Orion MPCV Touchdown Detection Threshold Development and Testing Jared Daum, Robert Gay
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A robust method of detecting Orion Multi-Purpose Crew Vehicle (MPCV) splashdown is necessary to ensure crew and hardware safety during descent and after touchdown. The proposed method uses a triple redundant system to inhibit Reaction Control System (RCS) thruster firings, detach parachute risers from the vehicle, and transition to the post-landing segment of the Flight Software (FSW). The vehicle crew is the prime input for touchdown detection, followed by an autonomous FSW algorithm, and finally a strictly time based backup timer. RCS thrusters must be inhibited before submersion in water to protect against possible damage due to firing these jets under water. In addition, neglecting to declare touchdown will not allow the vehicle to transition to post-landing activities such as activating the Crew Module Up-righting System (CMUS), resulting in possible loss of communication and difficult recovery.

A previous AIAA paper "Assessment of an Automated Touchdown Detection Algorithm for the Orion Crew Module" concluded that a strictly Inertial Measurement Unit (IMU) based detection method using an acceleration spike algorithm had the highest safety margins and shortest detection times of other methods considered. That study utilized finite element simulations of vehicle splashdown, generated by LS-DYNA, which were expanded to a larger set of results using a Kriging surface fit. The study also used the Decelerator Systems Simulation (DSS) to generate flight dynamics during vehicle descent under parachutes. Proto-type -IMU and FSW MATLAB models provided the basis for initial algorithm development and testing.

This paper documents an in-depth trade study, using the same dynamics data and MATLAB simulations as the earlier work, to further develop the acceleration detection method. By studying the combined effects of data rate, filtering on the rotational acceleration correction, data persistence limits and values of acceleration thresholds, an optimal configuration was determined. The lever arm calculation, which removes the centripetal acceleration caused by vehicle rotation, requires that the vehicle angular acceleration be derived from vehicle body rates, necessitating the addition of a 2^{nd} order filter to smooth the data. It was determined that using 200 Hz data directly from the vehicle IMU outperforms the 40 Hz FSW data rate. Data persistence counter values and acceleration thresholds were balanced in order to meet desired safety and performance. The algorithm proved to exhibit ample safety margin against early detection while under parachutes, and adequate performance upon vehicle splashdown. Fall times from algorithm initiation were also studied, and a backup timer length was chosen to provide a large safety margin, yet still trigger detection before CMUS inflation. This timer serves as a backup to the primary acceleration detection method. Additionally, these parameters were tested for safety on actual flight test data, demonstrating expected safety margins.

The persistence counter and acceleration thresholds were further refined and tested using high fidelity environment, vehicle and FSW simulations. An improved and more efficient approach to the Kriging method was also employed. A module was developed for the high fidelity Trick-based dynamics simulation, Advanced NASA Technology Architecture for Exploration Studies (ANTARES), to perform on-the-fly calculations of touchdown detection margins during vehicle descent under parachutes. ANTARES connects to the Rapid Algorithm MATLAB/Simulink Engineering Solution (RAMSES) simulation, an auto-coded FSW Simulink model, to close the loop on the environment and vehicle simulation. This high fidelity simulation package was used to simulate the vehicle under various scenarios, including parachute failures, other hardware failures and extreme winds.

Furthermore, a new analytical approach to defining the set of LS-DYNA impact cases computed, called adaptive sampling, was used to increase efficiency in establishing the training set of data needed to perform the Kriging expansion. The impact analysis was completed using the Osiris simulation, packaged with the RAMSES FSW simulation, driven by the trajectories provided by LS-DYNA. Each trajectory provides a performance Factor of Safety (FOS) and time to detection, which is then expanded to a larger set of cases using Kriging. By again trading this detection performance upon impact with vehicle safety under parachutes from ANTARES, refined acceleration thresholds and persistence counter values were chosen. Vehicle descent times of higher accuracy were also generated and analyzed to further refine the length of the backup timer.