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END-TO-END GNC DESIGN, TEST AND VALIDATION OF MARS PINPOINT LANDING WITH SUPERSONIC RETROPROPULSION

Abstract

In the scope of both future Sample Return and Manned Mars missions, a key enabling technology will be the ability to land in a precisely defined area to reach pre-existing ground assets (in support of a manned or sample return mission). Supersonic retropropulsion has been identified as a means of enabling pinpoint Mars landings, especially for large payloads. A recently proposed mission, SpaceX's Red Dragon, proposed to use a modified entry capsule for Mars, applying retropropulsion for the last few kilometres (and 100s of m/s) down to the surface. This would allow skipping the parachute phase entirely - along with the associated drift caused by atmospheric uncertainty and winds during this phase - and to have high control authority throughout the Entry, Descent and Landing of a mission, increasing the likelihood that true pinpoint landing is achievable with incremental technological advances as opposed to new, major investments. The work presented here describes how a new, end-to-end (from pre-entry IMU calibration to touchdown) Guidance, Navigation and Control architecture was developed at Spin.Works for the case of a guided entry followed by a supersonic retropropulsive phase leading to a pinpoint landing (well within 100m of the targeted site). We first establish a realistic Mars entry scenario using a low lift-to-drag vehicle (a capsule) with a shape similar to the Mars Science Laboratory's. We then explain how we applied the lessons from past atmospheric guided entries (on Earth and at Mars) to derive each of the Guidance, Navigation and Control algorithms, with an emphasis on real-time guidance and multi-sensor navigation aspects. Furthermore, we assume that in-situ two-way ranging data is available during the last portion of the Mars approach via the use of navigation data provided by a potential repurposing of the Electra SDR devices currently onboard ESA's Trace Gas Orbiter, NASA's Mars Reconnaissance Orbiter and MAVEN. We also demonstrate the performance of image processing techniques (terrain matching for absolute navigation and feature tracking for lateral velocity control) used in key phases of the mission to reduce uncertainties to within 100m prior to entry, and to enable landing well within 100m of the intended spot. Finally, we show the results of a Monte Carlo simulation campaign with an realistic set of mission,

environment and vehicle uncertainties and where the full GNC is implemented in an external processing unit reacting in real-time with a high-fidelity simulation tool, further demonstrating the adequacy of our approach.