BTERM II -- 5” Gun Launched Projectile

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Agenda

- System Overview
- Major Subsystems
  - Rocket Motor
  - Low Cost Guidance Electronic Unit (LCGEU)
  - Canard Actuation System
  - Warhead
- Recent Tests
- Program Accomplishments

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Ballistic Trajectory Extended Range Munition (BTERM)

- Flies a primarily ballistic path, correcting for
  - Gun pointing errors
  - Winds aloft
- Compatible with MK45 Mod2 and Mod4 guns
- Technology demonstration effort funded by the Navy
- Proven success in boosted and un-boosted guided flight tests

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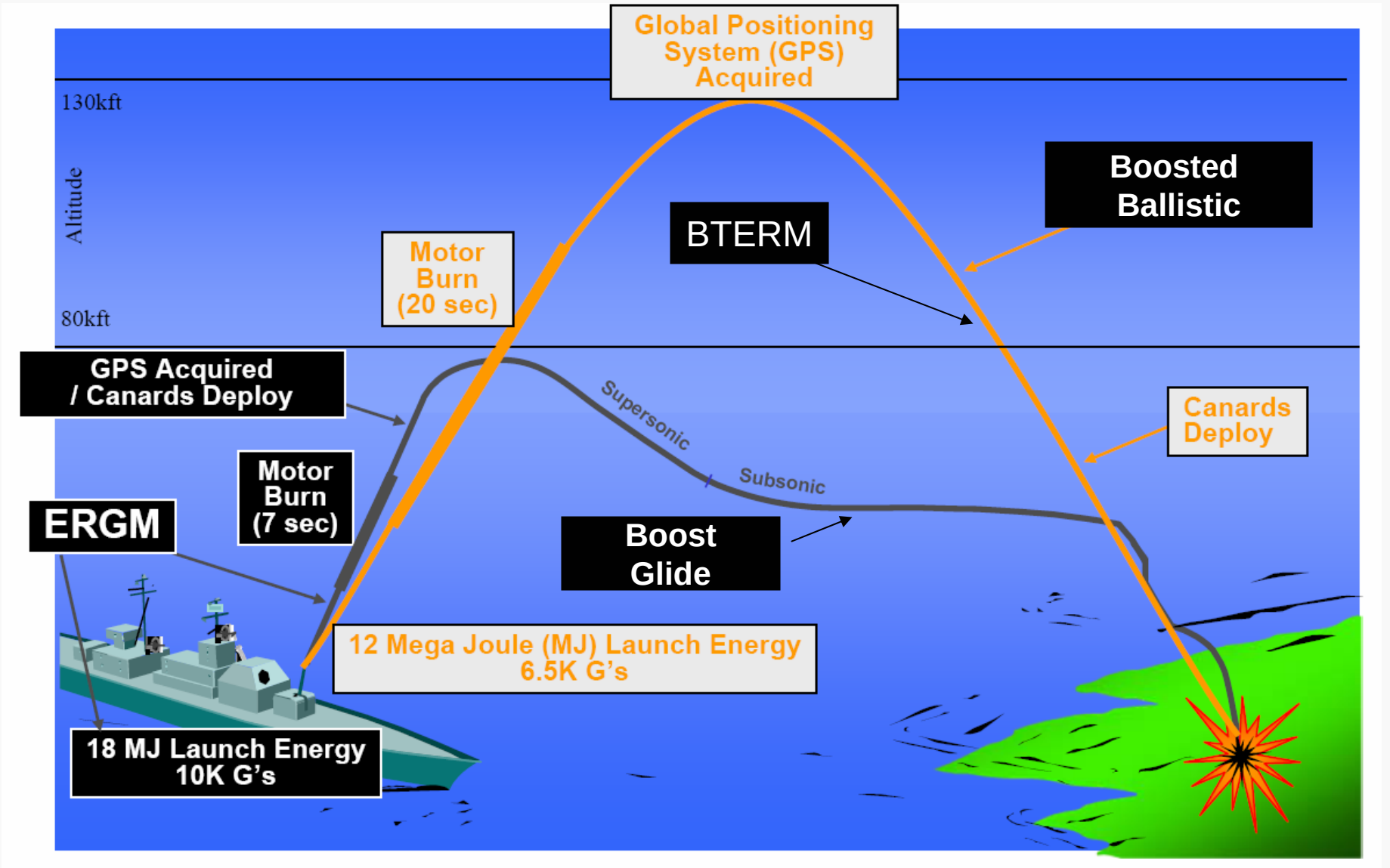
BTERM Mission Profile



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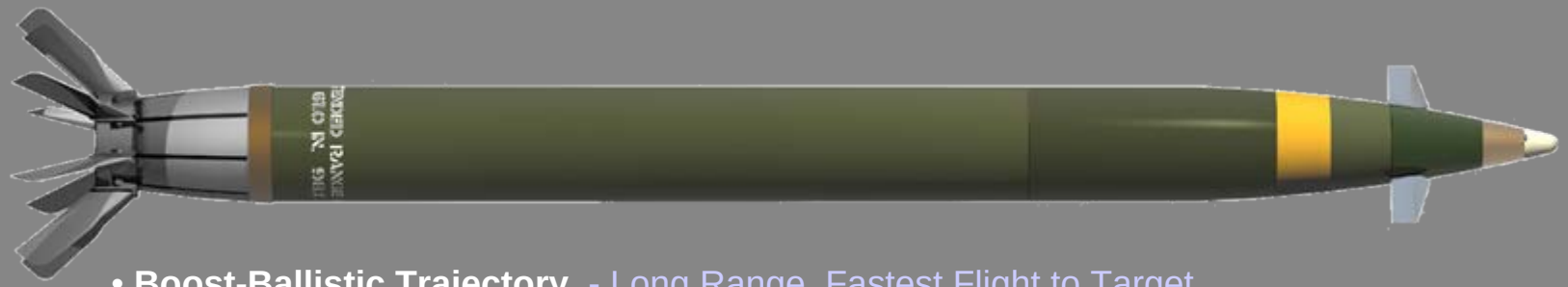
System Overview



