Range Extension of Gun-Launched Smart Munitions

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Army Research Laboratory
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Introduction

Motivation

- Extending the range of gun-launched smart munitions enables larger area of influence, more timely fires, enhanced effectiveness, and improved urban operations.

Goal

- Identify the critical technical drivers for extended range of precision munitions

Approach

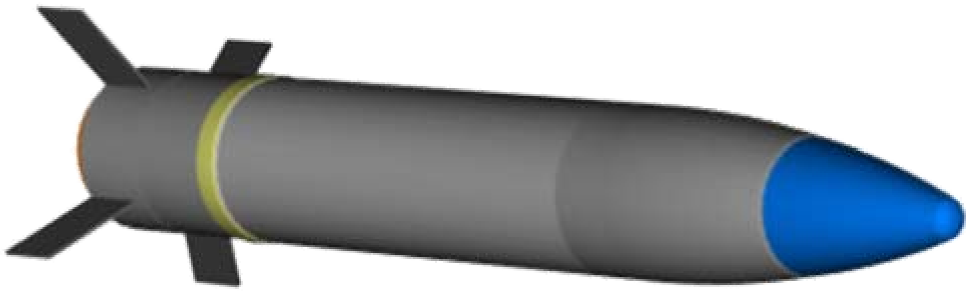
- 105-mm fin-stabilized projectile with rocket motor and general control mechanism studied in six degree-of-freedom simulation
- Guidance, navigation, and control (GNC) techniques
- Optimization of quadrant elevation, ignition time of rocket motor, start time of glide actuation
- Trade-offs in aerodynamic/control mechanism strategies

Configuration of Candidate Projectile

- 105-mm fin-stabilized projectile

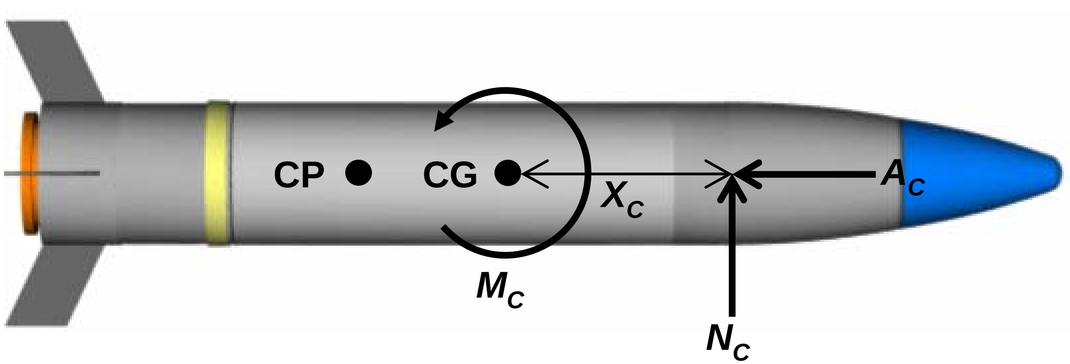
Mass (kg)	Axial Inertia (kg-m^2)	Transverse Inertia (kg-m^2)	Center of Gravity From Nose (mm)	Diameter (mm)	Overall Length (mm)
18.40	0.03199	0.5607	422.7	104.7	762.0

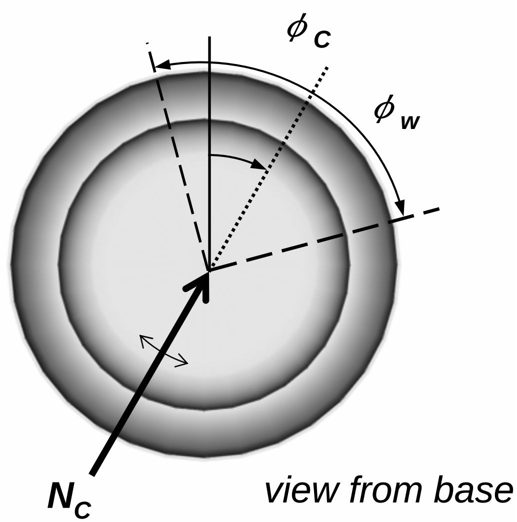
- Generalized control mechanism
- Solid grain rocket motor
  - 3.6 sec burn time
  - 491.8 N thrust
  - Variable ignition time



Modeling of Control Mechanism

- Control mechanism (canards, thrusters, etc.) modeled as axial control force (***A_C***), normal control force (***N_C***) with control moment arm (***X_C***), producing control moment (***M_C***).
- Maneuver direction of given control mechanism prescribed by commanded roll orientation (ϕ_C) and duration of roll cycle (ϕ_w).





