Design of a Multi-Moon Orbiter

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Abstract

The Multi-Moon Orbiter concept is introduced, wherein a single spacecraft orbits several moons of Jupiter, allowing long duration observations. The ΔV requirements for this mission can be low if ballistic captures and resonant gravity assists by Jupiter's moons are used. For example, using only 22 m/s, a spacecraft initially injected in a Jovian orbit can be directed into a capture orbit around Europa, orbiting both Callisto and Ganymede enroute. The time of flight for this preliminary trajectory is four years, but may be reduced by striking a compromise between fuel and time optimization during the inter-moon transfer phases.

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Mission to Europa is Strongly Recommended. The National Academy of Sciences recently issued a report calling on NASA to deploy a large mission every decade, one in which extended observation and experiments could be performed. In particular, the NAS report called on NASA to resurrect a mission to Jupiter's moon Europa—a project the space agency canceled earlier for budgetary reasons. Europa is thought to be a place hospitable to life because of the vast, liquid oceans that may exist under its icy crust. Two other Jupiter moons, Ganymede and Callisto, are now also thought to have liquid water beneath their surfaces. A proposed mission to Europa, and perhaps also Ganymede and Callisto, would attempt to map these regions of liquid water for follow-on missions.

Multi-Moon Orbiter. In response to the scientific interest in Jupiter's moons and the guidelines set forth by the NAS, a tour concept called the Multi-Moon Orbiter is introduced, wherein a single spacecraft "leap-frogs" between the moons of Jupiter, orbiting each moon for a desired duration in an elliptical orbit. This would allow long duration observations of each moon, compared to brief flybys. The ΔV requirements for such a mission can be very low if the techniques of low energy inter-moon transfer and resonant gravity assists by Jupiter's moons are used. As an example, by using small impulsive thrusts totaling only 22 m/s, a spacecraft initially injected in a Jovian orbit can be directed into an elliptical capture orbit around Europa. Enroute, the spacecraft orbits both Callisto and Ganymede for long duration using a ballistic capture and escape methodology developed previously. This example tour is shown in Figure 1. The Multi-Moon Orbiter, constructed using a patched three-body approach, should work well with existing techniques, enhancing NASA's trajectory design capabilities.

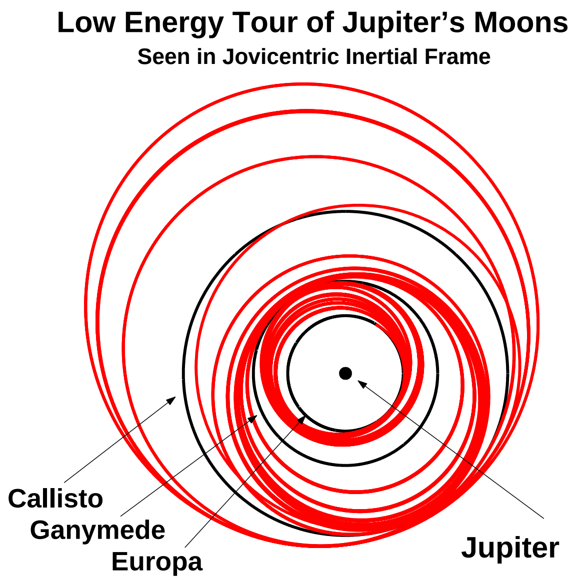

Figure 1: **The Multi-Moon Orbiter space mission concept for the Jovian moons** involves long duration orbits of Callisto, Ganymede, and Europa, allowing for extensive observation. By utilizing resonant gravity assists with the moons, in addition to the tubes of orbits leading toward or away from temporary capture orbits about a moon, a tour can be constructed using very little fuel. The trajectory shown is a simulation of a restricted 5-body problem and requires a ΔV of only 22 m/s. The Multi-Moon Orbiter is a general concept applicable for any multi-moon system and is not limited to the specific example shown.

Compromise Between Fuel and Time Optimization. This dramatically low ΔV is achieved at the expense of time—the present trajectory takes about four years, most spent in the inter-moon transfer phase. We conjecture that it is possible to reduce the ΔV to zero, providng a theoretical lower bound for the energy requirements for a Multi-Moon Orbiter.

More importantly for missions, we conjecture that for slightly larger ΔV, a reasonable time of flight of several months can be achieved. This conjecture is based upon evidence in a similar astrodynamics problem using the planar, circular, restricted three-body problem as the model; a time and fuel optimized trajectory from an Earth orbit to the Earth's moon. Bollt and Meiss [1995] considered the transfer from a circular Earth orbit of radius 59669 km to a quasi-periodically precessing ellipse around the moon, with a perilune of 13970 km. Their method takes advantage of the fact that long trajectories in a compact phase space are recurrent. Starting with a long unperturbed chaotic trajectory that eventually reaches the target, the use small well chosen ΔV's to cur recurrent loops from the trajectory, shortening it whenever possible. They find a transfer (see Figure 2(a)) that achieves ballistic capture requiring 749.6 m/s, 38% less total velocity boost than a comparable Hohmann transfer, but requiring a transfer time of 748 days. Schroer and Ott [1997] also considered this problem with the same initial and final orbits, but found a transfer requiring about half the flight time, 377.5 days, but using roughly the same total ΔV, 748.9 m/s, suggesting that this is near the minimum required for a transfer between these two orbits.

