Applying Space Safety Methodology to Unmanned Aerial Vehicle Risk Assessments

Lessons Learned

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Discussion Topics

- Public risk drivers
- Space Launch Vehicle vs. UAV Risk Modeling
  - Failure histories
  - Debris Properties
  - Affected population
  - Failure response modes
  - Impact dispersion
  - Trajectories and flight paths
- Estimating and presenting public risk for UAVs

Public Risk Drivers

Primary

- Mission failure probability
- Debris
  - Debris lists
  - Probability of occurrence
  - Casualty area
- Population density

Secondary

- Failure response modes
- Impact dispersion
- Flight path

Space Launch vs. UAV Risk Modeling
Mission Failure Probability (P_f)

Space Launch

- Slow launch rate causes slow changes to P_f
- Typically a small dataset from which to derive statistically valid estimates
- Each launch has an updated P_f

UAV

- Due to high rate of flight hours gathered and multiple mishaps, P_f changes daily
- Extensive flight data results in the P_f reaching equilibrium quickly
- Establish a schedule on which to update P_f for analysis purposes

Risk analyses must allow for constantly changing P_f values

Space Launch vs. UAV Risk Modeling
Debris Properties

Space Launch

- Many debris lists
  - Engine or fuel tank explosion
  - Aerodynamic breakup
  - Flight termination system
  - Intact impact
- Debris tends to be small tank, structure, or electronic fragments
- Few fragments will experience a high degree of lift

UAV

- Large majority of UAV failures are from intact impacts with a high number of secondary fragments
- In-flight breakup scenarios generate small number of high lift fragments

Fragment number vs. vehicle weight charts used in space launch analyses cannot be used for UAVs

Space Launch vs. UAV Risk Modeling
Population Density

Space Launch

- Detailed launch area population density is available for space launch sites
- Global population models are used successfully for overflight risk assessments

UAV

- Requires detailed population model for each airfield to properly assess risk
- APT devised a method of creating a hyper-local population model without detailed site assessments
- Sensitive locations (schools, hospitals) must be identified

Detailed launch area data is too time consuming to generate and global data is too granular

Space Launch vs. UAV Risk Modeling
Population Density

Cecil Airfield, Jacksonville, Florida

Space Launch vs. UAV Risk Modeling
Failure Response Modes

Space Launch

- Mode 1: Vehicle topples over or falls back on the launch point after a rise of, at most, a few feet
- Mode 2: Vehicle loses control immediately or shortly after liftoff, with all flight directions equally likely
- Mode 3: Vehicle fails to pitch-program normally, producing near-vertical flight

UAV

- Mode 1: Vehicle explodes at throttle up for takeoff after movement of, at most, a few feet
- Mode 2: Vehicle loses control immediately or shortly after throttle up for takeoff. The vehicle will either skid to a stop or impact an obstruction and explode after impact.
- Mode 3: Vehicle either fails to climb or impacts the ground shortly after takeoff

Space Launch vs. UAV Risk Modeling
Failure Response Modes

Space Launch

- Mode 4: Vehicle flies within normal limits until some malfunction terminates thrust, causes spontaneous breakup, or produces a rapid tumble that results in immediate destruct action
- Mode 5: Vehicle may impact in any direction from the launch point within its range capability
- Mode 6: Normal flights and normal impacts of separated stages and components

UAV

- Mode 4: Vehicle flies within normal limits until some malfunction causes loss of stability, causes spontaneous breakup, or causes the vehicle to explode
- Mode 5: Vehicle may impact in any direction within its flight range capability
- Mode 6: Successful mission, normal impacts of separated stages and components (where applicable), and failures that lead to successfully executed abort events