- **Boost-Ballistic Trajectory** - Long Range, Fastest Flight to Target
- **Rolling Airframe with Single-Axis Control** – Small Delivery Errors
- **Rear Obturation** – Simple, Robust Rocket Motor
- **High-Density Frag Warhead** – Lethal Across Target Set
- **GPS with Anti-Jam** – Short Time in Jammed Zone
- **MEMS Accelerometers/Rate Sensors** – Low Cost, Rugged
- **Compatible with any gun modified for precision projectiles** – MOD2 and MOD4

Rocket Motor
- End-Burning with Centerport Inhibitor
- SAA-139 Propellant
- Titanium Beta-C Rocket Motor Case

Fragmenting Warhead
- Warhead
- PBXN-9 Explosive
- Warhead S&A (Safe & Arm)
- Booster Cup and Detonator

Fuze
- Gun Interface
- Safe Separation
- HOB Sensor

TFA (Tail Fin Assembly)
- Blast Tube/Rocket Motor Nozzle
- ISD (Ignition Safety Device)
- 8 Taper Fins
- Fin Locking Mechanism

GEU (Guidance Electronics Unit)
- ISA (Inertial Sensor Assembly)
- GPS Module/Anti-Jam Module
- Flight Processor Module
- PCE (Power Conditioning Electronics) and I/O

CAS (Control Actuator System)
- COTS Servo Motor
- Battery Pack (8 Storage Batteries)
- Canard Deployment Mechanism

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Rocket Motor

- Many subsystems on BTERM II had been proven during BTERM I and ANSR which were predecessors to BTERM II
- Changes were implemented in the manufacturing processes towards a more producible design
- The rocket motor was a pacing factor that required significant and unplanned attention
- Two areas were improved over a 2 year span and ultimately proven successful
  - Over pressure during testing
  - Nozzle burn-through

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BTERM II Rocket Motor Summary

- BTERM II motors have exhibited two different anomalies
  - Over pressurization
  - Blast tube insulation burn through
- These only occurred in flight or spin tests, not static
  - Anomalies are associated with unanticipated interaction between environments and process/material variabilities or design margins
- Overpressurization can be caused by:
  - Excess propellant surface area
  - Nozzle area reduction/blockage
  - Change in propellant combustion properties
- Testing and analysis quickly reduced the cause to excess surface area
  - Manufacturing techniques were modified
  - Rocket motor burn was consistent

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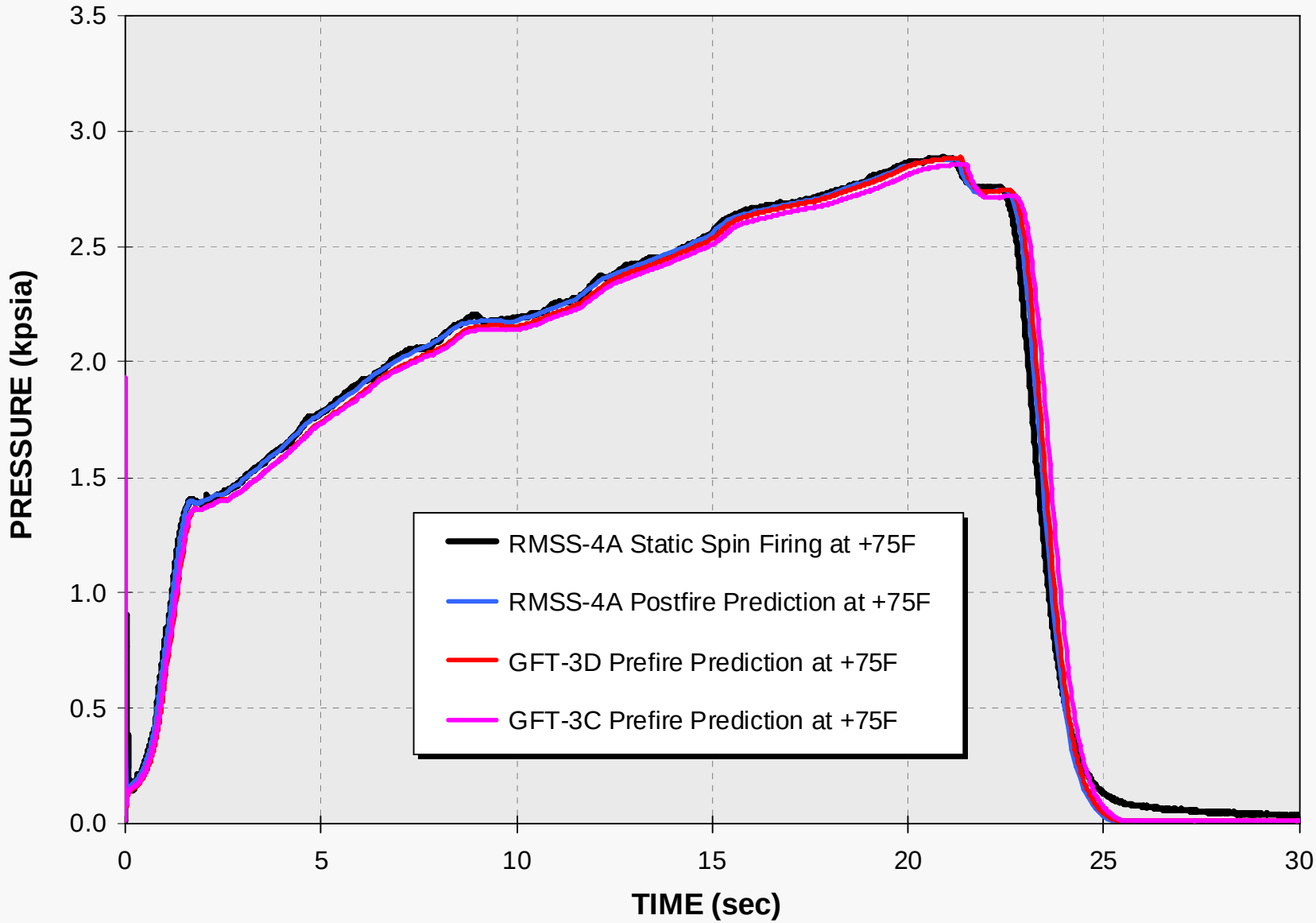
Performance Predictions – Pressure vs. Time



