U.S. Army Research, Development and Engineering Command

DESCENT Modeling in Rotorcraft Vulnerability Assessment

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Mission Background

- Army Research Laboratory's Survivability/Lethality Analysis Directorate (ARL/SLAD) performs survivability/vulnerability analyses on Army vehicles, including rotorcraft

- An important factor in rotorcraft vulnerability analyses is the outcome of a ballistic event that leads to reduced or zero levels of available power

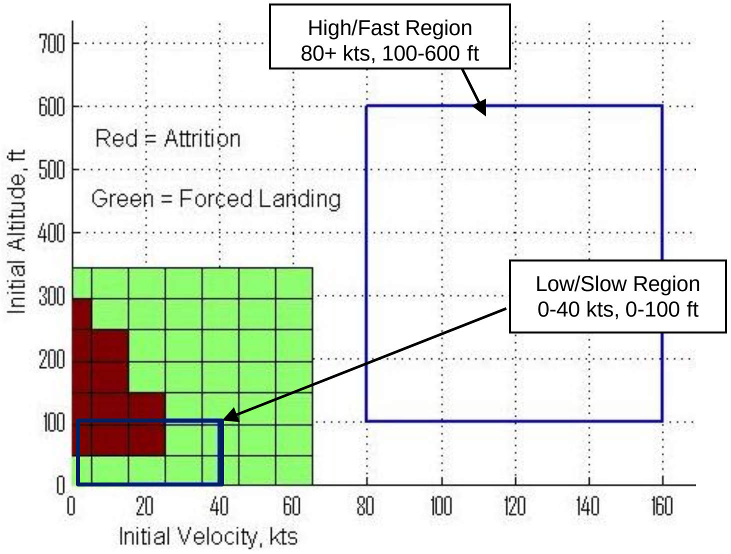
- Modeling of the post-event transition to one-engine-inoperative (OEI) flight or an autorotative impact is used to quantify the rotorcraft outcome

Outcome Definition

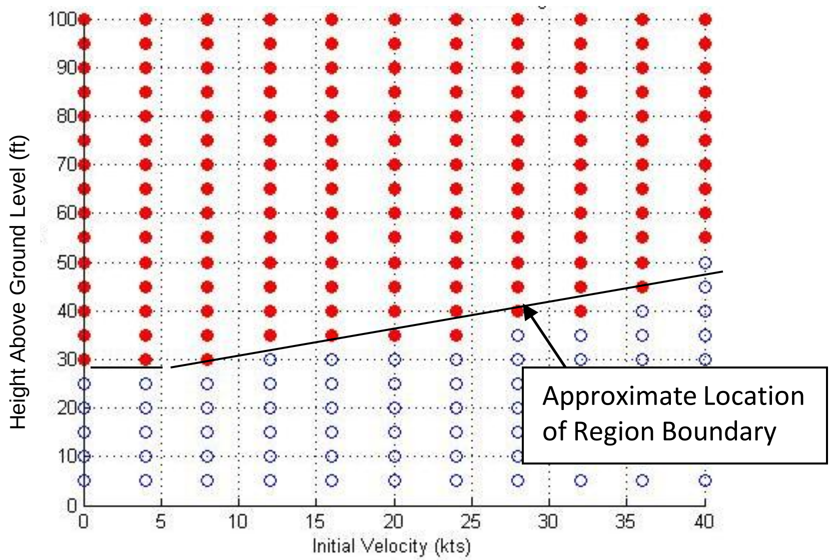
- The outcome of a power-loss ballistic event is binned into one of three “kill categories”:
  - Mission Abort (MA)
    - The rotorcraft is able to transition to steady, level flight from its flight conditions at the time of the event
    - It can return to base for repair
  - Forced Landing (FL)
    - The rotorcraft is forced to perform an immediate, but controlled, landing
    - This is the equivalent of a successful autorotation; repairs may be performed on the ground as necessary
  - Attrition (Att)
    - The rotorcraft’s impact velocity exceeds the designated critical velocity for avoiding extensive structural damage
    - Repairs are not feasible, and the vehicle is removed from inventory

