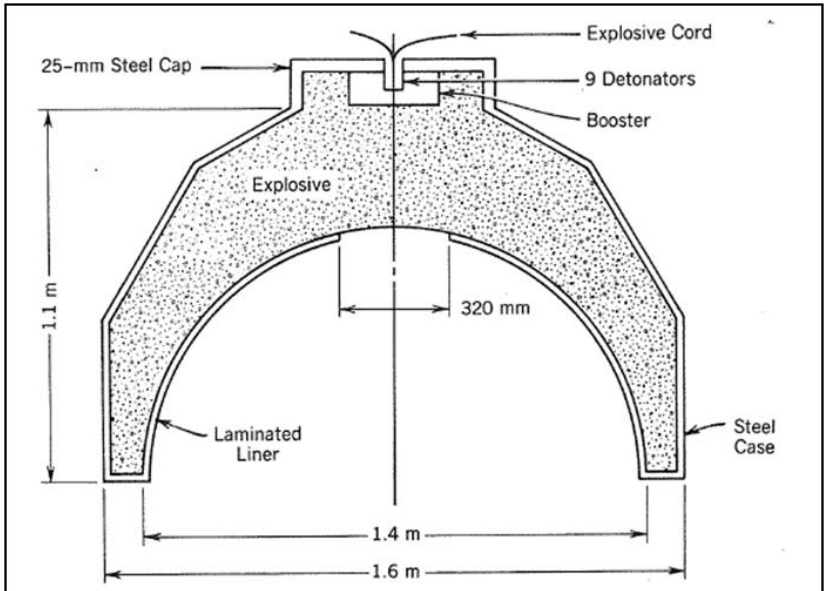


SAKURA Bombs Were Employed By Japanese Aviators to Attack Allied Navy Vessels



	Type I	Type II
Diameter of bomb	1.6 m	1.12 m
Length of bomb	1.1 m	1.0 m
Diameter of hemispherical liner	1.4 m	1.0 m
Size of hole at top of liner	260 mm 320 mm	200 mm
Liner, laminated steel plates	4 pc 8 mm thick (poor) 8 pc 4 mm thick (good)	4 pc 4 mm thick
Explosive (RDX)	1700 kg	500 kg
Booster (Picric Acid)	2 kg	2 kg
Case of bomb (steel)	7 mm thick	4 mm thick
Total weight	2908 kg	1300 kg

One of the largest known designs is the SAKURA. It was used on the nose of Japanese Kamikaze fighters to attack allied capital ships. (OTIR, 1946)

RMS Has Developed Large Shaped Charges In The Range Of 6” – 24” Diameter For Missile Integration

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Missiles With Large Shaped Charges Are Required To Prosecute A Variety Of Targets

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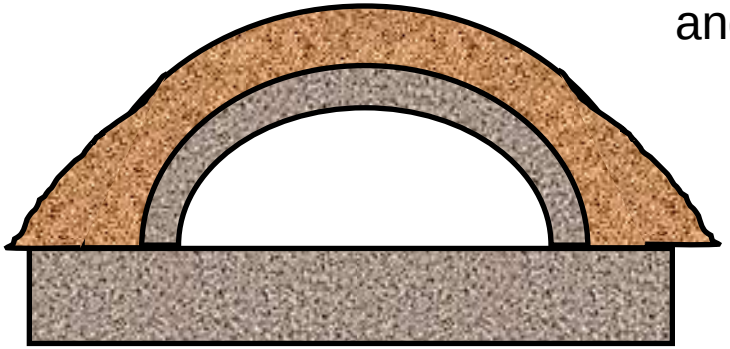
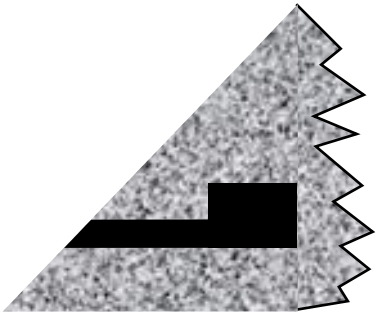
In general, large shaped charges are designed to be effective against Hard and Deeply Buried Targets (HDBTs) and ships. HDBTs often consist of multiple layers of soil, reinforced concrete, and countermeasures.

