Electromagnetic Formation Flight

Progress Report

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DESCRIPTION OF THE EFFORT

The Massachusetts Institute of Technology Space Systems Lab (SSL) and the Lockheed Martin Advanced Technology Center (ATC) are collaborating to explore the potential for a Electro-Magnetic Formation Flight (EMFF) system applicable to Earth-orbiting satellites flying in close formation.

PROGRESS OVERVIEW

At MIT, work on electro-magnetic formation flight (EMFF) has been pursued on two fronts: the MIT conceive, design, implement and operate (CDIO) class, and the MIT Space Systems Lab research group. The CDIO class, a three semester undergraduate course where students will design, build, test and operate an electro-magnetic testbed for formation flight, is currently in its first semester. The testbed that the class is designing will allow for six degree of freedom testing of EMFF systems and give students the chance to see the life cycle of a real aerospace system. The MIT Space Systems Lab research staff has been working on optimal systems design of spacecraft formations that will utilize electromagnets to control formation size and attitude. The details of the work accomplished by both the class and the lab are described in more detail below.

CDIO CAPSTONE COURSE

Formation flight of satellites is a concept that has been proposed for many purposes, including space interferometry. Unlike monolithic telescopes, interferometers are based on the concept of combining light from multiple apertures spaced a distance apart. Just as a monolithic telescope's angular resolution improves with aperture size, an interferometer's resolution improves with increased distance between apertures. Hence formation flight of separated spacecraft appears to be a useful tool in implementing space interferometry.

Until now, traditional thrusters have been proposed for formation flight attitude and positional control. However, there are several concerns with the use of thrusters, including plume contamination of neighboring spacecraft and sensitive optics, and the use of fuel as a nonrenewable energy source. Rather than thrusters, electromagnets could be used for formation flight control. Electromagnetic formation flight control has the potential to:

- Eliminate concerns about thruster plume impingement and optics contamination
- Control relative degrees of freedom, as opposed to the inertial degrees of freedom controlled by thrusters
- Rely on electricity provided by solar arrays, a renewable energy source, as opposed to thrusters whose finite fuel supply often limits the life of the spacecraft

Therefore, the objective of this class is to demonstrate the feasibility of an electromagnetically controlled array of formation flying satellites. This objective is cast as the following Mission Statement:

Demonstrate the feasibility of electromagnetic control for formation flying satellites.

- <u>Demonstrate</u> implies operating an electromagnetic formation flight testbed in a mode representative of a real world application, or "scaled" to demonstrate real-world feasibility.

- Electromagnetic control implies the design and implementation of a controller using electromagnets as actuators to control relative position and attitude.
- Formation flying satellites implies a testbed composed of multiple rigid bodies that must exhibit the functionality of a real cluster of satellites in formation flight.

In pursuant to this goal, the CDIO class was divided into four teams:

- The architecture team investigated all plausible technical options for implementing the various mission elements. Open literature, space mission databases, textbooks, internet, engineering advisors, as well as other sources were used to identify these options. Then the element options that were compatible with other element options are combined into system architecture. If an architecture meets the customer and functional requirements, it was considered a candidate architecture for the mission.
- The requirements team's first responsibility is to determine the customer requirements. This is done by determining the customer's needs and desires. Functional requirements based on the customer requirements and mission timeline were created that describe what must be achieved without going into details on how it will be accomplished.
- The databasing team was responsible for generating a database of possible vendors for many of the components that will be purchased later in the project. This database that was created will allow the teams to purchase items more efficiently later in the project.
- The processes team was responsible for determining and implementing the program budgets and timelines. The budgets include cost, as well as mass, power and other commodities. This team also developed a verification processes and configuration control so that all requirements will be met.

The four teams worked over the first half of the semester and presented their work in a Trade Analysis and Requirements Review (TARR) on March 19th. The power point presentation that was presented along with annotated notes is attached to this report.

MIT SPACE SYSTEMS LAB

The MIT Space Systems Lab research staff has been continuing research in the area of optimal designs and configurations for satellite formations utilizing electromagnets for relative attitude, relative separation and inertial rotation control. A paper was presented on this work at the last IEEE conference in Big Sky, Montana. The abstract of the paper is shown below with the complete paper attached to this report.

ABSTRACT - The use of propellant to maintain the relative orientation of multiple spacecraft in a sparse aperture telescope such as NASA's Terrestrial Planet Finder (TPF) poses several issues. These include fuel depletion, optical contamination, plume impingement, thermal emission, and vibration excitation. An alternative is to eliminate the need for propellant, except for orbit transfer, and replace it with electromagnetic control. Relative separation, relative attitude, and inertial rotation of the array can all be controlled by creating electromagnetic dipoles on each spacecraft and varying their strengths and orientations. This paper not only discusses optimized designs for a generic system but also shows that feasible designs exist for a five spacecraft, seventy-five meter baseline architecture for TPF.
(End of Report)