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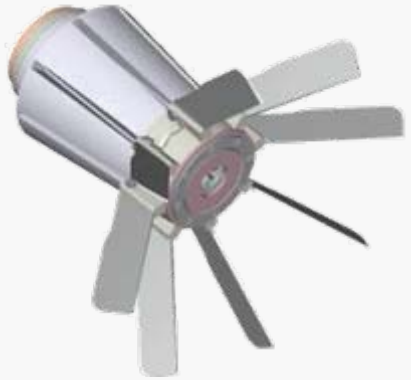
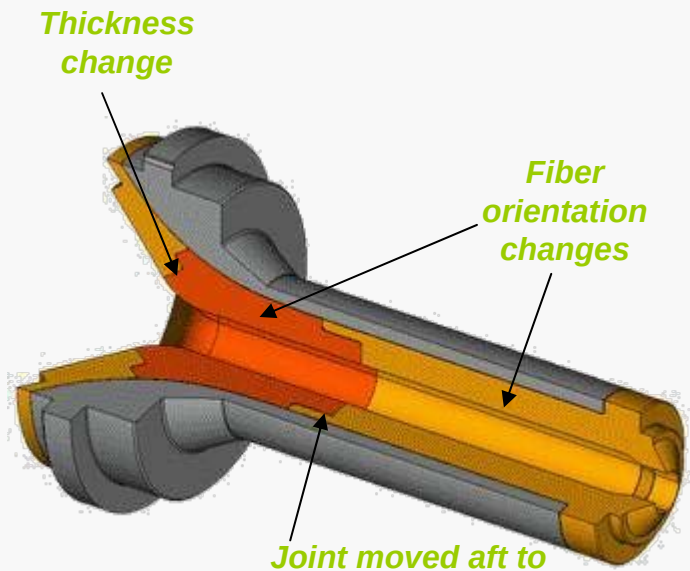
Nozzle Improved to Provide Thermal Margin



Nozzle Insulation Improvements

- Conducted detailed review with NSWCDD on 01 Jun 06
  - Agreement on changes & test plan
  - Team agreed on a material fiber orientation changes to approach and blast tube to resist erosion
- Approach thickness changed to better resist charring / heat
- Spinning static fire tests validated changes
  - Erosion analysis added confidence



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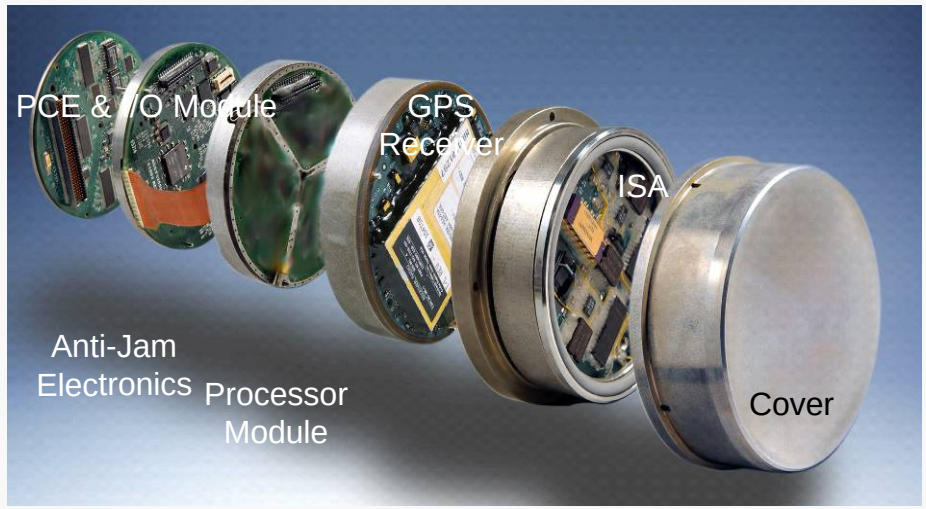
Low Cost Guidance Electronic Unit (LCGEU)

- Developed by Draper Laboratory
  - – Navy funded
  - – Originally developed as risk reduction for ERGM
  - – Rockwell-Collins SAASM GPS receiver
    - •Direct-Y acquisition
- Survives and operates in gun environments > 10,000 g's
- Deep Integration GPS anti-jam algorithms
  - – Allows inexpensive commercial MEMS gyros and accels
- Proven success and robustness in laboratory and live fire tests
  - – Multiple platforms
- Guidance control laws are robust to system errors



