SCATTER STRATEGIES FOR SEMI-AUTONOMOUS CLUSTER FLIGHT

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ABSTRACT

DARPA's System F6 (Future, Fast, Flexible, Fractionated, Free-Flying Spacecraft United by Information Exchange) program seeks to address the challenge of developing future space systems via fractionated architectures wherein a network of 1-20 spacecraft modules would communicate, collaborate and share resources to accomplish their mission. During normal orbit operations, the spacecraft modules would maintain a loose cluster formation through station-keeping and reconfiguration maneuvers. A previous objective of the System F6 program was to demonstrate the capability to scatter the clustered spacecraft to rapidly evade a debris-like threat and then re-gather the scattered spacecraft into a re-formed cluster. It was dictated that within 5 minutes after a scatter command was received from the ground, the spacecraft modules would disperse from their initial positions such that each spacecraft would be at least 10 km from where any spacecraft would have been under normal orbit operations. The planning and execution of the scatter and re-gather maneuvers would be performed autonomously without intervention or communication from ground operators.

Emergent Space Technologies has developed robust and scalable cluster guidance, navigation, and control (GN&C) flight software called the Cluster Flight Application (CFA). The CFA optimizes ΔV consumption while maintaining mission and state constraints for both long-term station-keeping and rapid scatter, seamlessly integrating functionality for both within a consolidated guidance and control system. The integration of these unique use cases is achieved through a robust simulated annealing heuristic search algorithm with an underlying linear programming impulsive burn solver. The maneuver planning software can account for initial, final, and interior state constraints while also minimizing ΔV consumption.

In order to rapidly execute scatter within the relatively short 5 minute window, the CFA maintains a database of pre-computed scatter maneuver plans that may be retrieved and quickly corrected to account for the latest navigation state estimates. The correction operations are conducted independently onboard each spacecraft using computationally-fast algorithms that help to minimize the delay between reception of the scatter command and maneuver execution. During the generation of the pre-computed scatter maneuver plans, the ΔV is minimized across the scatter and re-gather maneuvers in unison through a set of optimized hold orbits. These hold orbits serve as a staging point for subsequent ingress maneuvers to return the cluster to its nominal mission orbit.

Results from typical cluster scatter and re-gather simulations are presented below. For each spacecraft in the cluster, an initial scatter burn is applied to achieve the rapid scatter constraint and is followed by a series of closed-loop re-gather maneuvers for cluster rendezvous down-range from the initial conditions. The spacecraft re-gather to a set of hold orbits and then ingress back to the nominal mission orbits. While the initial scatter burns must be of sufficient magnitude to achieve the 10 km in 5 minutes scatter constraint, the burn directions are optimized to minimize the ΔV consumption during re-gather. Figures 1 and 2 depict 4-spacecraft and 12-spacecraft clusters performing scatter and re-gather to a set of hold-orbits offset 200 km downrange.

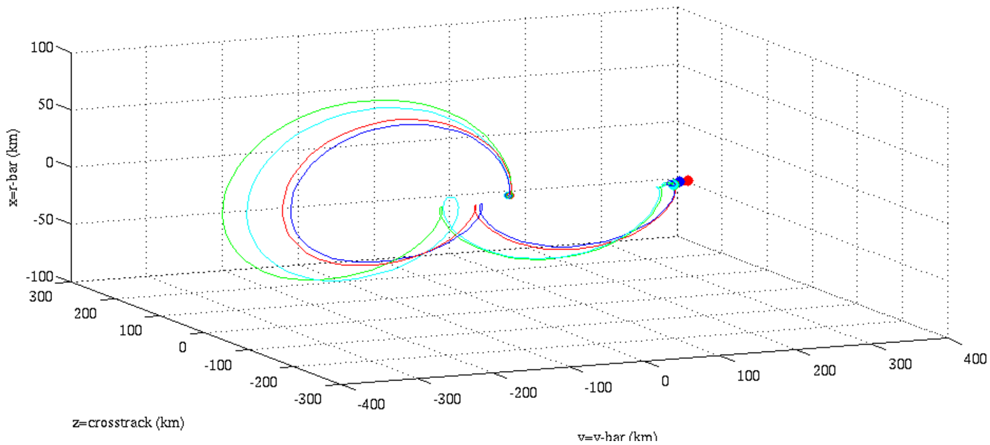

Figure 1: Cluster Scatter and Re-gather to Down-Range Hold-Orbits (4 Modules)

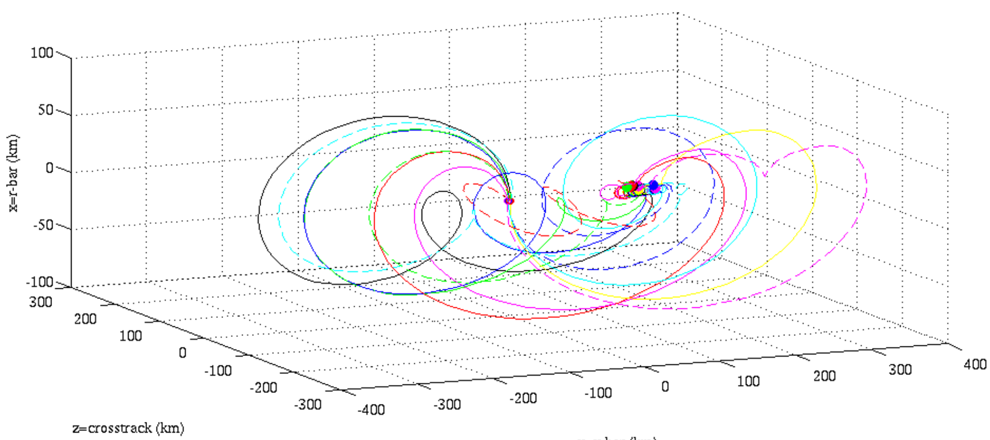

Figure 2: Cluster Scatter and Re-gather to Down-Range Hold-Orbits (12 Modules)