PROPULSIVE TRAJECTORY OPTIMIZATION TO MINIMIZE SURFACE CONTAMINATION

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Brief Presenter Biography: *Alvin Yew is currently a research engineer with an interest in planetary and lunar sample acquisition and trace species enrichment technologies, and is the Gas Processing Lead for the DAVINCI mission. He has Mechanical Engineering degrees from the University of Maryland, with a Ph.D. focused on microfluidics and microscopy techniques for ground based cellular space biology investigations.*

Introduction: Descent retroburns using hydrazine thrusters will generate contaminants in their exhaust that can alter underlying samples, such as water-rich surfaces coinciding with possible life signatures or other science measurements of interest [1]. We present an optimization technique that aims to autonomously minimize contamination during surface approach and landing for propulsive vehicles. In addition to short-range hoppers, the optimization technique is also fully applicable to traditional orbit-to-surface landers [2].

This study addresses scenarios where surface alterations from propulsion events are counterproductive or hazardous to the mission objectives. This is of interest for landers (whether human or robotic), that may rely on pristine soils collected in the immediate vicinity of landing sites to accomplish science investigations, mining, or In Situ Resource Utilization (ISRU) surface operations. Such missions [3] are averse to various surface-plume interactions such as thermal scoring, physical agitation, and contamination. The capability can be applied with minimal impact to the baseline concept.

Methods: Optimization algorithms have been developed to simulate descent trajectories and maneuvers, thrust magnitude, and attitude for various mission cases. Using direct collocation and nonlinear programming outlined in Policelli's model [4], these parameters were determined as a multi-objective optimal solution when minimizing fuel consumption and contamination deposited at the landing site. The state space representation for these trajectories comprise of the two-dimensional equations of motion, a function describing the change in spacecraft wet mass, and a contamination deposition function. This last state variable specifies the contamination rate, defined as the exhaust mass from spacecraft thrusters that for a given state, would project onto a specified ellipse centered at the landing coordinates.

Among constraints imposed on the solution, we examined pitch rate, vertical takeoff and vertical landing (VTVL) requirements, size of the contamination zone, and minimum ground clearance during flight. This tool provides unique, non-intuitive solutions and can be a valuable resource for mission planners.

Results: A variety of agile trajectory solutions were obtained, each yielding different reductions in landing site contamination and corresponding to only modest increases in fuel consumption. For many 2D trajectories, 2-3% more fuel could reduce contamination at the landing site by greater than 50%. In each simulation, a unique linear combination of objective weights was applied to the optimization fitness function. When the contamination weight was zero (and fuel utilization weight was unity), the trajectory appeared close to parabolic and similar to a standard ballistic trajectory profile. In contrast, for contamination weights greater than zero, trajectory inflections were observed in the descent phase, which manifests as hovering or additional mini "pseudo hops" before the final touchdown (see Fig. 1). A trajectory inflection is characterized by arresting the majority of the spacecraft vertical velocity component at a coordinate outside of the landing target, and without violating ground clearance constraints

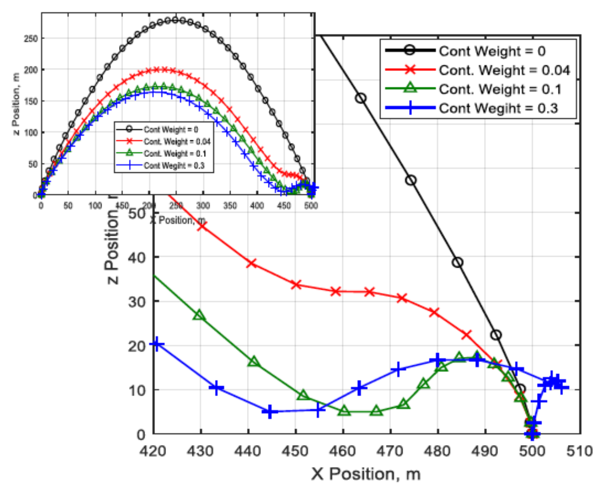

Figure 1 As contamination coefficient is increasingly weighted in the optimization function, the descent is drastically perturbed, reducing site contamination. (embedded): Full trajectory solutions for 500 m hops.

. **Conclusions:** Dual minimization of both fuel consumption and landing site contamination can be achieved by adjusting their weighting coefficients in the fitness function, and return unique trajectory solutions. Prescribing a small value for the contamination weight requires a small fraction more fuel to perform the hop when compared to zero contamination weight, and perturbs the descent trajectory sufficiently to substantially reduce landing site contamination. However, larger increases in the contamination weight yields diminishing returns in contamination reduction while the fuel requirements increase. Thus, if extra fuel is available and contamination minimization is paramount, higher contamination weights can be considered.

The optimization technique is ready for laboratory or field demonstrations to validate the sophisticated maneuvering solutions obtained for fuel optimization and surface preservation. An appropriate testbed would validate the optimal guidance algorithms, the navigation system, and a notional sensor suite by emulating vehicle flight and feedback control in closed loop robotic tests. Critically, these algorithms could then be ported to flight software for implementation.

References: [1] Steltzner A. D., et. al. (2006) *IEEE Aerospace Conference,* Big Sky, MT. [2] MacKenzie, S. M., et al. *PSJ,* 2:77 (18pp). [3] Dworkin J. P., et. al. (2018) *Space Sci Rev*, 214(1):19. [4] Policelli M. J. (2014) *The Pennsylvania State University,* MS Thesis.