Very Affordable Precision Projectile System and Flight Experiments

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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ARDEC/ARL

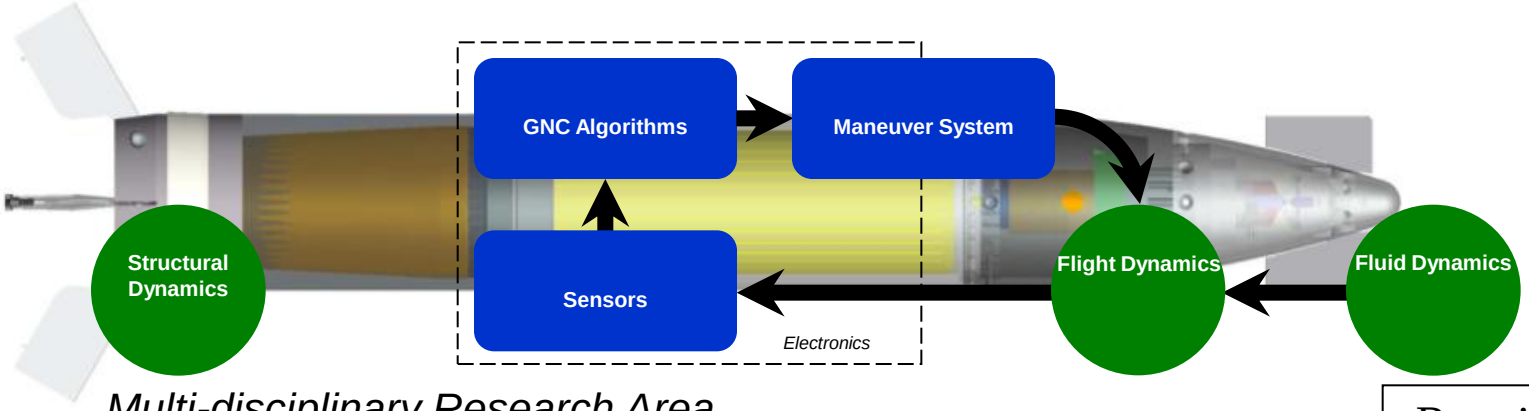
Motivation

- Provide soldier with an organic precision lethality solution for indirect fire systems
- Growing demand for precision capability across multiple caliber systems
  - First-round lethality
    - more stowed kills
    - more timely
  - Limit collateral damage
    - use in urban terrain
    - use in close proximity to friendly troops and civilians
- Deliver scalable effects warheads

Guidance, Navigation, and Control (GNC) Overview and Challenges

Three basic questions:

Where am I? **Where do I need to go?** **How do I get there?**



Multi-disciplinary Research Area

Requirements

Integrate into miniature, gun-hardened package with real-time processing

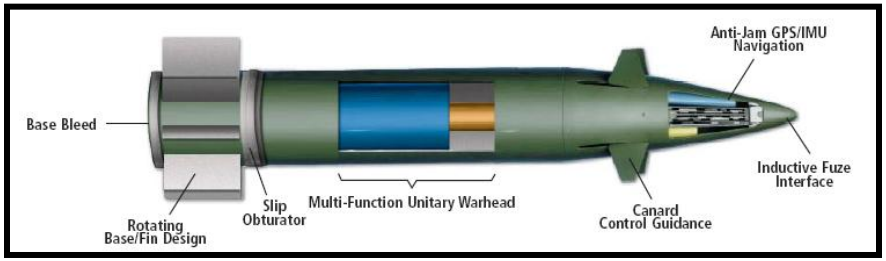
Unique Challenges for GNC in the Gun-Launched Environment:

- Rifled guns → spin-stabilized projectiles (Magnus moment, gyroscopic action, actuation freq.)
- Survivability of components at gun launch event
- Sensors in high-dynamic environment
- Physics of flight for novel concepts
- Embedded processing
- Varied applications (*1*s < *time-of-flight* < *100*s, *0*Hz < *spin rate* < *1000*Hz)
- Size, weight, and power
- Affordability ($/round, $/kill)

Technical Approaches

Current Approaches:

- Gun-hardened missile technology
  - maneuver system complexity/tolerance
  - high grade sensors
  - expensive
- Retro-fit existing stockpiles
  - narrowed design space



Alternate Approach for Affordable Precision

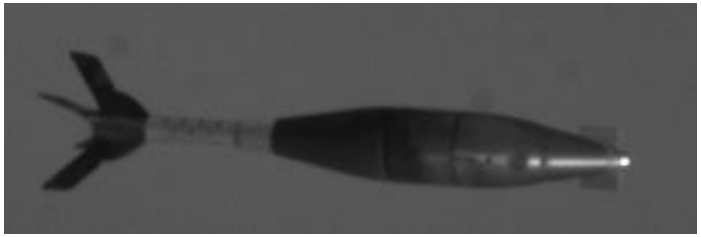
- DoD scientists and engineers develop technical underpinnings
  - Accept greater technical risk
  - Non-proprietary
  - Fund R&D once and apply to all

Fundamental understanding of science and technology enables general, caliber-independent GNC solutions

Very Affordable Precision Projectile - Overview -

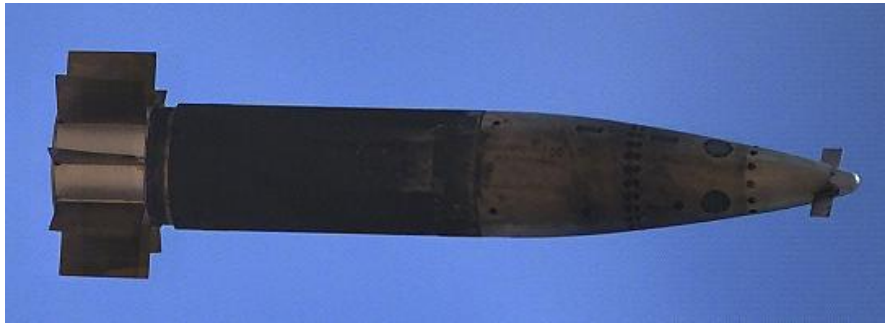
Objective

- To develop and demonstrate affordable precision technologies independent of projectile caliber applicable across all indirect fire platforms
- Requirements
  - Cost
  - Precision
  - Angle-of-Fall
  - Range



