United Defense

Modeling Efforts for Autorotation Delivery System Concept Development

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**** Autorotation Delivery Systems is patent pending***

Presentation

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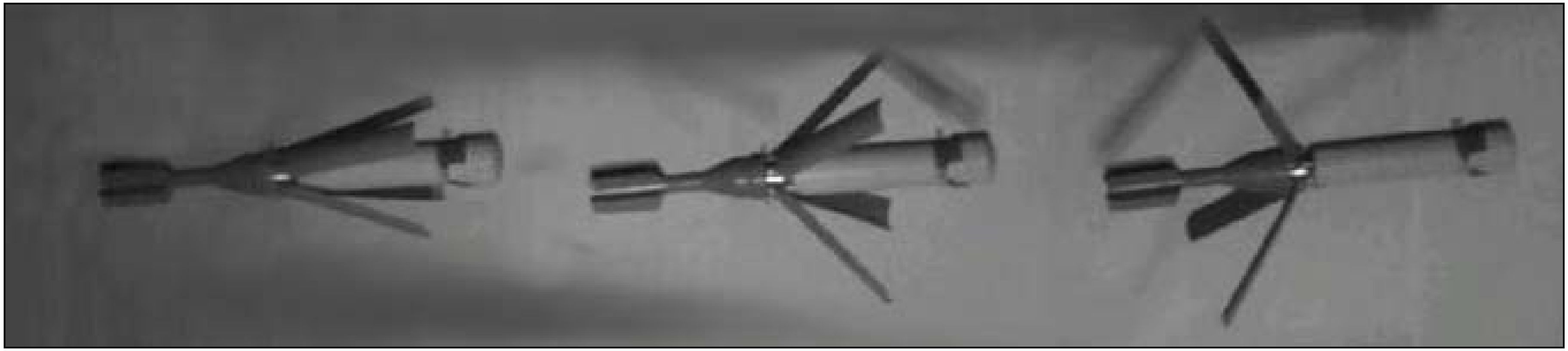
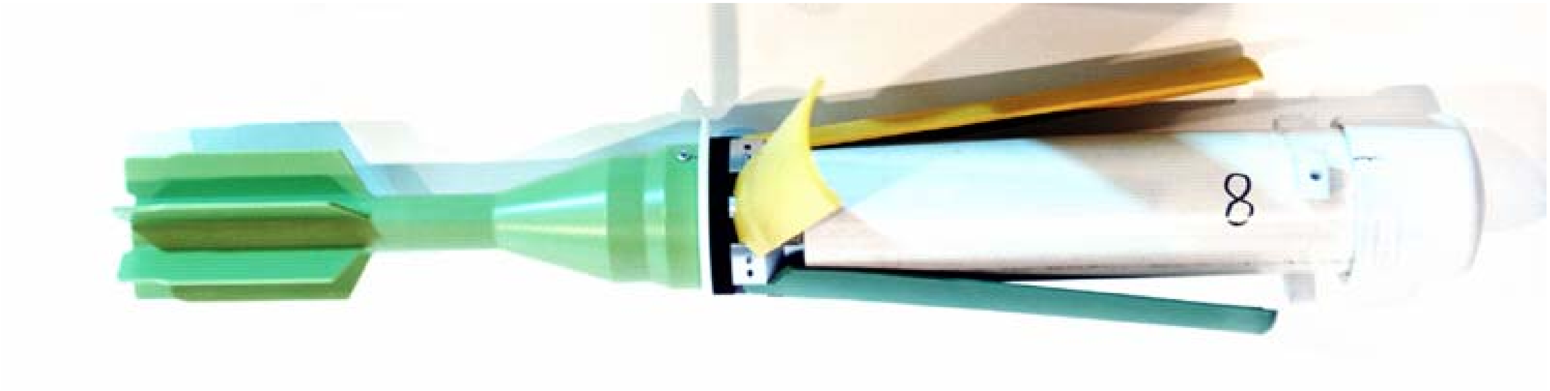
- Overview
- Deployment Sequence
- Applications
- Modeling Performed
- Axisymmetric Model
- BOOM Model
- Summary and Video



Overview

- The Autorotation Delivery System, formerly known as Projectile Kinetic Energy Reduction System (PKERS), is a concept developed by United Defense as an autorotation decelerator for high-value tactical payloads
- Combines a projectile body with a deployable rotor that reduces descent velocity via autorotation
- Modeling and simulation will facilitate the optimal design process during each stage of development



