Short Abstract

Flying a Four-Spacecraft Formation by the Moon...Twice

J.J. Guzmán and A. Edery
a.i. solutions, Inc.

Spacecraft flying in tetrahedron formations are excellent for electromagnetic and plasma studies. To better understand the Earth's magnetosphere and its interaction with the solar wind, the NASA Goddard Magnetospheric Multiscale (MMS) mission will fly a tetrahedron formation through different regions of the magnetosphere close to the magnetic equatorial plane. However, to explore regions that are almost perpendicular to the ecliptic plane a dramatic plane change is needed. To minimize fuel, a double lunar swingby can be used to perform the plane change. This paper investigates the feasibility of flying a four-spacecraft formation through the required double lunar swingby.

Extended Abstract

Flying a Four-Spacecraft Formation by the Moon...Twice

J.J. Guzmán and A. Edery
a.i. solutions, Inc.

The NASA Goddard Magnetospheric Multiscale (MMS) mission will conduct investigations of magnetic reconnection, charged particle acceleration and turbulence in the Earth's magnetosphere [1]. To accomplish these studies, a 4-spacecraft formation will be used to fly through some of the key boundary regions of the magnetosphere. MMS will launch no earlier than 2009 and will, initially, orbit the Earth close to its magnetic equatorial plane (which is "close" to the equatorial plane). Later, in order to explore regions that are almost perpendicular to the ecliptic plane, a dramatic plane change is needed. To minimize fuel (the plane change costs a prohibitive amount of fuel) a double lunar swingby can be used to perform the plane change [2].

The trajectory design strategy for MMS involves obtaining a reference or nominal path that traverses the magnetospheric regions of interest. Specifically, the mission is divided in four phases: the first two phases traverse regions of the magnetosphere close to the magnetic equatorial plane, the third phase contains a double lunar swingby sequence (with an investigation of the deep tail magnetospheric region), and the fourth phase explores regions perpendicular to the ecliptic. Figure 1 displays phases III and IV for the reference path in the Sun-Earth rotating frame. The ecliptic plane is displayed to visualize the inclination change after the second lunar swingby. This paper investigates the feasibility of flying a four-spacecraft formation through the required double lunar swingby.

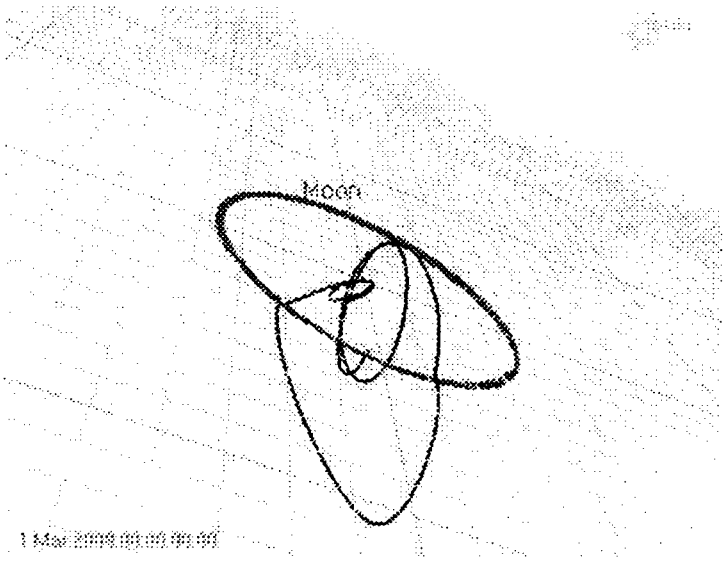


Figure 1: Double Lunar Swingby Sequence

Relative to the defined reference path, a tetrahedron formation is established at certain points during the mission. The problem of interest in this paper is the following: given a phase III nominal orbit that leads to the appropriate inclination at phase IV, find the relative paths and maneuver sequence that will allow four spacecraft, initially in a tetrahedron formation, to

1. fly by the Moon once,
2. explore the deep tail region of the magnetosphere
3. fly by the Moon once again — effecting the required plane change — and,
4. end up in orbits that allow the science mission to continue (phase IV).

During this sequence of events (i.e., between the lunar swingbys) the formation is not expected to be in a tetrahedron. In particular, a "string of pearls" (one spacecraft after the other in about the same orbit) configuration has been recommended for the deep tail region [1]. In this preliminary analysis we explore only the feasibility of the tasks. For example, consider a phase III to phase IV sequence given by the schematic representation in Figure 2.