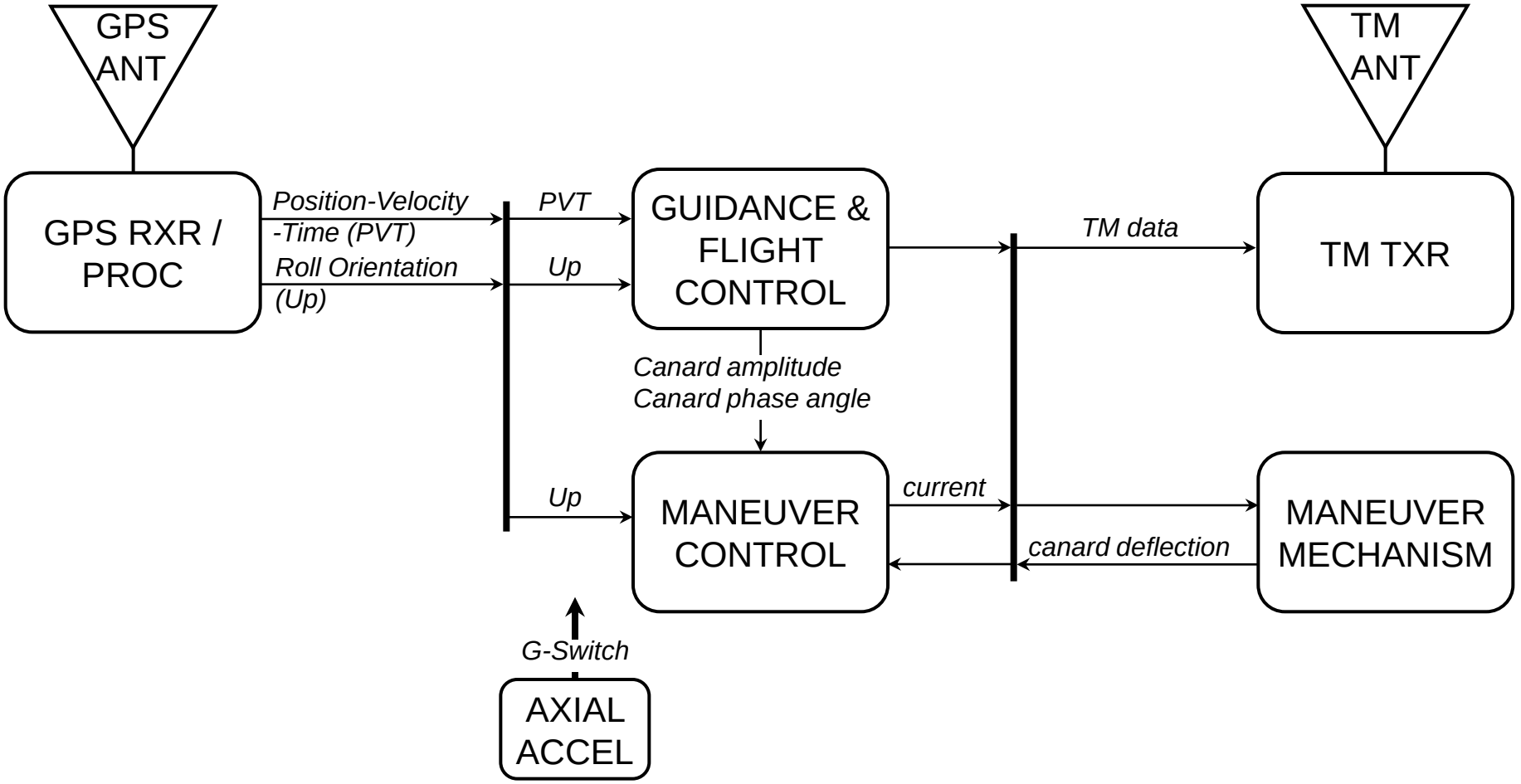
- ***Solution***: rolling airframe with single-axis maneuver mechanism, reduced sensor requirements and ballistic-based guidance algorithm

- Joint ARDEC-ARL effort with support from PM-CAS
- CRADA with industry for GPS expertise
- Fuzing, warhead, rocket, tactical battery leveraging other efforts