Deployment Sequence

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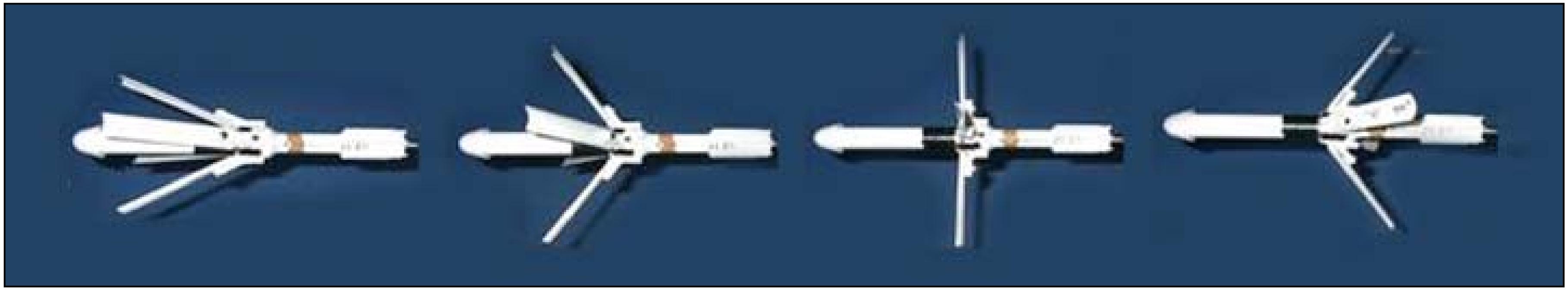
- Rotors stowed conformal to the sides of projectile body prior to deployment
- During deployment, rotors rapidly rotate outward due to projectile spin and aerodynamic drag
- Transition to autorotation occurs as the rotor blades become aerodynamically loaded coupled with an increasing spin rate
- System attains a steady descent velocity when the inertial and aerodynamic forces reach equilibrium



Applications

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- United Defense is developing the Autorotation Delivery System as an alternative to conventional parachutes for certain applications
- Flight characteristics and descent velocities are tailorable for different missions and payloads *(e.g., land and sea sensors, cargo, battle damage assessment, munitions)*
- Can be gun launched, mortar launched, or air dropped
- Modular design allows accommodation of all the necessary components required for precision guidance

First Generation Autorotation Delivery System integrated with Talley SMAW-D Motor

Modeling Performed

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- An axisymmetric spreadsheet-based model was developed to estimate the dynamics and loads as the rotors initially open and impact the damper
- A detailed flight mechanics model was developed and integrated into the BOOM smart weapon simulation system to model the flight dynamics from initial rotor deployment to full autorotation

Axisymmetric Model:
Initial Deployment

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- The Axisymmetric Model is a quasistatic spreadsheet-based concept development tool
  - Allows estimates of system performance and parametric studies
  - Assumes symmetry about the longitudinal spin axis, zero spin rate, and conservation of rotor angular momentum
  - Provides 2 Degrees of Freedom (DOF) for the projectile body (forward velocity and spin) and 1 DOF for each rotor blade (deployment angle)

