Test and Evaluation of Electromagnetic Railguns

NDIA Gun & Missile Systems
April 23-26, 2007
EM Railgun – Game Changing

Above Sensible Atmosphere
Simplifies deconfliction

Ballistic Trajectory
500,000 ft
GPS guidance, navigation, & control

Hypervelocity Electromagnetic Launch
(MACH 7.5)

Hypervelocity Impact
(MACH 5.0)

Indirect Fire (200+ nm in 6 minutes)

Direct Fire (Horizon in 6 seconds)

- Long-Range
- Time-Critical
- Persistent
- All-Weather (24/7)
- No Unexploded Ordnance Issues

- Large Capacity Magazines
- No Propellants
- No Explosive Warheads
- Increased Ship Design Options
- Reduced Ship Vulnerability
- Leverages Navy Investment in Integrated Power System

Fixed and Relocatable Targets at Long Range

Support for Distributed Ops
How it Works

1. Switch closes, current flows through rails & armature

2. Magnetic field generated around rails as current flows through circuit

3. Magnetic field interacts with armature current generating a Lorentz force

4. Lorentz Force accelerates armature and projectile down barrel

Lorentz Force = \(1/2 \text{ Inductance Gradient (L')} \times \text{Current (I)^2}\)

or

Lorentz Force = \(\text{Current (J)} \times \text{Magnetic Field (B)}\)
Key Statistics (2007)
• Operating Muzzle Energy: up to 7 MJ
• Terminal Area: 16-MJ Slug
• Gun lines: 1

Terminal Catch: Up to 16-MJ Slugs

Temporary Control Vans
Current Facility
32-MJ PFN

- Controls Cabinets
- System Controller (Located in Control Van)
- Fiber Optic Cable
Switching and Output Cables

- Spark Gap Switch
- 350-MCM Coaxial Cable
SSG Construction

- Breech Studs
- Containment Studs
- Safety Shield (capable of stopping broken studs)
- Bore Insulators
- Upper Containment Plate (3 total)
- Side Containment Plate (8 total)
- Lower Containment Plate (3 total)
- Rail Backing Insulators
- Pre-Injector Tube
- Launch Package
- Rails
Launch Package

- Total Mass = 2.3-3.4 kg
- Aluminum Slug and Armature
- Nylon Bore Riders
- Design based on earlier work at Kirkcudbright and Greenfarm

Slide 9
Gun - Facility Interfaces

Muzzle Chamber
- 1" Thick A36 Steel Plate
- Bolts Directly to Gun Foundation
- Bolts Directly to Bridge Section
- Adaptable to Variety of Launchers

Recoil Plates
- 3" Thick A36 Steel Plate
- Bolt Directly to the Gun Foundation Plates
- Bolt Directly to Underside of SSG
Terminal Area Design

7 Each Bridge Sections
(8’ L x 16’ W x 10’ H x 10” Thick)
Free Standing, Reinforced Concrete, Flash X-Ray Cutouts

7 Each Sand-Filled Steel Boxes
(4’ x 4’ x 3’)
(21’ of Sand Along Line of Fire)

I-Beam Catch Cart
(8 mini-RR wheels, 12’ long)
Move/Replace first 4 Sand-Filled Steel Boxes

Terminal Pad
(100’ L x 32’ W)
Standard Gage Crane Rails, 3 Rows of Tie Downs every 8’, 2 Instrumentation Troughs

20 Each NRL Shield Blocks – Double Course
(8’ L x 2.5’ W x 1.5’ Thick)
Interlocking, Reinforced Concrete

Concrete Blocks
Statically Support last 3 Sand-Filled Steel Boxes

Shot Line
~75” Above the Ground
~66’ to 1st Sand Box

Steel Muzzle Chamber

~37 ft Opening

~24 ft

32 ft

~20 ft

~32 ft

~37 ft
Catch Component

- 7 Each Sand-Filled Steel Boxes, Total of 14 On Hand
  - 4 ft x 4 ft x 3 ft
  - Wt 5740 lbs when Filled
  - 21 ft of Sand along Line of Fire
  - Open Top, Stackable, 4-Way Forklift Entry

- I-Beam Catch Cart
  - Support the First 4 Sand Boxes to Allow Quick Movement & Replacement
  - Runs on Crane Rails Using Mini-Railroad Wheels

- Concrete Blocks
  - Support the Last 3 Sand Boxes
Shot 13 Breech Current and Muzzle Voltage
Muzzle Launch View

- Shot 7
- Muzzle Arc is 500K Amps at 2.3 KV
- 9 PSI Overpressure at 99” from muzzle
Flash X-ray Images

Static X-ray Image  
Shot 2 X-ray Image  
Shot 4 X-ray Image

Top View  
Side View

All images are 3 feet from muzzle
In-Flight Images

Shot 8:

Shot 9:

Shot 10:

Shot 21:

Tue Jan 30 2007 16:00:09.355 793
Target Impact

Shot 1:

Shot 2:

Shot 10:
S&T Technology Challenges

• Launcher
  – Multi-shot barrel life
  – Barrel construction to contain rail repulsive forces
  – Scaling from 8MJ (state of the art) to 32MJ → 64MJ Muzzle Energy
  – Thermal management techniques

• Projectile
  – Gun launch survivability (45 kGee acceleration, Electromagnetic Interference Potential)
  – Hypersonic guided flight for accuracy
  – Lethality mechanics

• Pulsed Power System
  – Energy Density
  – Rep rate operation & thermal management
  – Switching
  – Torque management and multi-machine synchronization (rotating machine)
ONR I NP Phase I Program

<table>
<thead>
<tr>
<th>FY05</th>
<th>FY06</th>
<th>FY07</th>
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<td>Program Initiation Aug 05</td>
<td>Initial 8MJ Test Capability</td>
<td>Initial 32MJ Test Capability</td>
<td>Go – No Go Decision Point Aug 09</td>
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**Concept Design**
- BAE
- General Atomics

**Exercise Options**
- A
- B
- C

**Technology Development & Preliminary Design**
- 32MJ Lab Gun For Bore Life Development
- 100MJ Capacitor Bank For Launcher Testing

**Advanced Containment**
- Advanced Containment
- EMLF Test Facility NSWCDD
- 32MJ Advanced Containment Demo

**Rotating Machine Component Development**
- Advanced Capacitor Development
- Integrated Launch Package (ILP) Development

**Multiple Awards**
- Boeing
- Draper

**Executive Steering Committee Conclusion and Recommendation**
- Go – No Go Decision Point Aug 09
Key Statistics (2009)
• Muzzle Operating Energy: 32 MJ
• Terminal Area: 64-MJ Projectile
• Gun lines: 2

Terminal Catch: Up to 16-MJ Slugs

100+ MJ Pulsed Power System

Protected Control Room

P306 FY09 MILCON ($9.9 M)

Gun Line #1

Gun Line #2

Ballistic Tunnel

Terminal Area: 64-MJ Projectiles

2009
Video of Test Results
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Back-up
Power Ramp Up Testing Plan (2.4kg)

- Velocity – km/s
- Energy – MJ

Banks

10 KV
8.5 KV
3.5 MA@T=0

Graph showing velocity and energy against banks with different power levels.
# Test Results

<table>
<thead>
<tr>
<th>Shot</th>
<th>Mass (KG)</th>
<th>Charge Voltage (KV)</th>
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<th>Muzzle Velocity (m/s)</th>
<th>Muzzle Energy (MJ)</th>
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Launch Package Results

Original Launch Package

Recovered from Shot 1

Recovered from Shot 2
Bore Life
EMLF Testing Concept

FY07

Series A (SSG)
20 Shots
Procure parts Test Analyze

Series B (SSG)
20 Shots
Procure parts Test Analyze

Series C (SSG)
20 Shots
Procure parts Test Analyze

Series D (LL32)
20 Shots
Procure parts Test Analyze

Series E (LL32)
20 Shots
Procure parts Test Analyze

FY08

8MJ Testing
18 months

2Q/3Q

Series U (LL32)
20 Shots
Procure parts Test Analyze

Series V (LL32)
20 Shots
Procure parts Test Analyze

Series W (LL32)
20 Shots
Procure parts Test Analyze

Series X (LL32)
20 Shots
Procure parts Test Analyze

FY09

16-32MJ Testing
18 months

2Q/3Q

FY10

Go No-Go

Order Core

FY11

100 Shot INP Demo
Potential 32 MJ Option

• 32MJ
• Half mass-full velocity (10kg, 2.5km/sec)
• Full mass-full current-2/3 velocity (20kg, 5.5MA, 1.7 km/sec)

INP DEMO - 32MJ
Test Analyze
100 Shot

SSG - Army Single Shot Gun
LL32 - 32MJ Lab Launcher

Contractor Tests on Gun-line #2

GA Adv Containment Launcher

BAE Stub Tube

Adv. Containment Launcher

BAE & GA

PDR

CDR

FAB

FY11

FY10

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FY08
Navy Electromagnetic Railgun

What is it?
• Gun fired with electricity rather than gunpowder
• Revolutionary **250 mile range in 6 minutes**
• Mach 7 launch / Mach 5 hit
• Highly accurate, lethal GPS guided projectile
• Minimum collateral damage

Why is it important?
• Volume & Precision Fires
• Time Critical Strike
• All weather availability
• Variety of payload packages
• Scalable effects
• Deep Magazines
• Non explosive round/No gun propellant
  – Greatly simplified logistics
  – No IM (Insensitive Munitions)
• Missile ranges at bullet prices

Who needs it?
• Marines and Army troops on ground
• Special forces clandestine ops
• GWOT
• Suppress air defenses

