Modeling and Simulation for Guided Mortar Projectiles

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If you can't get a bigger target...

Requirements

- **Very Low Cost**
  <$15K

- **Survivability**
  Launch environments
  5K+ Gs

- **Form Factor**
  Limited space on small airframes

- **Spin Dynamics**
  Spin rates from 5 – 250 Hz

GNC Design

- **Reduced Sensing**
  Sensors are inaccurate or nonexistent

- **Reduced Control**
  Actuators are simple, axes are coupled

- **Novel Guidance Algorithms**
  Must be robust for compatibility with reduced sensing and control

High fidelity modeling and simulation is critical for the success of guided projectiles!
GNC Design - 60mm Guided Mortar

- Larger fins for lift, stability, and roll
- Standard Mortar Body
- Extended Ogive for GNC Components

Reduced Control
Canards with Limited Actuation
Reduced Sensing
GPS-Only w/ Roll Angle Output
Flight CONOPS

1. Drop in Tube
2. GPS Acquisition
3. Canards Deploy
4. Begin Guidance
5. Terminal Guidance
6. Target
• Guidance algorithm must take advantage of ballistic trajectory
• Do not want to fight gravity
• Additional trajectory shaping can improve angle of fall
Aerodynamic Model

**Direct Table Lookup Coefficients**
- Extremely versatile – capture any asymmetries and nonlinearities
- Wind tunnel / CFD compatible format
- High angle of attack

\[
F_z = \bar{q}A \left( C_z + \frac{pd}{2V} C_{zp} + \frac{qd}{2V} C_{zq} \right)
\]

\[
m = \bar{q}Ad \left( C_m + \frac{pd}{2V} C_{mp} + \frac{qd}{2V} C_{mq} \right)
\]

**Polynomial Approximations**
- Physics-based simplifications
- Spark range / aero predictor compatible format
- Flight test data reduction parameter fits

\[
F_z = \bar{q}A \left( - \left[ C_{N\alpha} + C_{N\alpha3} \sin^2 \bar{\alpha} \right] \frac{w}{V} - \frac{pd}{2V} C_{\alpha p} \frac{v}{V} + \frac{qd}{2V} C_{Nq} \right)
\]

\[
m = \bar{q}Ad \left( \left[ C_{m\alpha} + C_{m\alpha3} \sin^2 \bar{\alpha} \right] \frac{w}{V} + \frac{pd}{2V} C_{np\alpha} \frac{v}{V} + \frac{qd}{2V} C_{mq} \right)
\]
Error Budget

- **Body States**
  - Muzzle Velocity
  - Tipoff
  - WLE
  - QE
  - Azimuth

- **Mass Properties**
  - Mass
  - CG
  - Axial Inertia
  - Transverse Inertia

- **Aerodynamics**
  - Drag
  - Magnus
  - Lift
  - Pitching Moment
  - Pitch Damping

- **Rocket Motor**
  - Ignition Time
  - Torque
  - Thrust

- **Environment**
  - Temperature
  - Wind Magnitude
  - Wind Direction
  - Pressure

- **GNC**
  - Sensor Biases
  - Actuator Disturbances
  - Noise
  - Modeling Errors

- 3 Types: Mission-to-Mission, Weapon-to-Weapon, Round-to-Round
Accuracy Results

- Monte Carlo trials based on error budget
- CEP50 vs. CEP90
- Randomizing
  - Missions
  - Weapons
  - Rounds
PRODAS Environment

**Modeling**
- Projectile Modeler
- Aero Prediction
- Mass Properties
- Rocket Motor
- Initial Conditions
- Error Budgets
- MET

**Visualization**
- 3D Animations
- Extensive Plotting

MATLAB/Simulink Environment

**Development**
- Leverage All MATLAB/Simulink Toolboxes and Blocksets
- Focused Effort on GNC Design

**Simulation**
- Validated 6+DOF Trajectory Engine
- Seamless Data Interface and Execution Between PRODAS and MATLAB

Product Tests

**Hardware-In-the-Loop (HIL)**
- Use the same simulation to drive the HIL fixture

**Embedded Code Generation**
- Automatically generate flight code from the Simulink model

**Fire Control**
- Simulation software is the basis of fire control software