Ground Impact and Hazard Mitigation for Safer UAV Flight Response

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What's the Problem: When a UAV experiences engine failure or stuck control surfaces it becomes a risk to humans on the ground. There needs to be a way to allow for UAVs to safely and autonomously react to these unsafe conditions.

What does this work present?

- Development of a reachable flight envelope model for UAVs experiencing various faults
- Integration of the reachable flight envelope with high resolution population data (LandScan USA)
- Development of ground risk profiles for ground impact mitigation
- Integration of the ground risk models with a high-fidelity flight software that includes a mission plan, path planning module, 6-DOF aircraft model, and flight controller

Gliding Flight Equations

$$d_x = R\sin(d\psi) + D_{glide}\sin(d\psi)$$
$$d_y = R\cos(d\psi) + D_{glide}\cos(d\psi)$$

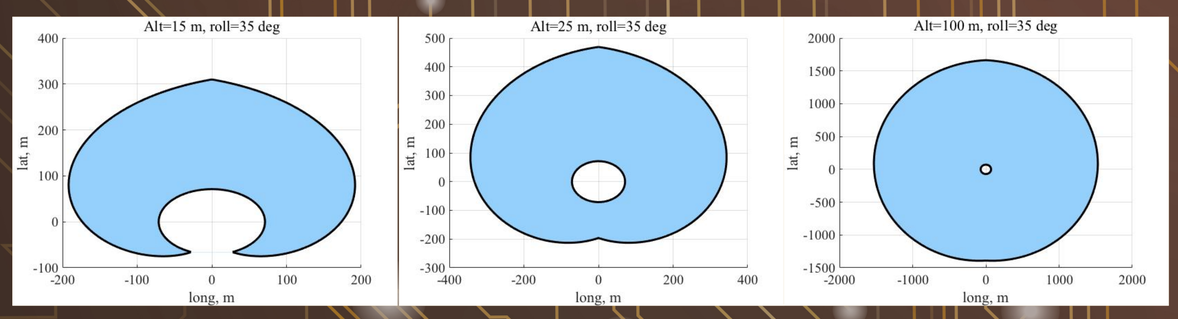
$$D_{glide} = (h_i - \Delta h_{turn})\frac{v}{v_s}, \qquad v_s = \frac{Dv}{W}$$

$$\Delta h_{turn} = Rd\psi\frac{v_s\sec^{\frac{3}{2}}(\phi)}{v\sec^{\frac{1}{2}}(\phi)}, \qquad R = \frac{v^2}{g\tan(\phi)}$$

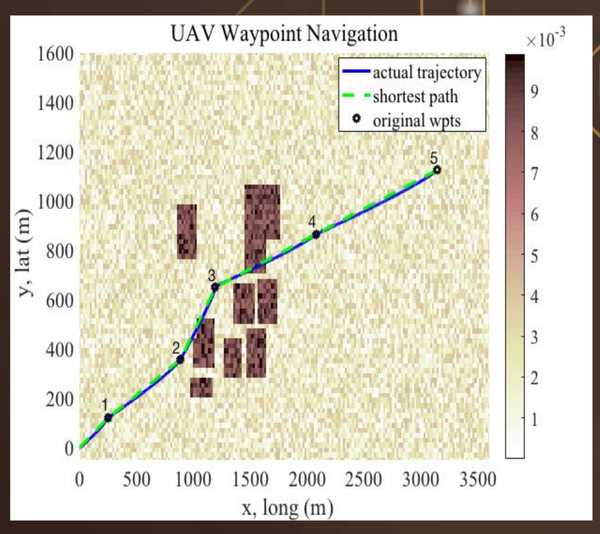
Casualty Expectation (CE) Equations

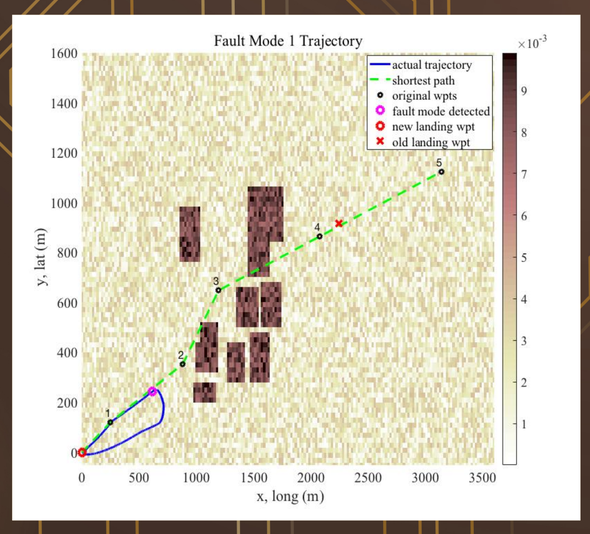
$$CE = PF \cdot PD \cdot AL \cdot PK \cdot S$$
$$AL = (L + DG + DS + 2B) \cdot (W + 2B)$$