BTERM II Low Cost Guidance Electronics Unit is a Mature Demonstrated Design

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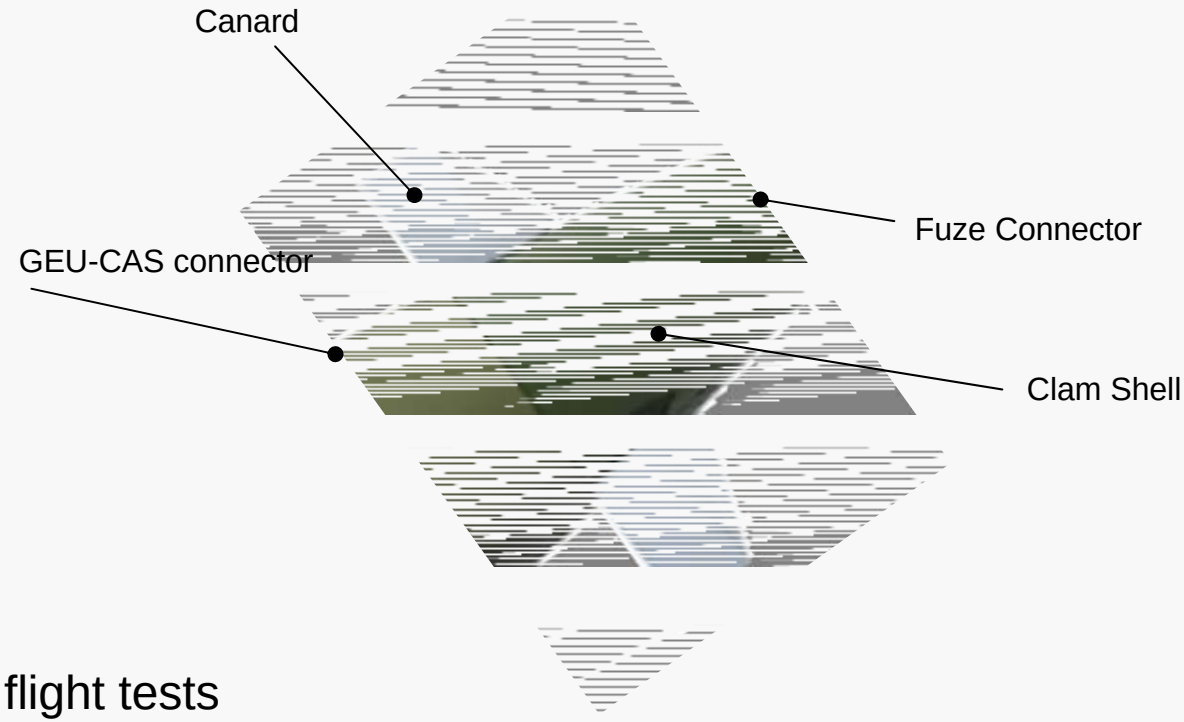
CAS Configuration and Performance History



- Improved design for interconnect to GS and Fuze sections
- Optional Al or Steel clam shells
- Proven battery pack in numerous flight tests
- Current design proven in flight tests
- Robustness demonstrated in GFT301-1C
- Added current limit to protect battery from over-current

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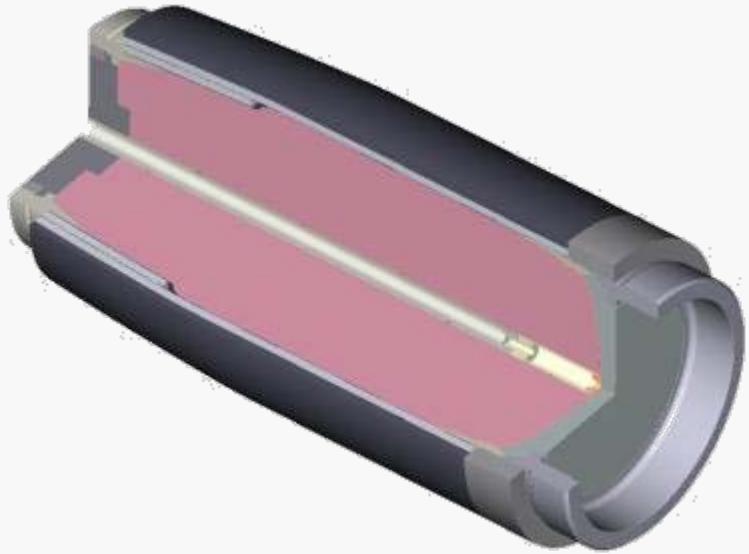
Warhead Configuration and Performance History

- Case showed excellent results in crush test
- System effectiveness, based on results of first warhead arena test, exceeded system performance requirements
- Recovered fragments demonstrated integrity with respect to explosive launch



Warhead Components	Description	Weight
Composite	**Graphite**	***0.9 lbm***
Explosive	***PBXN-9***	
Booster Charge	***PBXN-11***	***0.05 lbm***
Initiator	**RP-80**	***N/A***

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Guided Flight Results

- GUFT-1
  - February 2006
  - **G**uided **U**nboosted **F**light **T**est
  - 8.7nmi@ Yuma Proving Grounds-> 7.3nmi sea level
  - 5 foot miss distance from target

- GFT-301
  - September 2008
  - **G**uided **F**light **T**est
  - 54nmi@ White Sands Missile Range-> 49nmi sea level
  - 15 foot miss distance from target

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GUFT-1 Mission Overview

Test:

- Location: Yuma Proving Ground (YPG)
- Test dates – 08 February 2006

Test Conditions:

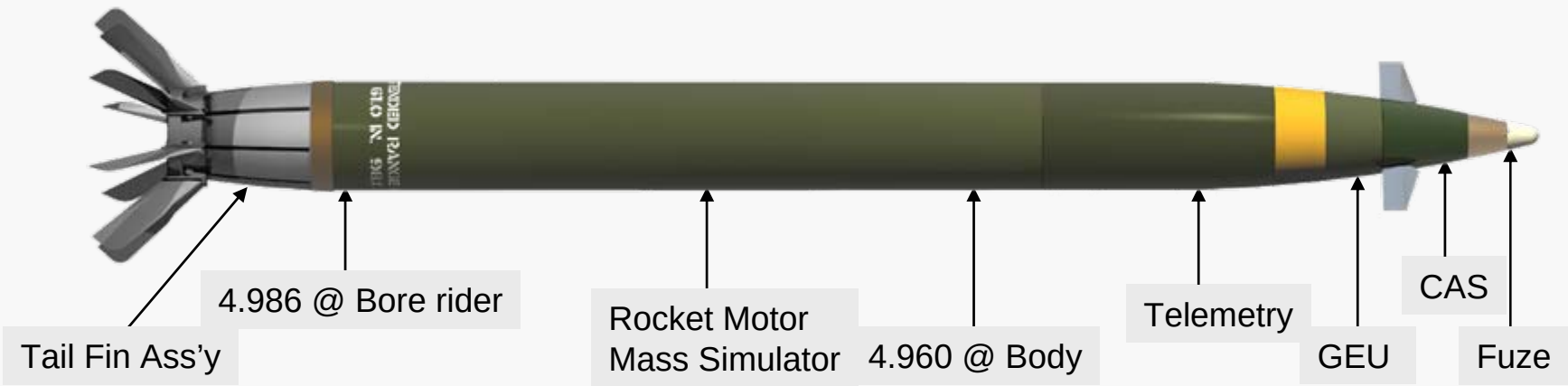
- 5”/62 Caliber Gun (S/N 17499)
- NACO Propellant Charges
- Muzzle Velocity = 2,170 ft/sec
- Expected Launch Accel = 7,200 G
- GUFT-1/ODT QE = 60.5°

