Simulation of Formation Flight Near Lagrange Points for the TPF Mission

Alan Barr
Computer Science, Graphics Group
California Institute of Technology
barr@gg.caltech.edu

Gerard Gomez
Departament de Matematica Aplicada i Analisi
Unviersitat de Barcelona
Barcelona, Spain
gomez@cerber.mat.ub.es

Martin Lo
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA, 91109
Martin.Lo@jpl.nasa.gov
Communicating Author

Josep Masdemont
Departament Matematica Aplicada I
Universitat Politecnica de Catalunya
Barcelona, Spain
josep@barquins.upc.es

Ken Museth
Computer Science, Graphics Group
California Institute of Technology
kmu@gg.caltech.edu

Simulation of Formation Flight Near Lagrange Points for the TPF Mission

A. Barr, G. Gomez, M. Lo, J. Masdemont, K. Museth

The TPF Mission

The TPF Mission (Terrestrial Planet Finder) is one of the center pieces of the NASA Origins Program. The goal of TPF is to identify terrestrial planets around stars nearby the Solar System. For this purpose, a space-based infrared interferometer with a baseline of approximately 100 m is required. To achieve such a large baseline, a distributed system of five spacecraft flying in formation is an efficient approach. The current concept has four 3.5 m diameter telescopes, each with its own spacecraft, and a central spacecraft that collects and combines the beams. Since the TPF instruments needs a cold and stable environment, near Earth orbits are unsuitable. Satellites in Earth orbit are exposed to the radiation of the Earth and the Moon. Furthermore, the thermal cycling from the frequent coming in and out of Earth's shadow creates a thermally unstable environment which is unsuitable for infrared missions. Two potential orbits have been identified: a SIRTF-like heliocentric orbit; a libration orbit near the L2 Lagrange point. In this paper, we focus on the second case: an orbit near the L2 Lagrange point.

The formation flight problem near the Lagrange points is of great interest. Recent work in the study of the feasibility of formation flight near the Lagrange points indicates that:

1. Formation flight near L2 is dynamically possible for the TPF Mission.
2. Linear control around a nonlinear baseline libration orbit near L2 is adequate for the TPF Mission.

This paper provides simulations which validate these conclusions.

Advantages of a Mission Near L2

There are several advantages to a libration orbit near L2. Such an orbit provides a constant geometry for observation with half of the entire celestial sphere available at all times. The environment is nearly constant with the Sun, Earth, Moon always behind the spacecraft thereby providing a stable observation environment, making observation planning much simpler. Since the libration orbit will always remain close to the Earth at roughly 1.5 million km, and the communications geometry is nearly constant, the communications system design is simple. And in the event of a failed spacecraft, a replacement spacecraft can be quickly and easily sent to complete the constellation. Furthermore, libration orbits are excellent staging areas for human presence in space. Hence, it is much easier to support the human servicing of missions in libration orbits.

Description of the Simulations

We model this problem with the Circular Restricted Three Body Problem (CRTBP). Solutions within this model are easily moved to the full N-body model with JPL planetary ephemerides. Previous work indicates that the results and conclusion of the simulations are preserved under this model transfer.

The use of dynamical systems theory provides additional structures such as invariant manifolds within the phase space. These global structures provide insights and crucial initial guess solutions for the trajectory design. For example, the transfer from Earth to libration orbit uses solutions on the stable manifold as a first guess.

In order to study such a complex problem, an interactive simulation environment with constant visual feedback is extremely powerful. Some of the issues such as the changing scale of the problem provide challenges to both the numerical as well as the graphical computations. For instance, the baseline lissajous orbit has amplitudes on the order of 700,000 km. Where as the diameter of the formation is a mere 100 m. Another example is the computation and visualization of the manifolds. Interpolation of points on the manifold for trajectory computations require highly accurate numerics; whereas the interactive visualization requires fast computations of the points on the manifold. The successful management of these conflicting requirements is crucial to these simulations.

From the dynamical point of view, the TPF Mission can be broken into four scenarios:

Launch and Transfer to L2 Libration Orbit,
Deployment into Initial Formation,
Pattern Maintenance,
Reconfiguration into New Formation.

In this paper, we describe the simulations performed for each of the scenarios. We describe the control algorithms and estimate the delta-V required for each of the scenarios. The formation pattern chosen for this study is that of an N-gon as described in “The Terrestrial Planet Finder (TPF)” [TPF 1999].

Main Conclusion: Formation Flight Near L2 Is Dynamically Possible for the TPF Mission

References:

“The Terrestrial Planet Finder A NASA Origins Program to Search for Habitable Planets”, May, 1999, JPL Publication 99-3.