Parameters and Metrics

- Fire control (max charge)
  - quadrant elevation (QE)
  - rocket ignition time (T_R)
  - glide start time (T_G)
- Projectile configuration
  - control normal force
  - control normal-to-axial force ratio
  - control axial location
  - static margin
  - roll window
- Metrics
  - extended range
  - total angle of attack (α_T)

GNC for Maximum Range

- Common sense: control normal force direction (ϕ_c) should be opposite gravity to maximize range.
- Problem: Projectile drift (interaction of gravity, spin, and pitching moment) can significantly bend the trajectory in the crossrange direction and reduce range.
- Solution: develop flight control system to maximize range while minimizing drift.

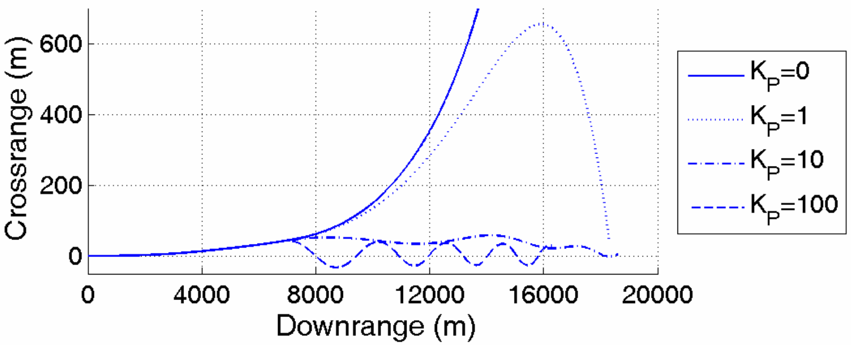
Flight Control Law for Maximum Range

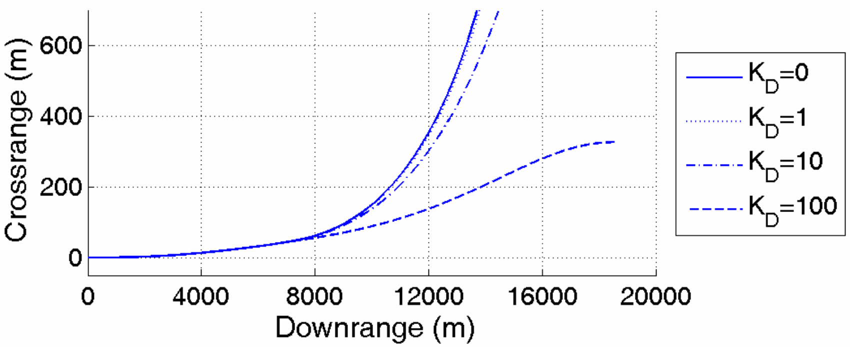
$$\varphi_C = \arctan\left(\frac{K_P e_y + K_D \dot{e}_y}{e_z}\right)$$

$$e_y = y_p - y_t \qquad \dot{e}_y = \dot{y}_p - \dot{y}_t \qquad e_z = z_p - z_t$$

