Electromagnetic Formation Flight

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Formation Design

This progress report will focus on the work done on the satellite formation design and trajectory control. This includes the spin-up of satellite formations, angular momentum management, and disturbance rejection.

Satellite Formation Spin-Up

In order to simplify the problem, the MIT SSL initially looked at interferometer formation flight missions outside the Earth's gravity well. Space-based interferometry missions must have a spinning formation in-order to fill the uv-plane. The specific problem that was addressed first was how to spin-up and de-spin the satellite formations using only electromagnets.

If the electromagnetic dipoles are oriented perpendicular to one another, shear forces result. This force allows the magnets to move perpendicular to the line between the two magnets. As the two satellites begin to rotate around each other, the magnets are rotated so that their dipoles align, and the formation is held together. The left side of Figure 1 shows two magnetic dipoles initially at rest along the x-axis. The dipoles, represented by arrows, are initially perpendicular to each other. As the formation begins to rotate, the dipoles are rotated so that they provide an attractive force to counteract the increasing centrifugal acceleration action on the spacecraft.

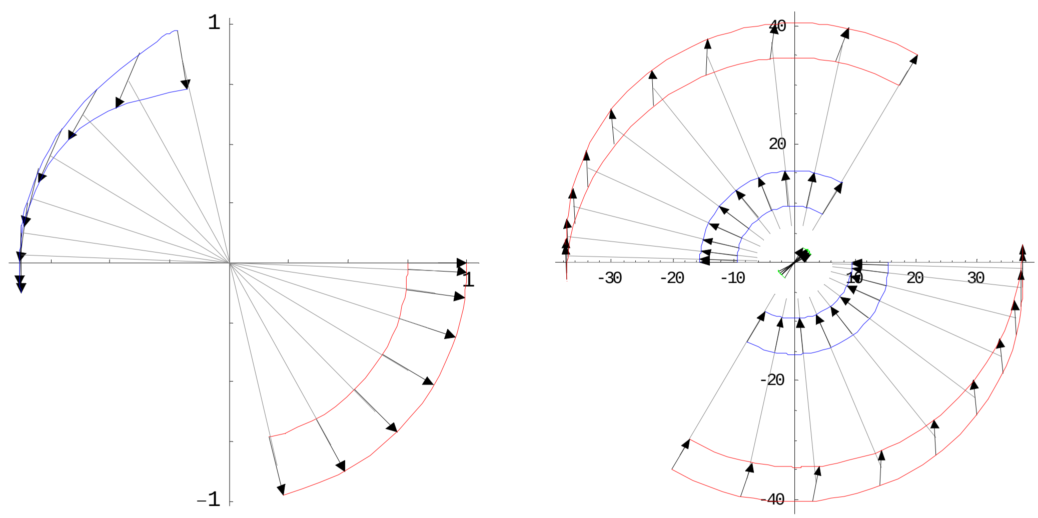

Figure 1: Satellite Formation Spin-Up

Having shown the ability to spin-up two satellite formations, the technique was applied to satellite formations of three and five satellites. The satellites are initially at rest, and are spun-up to a steady state rotation rate.

Angular Momentum Management

The MIT SSL is also looking at the problem of angular momentum management for these multiple satellite formations. When these shear forces are used to spin-up a satellite formation, torques are also placed on the individual satellites due to conservation of angular momentum. These torques are not the same for both spacecraft. While adding complexity to the problem, it also allows for the ability to actively select which satellites receive more or less angular momentum on them.

An example is easily shown in the three satellite case. The right formation has an even distribution of torque between the three satellites. This type of formation would lend itself to formations with identical satellites. In the left simulation, the outer satellites receive ¼ the torque as the center satellite. This type of formation would benefit formations with a large combiner satellite, and light collector satellites.