Analysis Domains

- Outcomes are modeled in two distinct regions of the rotorcraft's flight envelope
  - High/Fast (H/F):
    - Above 80 kts initial ground speed
    - Between 100-600 ft above ground level
  - Low/Slow (L/S):
    - Below 40 kts initial ground speed
    - Below 100 ft above ground level
- A power-loss event will be modeled at many height/ velocity points throughout each region, and a kill category assigned at each point



Compiling Results



- The percentage of the area of a given region occupied by points binned into each kill category is the kill probability (P_k) for the rotorcraft in that region for that level of power loss
- In the example shown, since about 72% of the Low/Slow region shows an Attrition (red), and 28% shows a Forced Landing (white), the P_k will be:
  - Low/Slow (Zero Power Remaining)
    - MA 0.00
    - FL 0.28
    - Att 0.72

Using the Results

- In this example, the DESCENT model predicts that for total power loss anywhere in the Low/Slow flight region, there is a 72% probability of Attrition and a 28% probability of Forced Landing

- This probabilistic approach allows us to compute P_k inputs before vehicle-level vulnerability modeling occurs and speeds up the processing of the survivability/vulnerability analysis

Model Development

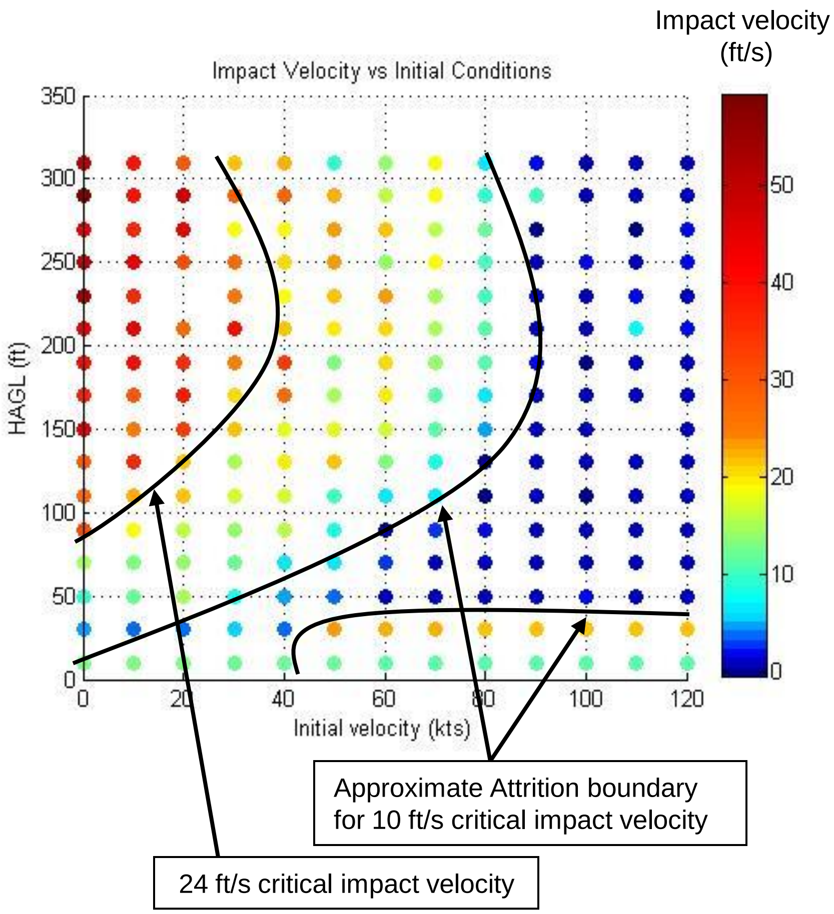
- DESCENT is a rotorcraft flight optimization script developed by ARL/SLAD and ARL’s Vehicle Technology Directorate (ARL/VTD)
- The optimization engine is SNOPT, a sparse-matrix non-linear optimization algorithm written at Stanford University
- DESCENT’s aerodynamic model is a 2-D actuator disk that allows two degrees of control freedom: lift coefficient, which roughly corresponds to collective pitch, and disk tip-path-plane pitch, which corresponds to longitudinal cyclic