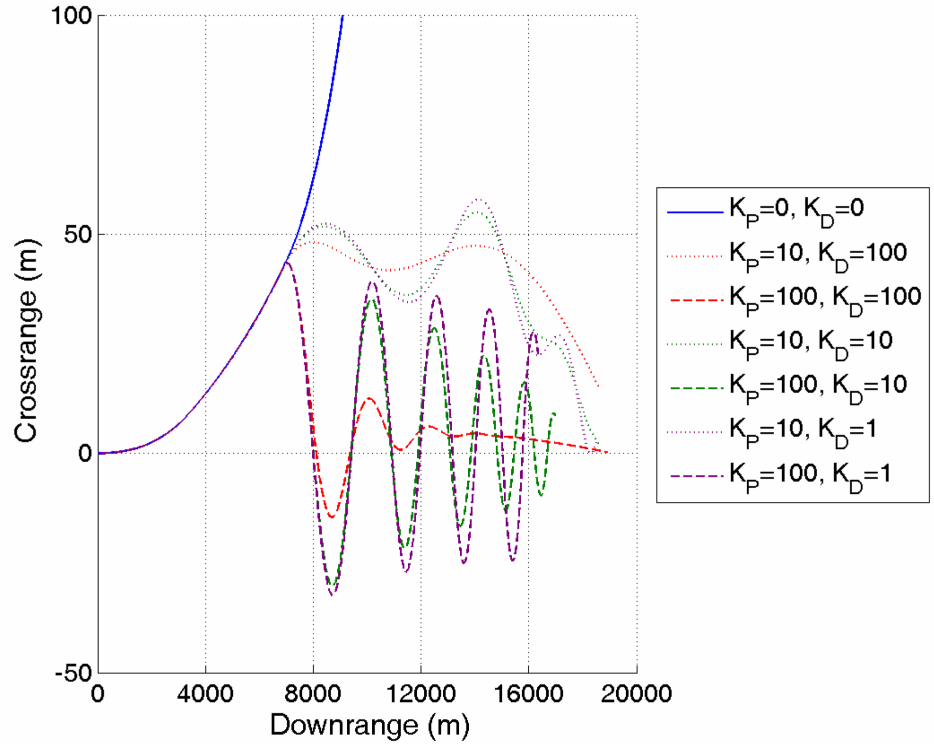
- Projectile inertial position (y_p, z_p) and velocity ($\dot{y}_p$) input from GPS, IMU, etc.
- Target inertial position (y_t, z_t) and velocity ($\dot{y}_t$) provided from fire control
- Proportional (K_P) and derivative (K_D) gains
- Flight controller seeks to maximize pitch angle of attack, minimize yaw angle of attack

Flight Control System Performance



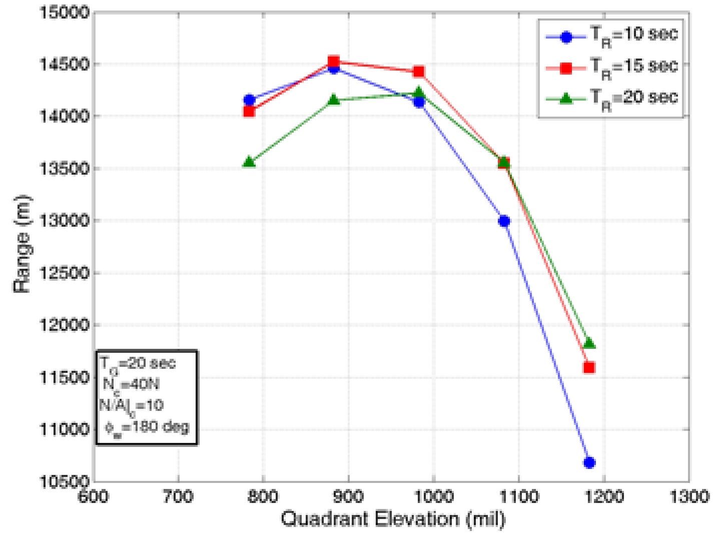


QE = 883 mils
T_R = 13 sec
T_G = 29 sec
N_c = 40 N
N_c / A_c = 10
X_c = 0.4 cal from CG
ϕ_w = 180 deg
static margin = 0.96

