

DECISION AID FOR CONJUNCTION RISK MITIGATION BY DIFFERENTIAL DRAG

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In the previous five years, the rate of conjunctions that the NASA Conjunction Assessment Risk Analysis (CARA) team processed and analyzed has more than tripled. (NASA CARA, 2024) New missions in the early development phases are now required to plan for dealing with conjunctions under the present space environment, and also projecting forward into a future likely with even further increased utilization of the space environment. Some missions are investigating the possibility of using differential drag to remediate conjunctions without expending limited fuel or for missions without propulsive capabilities. The NASA CARA team studied the historical record of conjunctions to evaluate the circumstances under which differential drag may be successfully applied and have developed a series of tables to use as a decision aid for missions considering differential drag.

CARA records all conjunctions of their protected payloads, with historical records starting in 2005 (with significant conjunction events starting to occur on or after 2013). From this record, approximately 7,300 had a probability of collision (P_c) greater than 1 in 10,000, the nominal requirement for a risk mitigation maneuver (RMM) to be made per NASA Procedural Requirements (NPR) 8079.1 (NASA, 2023), at 3 days prior to the time of closest approach, the time analyzed for differential drag efficacy. CARA's maneuver trade space tool (MTS) was used to propagate the primary satellite forward from that decision point with varying degrees of increase to ballistic coefficient (BC), and then recalculate the P_c to evaluate whether or not the conjunction was mitigated ($P_c < 3E-6$). These results were then binned and sorted along several axes, including altitude, amount of delta-BC, and (pre-maneuver) rate of energy dissipation, to identify underlying patterns. The altitude plot is shown in Figure 1.

We found that differential drag was most successful for satellites with perigees below 560 km, and which could adopt an average delta-BC of 2 or greater (that is, increasing their ballistic coefficient by a factor of 3). However, this is a difficult threshold for a mission to clear; very few spacecraft are capable of adopting a high-drag configuration for 72 hours continuously. Planet's Dove spacecraft use differential drag to remediate conjunctions (Griffith, et al., 2021), and they have a maximum delta-BC factor of 9, but in practice (with mission and charging constraints) they achieve a time-averaged delta-BC that is closer to 2 (Foster, et al., 2017). In contrast, a NASA mission in development reached out to CARA to evaluate the utility of differential drag to remediate potential conjunctions for a spacecraft which is capable of a similar high delta-BC, but with operational constraints that limit their time-averaged delta-BC to less than 1.

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CARA has developed tables that can be used as decision aids to advise missions-in-development about the best way to utilize their differential drag capabilities. For missions below 560 km with the operational flexibility to devote multiple days to holding a high-drag configuration (or a sufficiently high drag ratio to compensate for limitations on that time), they are able to successfully remediate high-risk conjunctions. Conversely, missions that do not meet these exacting criteria – most missions – can instead be advised to use on-board propulsion systems to perform RMMs or to turn their minimum-area face towards the approach vector, thereby reducing P_c at the moment of conjunction. (NASA, 2023)

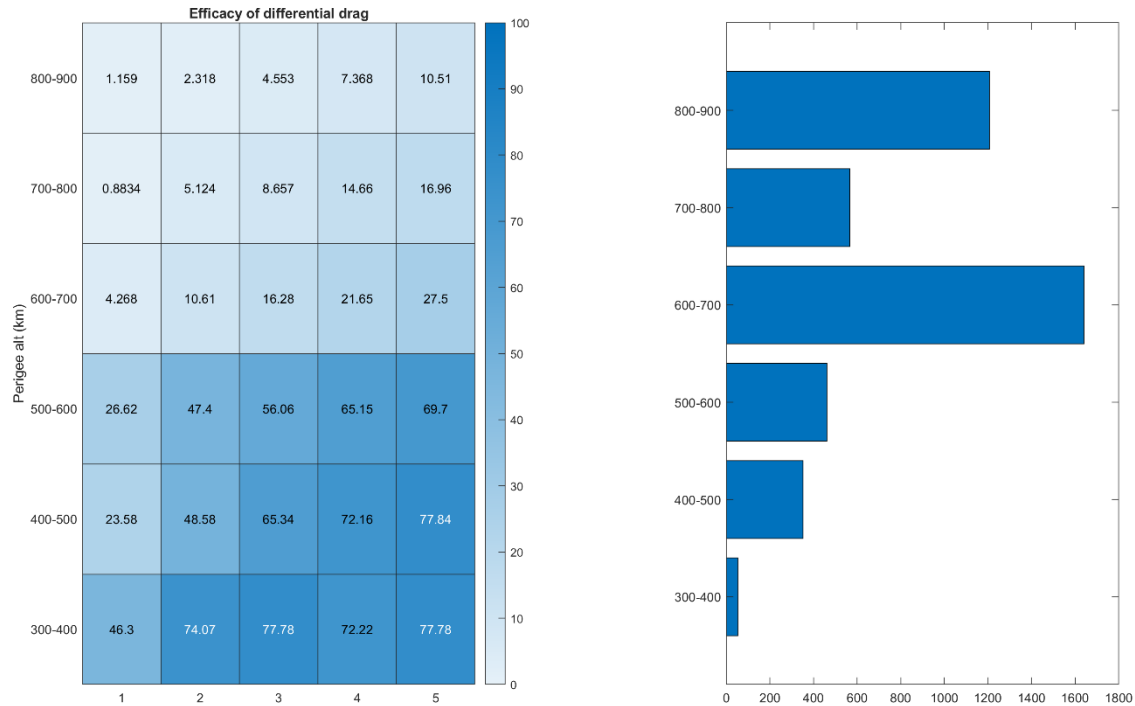


Figure 1: Left: a heat-map of the efficacy of differential drag for remediating conjunctions (%). Right: the number of valid conjunctions for each altitude bin.

Bibliography

- Foster, C., Mason, J., Vittaldev, V., Leung, L., Beukelaers, V., Stepan, L., & Zimmerman, R. (2017). Differential Drag Control Scheme for Large Constellation of Planet Satellites and On-Orbit Results. *International Workshop on Satellite Constellations and Formation Flying*, (p. 18). Boulder, CO.
- Griffith, N., Bhatia, R., Nallapu, R. T., Siegers, M., Mallik, V., & Rosner, C. (2021). Small Satellite Collision Risk Mitigation Using Differential Drag. *International Astronautical Congress* (p. 7). Dubai: International Astronautical Federation.
- NASA. (2023, June 27). *NASA Spacecraft Conjunction Analysis and Collision Avoidance for Space Environment Protection*. Retrieved from NASA Online Directives Information System: https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PR_8079_0001_&page_name=main

NASA. (2023, February). *NASA Spacecraft Conjunction Assessment and Collision Avoidance Best Practices Handbook*. Retrieved from <https://www.nasa.gov/wp-content/uploads/2023/07/oce-51.pdf?emrc=c0a365?emrc=c0a365>

NASA CARA. (2024, March 1). *Unique Conjunction Events*. Retrieved from <https://www.nasa.gov/cara/unique-conjunction-events/>

Condensed Abstract

The CARA team has conducted a review of the historical record of high-interest conjunctions involving CARA-protected missions and evaluated whether (and how much) differential drag can remediate them. From this, we have identified a rule of thumb: missions with perigees below 560 km capable of tripling their drag area for 72 hours (or a larger factor for a lesser proportion of time) can reliably use differential drag to remediate high-interest events.