Aerodynamic Load Calculation

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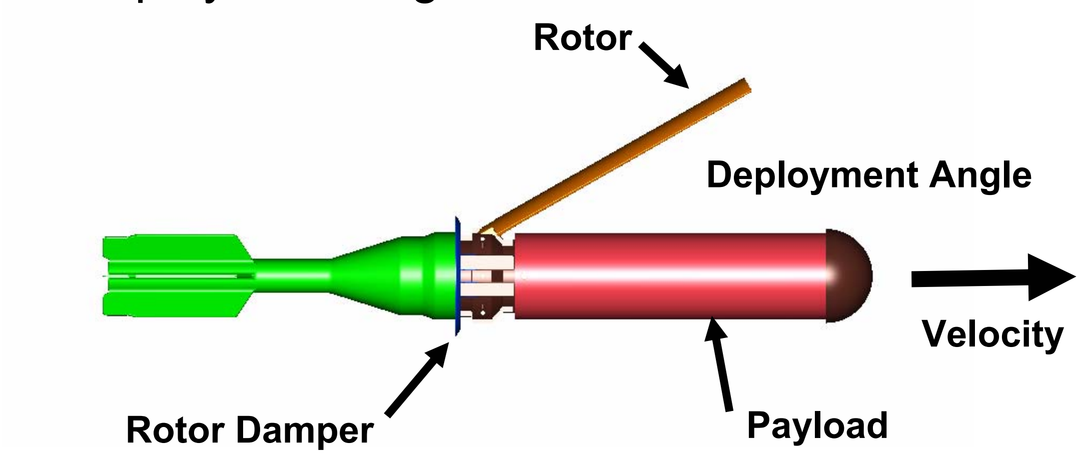
- Axisymmetric model assumptions:
  - Centrifugal loads due to flight element spin are a minor contributor during initial rotor opening (zero spin assumed)
  - Flight element velocity constant during initial deployment (worst case)
  - Aerodynamic drag is then a function of deployment angle
- Calculate upper limit on rotor force and moment about rotor hinge as a function of deployment angle



Aerodynamic Loads on Rotor

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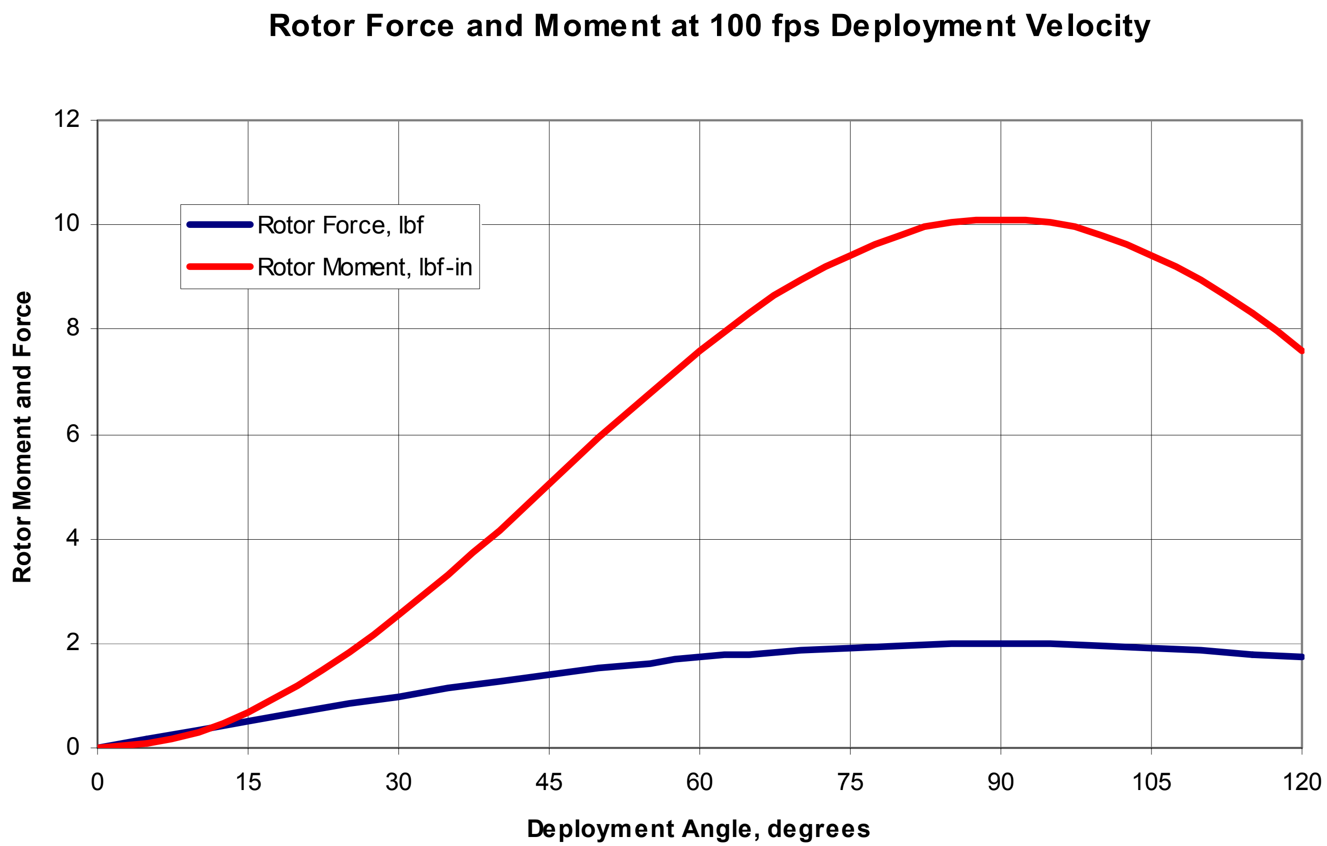