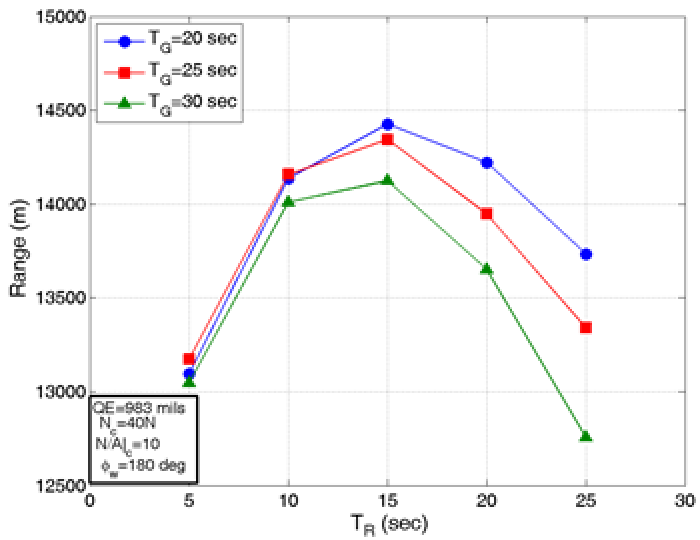


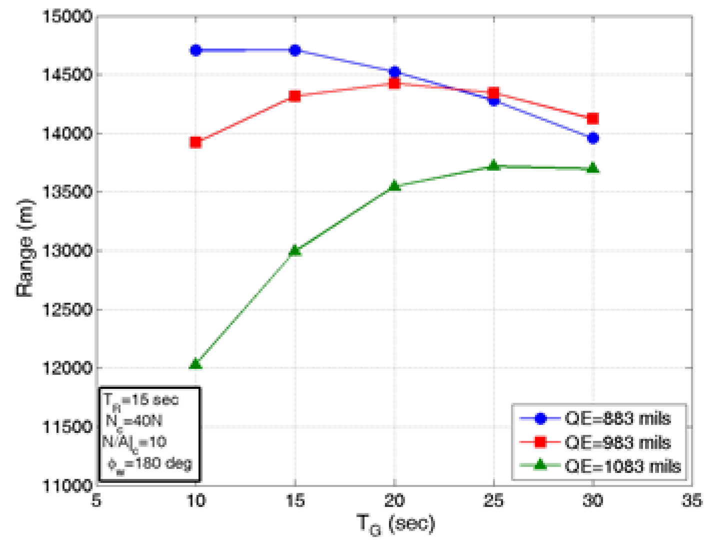
- 3000 m drift without GNC
- best combination of gains gets crossrange to zero without overcorrection and velocity heading along downrange axis (K_P=50, K_D=50).

