Setting the Bar for the Replacement of the Probability of Collision Metric

Matthew D. Hejduk, The Aerospace Corporation; matthew.d.hejduk@aero.org
Daniel E. Snow, Omitron Inc.; daniel.snow@omitron.com

To date, satellite conjunction assessment (CA) risk analysis has largely embraced the probability of collision (Pc) as the omnibus metric to evaluate collision likelihood, and its use in such assessments has mostly been straightforward: at the point at which a conjunction mitigation decision is required, the calculated Pc is compared to a threshold; and if the calculated Pc exceeds that threshold, then a mitigation action is warranted. With only minor variation, this approach is employed by major CA risk assessment centers (*e.g.,* NASA, EUSST, CNES, JAXA) and is advanced as the preferred method in the published CA best practices handbooks.

Despite this near unanimity of operational practice, there is a major strain of secondary literature critical of the Pc and willing to propose alternatives. Alfano (2005) pointed out the ability of the Pc to underrepresent the risk in certain situations and counselled a maximum Pc construct. Carpenter (2017, 2019) reiterated this criticism and proposed using instead a confidence interval on the miss distance. Balch *et al.* (2019) identified what they argued was a defect in the entire Bayesian Pc construct and believed that the use of a more conservative methodology based on covariance ellipsoid overlap was necessary. Delande (2022) introduced the framework of collision "plausibility" to the risk assessment process and sketched out how this might be used operationally. Elkantassi (2022) published a full development of the miss distance confidence interval approach and applied it to several worked examples. While these different approaches to collision risk assessment do differ in their details, they all converge on two central points: first, the Pc's failure to give an adequate expression of the risk in dilution region situations is a fatal flaw; and second, a conjunction should be presumed risky and in need of mitigation until the evidence of the situation can establish otherwise. These criticisms, if correct, would counsel a number of modifications to current CA operational practice; as such, they force a re-examination of fundamental aspects of the CA problem, including the following:

1. Is the CA risk assessment a probability problem, a statistics problem, or something else?
2. If it is a statistics problem, does it lend itself naturally to a hypothesis test construction?
3. If it can be construed as a hypothesis test, what form should the null hypothesis take, to wit: what constraints exist on the choice of the null hypothesis, what selections are in best alignment with all of the attendant parameters of the problem, and what is implied philosophically by different choices?
4. What are the implications of using the different proposed risk assessment parameters for CA? This question should be answered both in determining how frequently the dilution region situation cited by the critics of the Pc actually appears in an operationally significant manner and the missed detection and false alarm rates of all of the proposed risk assessment metrics, compared both to the Pc and to each other.

This paper explores and offers preliminary answers to the above questions, presenting a researched treatment of the philosophical nature of the CA problem and the null hypothesis choice that achieves the greatest consistency with all of the different aspects of operational CA conduct. It then profiles all of the different proposed risk assessment metrics enumerated in the earlier paragraph against an extremely large database of conjunction events at both the 550km and 700km altitudes. The combination of the philosophical exploration of the CA problem and the results of the profiling activity articulates what a risk assessment metric will need to demonstrate, in terms of both innate construction and performance, in order to be a true competitor to the Pc.