Demonstrated guide-to-hit capability in flight experiments on multiple calibers

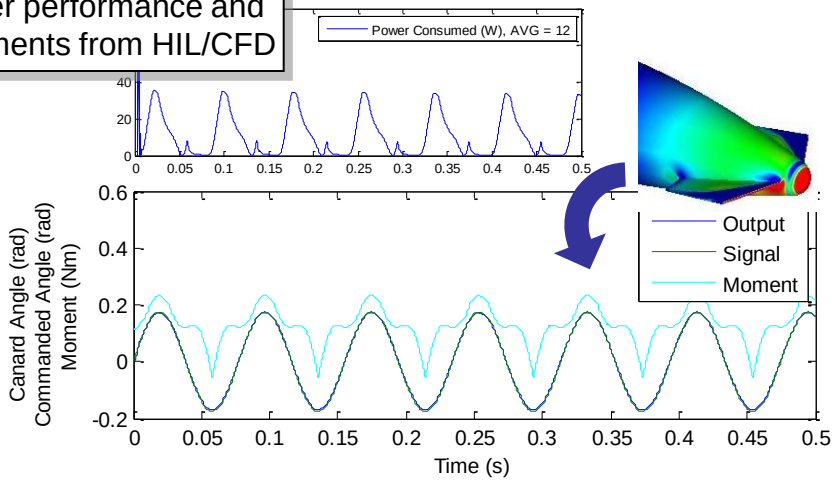
VAPP Architecture



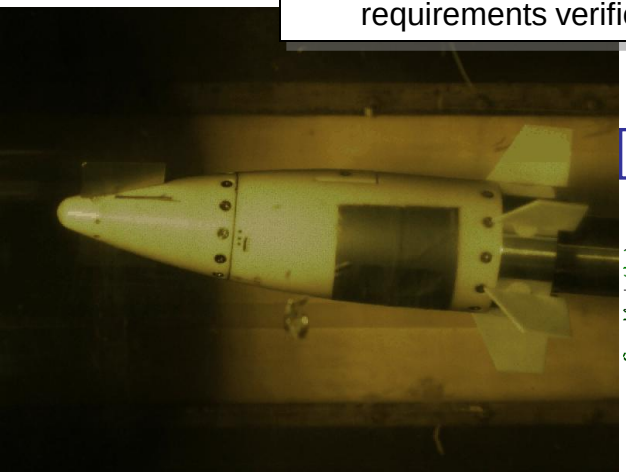
Maneuver System - Development -

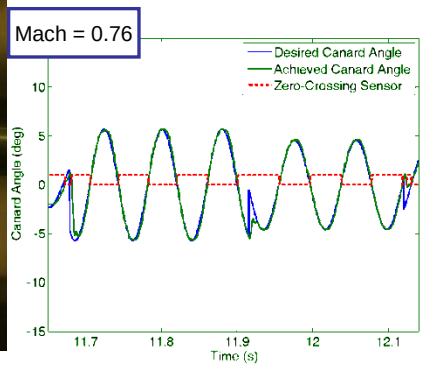
- Mechanical design
  - Linear voice coil coupled to canards with locking mechanism
- Electrical design
  - Algorithms embedded for real-time processing on DSP
  - H-bridge driven by pulse width modulated signals from DSP
  - Encoder and zero-crossing sensors provide feedback
- Controller algorithm
  - LQR controller tracks sinusoidal reference signal

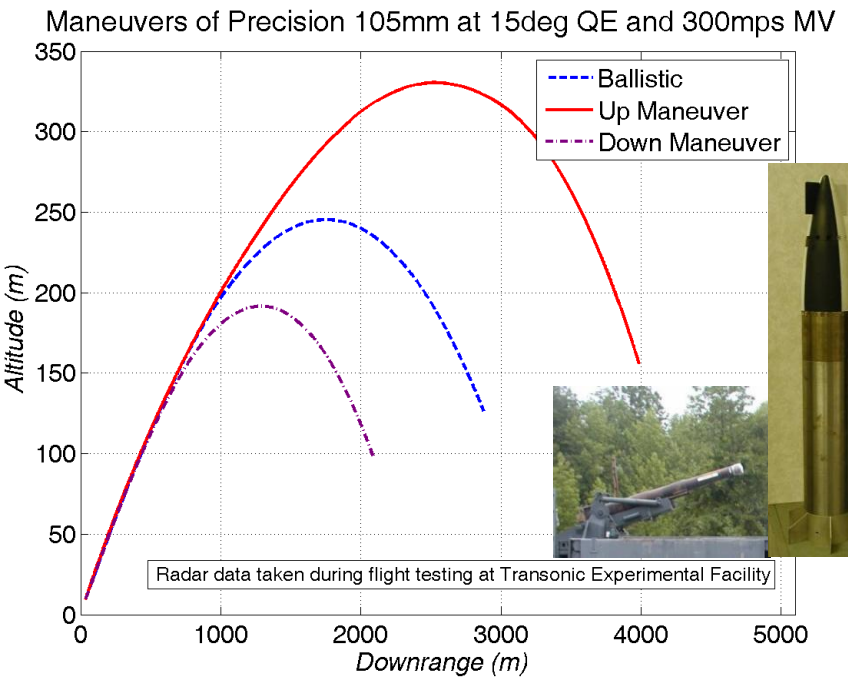
Initial controller performance and power requirements from HIL/CFD



Maneuver system performance and power requirements verified in wind tunnel







Maneuver system developed with M&S and verified in experiments

Guidance and Flight Control - Development -

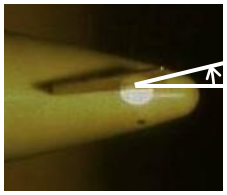
- Guidance algorithm based on flight dynamics → impact point p

$$\ddot{x} = \frac{-\pi C_{x0} d^2 \rho V_\infty}{8m}\dot{x} + \left(\cos(\phi_{CAN})\cos(\psi)\sin(\theta) + \sin(\phi_{CAN})\sin(\psi)\right)\frac{\left(L_{CAN} + L_B\right)}{m}$$

