**“The NewSpace Era: The Case for Space Traffic Management”**

CARA Evaluation

The CARA project has reviewed this Aerospace Corporation publication and finds it to be a well-researched, clear, accessible guide to the STM problem and good source of helpful policy recommendations. It is an excellent introduction to the issues and should be an item of required reading for those wishing a sophisticated understanding of the problem. There are, however, one significant technical comment and some additional minor comments that must be mentioned.

**Needed Atmospheric Density Prediction Research**

Significant technical comment: Research on improved atmospheric density modeling is at least as important as improving satellite position determination through on-board position reporting and increased/improved SSN sensor tracking.

The paper argues correctly that the probability of collision (Pc) for a particular conjunction is a function of the states and state uncertainties of the two satellites in a conjunction. It further states, and provides simulation results to try to establish, that improving the state estimates (and thus reducing the uncertainties at epoch) for the two satellites will notably improve the quality of the orbit determination (OD) and thus CA results. For primary satellites, this can be done with better position determination (*i.e.,* via on-board GPS positioning); for secondaries, which for most conjunctions are debris objects, it can be accomplished with more and better SSN tracking sensors.

These statements are certainly correct as given. However, what must be kept in mind is that CA is always conducted not with epoch results (*i.e.,* position information for the time right after the orbit determination fit) but with predicted results, usually days into the future. Only the most streamlined missions can make conjunction remediation decisions for expected conjunctions less than one day in the future; and the majority of missions require at least 2-3 days for maneuver planning, decision briefings, &c. One is thus typically making decisions with information that has been predicted 2-3 days into the future. Furthermore, in most cases, CA remediation taken further into the future can achieve similar levels of risk abatement with far smaller maneuvers than if one postpones the decision to close to the satellites’ time of closest approach (TCA). Even if one can plan remediation actions much closer to TCA, there are still advantages to making and implementing remediation decisions well before the encounter is to take place: orbit perturbations and propulsion expenditure can be kept to a minimum. There will thus be a continuing desire to perform CA calculations and take decisions days rather than hours before event TCA, which means that CA is likely to continue to be conducted very much in the realm of prediction. While, as the report authors suggest, improving the position determinations with the orbit determination fit (GPS tracking; more sensor observations) will help to reduce the prediction errors, with the present modeling approach externally-imposed prediction errors in most cases are likely to swamp these relatively modest improvements.

The principal source of prediction error in LEO is inadequate modeling of the atmospheric drag acceleration on the satellite, and the principal source of this inadequacy is poor predictive modeling of the neutral (as opposed to ionospheric) atmospheric density. Poor density modeling is mostly attributable to the forecast error in determining future space weather indices that drive the atmospheric density models; these include indices that are proxies for EUV heating (F10, S10, M10, Y10) and geomagnetic indices that reflect Joule heating (Ap, Dst). The prediction of these space weather indices is rudimentary and fraught with error (Vallado and Finkelmann, 2014) and has changed little in past decades. Solar storm prediction models have shown some recent research improvements but still are in their infancy (*e.g.,* Tobiska 2013). An extended study showed the substantial differences wrought on the adjudication of CA events by atmospheric density errors (Hejduk and Snow, 2018). NASA CARA experience with owner/operator ephemerides, which do represent solutions with much greater levels of tracking than DoD solutions for these objects, has indicated that this additional tracking (as well as spacecraft modeling knowledge) rarely affects conjunction event risk levels substantially; any improvements are outstripped by prediction errors, typically greater for the secondary object.

The NASA CARA position is thus that improved atmospheric density modeling in prediction is the research area that would yield the greatest overall benefit for CA in the LEO orbit regime. Even for mega-constellations that exist at an orbital altitude outside of the dense atmosphere region (*i.e.,* 1000-1500 km), the transit of these satellites from their injection orbit up to these altitudes and the descent back to decay to satisfy the 25-year disposal rule—which will be a continuous process given the projected constellation sizes and modest planned satellite lifetimes—will encounter acute drag modeling problems. CARA therefore recommends that research to improve atmospheric density modeling in prediction, which is likely to take the form of improved prediction of space weather indices, be pursued with at least the same level of urgency as improving primary and secondary object position determination through better on-board position reporting and additional space tracking sensors.