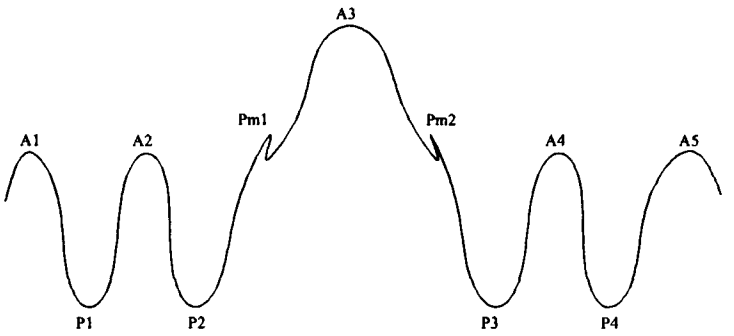


Figure 2: MMS Double Lunar Swingby Schematic

In this figure apoapsis/periapsis points are labeled with the letter A/P and a number. Furthermore, the periselene points have been labeled as Pm1 and Pm2. Note that A3 is the "apogee" that the scientists would like to be in the deep tail region. As a test, initializing the spacecraft formation as a regular tetrahedron, relative to the nominal path with a inter-spacecraft separation of 10 km and propagating with the same maneuvers as in the reference orbit, produces the inter-spacecraft distance versus time history in Figure 3. After, the second lunar encounter, labeled in the figure as Pm2 , the spacecraft separation dramatically increases. Closer examination of the orbital parameters also reveals that some of the spacecraft do not reach the desired ecliptic inclination. Now, if each spacecraft is targeted [2], that is, if a differential corrector is utilized to target (with maneuvers) some of the desired parameters at the first and second lunar encounter the time histories change. The new time history is displayed in Figure 4. Note the presence of distinct "event" points and the difference in the distance scale with the previous figure. Also, it turns out that at all the apogees (except at A3), the tetrahedron tends to get "back together". At A3, the

formation actually gets in a string of pearls configuration. These facts together with some preliminaries requirements given by Curtis [1], give some hope to the feasibility of Phases III and IV. In this paper, we will continue exploring the natural (and controlled) dynamics of the formation and formulating targeting and formation-orientation schemes to achieve the mission goals. Therefore, this analysis will help produce a preliminary formation flying fuel budget for phases III and IV.

References

[1] S.A. Curtis. The Magnetospheric Multiscale Mission...Resolving Fundamental Processes in Space Plasmas. NASA Goddard Space Flight Center, Greenbelt, Maryland, December 1999. NASA/TM—2000-209883.

[2] A. Edery and C. Schiff. The double lunar swingby of the MMS mission. In *16th International Symposium on Space Flight Dynamics*, Pasadena, California, December 2001.

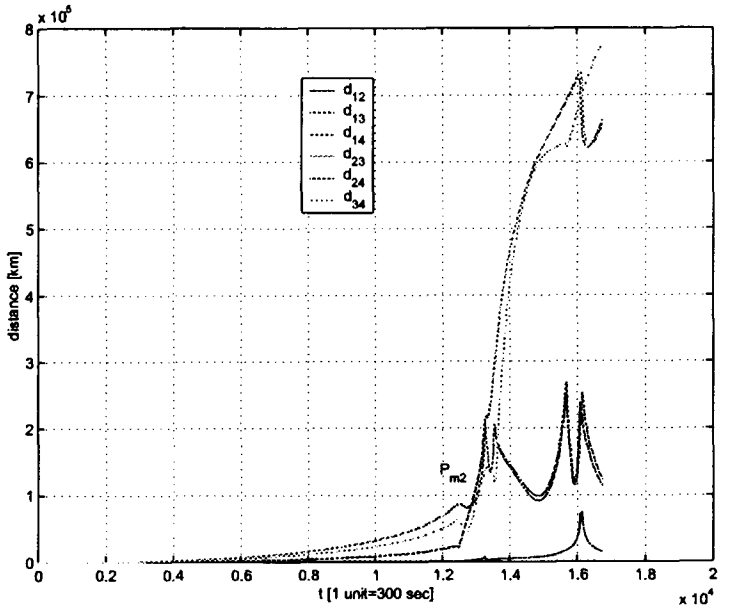


Figure 3: Double Lunar Swingby - No Targeting

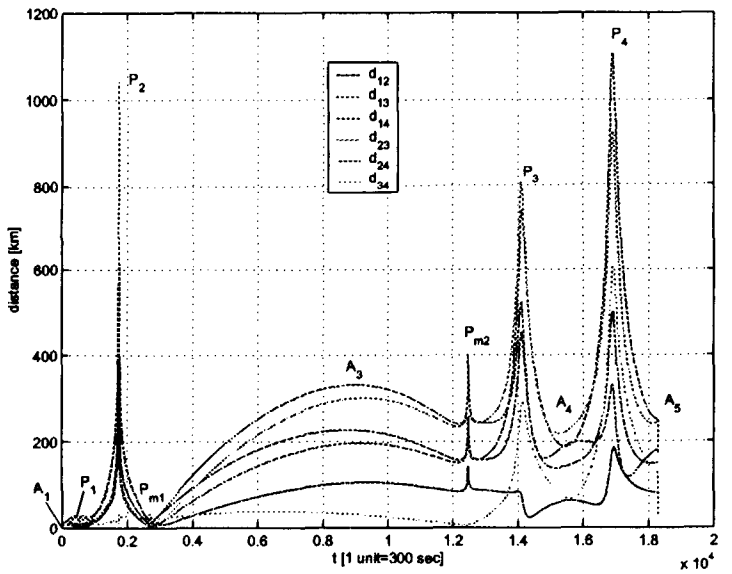


Figure 4: Double Lunar Swingby - With Targeting