Test Configurations:

- 3 Baseline Obturated TCD Slugs
- 1 Guided, Unboosted Flight Test (GUFT-1)

Instrumentation:

- 3 M11 and 2 Piezoelectric Pressure Sensors within Propelling Charges
- Barrel Pressure Data
- Camera Coverage at Gun and Target
- Trajectory and Muzzle Radar
- Telemetry for GUFT-1



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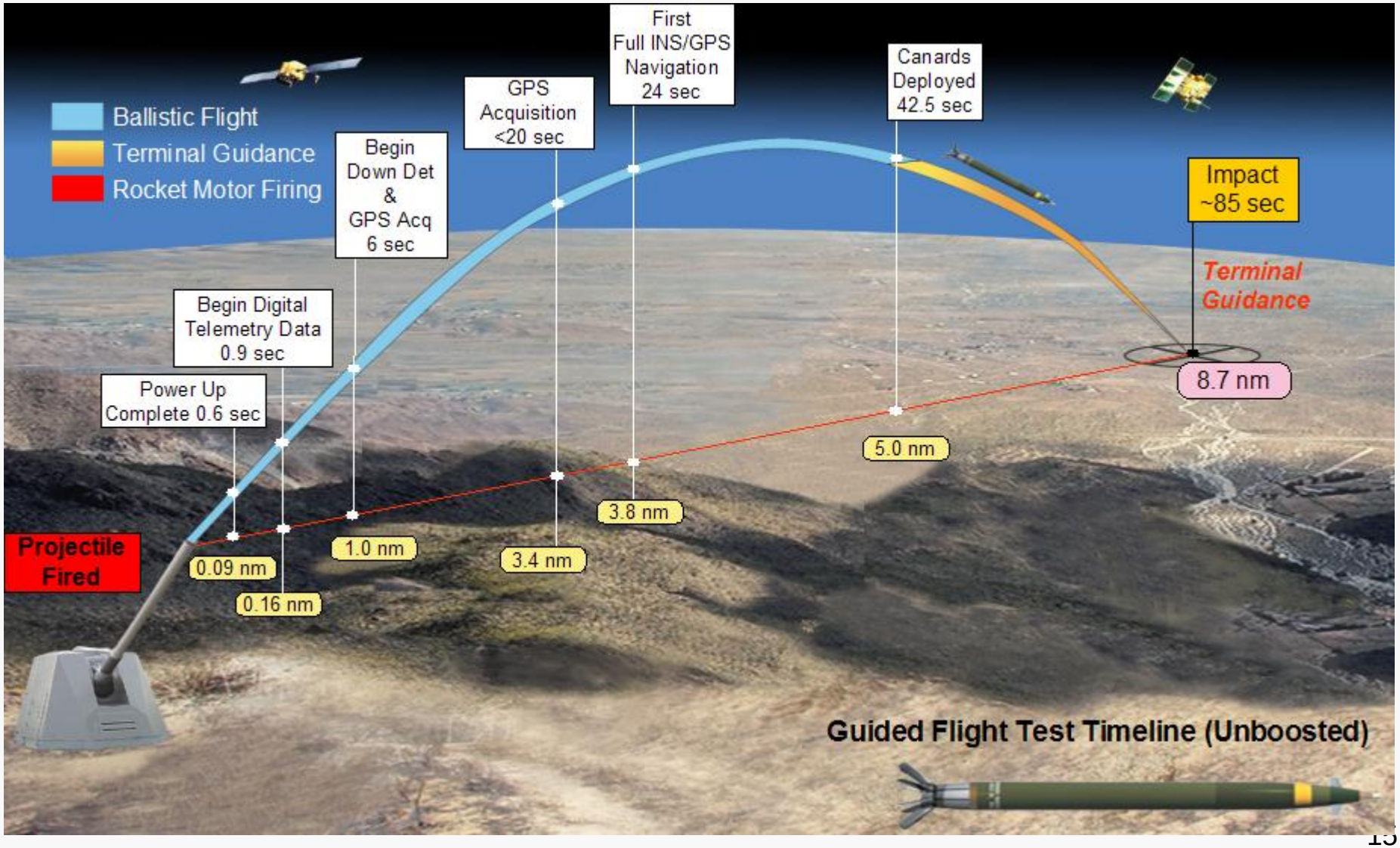
February 8, 2006 Guided Unboosted Results



