Path planning and optimal trajectories for Mars sailplanes subject to stochastic atmospheric conditions.

The exploration of planetary bodies such as Mars conventionally targets areas with high expected scientific return which are favorable to Entry Descent and Landing technologies. Yet, areas of higher value exist outside of destinations reachable with these typical landers and rovers, leading to a growing interest in unconventional exploration platforms. The use of small spacecrafts for such interplanetary studies has been demonstrated by the Ingenuity rotorcraft, opening access to previously unreachable science objectives such as canyons, craters, and mountains with airborne vehicles. Past research has demonstrated the feasibility of unpowered sailplanes for this purpose. They overcome the energy challenges of fixed wing flight on Mars by exploiting atmospheric energy in the form of unsteady winds, which are known to exist on Mars thanks to occasional measurements and extensive modeling.

The latter has enabled large scale studies but remains insufficient in predicting the environment accurately and rapidly for the purposes of flight planning, meaning that Mars sailplanes remains a high-risk high reward solution. The present work introduces methods to reduce this mission risk with risk adverse optimal flight planning methods. Sailplanes have the capability of packaging into the CubeSat standard for reduced cost, increased number of vehicles, and possible ride sharing for atmospheric entry. The associated challenges of low Reynolds flight are addressed with an efficient blended wing body design.

Flight planning and optimal trajectories are constructed using a three degree of freedom model under stochastic atmospheric conditions. Data for which is taken from an existing data set obtained with the Mars Regional Atmospheric Modeling System (MRAMS) for a section of Valles Marineris. Stochastic modeling enables the introduction of risk quantification and minimization, building robust flight paths for an initially unknown environment. Concepts from Model Predictive Control theory are implemented, constructing navigation algorithms for autonomous optimal flight in an unsteady atmosphere without reliance on complete initial knowledge of the Martian wind environment. Flight experiments are conducted on earth at high elevations, validating theories behind atmospheric energy harvesting, and demonstrating the long endurance observed when implementing the optimal flight algorithms. Overall, providing methods to reliably and autonomously extend the mission time of aircraft destined for Mars, opening the possibility of extensive atmospheric exploration and studies of high value geological features.