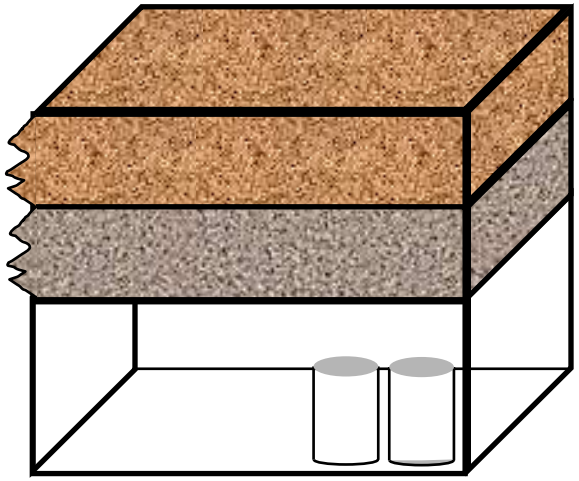


Aircraft Storage Bunker

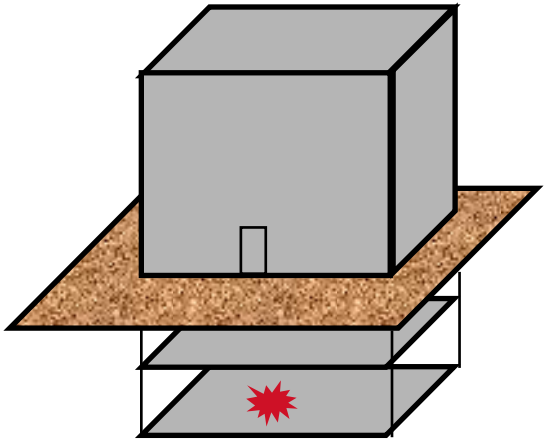


Tunnels

Ships



Under Ground Bunker



Basement Bunker

Large Missile Shaped Charges Must Satisfy Many Competing Requirements

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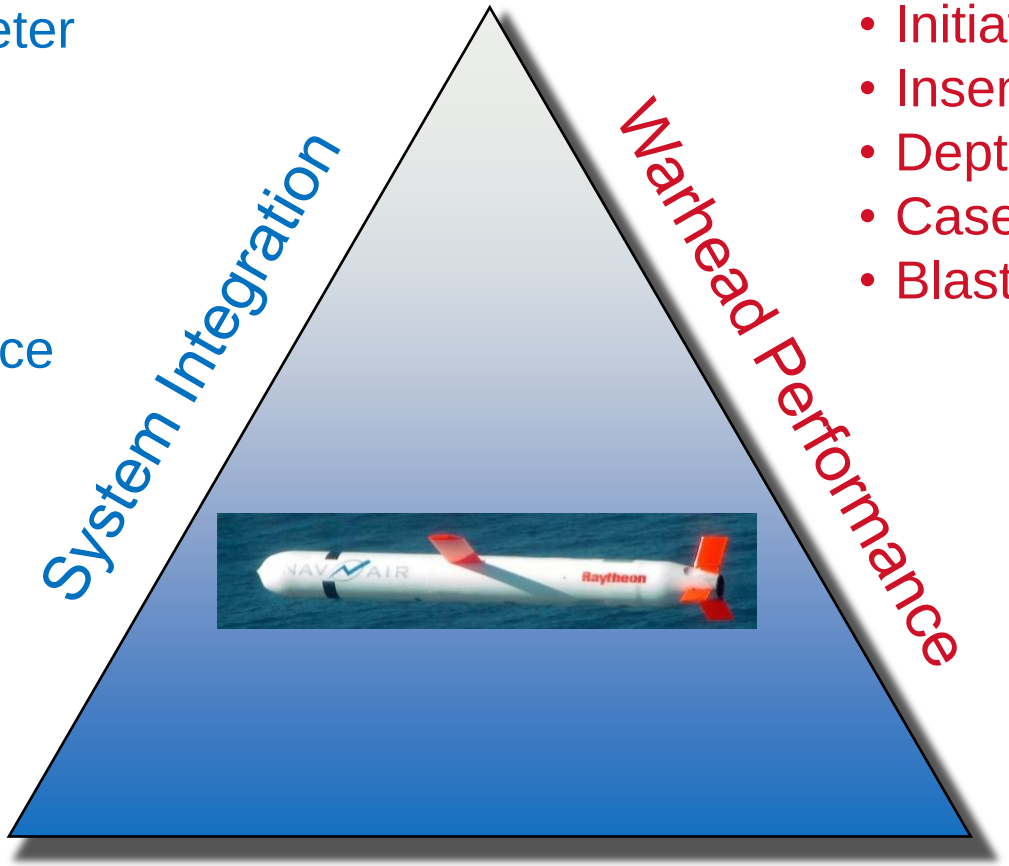
- Charge Diameter
- Length
- Weight
- CG
- MOI
- Missile Interface
- Connectors
- Cost
- Logistics