Fire Control Parameters

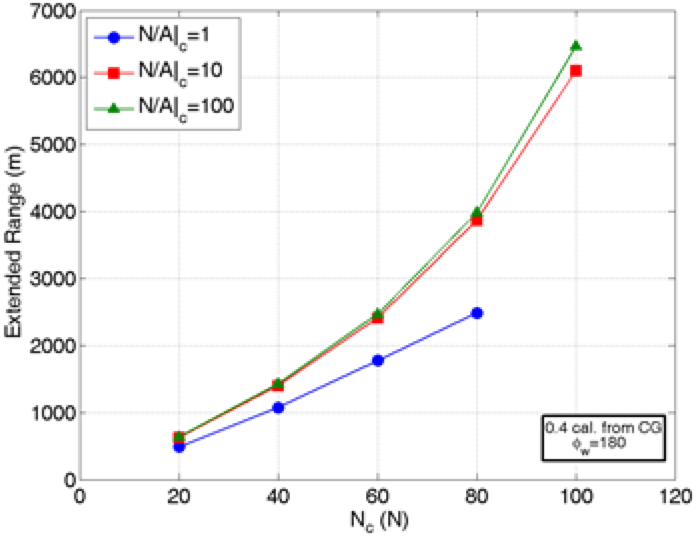


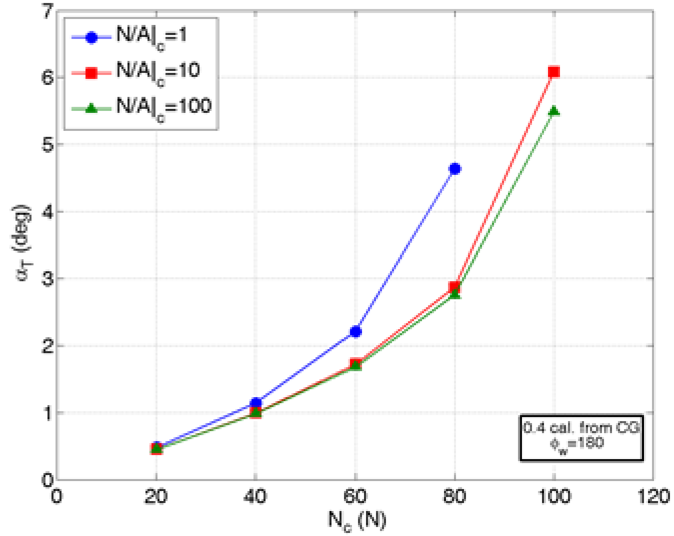
- optimize in parallel
- thrust/drag variation with atmospheric density for rocket ignition time
- lift/drag ratio of control mechanism for glide start time



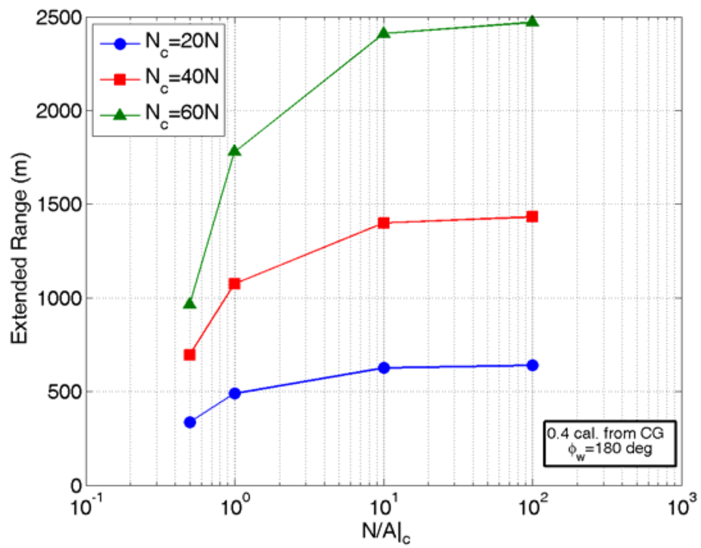


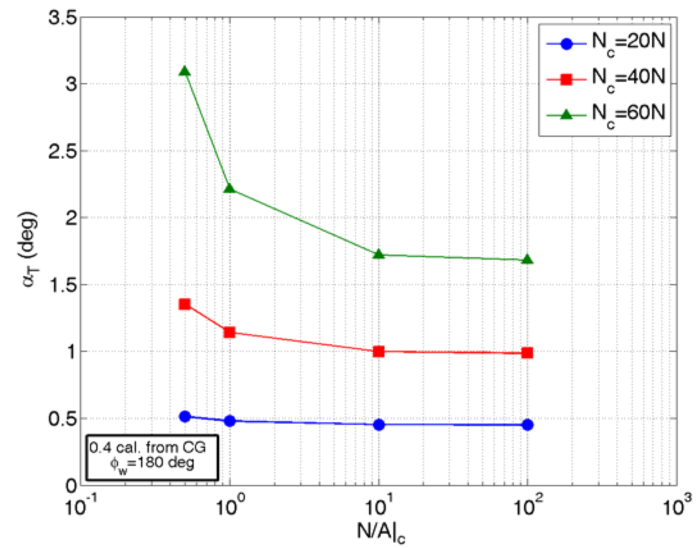
Projectile Parameters





- asymptotic behavior for range increase
- more drag results in lower dynamic pressure which induces higher angle of attack to balance control moment