Flight Path Optimization

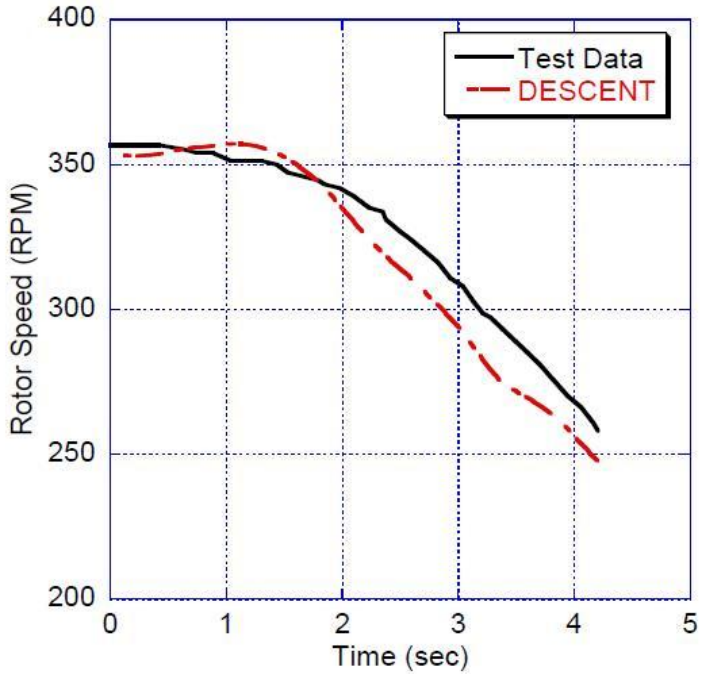
- DESCENT begins by assuming the controls are set in the trimmed condition for steady, level flight
- SNOPT, running internally, iteratively improves upon that assumption by perturbing the pilot controls (collective and longitudinal cyclic pitch) and “grading” the resulting flight path against an objective function and a set of inviolable constraints
  - Constraints enforce both physical restrictions, such as the rate at which drag slows rotor speed, and characteristics specific to the rotorcraft being modeled
  - The objective function quantifies whether the flight path is an improvement (i.e., exhibits a lower impact velocity) than the previous iteration
- DESCENT finishes when it is established that either 1) a transition to partial-power flight is possible, 2) autorotation to impact at less than a critical velocity is possible, or 3) the flight path is fully optimized without success (Att)