- Initiation
- Insensitive Munitions
- Depth Of Penetration
- Case Fragmentation
- Blast

- Thermal
- Launch Loads
- Flight Loads
- Life Cycle
- Reliability
- Maintainability

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A Successful Shaped Charge Design Has Many Contributing Elements

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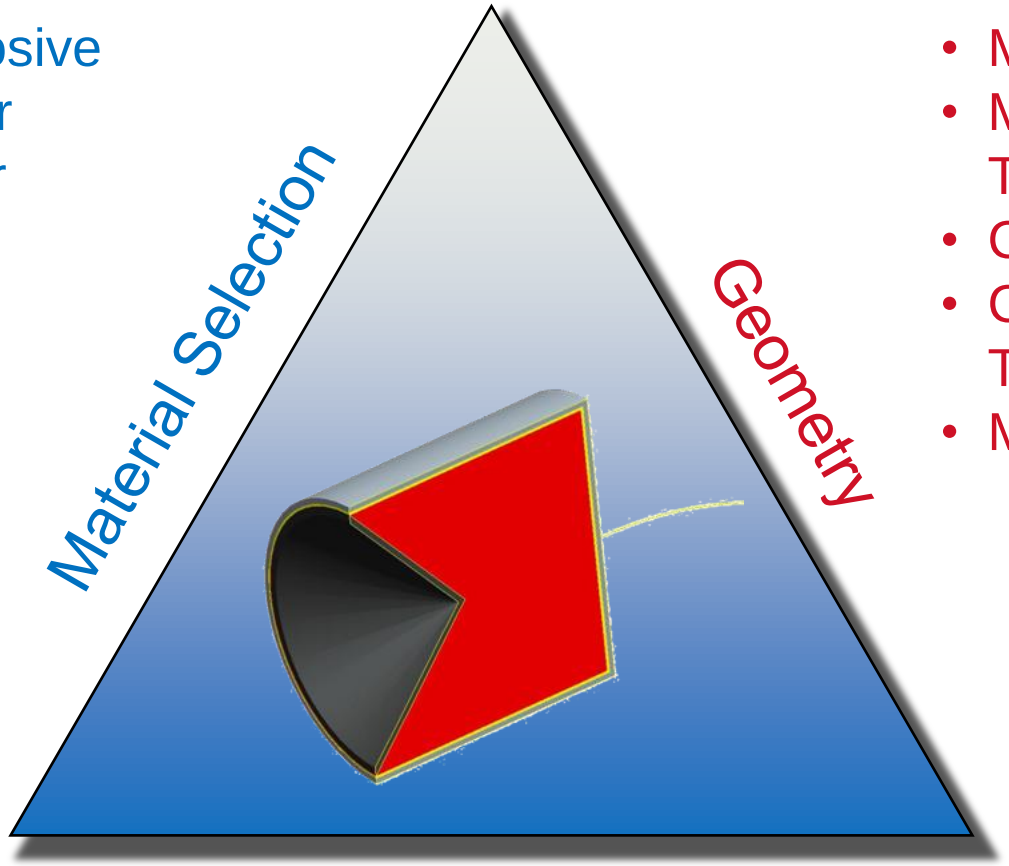
- High Explosive
- Metal Liner
- Case Liner
- Sealants
- Adhesives
- Booster
- Case