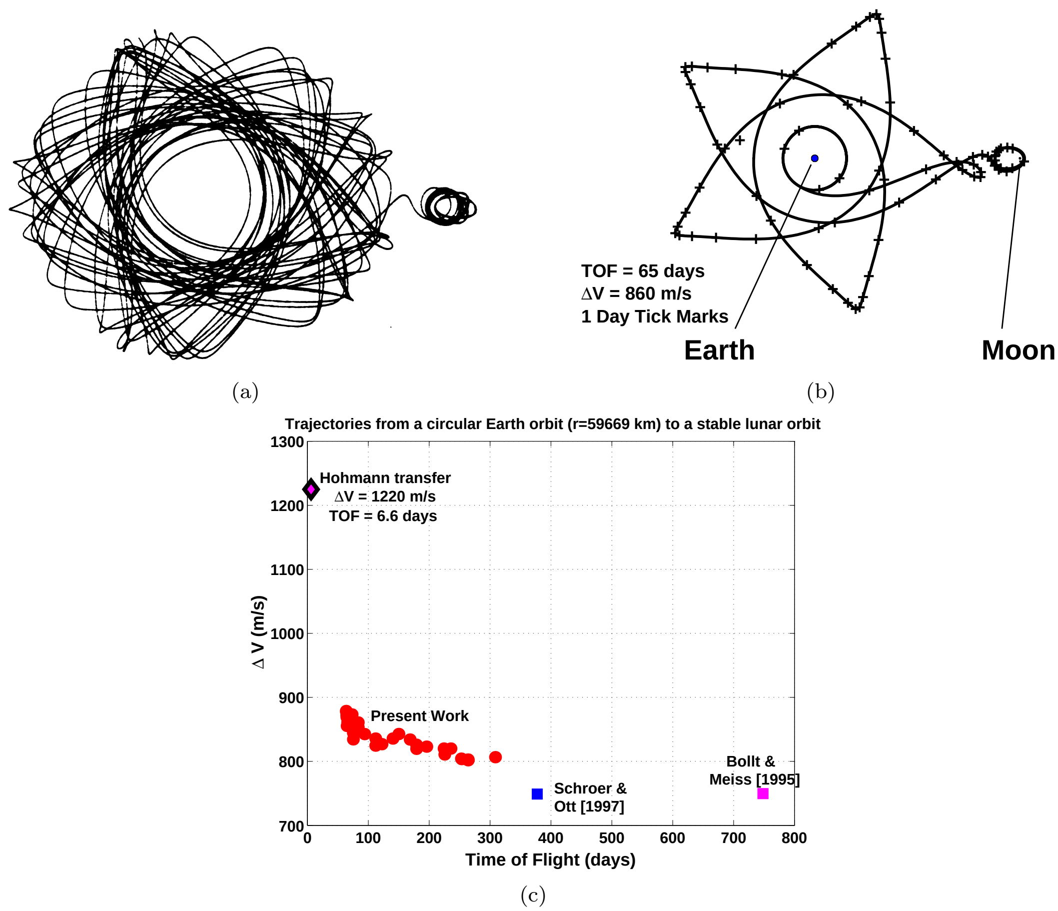

Figure 2: **Compromise between fuel and time optimization.** (a) The transfer from a circular earth orbit of radius 59669 km to precessing lunar orbit of perilune 13970 km found by Bollt and Meiss [1995] is shown in the rotating frame. The ΔV is 749.6 m/s and the time of flight is 748 days. (b) A transfer between the same initial and final orbits, using a ΔV of 860.1 m/s, but requiring a flight time of 65 days. (c) The ΔV vs. time of flight plot for several "chaotic" trajectories to the moon, compared with the Hohmann transfer. As can be seen, a trajectory of one-fifth to one-tenth of the flight-time of some previous fuel optimized trajectories can be achieved using only about 100 m/s more ΔV.

In the present work, we seek transfer trajectories that provide a compromise between time and fuel optimization. Using the method of Schroer and Ott [1997], together with methods for achieving ballistic capture (Koon, Lo, Marsden, and Ross [2000,2001]), we find a transfer, shown in Figure 2(b), with a flight time of 65 days which uses a total ΔV of 860.1 m/s. Thus we take one-tenth of the time as the Bollt and Meiss [1995] trajectory using only about 100 m/s more fuel. See Figure 2(c).

This "compromise" method has been applied to only one three-body system thus far. In the future, we wish to adapt the method to missions combining several restricted three-body systems, such as the Multi-Moon Orbiter, in order to seek more reasonable flight times.