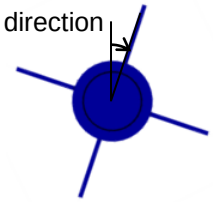
$$\ddot{y} = \frac{-\pi C_{x0} d^2 \rho V_\infty}{8m}\dot{y} + \left(\cos(\phi_{CAN})\sin(\psi)\sin(\theta) - \sin(\phi_{CAN})\cos(\psi)\right)\frac{\left(L_{CAN} + L_B\right)}{m}$$

$$\ddot{z} = \frac{-\pi C_{x0} d^2 \rho V_\infty}{8m}\dot{z} + g + \left(\cos(\phi_{CAN})\cos(\theta)\right)\frac{\left(L_{CAN} + L_B\right)}{m}$$

canard deflection



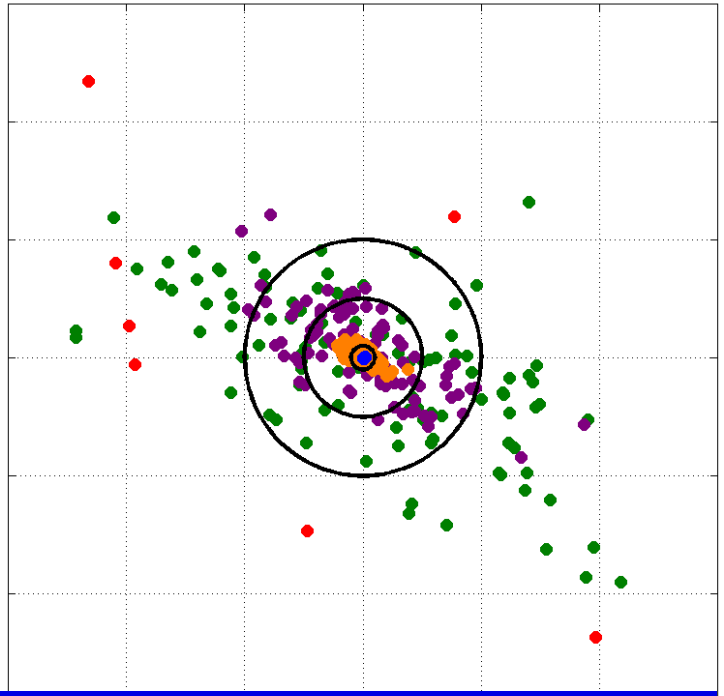
maneuver direction



- Guidance and flight control algorithms developed in 6DOF / system simulation environment with full-spectrum error sources
  - Initial conditions
    - muzzle velocity
    - roll rate at muzzle exit
    - gun pointing angles
  - Physical properties
    - mass
    - diameter/length
    - inertia tensor
  - Aerodynamics
  - Atmosphere
    - temperature
    - pressure
    - steady wind
    - turbulence
  - CAS
  - GPS

12 rigid body states

7 states for G&C

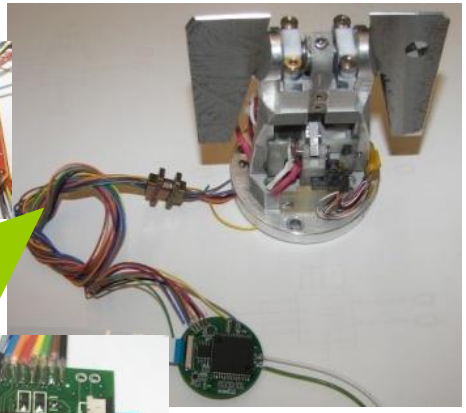


Guidance algorithm reduces sensor and actuator requirements

- Auto-code generation tools transfer algorithms to embedded proc.
- GNC implemented on DSP for flight experiments

