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IAF SYMPOSIUM ON COMMERCIAL SPACEFLIGHT SAFETY ISSUES (D6)
Interactive Presentations - IAF SYMPOSIUM ON COMMERCIAL SPACEFLIGHT SAFETY ISSUES (IP)

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IMPACT DISPERSION AREA ESTIMATION FOR STATE UNCERTAINTY USING NUMERICAL APPROXIMATION

Abstract

Flight safety is a critical issue in space launch vehicles due to the catastrophic consequences of fault scenarios. The rise of private-sector-driven space development has led to a higher frequency of launch operations and an even greater emphasis on flight safety.

Both pre-flight analysis and real-time operations are important for the safety operations of launch vehicles. The instantaneous impact point (IIP), defined as the ground location where the launch vehicle would fall if it were in a ballistic trajectory, is fundamental information for flight safety operations. The Keplerian IIP, which assumes that only gravity acts on the falling vehicle, is commonly used due to its real-time computational advantages. However, the actual mission environment contains various uncertainties, necessitating pre-flight safety analysis to establish an Impact Limit Line (ILL) that meets safety standards and to design a nominal trajectory that accounts for these constraints. The ILL is constructed based on risk contours obtained from probabilistic casualty analyses via impact dispersion analysis.

Usually, a Monte Carlo Simulation (MCS) incorporating various uncertainty sources can be used for the impact dispersion analysis. This paper introduces a dispersion area estimation method applicable to pre-flight safety analysis based on covariance propagation. The method can reduce computational costs and provide faster analysis than the MCS. The uncertainty elements in the launch vehicle's state (e.g., position and velocity) are considered. The nonlinear transformation in the Keplerian IIP algorithm is approximated using a first-order Jacobian. Numerical derivatives of each component are computed, and under the assumption of independence among components, the variance parameters of the IIP latitude and longitude are obtained. An elliptical impact dispersion area is estimated based on these variance parameters. A case study is conducted to validate the effectiveness of the proposed method - particularly in comparison to the MCS. The case study results demonstrate that the proposed method achieves acceptable accuracy while significantly reducing computational costs, making it a viable approach for impact dispersion prediction.