Calculation of Damper Force

- Worst case rotor loads accelerate the rotor open until they impact the damper at approximately 120 degrees
- Opening moment is numerically integrated versus deployment angle to get the angular momentum at initial impact with damper
- Corresponding kinetic energy is absorbed by the damper
- Maximum damper force is calculated for multiple damper locations, shapes, and materials to optimize design

Rotor Bending Stress Results

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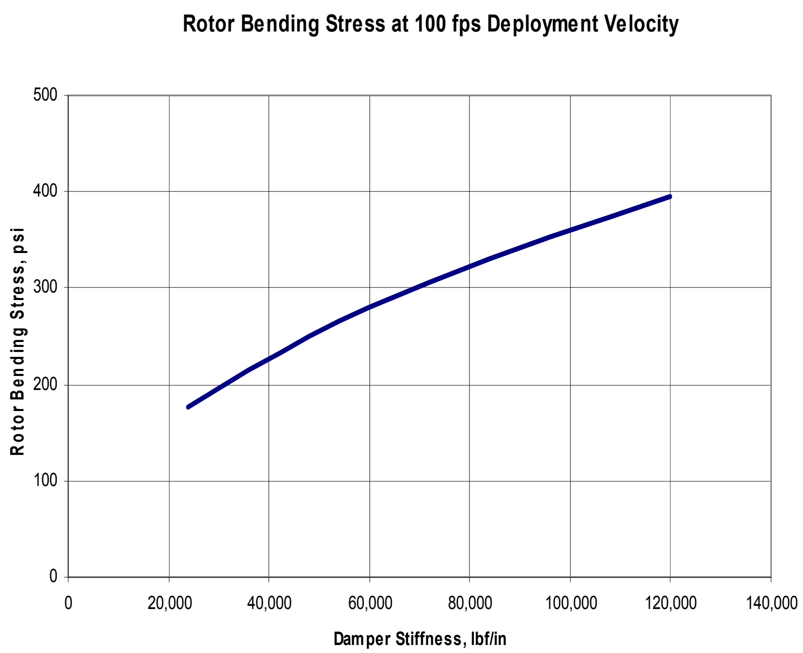
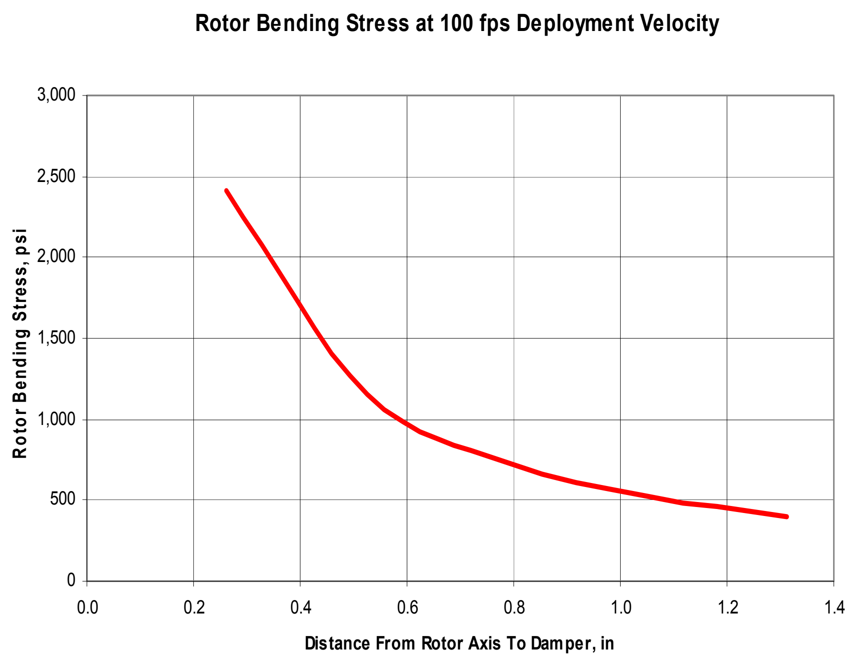
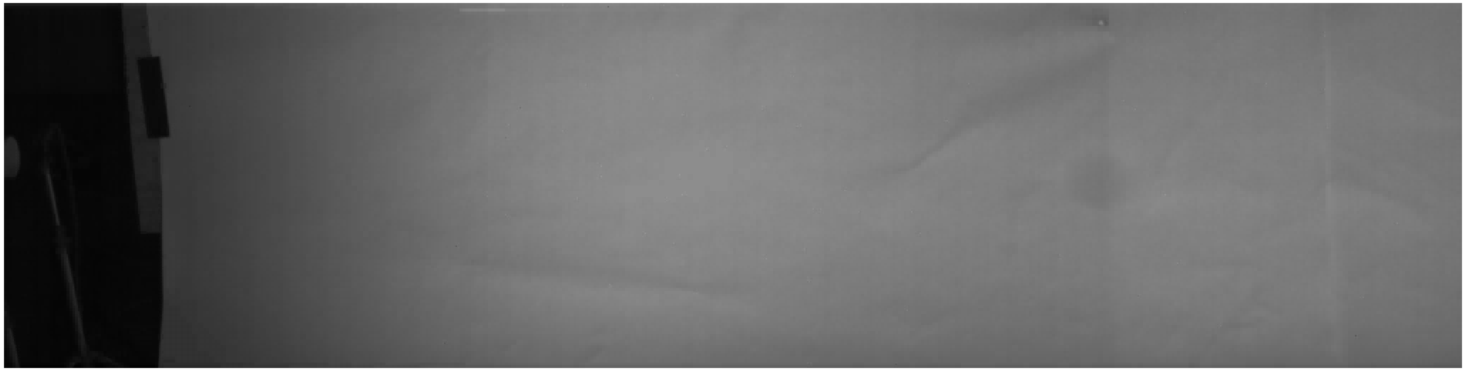