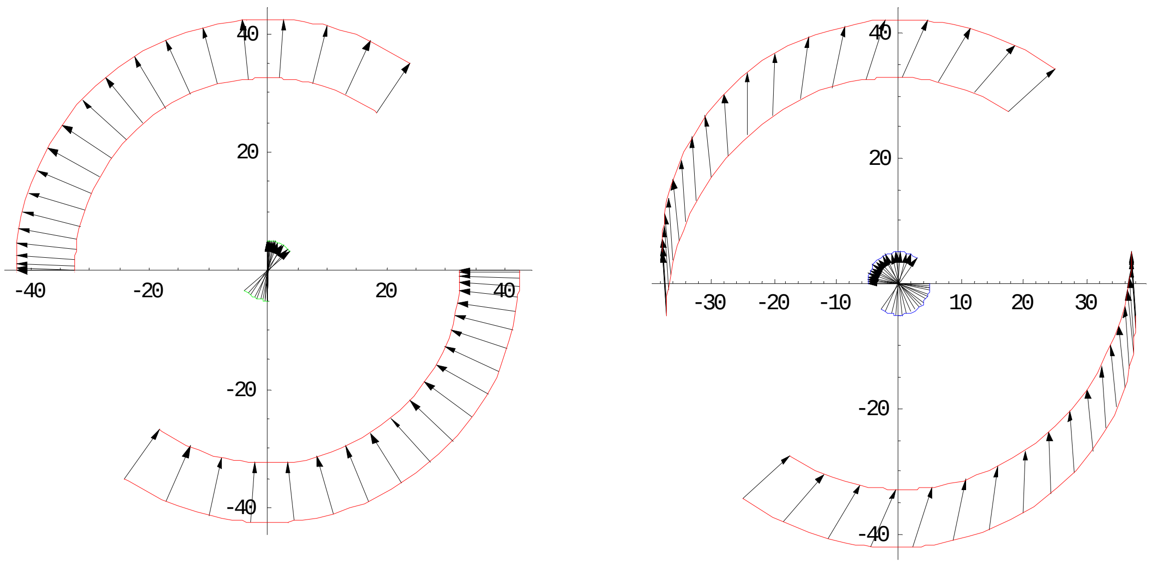

Figure 2: Angular Momentum Management

Formations in the Earth's Gravity

Most, if not all, of the NROs missions will lie within the Earth's gravity well. The MIT SSL is continuing to look at formation control and management within the Earth's gravity well. Instead of having to spin-up formations, the orbital mechanics of the formation causes the cluster to spin at a specific rate without effort from the formation. The difficulty lies not in spinning up the formation, but in holding the formation together (disturbance rejection), and initializing and changing the shape of the formation.

Disturbance Rejection.

Satellite formations will always be subject to some type of external disturbance force. EMFF must be capable of rejecting these formations if it is to be a useful means of formation control. When these formations are placed into Earth orbit, they are under the influence of many different disturbance forces. One obvious disturbance force is the Earth's own magnetic field. Because EMFF uses electromagnetics, any type of electromagnetic field created will interact with the Earth's magnetic field and cause a disturbance force on the satellite. The MIT SSL is currently evaluating the degree of this disturbance force and determining if it is a significant disturbance, or if it could be exploited and used to our benefit. For example, if the earth can be thought of as another spacecraft, could the angular momentum management techniques discussed earlier be used to move the angular momentum storage from the satellites to the Earth? This is already done with single satellites using magnetic torque rods, but the ability to do it with satellite formations is being actively researched.

Another disturbance force is the J_2 geopotential force. The MIT Space Systems Lab has much experience with satellite formations and the disturbances caused by the J_2 geopotential. This experience is being applied to the EMFF problem. The EMFF system must have enough control authority to reject the disturbances caused by the J_2 geopotential. EMFF systems are now being sized to counteract this disturbance force and still provide enough control authority for maneuvers.

Angular Momentum Management

While having enough control authority to reject these disturbances is important, another limiting factor is the reaction wheels of the system. The forces needed to counteract the J_2 forces include shear forces. As stated earlier, these shear forces cause torques on the satellites that must be absorbed in the reaction wheels. The MIT SSL has shown that many satellite formations produce a net gain in the angular momentum of the satellite as it rejects the J_2 disturbance forces. This will cause the reaction wheels to spin-up and over time cause them to saturate unless they can be desaturated using propellants or by exploiting the Earth's magnetic field.

However, the MIT SSL has found some satellite formations of two satellites that do not produce a net gain in the individual angular momentum of the satellite. Figure 3 shows 10 different two satellite formations that have zero angular momentum gain over the course of an orbit. The black dot's represent the position of the satellite's as they cross the equator.

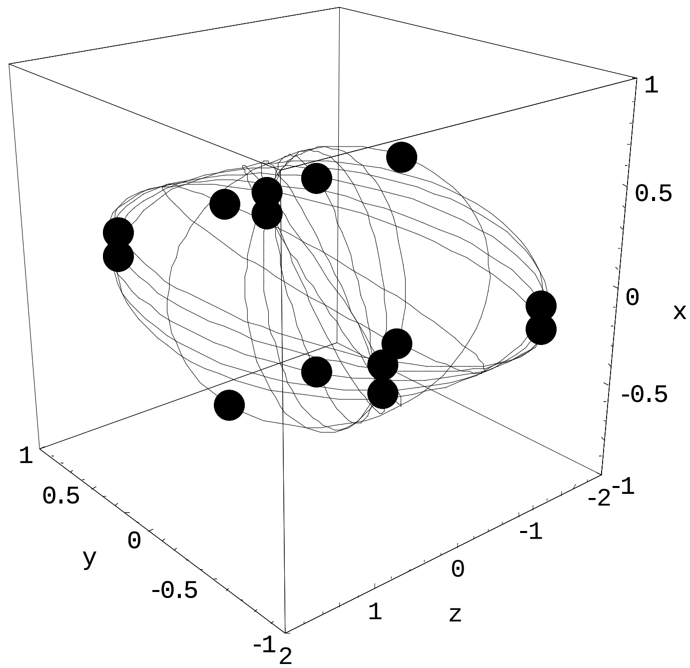

Figure 3: Satellite Formations that Have Zero Angular Momentum Gain

The lab is now looking at more complex formations of many satellites. These formations, while more complex, may have more control authority and a better ability to manage torque. It is the hope by adding more satellites and having better torque management, there will be a larger set of formations that produce zero net gain in the angular momentum.

Conclusion and Other Work

The MIT Space Systems Lab is continuing its research in the area of satellite formation design and control. Discussed above is the ongoing research on satellite formation spin-up, angular momentum management, and disturbance rejection. The lab is also currently working on control algorithms to produce these trajectories and reject disturbances, and to change the shape of the class. The undergraduate class (CDIO) is continuing to build an EMFF testbed where the control algorithms can be further developed and tested.