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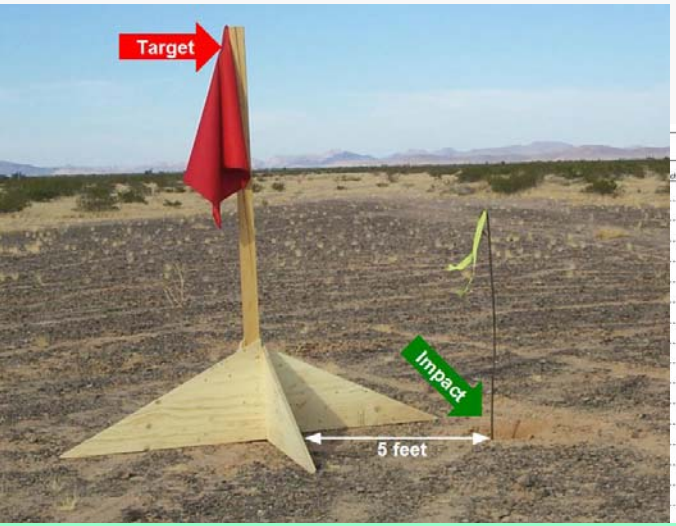
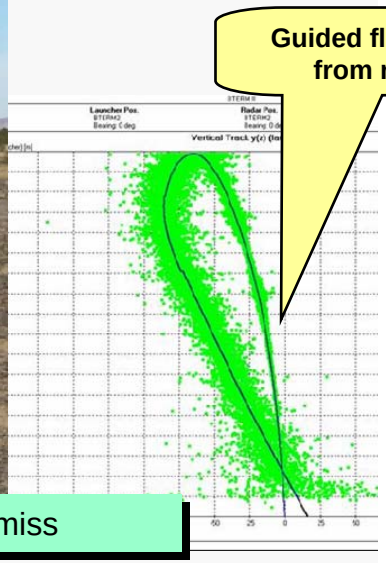
GUFT-1 Mission Objective Results

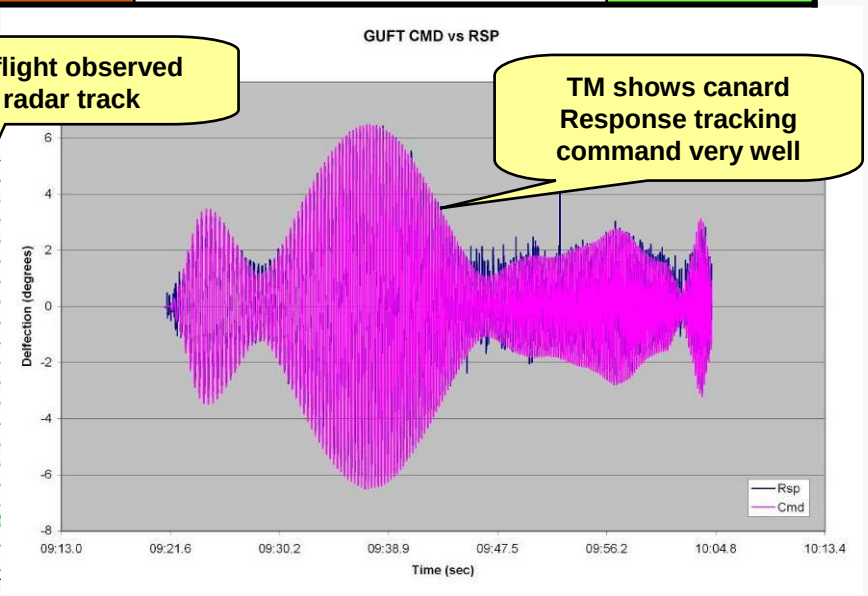
- New mag based down determination successful
- GPS acquisition successful
- Canard deployment successful
- Canard control successful
- **Hit the TARGET!**

Test Objective	Criteria	Results
Evaluate short range GNC algorithms	**Successful acquisition of telemetry and radar data**	Passed
Demonstrate CAS performance with COTS actuator	**COTS actuator demonstrates the ability to control the flight trajectory using commands issued by the GEU**	Passed



1.5m impact instead of 185m ballistic miss





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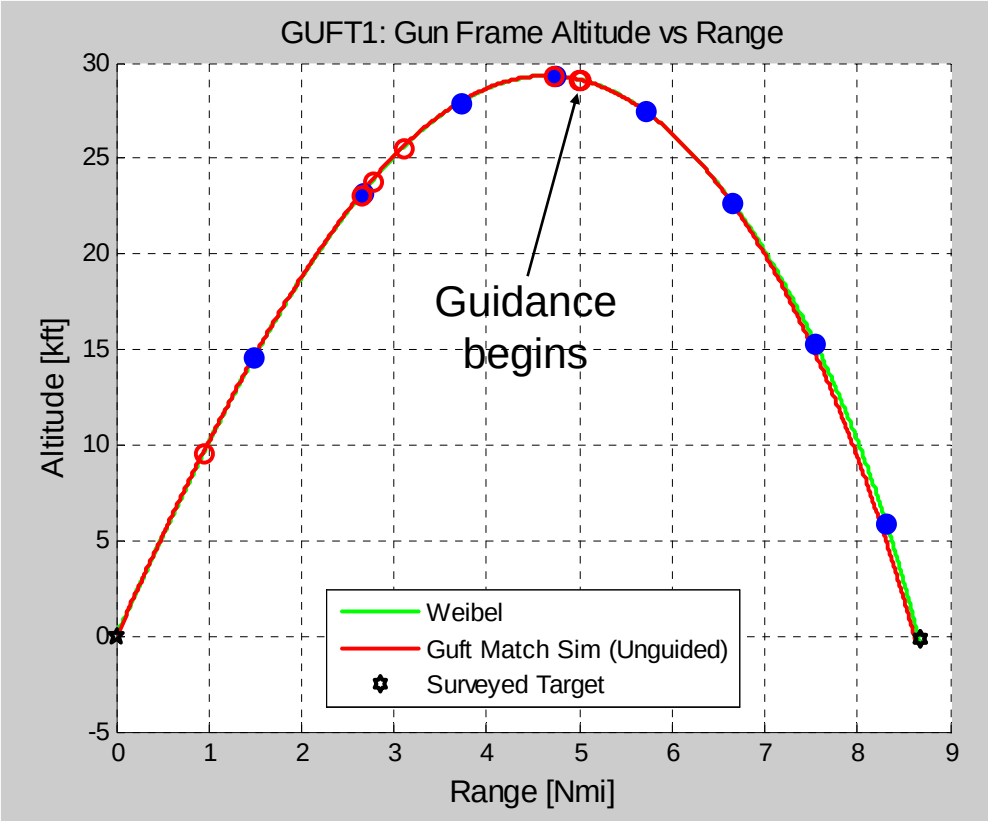
GUFT 1 – Flight Test Results