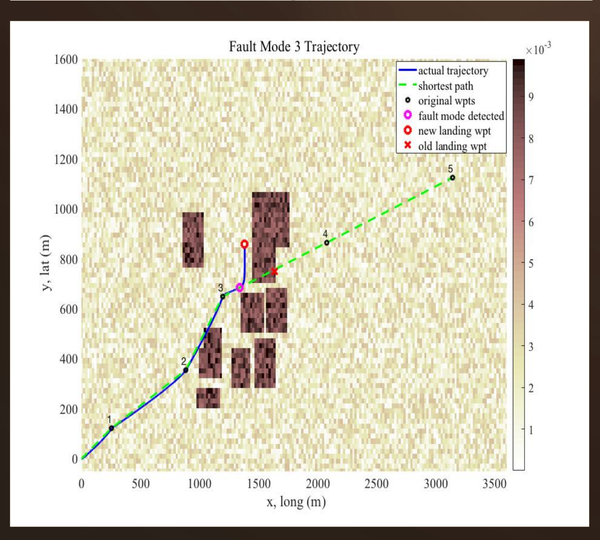
Reachable Flight Envelopes

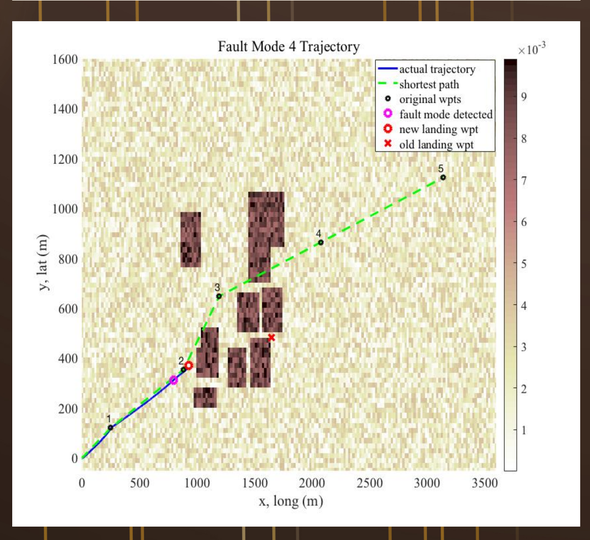


UAV Mission Simulation Results With and Without the Ground Impact and Hazard Mitigation Module









Fault Modes Investigated

- Fault Mode 1, Engine Failure – UAV engine malfunction, resulting in no thrust.
- Fault Mode 2, Engine and Rudder Failure – UAV engine and rudder control surface failure. Rudder control surface is stuck at the deflection it had during time of the fault
- Fault Mode 3, Engine and Elevator Failure – UAV engine and elevator control surface failure. Elevator control surface is stuck at trim deflection.
- Fault Mode 4, Engine and Ailerons Failure – UAV engine and ailerons control surfaces failure. Ailerons control surface is stuck at trim deflection.

Casualty Expectation Reduction Results

Fault Mode	Fault Time (s)	CE with GIHM (fatalities per 100,000 flight hrs)	CE without GIHM (fatalities per 100,000 flight hrs)
1	35	0.000	2.315
2	35	0.000	2.315
3	35	1.329	12.420
4	35	0.056	5.736
1	45	0.026	115.200
2	45	0.026	115.200
3	45	0.233	14.820
4	45	4.010	63.950
1	65	0.026	15.180
2	65	0.026	15.180
3	65	0.310	8.625
4	65	0.500	0.500
1	80	0.026	13.770
2	80	0.026	13.770
3	80	0.017	8.633
4	80	1.062	5.515
1	100	0.026	33.420
2	100	0.026	33.420
3	100	3.413	5.151
4	100	1.096	16.570
1	115	0.041	19.190
2	115	0.041	19.190
3	115	1.103	2.683
4	115	0.055	0.469
	Average	0.584	23.598

For this mission configuration, this work reduced simulated casualty expectation by 97.5%

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