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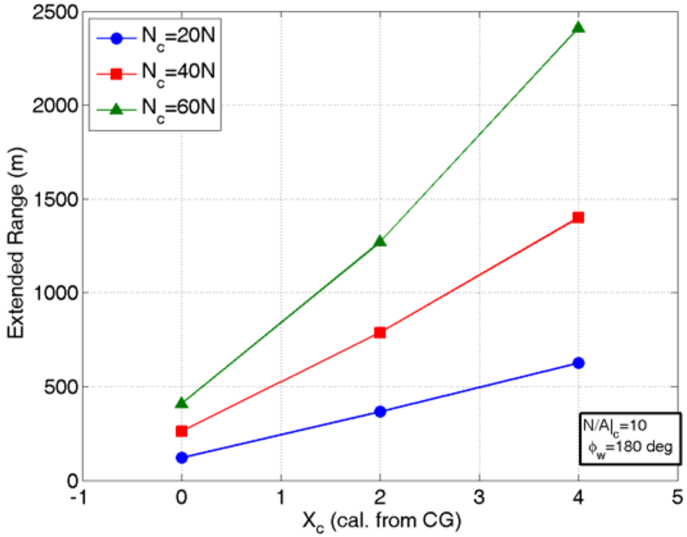
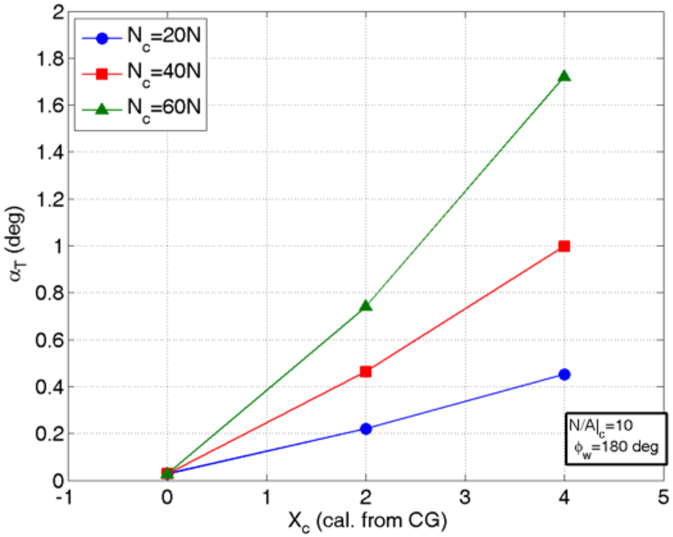
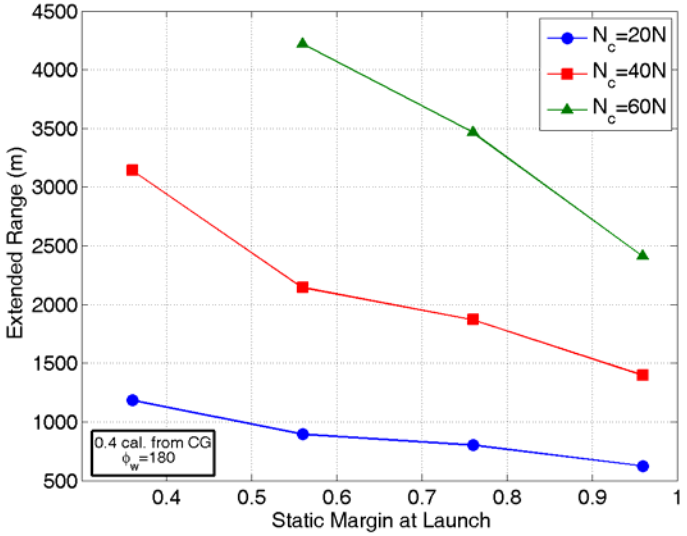
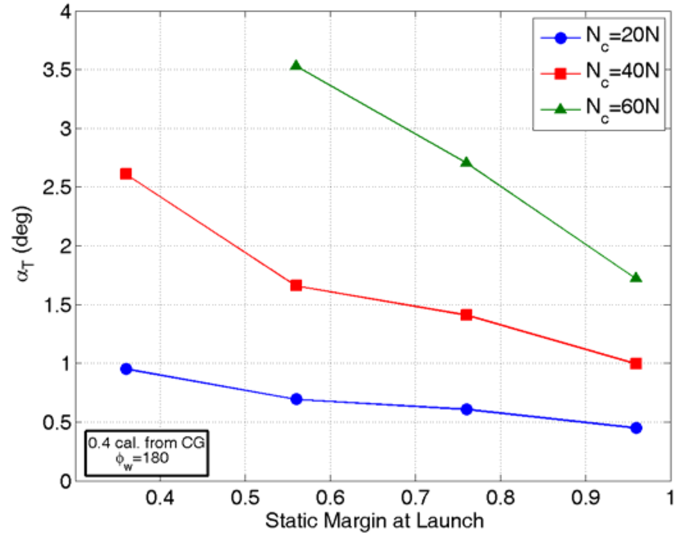




