Modeling Efforts for Autorotation Delivery System Concept Development

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* Autorotation Delivery Systems is patent pending
Presentation

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

- 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
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.
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.
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

- 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

Rotor Force and Moment at 100 fps Deployment Velocity

Deployment Angle, degrees

Rotor Moment and Force

- Rotor Force, lbf
- Rotor Moment, lbf-in
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.
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’
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
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 (141 ft/s)
- Spin (Roll) rate 20 rad/s (3.2 rev/s)
- Deployment angle fixed at 90 degrees
BOOM Model Rotor Kinematics

![Graphs showing rotor deployment angle and rotor angle of attack over time.](image-url)
BOOM Model Top View Animation
BOOM Model Results

- 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.
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