Integration of Technologies

RF



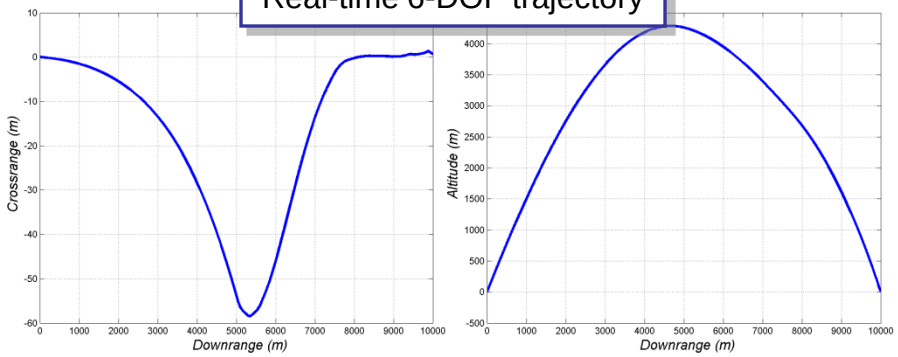
GPS data

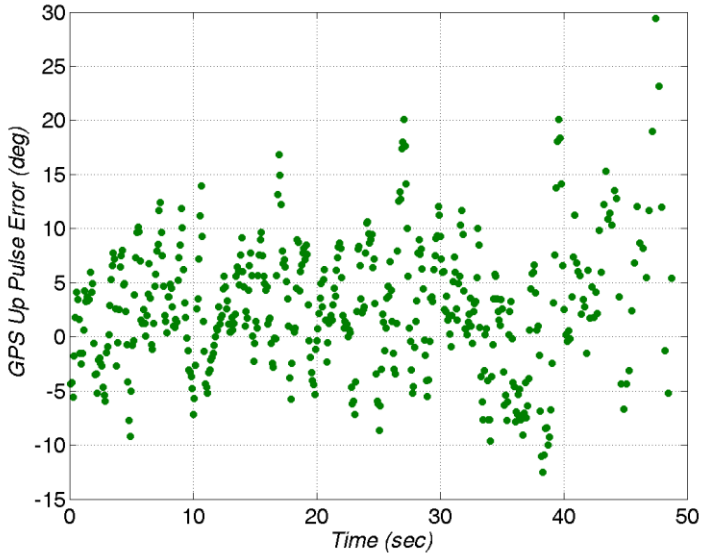
projectile states

Real-Time 6-DOF

canard position

Real-time 6-DOF trajectory



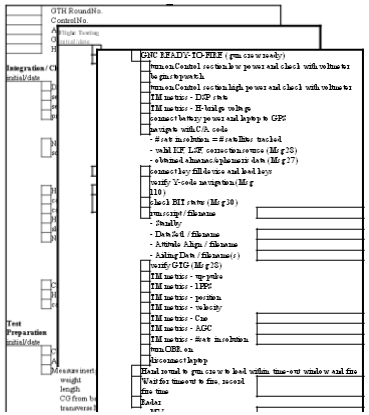


Extensive laboratory/field efforts reduce risk before flight experiments

Guided Flight Experiments - Check-out | Procedure | Setup -

120mm mortar

Detailed check-out and test procedure



Full ballistic range support

155mm artillery