- Metal Liner Shape
- Metal Liner Thickness
- Case Shape
- Case Liner Thickness
- Missile Joints

- Jet Tip Velocity
- Jet Breakup Time
- Jet Length

- Initiation System
- Liner Collapse
- Standoff

Modeling and Simulation Is Vital To Missile Shaped Charge Development Cycle

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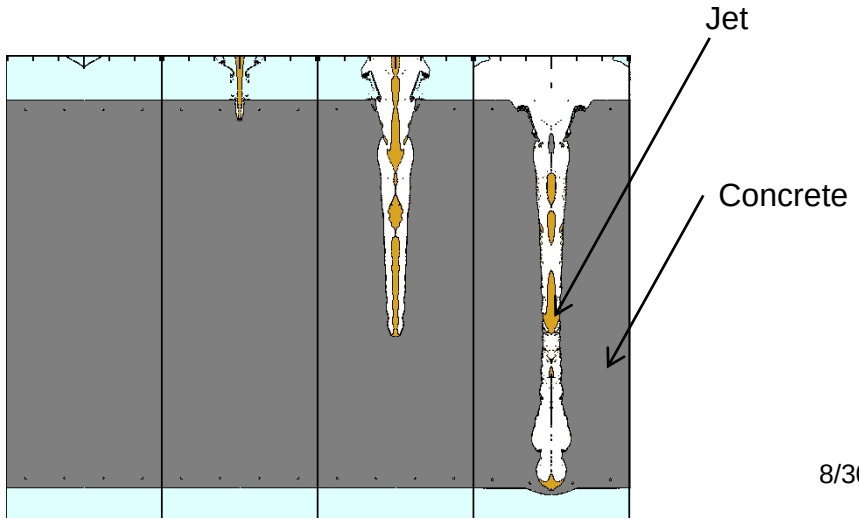
- Modeling and simulation is important because it
  - results in significant cost savings. Designing by test only is cost/schedule prohibitive. Large concrete targets can exceed $100,000. Several types of tests generally cost greater than $1,000,000 for event.
  - offers the customer predictive capability of weapon system vs. targets.
  - provides an insightful understanding of how systems which allows for better design.
  - allows for faster cycle time
- First order codes are available such as WINSC3D that are applicable to pre-design.
- Hydrodynamic codes are employed for designing jet formation and predicting effects on targets. Due to the extremely large deformations involved with jet formation, rezoning, Eulerian, or ALE capabilities are generally required.
- Other required analyses include transportation, hot temperature, cold temperature, firing train, ullage volume, flight loads, and insensitive munitions.

Penetration Analysis Example



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RMS Has Experience Fabricating a Range of Large Missile Shaped Charges

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System Weight: 20 – 650 lbs
Explosive Weight: 10 - 475 lbs
Diameter: 6” – 24”
Liner Shape: Various
Liner Material: Various
High Explosive: Various

Image courtesy of Spectra Technologies

Image courtesy of Precision Southwest Engineering

Image courtesy of Vagts Engineering

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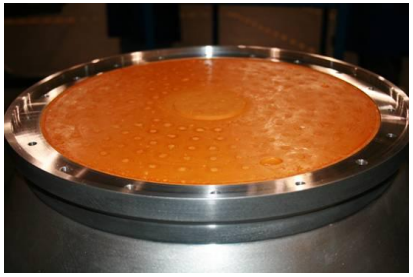

Image courtesy of Aerojet

Image courtesy of Anewco Products

Good Missile Target Construction Practices Are Important To Characterize And Model A Weapon System

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Geo-Materials

- **Engineered Soil**
  - Compaction
  - Sieve tests
  - Moisture content
  - Density
- **Concrete**
  - Rebar size and layout
  - Water Content
  - Air Entrainment
  - Cure time
  - Additives
  - Aggregate material and size
  - Vibration
  - Core samples
  - Density
  - Ratios of components
- A 28-day cure is the minimum required for concrete. Core samples will yield the unconfined compressive strength on the day of the test.
- Unless instructed differently, most contractors interpret unconfined compressive strength as a minimum, not a nominal.