Space Launch vs. UAV Risk Modeling
Impact Dispersion

Space Launch

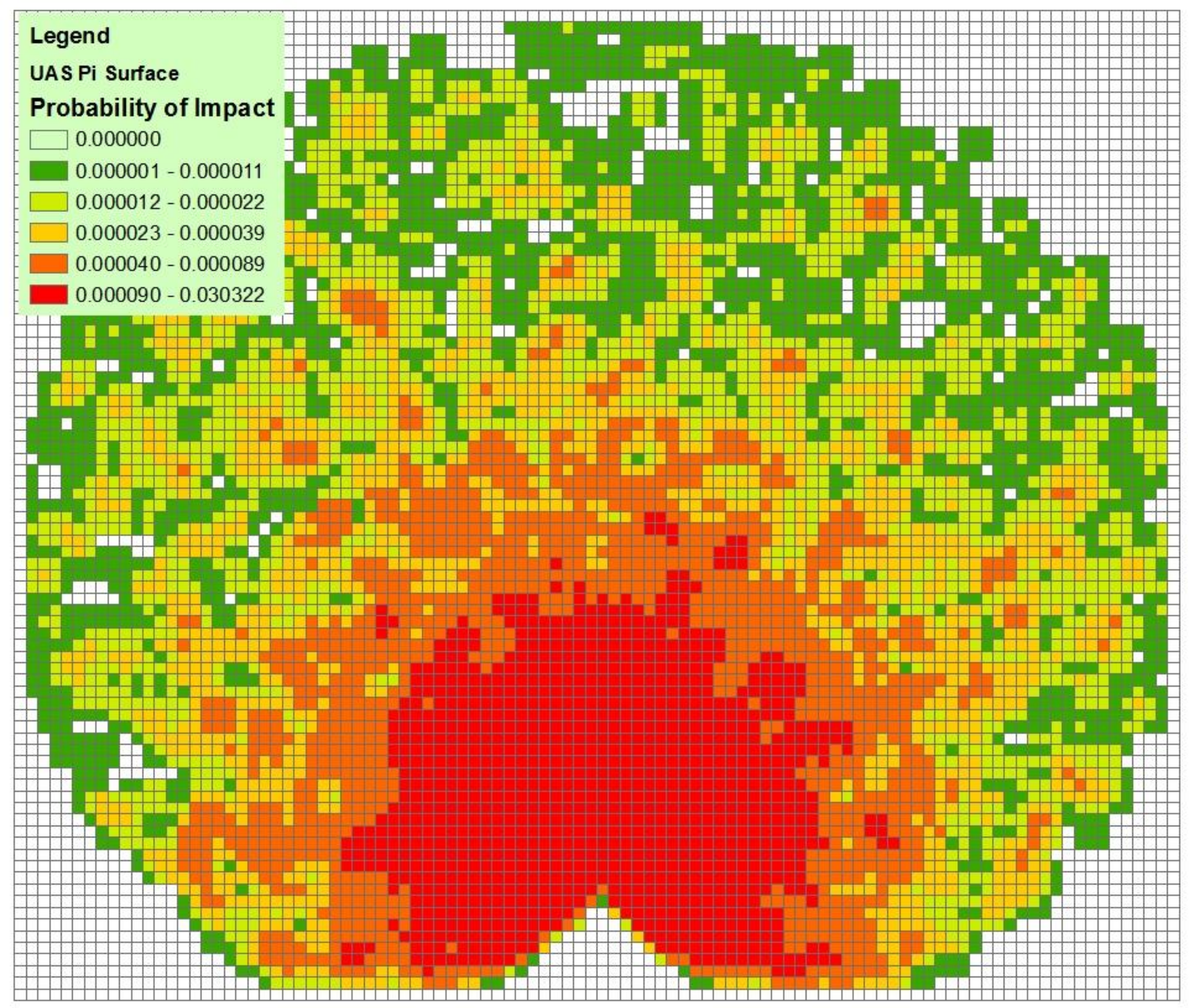
- No control of the vehicle after experiencing a failure (except FTS when applicable)
- Severe breakup events or an intact impact produces a well defined impact dispersion
- Variability in debris propagation can be accounted for

UAV

- Lifting properties of the intact vehicle or major components cause major dispersion
- Impact dispersion along the flight path resembles a cardioid
- Possible fly-away events
- Pilots-in-the-loop

Impact dispersion is a complicated function of impacts beneath the flight path, impacts around ditch points, and pilot flight tendencies

Space Launch vs. UAV Risk Modeling
Impact Dispersion



Raw cardioid impact pattern for a sample UAV

Space Launch vs. UAV Risk Modeling
Flight Path

Space Launch

- Programmed to follow a very precise trajectory
- Guidance system controls flight
- Deviation beyond the standard three-sigma dispersion can still be modeled with little uncertainty

UAV

- Flights based on waypoints
- Flight controlled partially or completely by remote pilots
- Significant flight path uncertainty is introduced as soon as a pilot takes control following a failure

The variability in actual UAV flight paths adds difficulty in estimating public risk

Conclusion

- Although there are distinct differences between space launch vehicles and UAVs, current space risk methodology can be applied to UAV flights
- Extreme care must be taken in modeling UAV
  - Debris properties
  - Impact dispersion
  - Nominal and off-nominal flight paths
- The space safety community can provide reviewed and accepted processes and tools for public risk estimation
- UAV programs can also benefit from risk mitigation techniques employed in the space safety community

Questions and Discussion