ON THE FOUNDATIONS, QUANTIFICATION, AND INTERPRETATION OF
STOCHASTIC COLLISION RISK INDICATORS IN SPACECRAFT
FORMATIONS

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416 Pages

Directed by Dr. E. Glenn Lightsey

This dissertation provides an overview of the benefits of spacecraft formation flying (SFF), of the sources of collision risk in SFF, and a discussion on how relative orbital dynamics make the problem of collision risk management (COLRM) in SFF different from the standard obstacle avoidance problem in robotics. Progress in SFF COLRM is classified in terms of foundational work, which consists of the formulation and basic properties of stochastic collision risk indicators, and operational work, which is concerned with SFF collision risk quantification, interpretation and decision-making, and reduction. Except for collision risk reduction, this doctoral investigation contributes to all aspects of the SFF COLRM problem.

First, a sampling method is developed for the computation of probability measures associated with rare event simulation, with the goal of computing instantaneous and joint-time collision probabilities in SFF with comparable performance to Monte Carlo. Second, a methodology is developed for examining the consistency between collision risk insights that may be gleaned from distance-based and probability-based collision risk indicators, with recommendations for certain distance-based collision risk indicators whose relationship to collision probability is in accordance with intuition. Third, a new collision region
is introduced which arises from the combination of mutually orthogonal circular constraint violations, and its application to the approximate satisfaction of spherical avoidance constraints is motivated by quantifying the extent of the overestimate of stochastic collision risk measures based on the proposed collision region when compared to their isotropic counterparts. Fourth, for sensitivity analyses of the direct and inverse instantaneous collision probability problems, their soundness is substantiated by proving the absolute continuity of the Euclidean norm of an absolutely continuous finite-dimensional random vector. For instantaneous collision conditions based on balls with respect to arbitrary norms in relative position space, their corresponding joint-time collision probability measures are shown to be well-defined and computable.

Together, these contributions to an integrated approach to SFF COLRM constitute progress toward the goal of practical implementations of mission concepts based on the spacecraft formation flying paradigm.