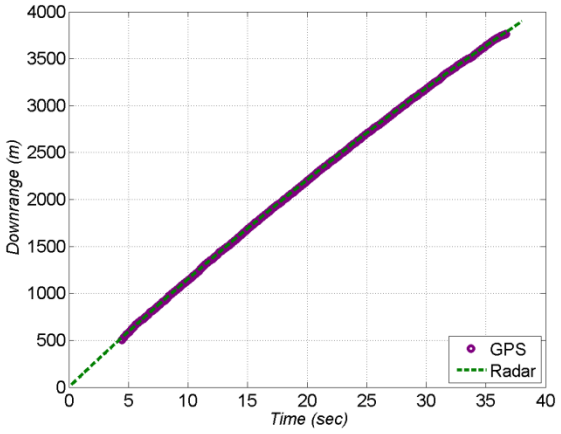
APG

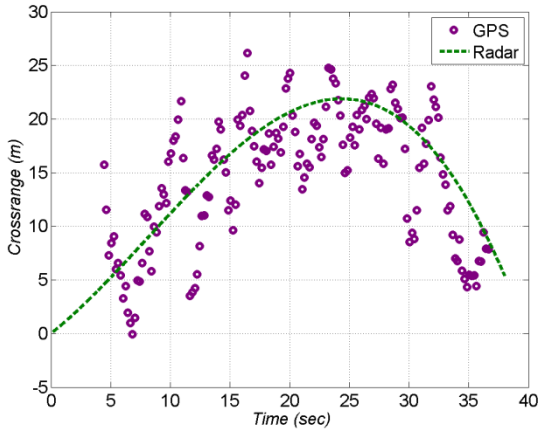
Target at 3.8 km

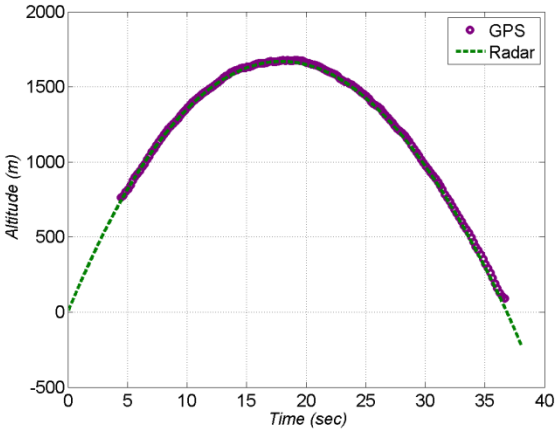
YPG

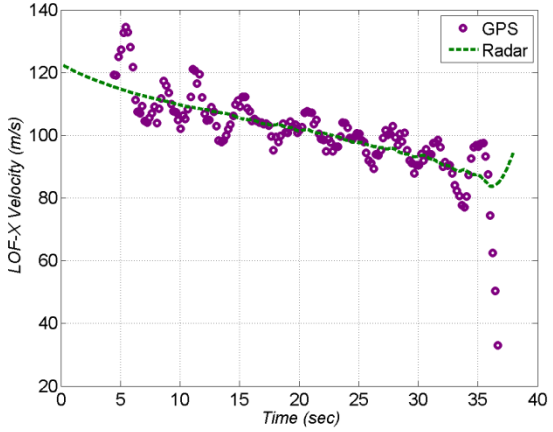
Target at 16.4 km

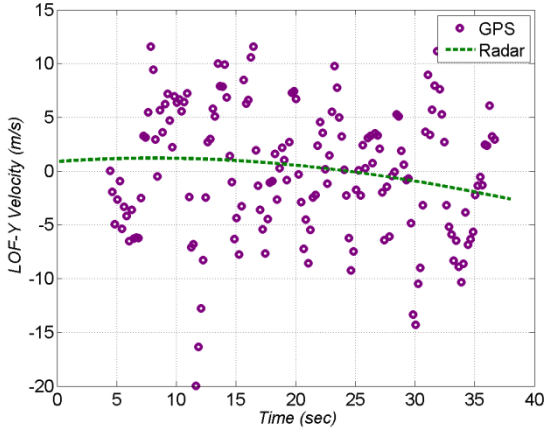
Flight Experiments
- GPS | Radar -

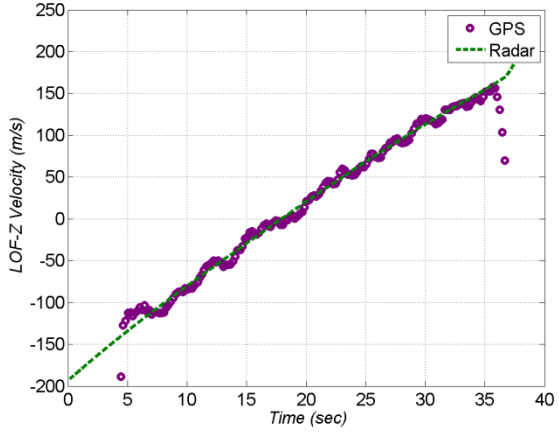




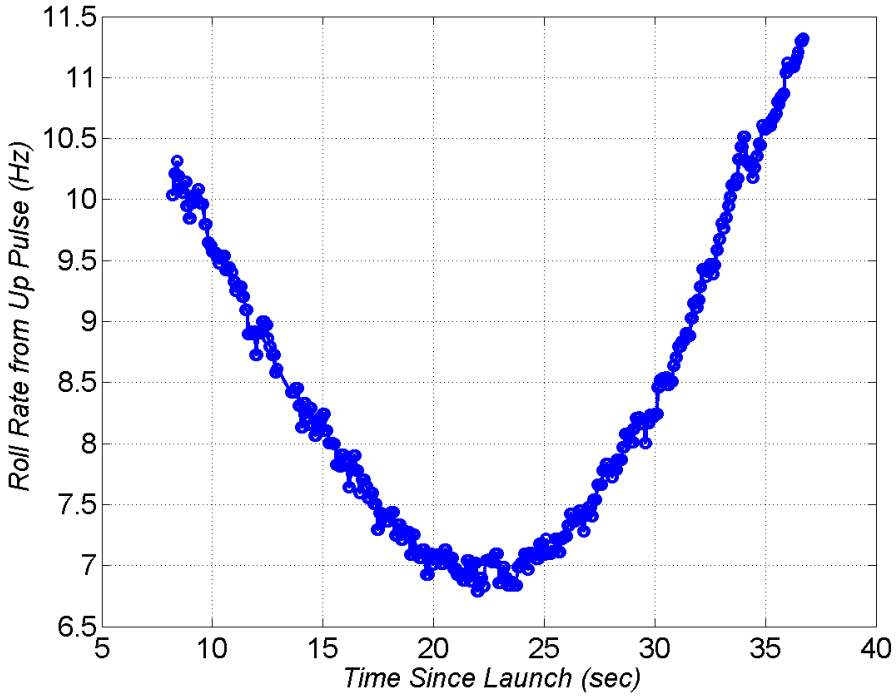


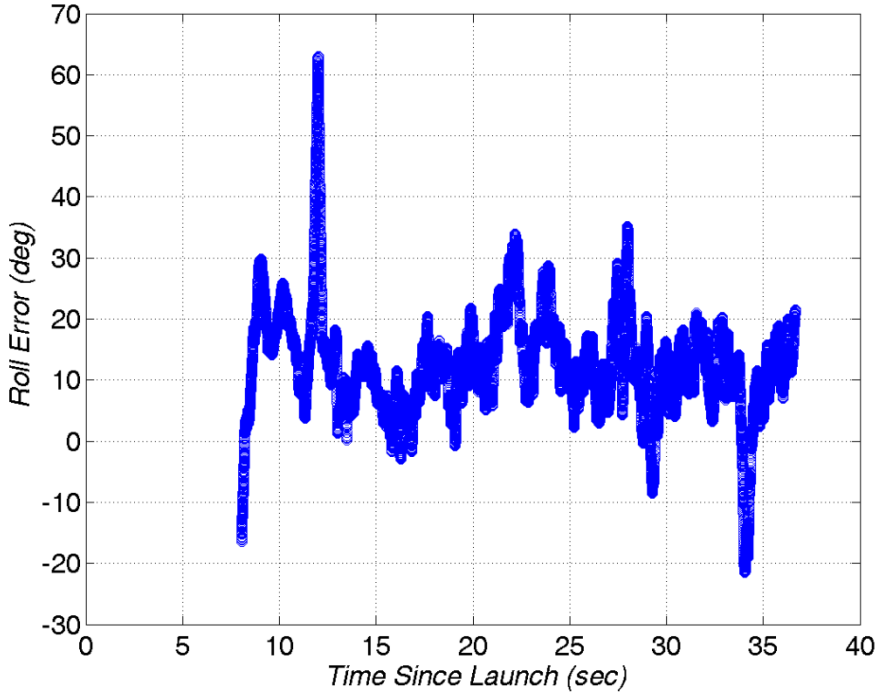




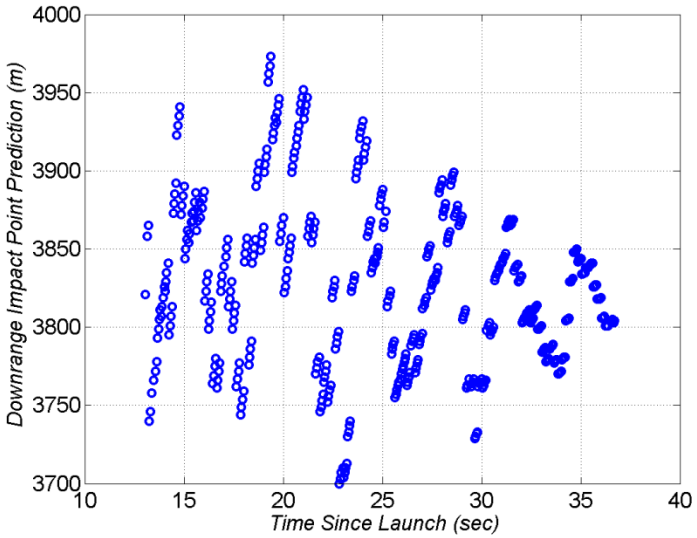


