LANDING MANUEVERS TO MINIMIZE SURFACE ALTERATIONS

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Introduction: Descent retroburns can alter underlying surfaces, such as water-rich soils and organics that coincide 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. Autonomy is key for landers on distant worlds where closed-loop trajectory control would be utilized to tackle complex landings.

The optimization technique is applicable for hoppers and traditional orbit-to-surface landers [2]. Such missions [3] are averse to various plume-surface interactions (PSIs) such as contamination, and also thermal scoring and mechanical agitation. Trajectory modifications can be applied with minimal impact to the baseline concept. In particular, they can greatly benefit missions with limited mobility, superficial sampling, and trace species science, including: Enceladus Orbilander, CORAL, Ceres Sample Return, CSSR, Halley 2061 Rendezvous, the Mercury Lander, and Abzu. Missions with deeper sampling capabilities such as Mars Life Explorer and Mars Icebreaker may also benefit, depending on the extent of PSIs from the lander.

Methods: Optimization algorithms have been developed to simulate realistic vehicle constraints, thruster specifications, and ground topography. Using direct collocation and nonlinear programming outlined in Policelli's model [4], control 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. Non-intuitive solutions are generated through detailed time-series thrust and pitch profiles.

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).

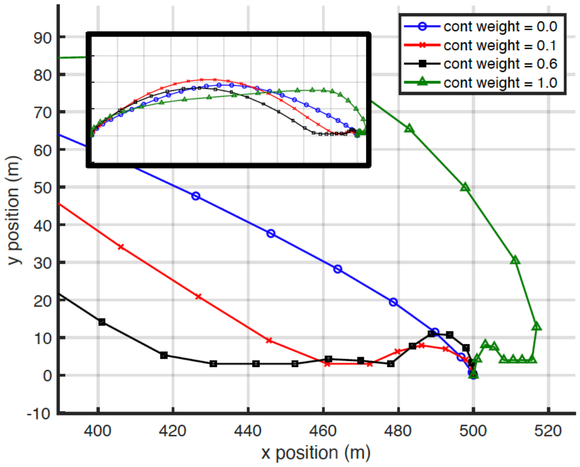

Figure 1 As contamination coefficient is increasingly weighted in the optimization function, the descent is drastically perturbed, reducing site contamination. (embedded): Full trajectory solutions for 500 m hops.

. **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. While we have thus far only investigated contamination models, other PSIs can also be included in the optimization.

The optimization technique is ready for detailed development for planetary mission concepts. Mission specific feasibility must be evaluated early in order to stem major changes as the concept matures, and should incorporate vehicle dynamics, surface characteristics, and topography. Laboratory or field demonstrations to validate the sophisticated maneuvering solutions would also be helpful. Critically, these algorithms could then be ported to flight software for implementation.

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