• range increases linearly with control moment arm

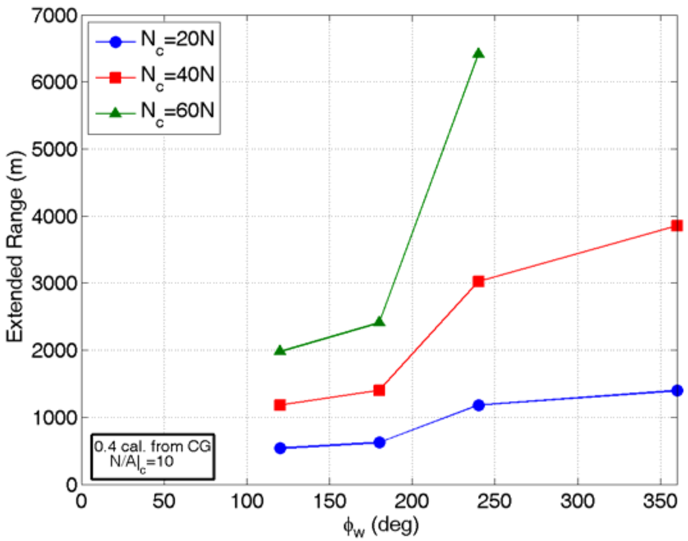
Projectile Parameters

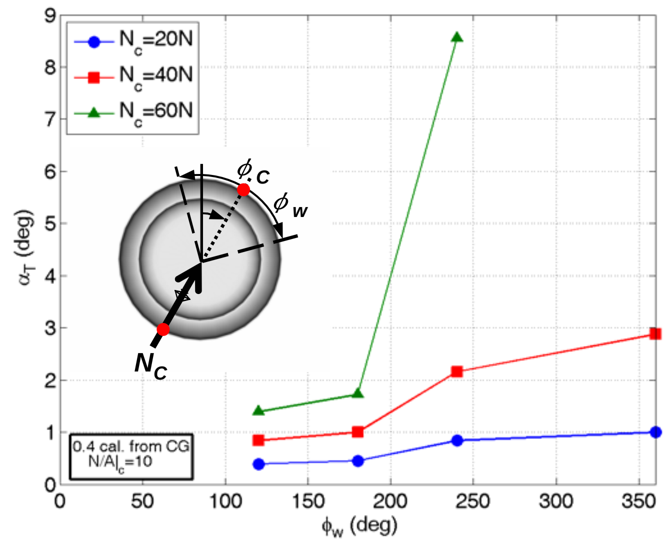




- lower static margin equals shorter moment arm for pitching moment to balance control moment

- adding more than one control element can significantly increase range





Summary

- Examined technical drivers to extending range of gun-launched precision munitions
  - fin-stabilized projectile with rocket motor and general control mechanism studied in six degree-of-freedom environment
  - Flight dynamics (projectile drift) required GNC algorithm development
    - maximize pitch angle and minimize yaw angle
  - Fire control parameters (QE, rocket ignition time, glide start time) must be optimized in parallel
  - Projectile configuration for maximum range: low static margin, large control normal force, control normal-to-axial force ratio of at least 10, control axial location at the nose, and large roll window

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