GNC

- GPS
  - Acq at 20 sec and held throughout
- Improved down determination enables early navigation
- GEU sensors survived launch and performed as expected
- Guidance/control commands issued starting at 42 sec
  - CAS response good
  - 5 ft miss at target
- Impact at 86 sec at 8.7 nm



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GFT-301 Mission Overview

Test:

- Location: White Sands Missile Range (WSMR) – Site L531
- Test Date – 29 Sep 2008

Test Conditions:

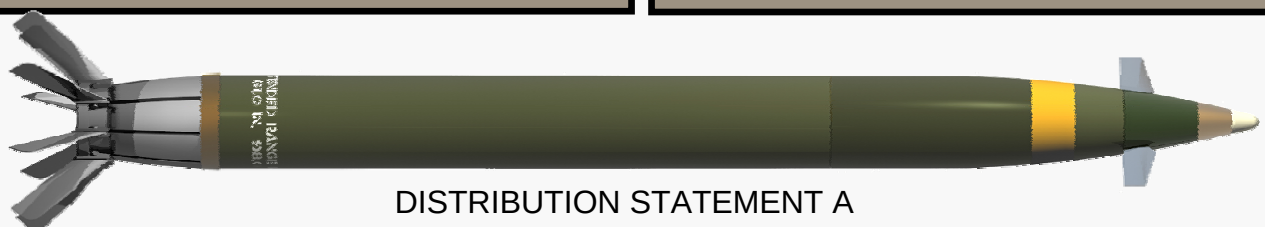
- 5”/62 Caliber Gun (S/N 17499)
- NACO Propellant Charges
- Muzzle Velocity = 2170 ft/sec
- Expected Launch Accel = 7200g
- Projectiles QE ~ 59.3°
- GFT-301 long range ~ 54 nmi

Test Configurations:

- 2 TCD Slugs + 1 backup
- 2 GFT-3 Guided, Boosted Flight Test
- 1 EET-3 Guided, Boosted Flight Test

Instrumentation:

- 3 M11 and 2 Piezoelectric Pressure Sensors within Propelling Charges
- Barrel Pressure Data
- Camera Coverage @ Gun & Targets
- Trajectory & Muzzle Radar
- ATK Telemetry



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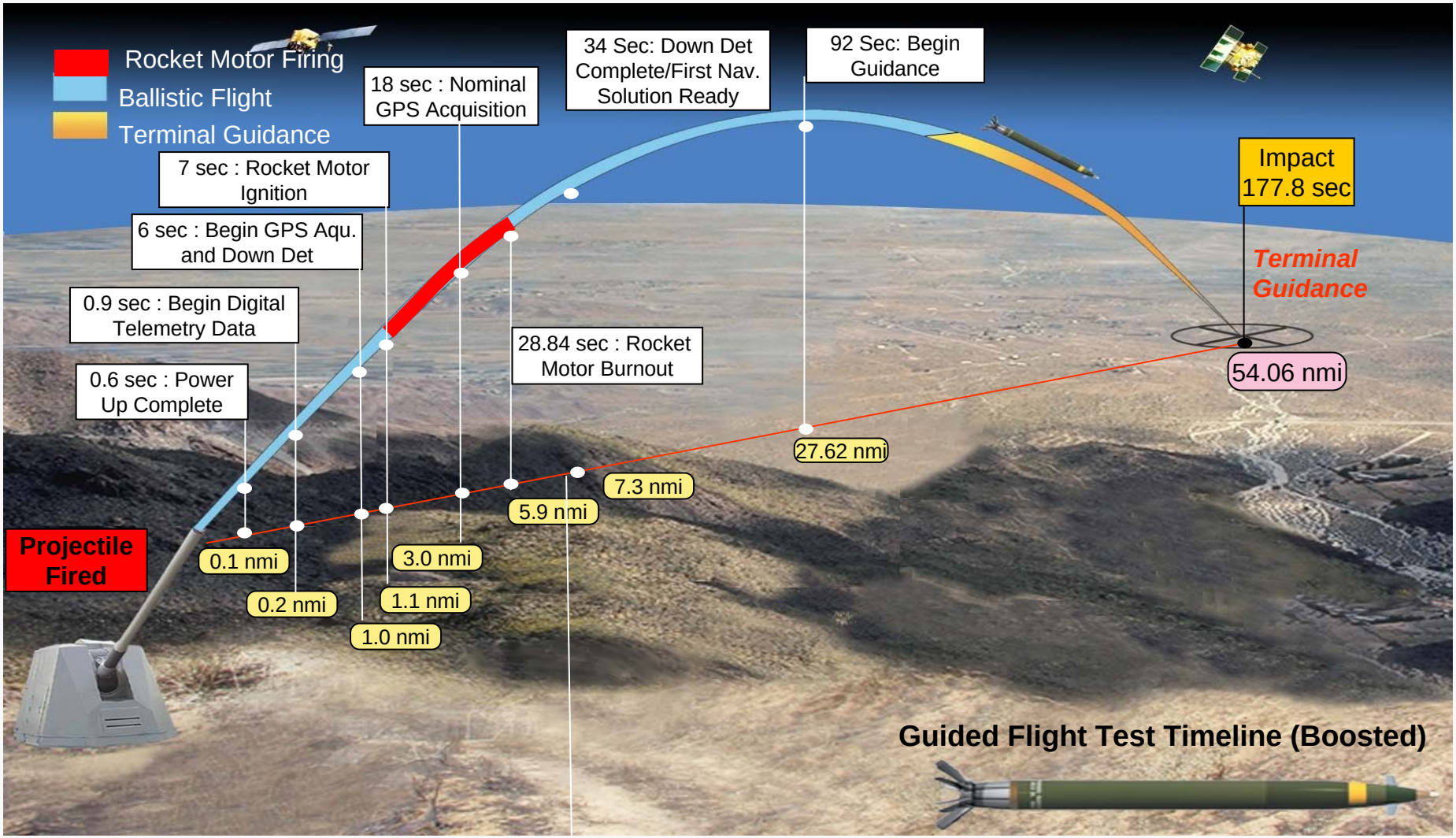
GFT-301 Flight Profile