Worst case force is used to design rotors so they can safely survive the bending stress during initial deployment

Rotor Deployment Video

Camera 2:
0 – 12’



Camera 3:
12 – 24’

Camera 4:
24 – 36’

BOOM Model:
Detailed Flight Dynamics

- The BOOM model is a detailed design and development tool
  - BOOM is a smart weapon simulation system
  - Full model of the delivery system flight mechanics was developed and integrated into BOOM
  - Provides 6 rigid-body DOF for the projectile body (flight element center of gravity position and orientation angles), 1 DOF for each rotor blade (deployment angle), and a 3-state rotor dynamic inflow representation

BOOM Model Description

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- Aerodynamic loads on the projectile body are a function of angle of attack and Mach number
- Aerodynamic forces and moments on the rotors are computed using blade element theory; airfoil lift and drag coefficients are a function of local rotor section angle of attack and Mach number
- BOOM simulations then provide the dynamics of the system as a function of time
- The simulation presented here has the following initial conditions:
  - Linear velocity 43 m/s (141ft/s)
  - Spin (Roll) rate 20 rad/s (3.2 rev/s)
  - Deployment angle fixed at 90 degrees

BOOM Model Rotor Kinematics

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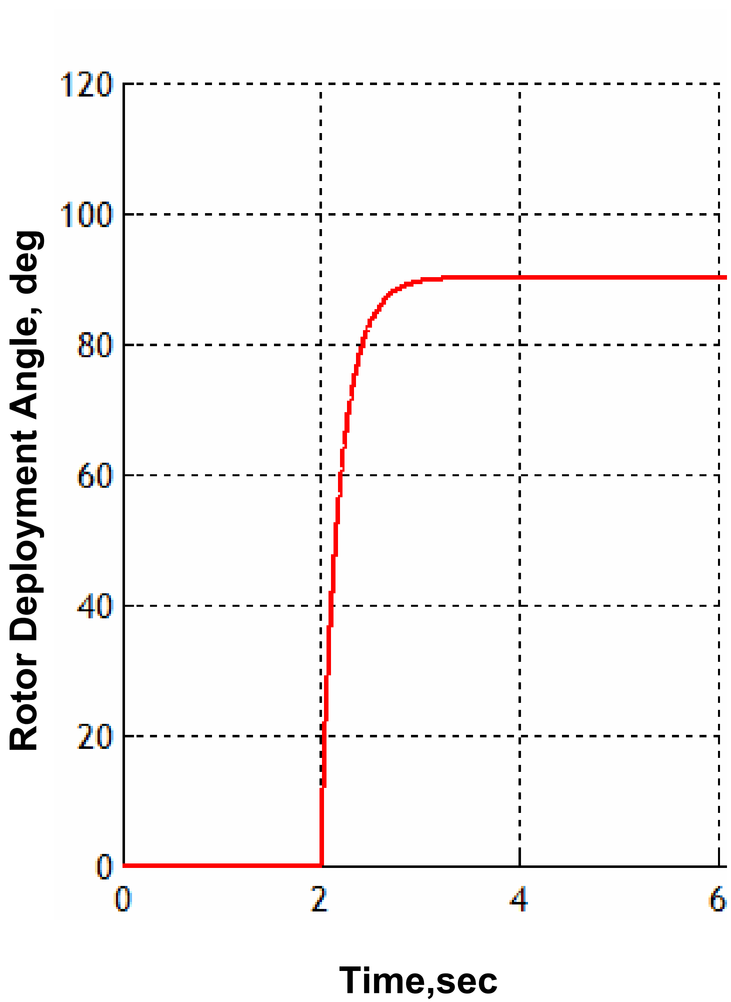