Vallado, D.A. and Finkleman, D. “A Critical Assessment of Satellite Drag and Atmospheric Density Modeling.” *Acta Astronautica* 95 (2014), pp. 141-165.

Tobiska, W.K. *et al.* “The Anemomilos Prediction Methodology for Dst.” *Space Weather* (Vol. 11, No. 9 (September 2013). DOI: 10.1002/swe.20094.

Hejduk, M.D. and Snow, D.E. “The Effect of Neutral Density Estimation Errors on Satellite Conjunction Serious Event Rates.” *Space Weather* (June 2018). DOI: 10.1029/2017SW001720.

**“False Alarm” vs “Proximity Alert”**

The article uses the term “false alarm” to refer to conjunction data messages (CDMs) that do not result in events sufficiently serious to merit a remediation action; and because relatively few conjunctions rise to the level of remediation, most such messages would be characterized by this term. In CARA’s opinion, this is not the best way to describe what a CDM is intended to do. Such messages are not constructed and sent in order to warn owners/operators of a truly dangerous situation; rather, they function as “proximity alerts” between the protected primary asset and another catalogued object. It is rather like the proximity beeping present on some model cars when, backing up, the car becomes close to another vehicle or an obstruction. The beeping is not warning of an imminent danger; rather, it is an alert that a dangerous situation could develop if certain present trends continue. Conjunction analysis risk assessment is the practice of collecting and analyzing such alerts to determine which of the situations they identify seem to be developing into an encounter that will manifest a significant probability of collision, with enough lead-time for the owner/operator to plan and execute a safe remediation action. It is thus expected that the number of CDMs issued will always greatly exceed the number of actual dangerous situations; and given the difficulty of prognosticating which identified events will ultimately prove dangerous, this is perhaps as it should be. Even with the improvements the authors recommend, if current CA screening practices are used the same number of CDMs will be produced; it will just be easier to dismiss some portion of them as unlikely ultimately to develop into a dangerous situation.

**Covariance Adequacy**

The paper states that JSpOC-provided covariances “are generally insufficient to support maneuver decisions.” There was a time when JSpOC covariance realism was poor, and the paper’s judgment on covariance quality would have met with broad agreement. However, there have been a number of important improvements to the JSpOC OD algorithm set (*e.g.,* along-arc batch solutions and dynamic drag consider parameters to account for satellite frontal area variation and atmospheric density forecast error) that have greatly improved the JSpOC covariance realism. As long as a certain conservatism is practiced when performing maneuver planning (*i.e.,* remediating to a somewhat lower probability of collision than might be strictly necessary from the calculations) and the quality of the OD update is considered, CARA believes that in most cases JSpOC covariances can serve as the basis for remediation actions. Indeed, this is the established CARA practice and guides tens of risk mitigation maneuvers for the NASA protected satellite fleet each year.

**Collision Consequence**

The paper provides a number of different space debris density curves and points out, correctly, that objects represented by the “blue” curve are potentially lethal. One could suggest, however, a difference between secondary objects that would be merely lethal to a satellite and those that are large enough to produce a catastrophic collision and thus would constitute a major debris-producing event. The NASA Orbital Debris Program Office has developed algorithms that allow this determination to be made for a particular conjunction. Such a distinction (between conjunctions with large debris-production potential and those in which only the piece of debris but not the protected asset will be fragmented) could be helpful to situations in which conjunction remediation may need to be triaged due to a large number of events.

Lethal conjunctions that do not produce debris are, of course, still problematic: not only is there loss of mission for the protected asset, but this “dead” asset has not reached a disposal orbit and thus poses a debris threat from future conjunctions. The paper documents capably the debris-production hazards posed by dead payloads that cannot achieve disposal orbits. However, intact payloads are much better candidates for active debris removal activities, so there is value—if event densities require it—to focus remediation attention on conjunctions that are likely to produce large amounts of debris.