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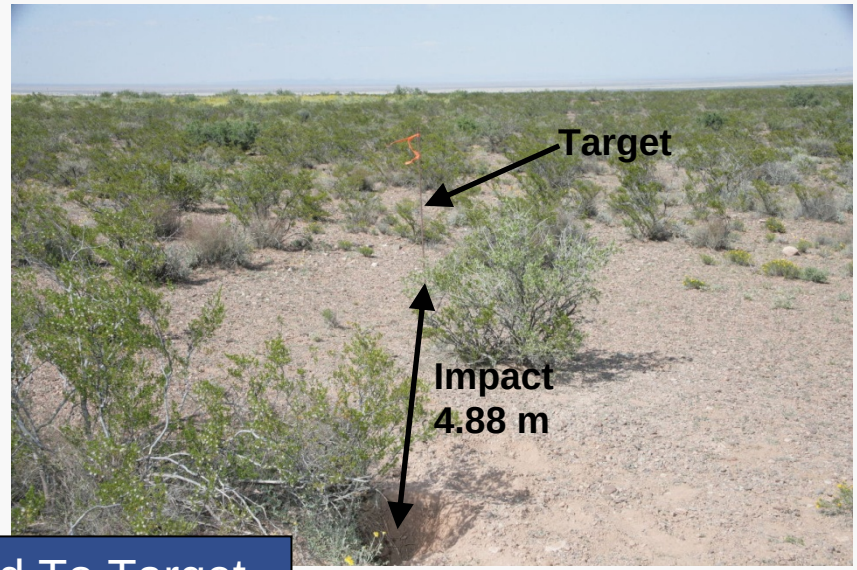
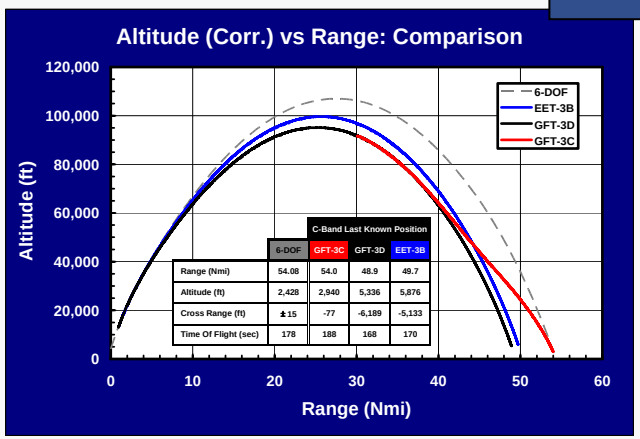
Recent BTERM Success

Sept 2008 test success

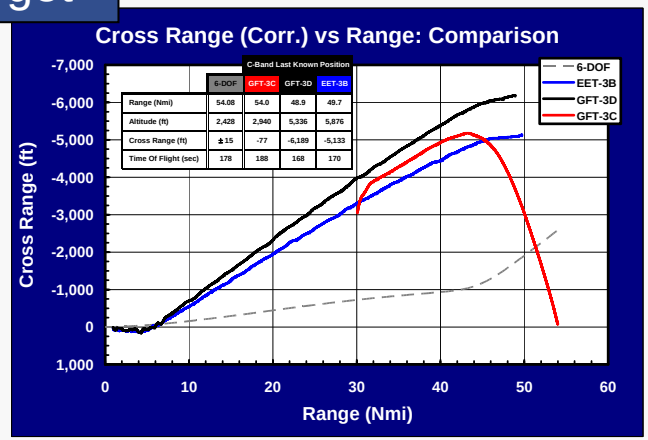
- **Achieved 54 nmi range**
  - Full duration rocket motor burn
- **4.9 m miss distance**
  - Acquired 10 satellites in direct Y
  - Corrected 5 nmi of range error
  - Corrected 0.9 nmi of cross range error



GFT-3C Guided To Target



All Three Test Projectiles On Very Similar Trajectories



Recent Success Validates 5” Gun Solution for NSFS

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Program Accomplishments

- Demonstrated short and long range guidance accuracy
  - 8-nmi guided flight test within approximately 5-feet of the intended aim-point
  - 54-nmi guided flight test within approximately 15 feet of the intended aim point
  - Low Cost Guidance Electronics Unit (LCGEU) continues to demonstrate robust performance meeting all requirements
  - 6-DOF simulation accurately predicts actual guidance performance
  - CAS (w/COTS components) provides sufficient control authority to meet guidance accuracy requirements
  - Tail fin deployment and locking
  - Electronic ISD demonstrated

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Program Accomplishments

- Demonstrated subsystems
  - Guidance, navigation and control subsystem and algorithms
  - Composite blast fragment warhead
  - Single Axis CAS including the COTS actuator
  - Electronic Ignition Safety Device
  - Reliable rocket motor performance
- Demonstrated lethality of warhead
  - Arena tests at NSWC-DD demonstrated lethality meets or exceeds requirements against the ERM target set
  - Actual performance better than simulation/model
  - Crush test demonstrated strength exceeds requirement for BTERM launch environment of ~7500-g
- Demonstrated the data communications interface (DCI)
  - Benchtop tests with ERM setter