SATELLITE CLUSTER FLIGHT DESIGN CONSIDERATIONS

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Keywords: *Satellite Clusters, Relative Orbit Elements, Relative Motion*

ABSTRACT

The challenges of designing optimal satellite cluster configurations are presented with respect to several key considerations including passive safety, stability, packing ratio, minimization of the inter-module cone angles, scalability, and observability with relative range measurements. A short primer on relative orbit elements (ROEs) and relative satellite motion precedes a discussion of these metrics. ROE and safety ellipse concepts can be used to intuitively construct several different cluster geometries that optimize different constraints such as packing ratio, stability, or inter-module cone angles. Unique contributions from the authors include cluster stability in terms of ROEs, optimizing the packing ratio while maintaining passive safety, radial, intrack, crosstrack (RIC) and inertial intermodule cone angles for passively safe trajectories, relative state observability using intermodule range measurements in four module clusters, and the pros and cons of three general configurations known as Nested, Circles-in-Circles, and Cross configurations.

The key considerations discussed are summarized below:

Passive Safety: Even if it was possible to perfectly insert satellites into their desired orbits, satellites experience different forces due to perturbations, such as drag and solar radiation pressure, that cause the total energy or the period of their orbits to differ. This manifests itself in differential drift primarily in the in-track direction (v-bar). Thus, for configurations that primary experience intrack drift, the main factor affecting the passive safety, or the probability of collision when active control is turned off, is the separation between modules in the radial/cross-track plane (r-bar, h-bar).

Stability: While the initial cluster configuration may be designed to be passively safe, the effect of higher order gravity perturbations on the cluster configuration can distort the original geometry. The effect of these perturbations is examined in the context of Relative Orbit Elements (ROEs). The goal is to design the cluster configuration in a way that minimizes cluster distortion due to higher-order gravity, decreases fuel usage required for orbit maintenance and improves passive cluster safety. Creating a cluster that keeps all of the modules, or cluster members, at the same inclination or by flying the whole cluster at the 63.43 degree critical inclinationSabatini:2008; Vadali:2008 are two key methods for mitigating these effects.

Packing Density: Clusters will maintain radio communications to share navigation, coordinate maneuvers, and distribute mission data. Communication systems are sensitive to distance, and

are, with fuel usage, drivers to minimize the maximum distance between modules. The ratio of the maximum separation distance to the minimum separation distance is known as the packing density. Smaller packing density ratios allows for smaller cluster sizes while still maintaining minimum separation distances required by safety constraints.

Cone Angle: The inter-module cone angle defines the narrowest cone that captures the line-of-site vector between two modules over the course of an orbit. Many high-bandwidth communication systems utilize antennas that have tight pointing constraints. In order to minimize slewing, the cone angles between modules should be taken into account in either the inertial or radial, in-track, cross-track, (RIC) frames. Additionally, any future missions utilizing power beaming between modules will benefit from a small maximum inter-module cone angle.

Scalability: The ability to add more modules to an existing cluster in a uniform and systematic fashion should also be taken into account. Scalability can be viewed in two different ways. Dynamic scalability will allow the cluster to add modules without significantly altering the configuration, minimizing fuel cost when ingressing a module into the cluster. Static scalability allows a cluster configuration method that optimizes certain constrains to be adapted to different numbers of satellite modules.

Observability: In the absence of GPS, satellites in a cluster may use range measurements to the other modules in order to estimate their relative state. In order to observe the entire relative state it is important that the cluster geometry ensures that these relative measurements provide observability in three dimensions. For example, a planar configuration (like circles-in-circles in Figure 1 will not provide any observability in the out-of-plane direction.

A few cluster configurations created by Emergent Space Technologies and others that optimally satisfy some of these constrains are presented. Two formations developed by Emergent that optimize packing density (circles-in-circles) and stability (cross) are shown in Figure 1. Both of the designs are scalable from two to twenty modules.

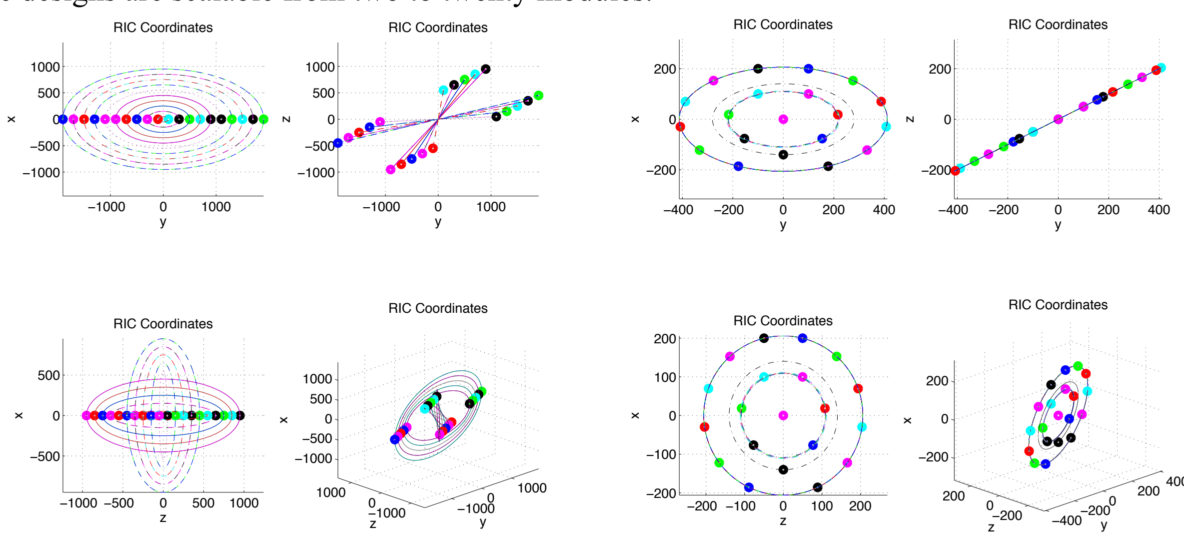

Figure 1: Circles-in-circles and Cross cluster configurations