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Operating Small Sat Swarms as a Single Entity: Introducing SODA

Swarm concepts are a growing topic of interest in the small satellite community. Compared to a small satellite *constellation*, a *swarm* has the distinction of being multiple spacecraft in close proximity, in approximately the same orbit. Furthermore, we envision swarms to have capabilities for cross-link communication and station-keeping. Of particular interest is a means to maintain operator-specified geometry, alignment, and/or separation.

From NASA's decadal survey, it is clear that simultaneous measurements from a 3D volume of space are desired for a variety of Earth scientific studies. As this mission concept is ultimately extended to deep space, some degree of local control for the swarm to self-correct its configuration is required. We claim that the practicality of ground commanding each individual satellite in the swarm is simply not a feasible concept of operations. In other words, the current state-of-practice does not scale to very large swarms (e.g. 100 spacecraft or more) without becoming cost prohibitive. To contain the operations costs and complexity, a new approach is required: the swarm must be operated as a unit, responding to high-level specifications for relative position and velocity.

The Mission Design Division at NASA Ames Research Center is looking to the near future for opportunities to develop satellite swarm technology. As part of this effort, we are developing SODA (Swarm Orbital Dynamics Advisor), a tool that provides the orbital maneuvers required to achieve a desired type of relative swarm motion. The purpose of SODA is two-fold. First, it encompasses the algorithms and orbital dynamics model to enable the desired relative motion of the swarm satellites. The process starts with the user specifying the properties of a swarm configuration. This could be as simple as varying in-track spacing of the swarm in one orbit, or as complex as maintaining a specified 3D geometrical orientation. We presume that science objectives will drive this choice. Given these inputs, the tool provides the most efficient maneuver(s) to achieve the objective.

Second, SODA provides a variety of visualization tools. We acknowledge that the relationship between a desired relative motion amongst the swarm, and the corresponding orbital parameters for each individual satellite may not be immediately apparent for ground controllers and mission planners. The purpose of SODA's visualization tools is to illustrate this concept clearly with a variety of graphics and animations. After computing the optimal orbital maneuvers to modify the swarm, these results are simulated to demonstrate successful swarm control.

Our emphasis in this paper is on the importance of relating the desired motion of the swarm satellites relative to one another with the required orbital element changes. One cannot "joystick" a drifting swarm satellite back into position; the underlying orbital mechanics dictate the most efficient recovery maneuvers. To illustrate this point, results from several case study simulations are presented. We conclude with our forward work for ongoing SODA development and potential science applications.