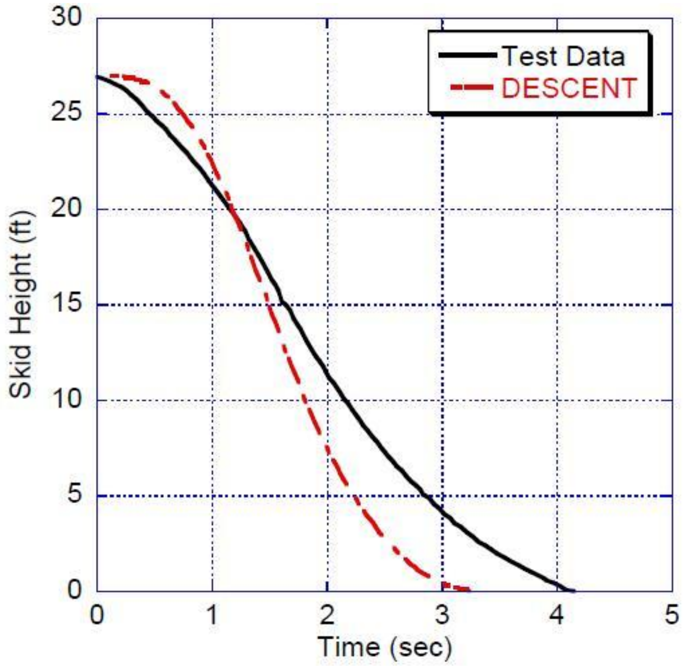
Height-Velocity Diagram

- Comparing DESCENT modeling predictions of rotorcraft autorotation to manufacturer's height-velocity diagram is an accuracy check
- DESCENT-produced diagrams consistently present the same trends as the standard "dead man's curve" with similar no-fly regions
- Differences in the curves are often due to different assumptions about pilot experience and damage tolerance



V&V Work (Case Studies)

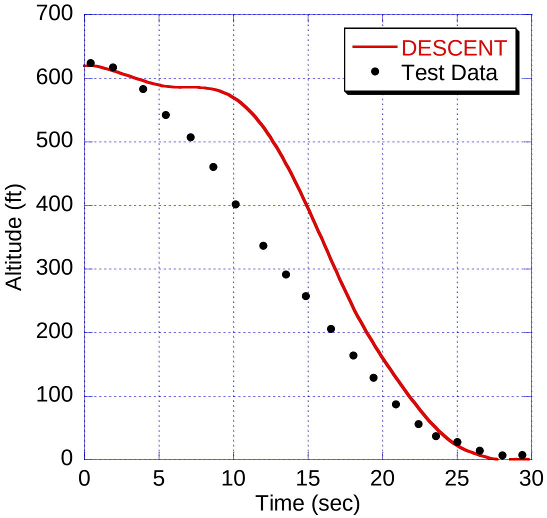


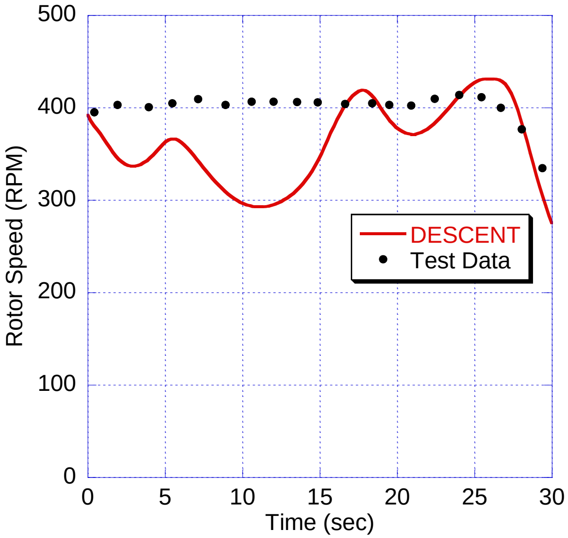


- DESCENT verification and validation work shows good correlation to flight test data state variables in most cases
- A comparison to modified OH-58 autorotation test is shown

Case Studies cont.

- However, other cases demonstrate the need for well-defined constraints and objective (grading) function
- DESCENT identifies a flight path that satisfies the critical velocity requirement and exits (upper graph); nevertheless, the state variables might not match the flight test (lower graph)
- This discrepancy points to differences among a suitable control strategy, an optimal control strategy, and the actual control strategy from test data





Conclusions

- DESCENT shows good correlation to manufacturer-provided "no fly" curves in identifying Attrition regions
  - Flexibility to assess effect of design changes on vulnerability
- While there is often no single "right" autorotation path, using DESCENT as a predictive tool for flight path details in each particular case is still subject to empirical results
  - Semi-empirical application is possible given enough data to inform constraints and objective function
  - Flight path data often shows considerable variability
- Identifying commonalities between autorotation paths will help transition from aggregate analyses to particular cases