Well Characterized Targets Put Test Results In Context

Engineered Target With In Process Material Testing

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Rebar Cage

Forms

Pumper Truck

Concrete Pour

Images courtesy of EMRTC, New Mexico Institute of Mining and Technology

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A Variety of Tests Are Used to Validate Models and Demonstrate Performance

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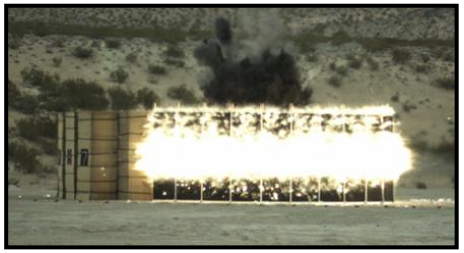
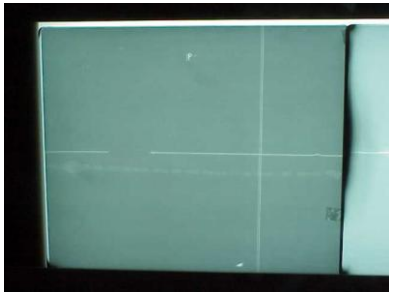
Static Tests – Offer high degree of control over variables compared to dynamic testing.

- **Arena**
  - Characterize fragmentation with fragment collection bundles, velocity witness panels, blast pressure sensors, and other instrumentation.



- **Penetration**
  - Quantify shaped charge penetration into selected medium
    - Geo-material targets such as sand and concrete represent real targets
    - Rolled Homogenous Armor (RHA) is more consistent than geo-materials and is a common benchmark to compare shaped charge performance.

- **Flash X-Ray**
  - Provides a detailed record of the jet particle size and velocity. Used to verify quality of manufacture, verify hydro-code models, feed fast running penetration models.



A Variety of Tests Are Used to Validate Models and Demonstrate Performance

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Dynamic Tests – More operationally representative than static testing but also more expensive and less control over test variables.

- **Sled**

  Missile is put on sled and propelled by rocket motor down sled track rail. At the end of the rail is a target and/or instrumentation. Offers better control of variables such as standoff and firing train reliability than flight testing. Imparts forward velocity to test article.

- **Gun**

  Missile or subcomponent is fired from a large bore gun. Imparts forward velocity to test article. More limited in size and weight than sled testing. Imparts high in-bore loads to article.

- **Flight**

  Full up test where missile flies, reaches target, and shaped charge initiates. Include full missile dynamics, angle of attack, and generally full size targets.

Thorough Penetration Test Data Collection Is Critical To Understand System Performance

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- Having a good data collection plan is important so details are not forgotten. Some test ranges will not allow ad-hoc data collection and require a pre-meditated written plan.
- Items to capture are
  - Pre-test
    - Final test area layout
    - Standoff to target
    - Still photography
  - Post-test
    - Target hole mapping
    - Still photography
    - Real time video
    - High speed video
    - Pressure gage data
    - Case remnants
    - Jet slug remnants

Measuring Target Debris

Over 30 Full Scale Tests of Large Shaped Charges Conducted

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Over 30 Full Scale Tests of Large Shaped Charges Conducted

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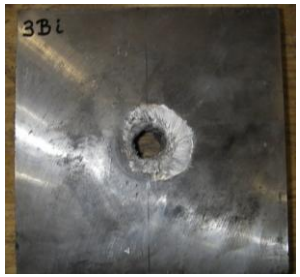









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Summary

- Raytheon Missile Systems Has Experience Designing, Fabricating, and Testing Large Missile Shaped Charges

- Good System Design Practices Considering The Entire Weapon System Are Essential For An Effective Overall Shaped Charge Design.

- Missile System Prime Contractors Have An Advantage In Shaped Charge Design Because They Have Insight Into The Entire Weapon System

- Effective Use Of Modeling And Simulation Results In Large Savings In Cycle Time And Test Expense.

- A Good Understanding Of What The Results Were AND What Target Was Is Mandatory To Characterize System Performance And Validate Models.

References

- OTIR. (1946). *Ordnance Technical Intelligence Report Number 11.* Tokyo: Office of the Chief Ordnance Officer GHQ, AFPAC.

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Acknowledgements

- RMS Energetics Department
- RMS AWS Product Line
- Various Government Organizations
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