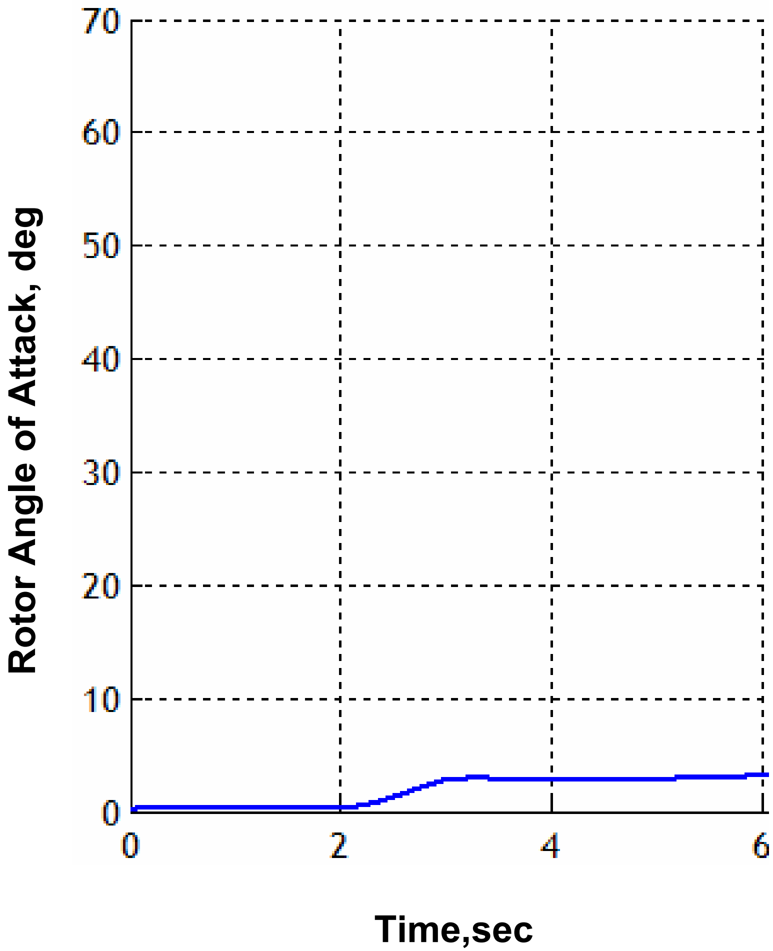

BOOM Model Top View Animation

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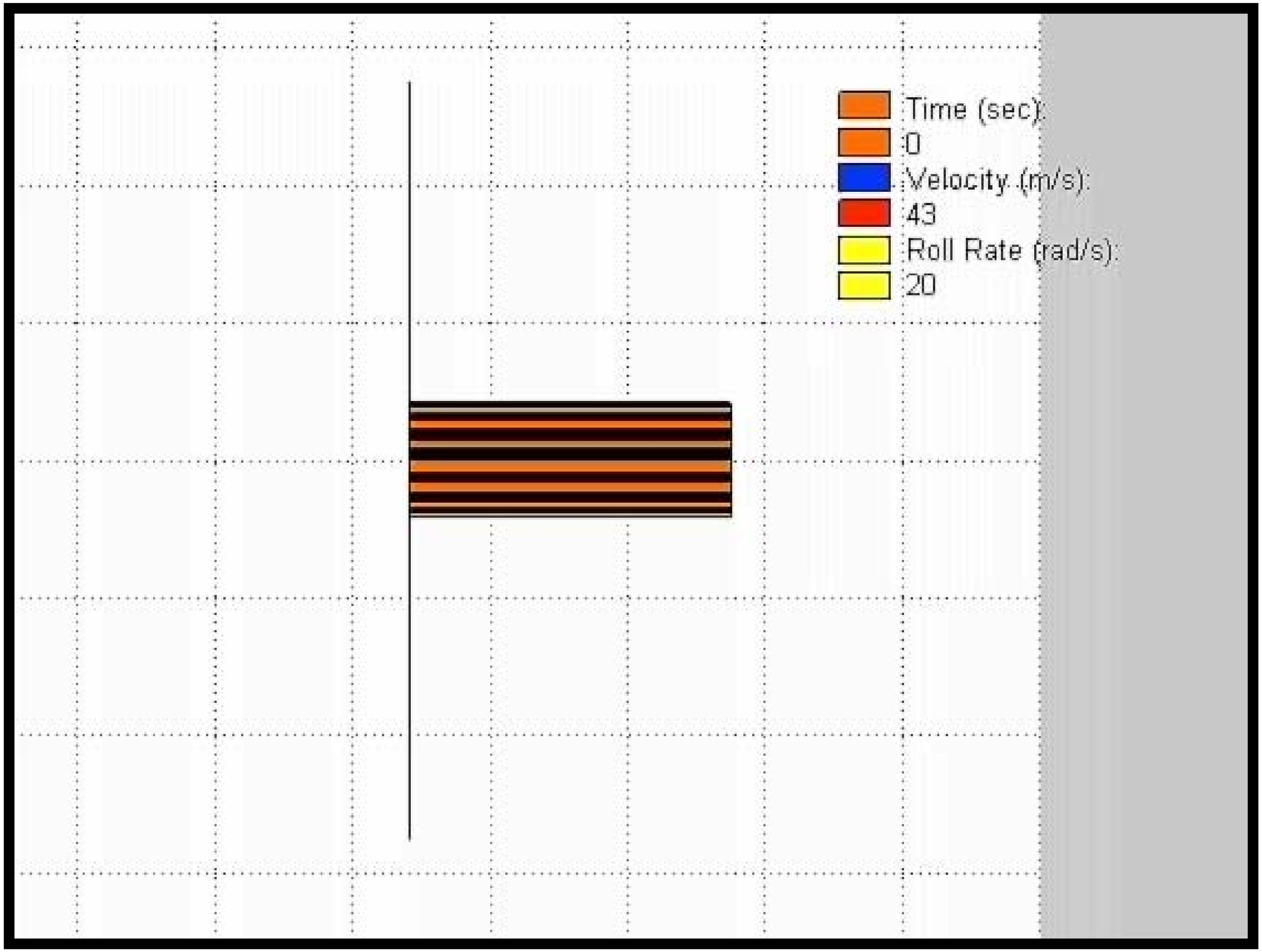

BOOM Model Results

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- BOOM model results indicate that the concept will deploy in a manner consistent with flight tests
- Model has not been validated yet. Validation with test data is planned for the future, making the model capable of supporting future design, flight control system development, and payload integration
- This simulation assumes that all rotors have the same deployment angle at any time; this causes a short numerical instability that's not present in the actual system
- Model to be modified to allow each rotor to have different deployment angles

Summary and Video

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- Test configurations have proven to be robust enough to survive deployment stresses
- Additional development, testing, and demonstration is planned to validate the 6-DOF model and applications
- Exploring a variety of Payloads and Applications
  - Sensors, Cameras, Munitions
  - Reconnaissance, Surveillance, Repeaters