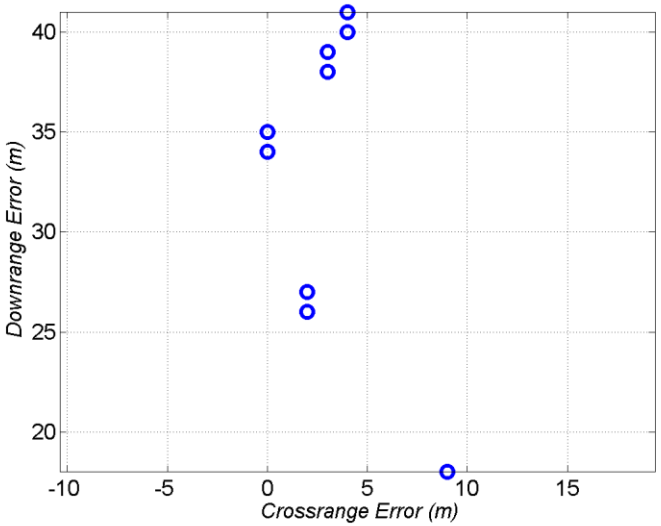
Flight Experiments
- Upfinding -

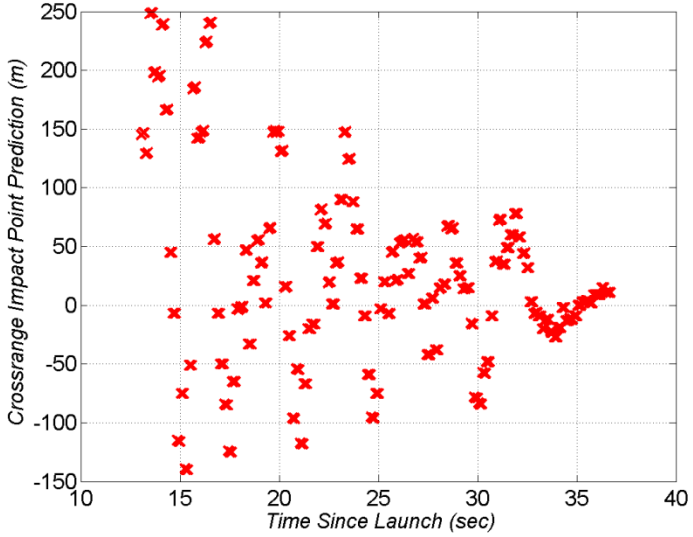




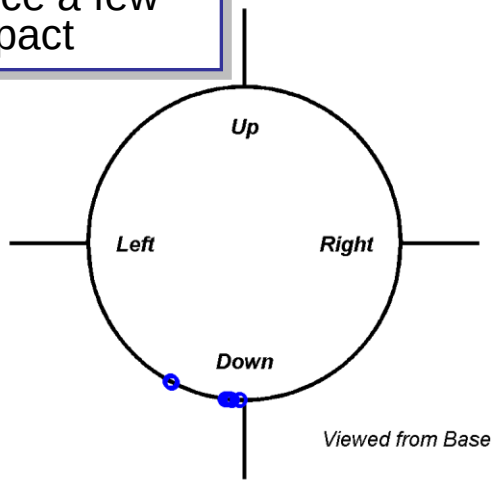
Flight Experiments
- Guidance -



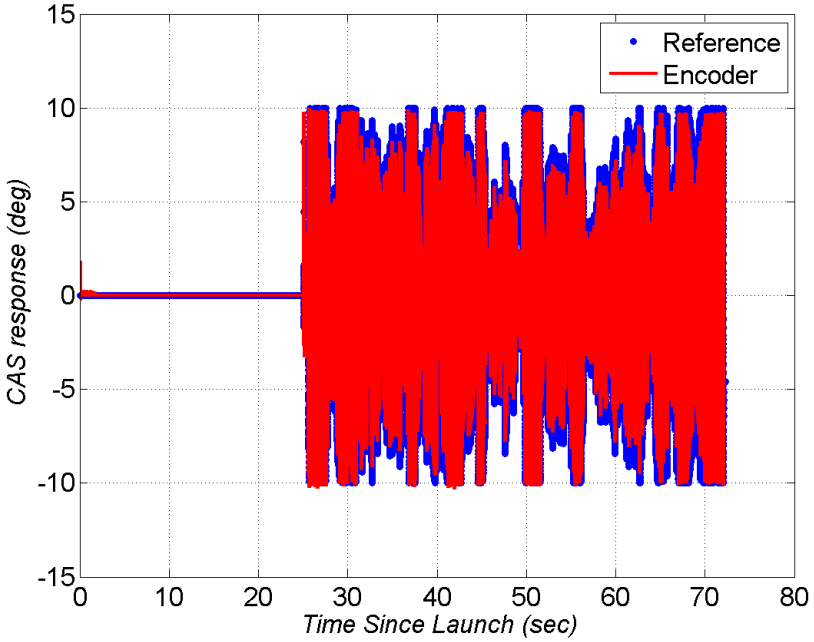


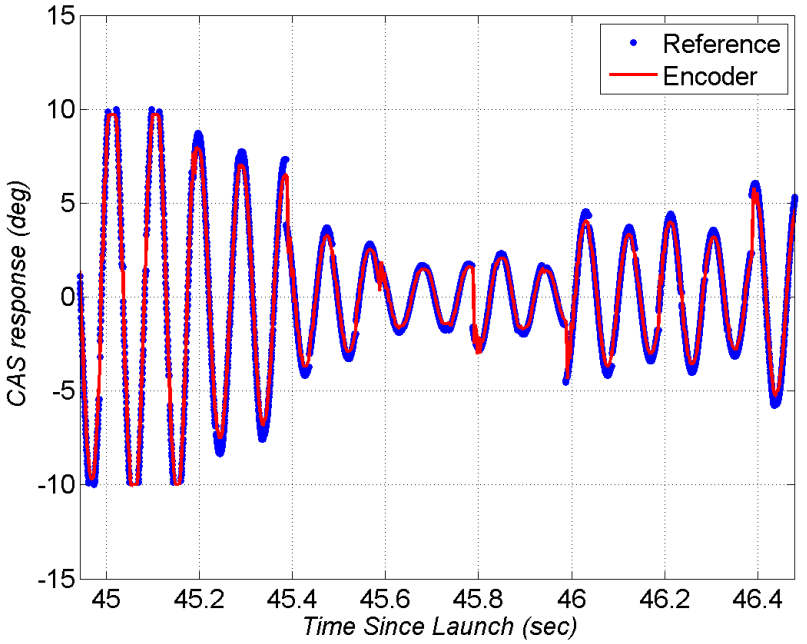


Snapshot of guidance a few seconds prior to impact

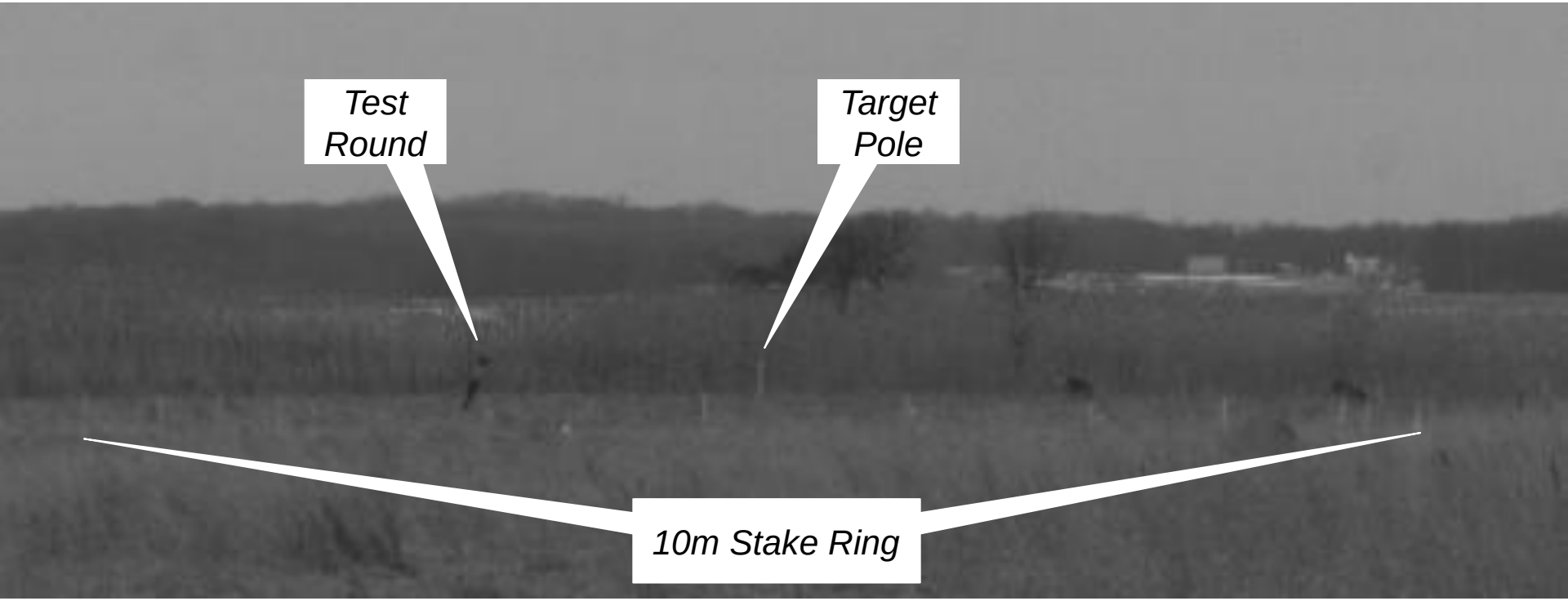


Flight Experiments
- Maneuver System -





Guide-to-Hit Flight Experiments - 120mm -

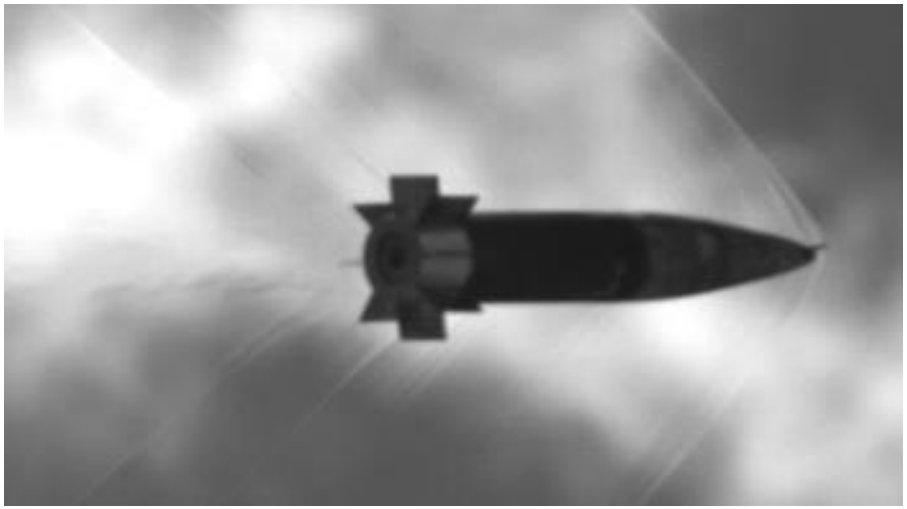


Guide-to-Hit Flight Experiments
- 120mm -

Guide-to-Hit Flight Experiments
- 155mm -

Flight Experiments – VAPP-26

Summary

- Affordable precision solutions enabled through fundamental understanding of technology by DoD scientists and engineers
  - accept higher technical risk
  - caliber-independent (fund R&D once)

- Successful guide-to-hit flights
  - validated technologies and approach
  - confirmed TRL
  - provided transition vehicle to other government labs and industry