When?
• Feasibility Demo 2011
• System Demo 2015
• IOC 2020-2025
Naval Railgun - Key Elements

- Launcher
- Projectile
- Pulse Forming Network (PFN)
- Ship Integration
- Capacitors or Rotating Machines
Key Parameters for Sizing a Naval EM Launcher

\[
\frac{1}{2} \times \text{Launch Mass} \times \text{Muzzle Velocity}^2
\]

\text{Desired Muzzle Energy}

\begin{align*}
\text{Current Profile} & \quad \text{Bore Size & Shape} \\
\{ - \text{Rail Separation Forces} \\
- \text{Transient Localized Heating} \} & \quad \{ \text{Launcher Efficiency} \} \\
\end{align*}

\begin{align*}
\text{Barrel Length} & \\
\{ - \text{Max Projectile Acceleration} \\
- \text{Bulk Rail Heating} \} & \\
\end{align*}
Risk Matrix Summary

Risk Ranking & Key Impacts

- **A** Launcher
  - Failure Impacts
  - Capability

- **P** Projectile
  - Failure Impacts
  - Volume, Weight & Cost

- **ER** Rotating Machine PPS

- **EC** Capacitor PPS

- **S** Ship Integration

Consequence of Failure, $C_F$

Probability of Failure, $P_F$
ONR I NP Phase 1 Objectives

- Traceability to 64MJ, 6-10 round / min indirect fire weapon system
- Bore Life
  - 32 Mega-Joule (Muzzle Energy) EM Lab Launcher
  - 10kg launch package; full muzzle velocity of 2.5km/sec
  - 20kg launch package with full current of ~5.5MA
  - Demonstrate more than 100 shot bore life
- Containment
  - 32 Mega-Joule Advanced Containment Launcher
  - 10kg launch package; full muzzle velocity of 2.5km/sec
  - 20kg launch package with full current of ~5.5MA
  - 1000+ round predicted containment structural barrel life
  - Design for thermal management at a rate of 6 round / min
  - Design launcher for minimal round dispersion
  - Transportable on pallets and/or in sea containers,
  - Consider marine environment
Integrated System Demo Strategy

INP I 2005-2011

- EM Lab Gun for Bore Life Development
- INP Phase I EM Railgun Demonstration Launcher
- Launcher Technology Dev.
- Projectile Trades & Concept Dev.
- Electromagnetic Test Facility

INP II 2011 - 2015

- INP Phase II EM Railgun Demonstration Launcher
- INP Phase II Long Range Integrated System Demo
- Endo-Exo Testing
- Mid-Range
- Terminal High Velocity Powder Gun
- Terminal Range
- Railgun ILP Tests
- ILP Interface in bore dynamics

INP Phase II EM Railgun Demonstration Launcher
Bore Life Consortium

- Spans Basic Research to Full-Scale Demo’s
- Parallel development paths via multiple research sites
- Avoids Duplication
- Efficient use of test resources

- Supports both Navy and Army EM Efforts
- Government purpose data rights to permit competition during the acquisition phase.

**Coordinated Development!**
Bore Life and Containment

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<th>Period</th>
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Lab Launcher - EMTF

- Greenfarm 32MJ PPS

Advanced Containment Launcher

32MJ Lab Launcher for Bore Life
### Advanced Containment Launcher

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**General Atomics Team**
- General Atomics
- Boeing
- L3 Communications
- DRAPER Laboratory
- Jackson Engineering

**Northrop Grumman Team**
- Northrop Grumman
- ATK
- CEM

**BAE Team**
- BAE Systems
- SAIC
- EMD
Projectile Concept Trades

Description of Effort

- Develop long range projectile concept
  - Lethal
  - Consistent with Navy CONOPS
  - Compatible with any EML gun development
- Identify critical development
  - GN&C
  - Aerobody (drag and thermal protection)
  - Launched survivability
- Produce a development plan

The Boeing AASP Team

Draper Team
Advanced Pulsed Power

• Rotating Machine
  – Watch Army Effort (Demo in FY08)
  – Navy Specific Critical Component Development

• Advanced Capacitor
  – Increased Energy Density
  – Thermal Management for Multi Shot Operation
Steel Muzzle Chamber Component

- Steel Muzzle Chamber
  - Mates to both SSG & Lab Launcher
  - Bolts to 1st Concrete Bridge Section
- Collar Plates Seal Gaps between Launcher & Chamber

Holes to Allow Bolting to Threaded Inserts Cast Into Bridge Section (7/8"-9 Thread)

1"-8 UNC Grade 8 Bolts

1" A36 Steel Plate – Custom Made to Adapt to Each Launcher

1" A36 Steel Plate

8" x 6" x 1" Steel Angle

1st Precast Concrete Bridge Section
Vans on Van Pad

Overflow Van
VIP Van
Control Van
Storage Van

Pole with PTZ camera for Range Control