



FORTUNE EIGHT
Aerospace Industries, Inc.
International Technical Services

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MEMORANDUM

To: CMA Class
From: Chauncey Uphoff
Subject: Class Notes for Lecture #8

In Lecture #8 I gave my paper on "Lunar Cyler Orbits with Alternating Semi-monthly Transfer Windows." Drew Crouch was co-author and was a great deal of help in proving that we could do the navigational targeting for very little ΔV . The important thing about the "Lunar Cyler ..." paper is that it provides a mechanism for continuous, periodic transfer from Earth to moon or from moon to Earth that requires no nominal ΔV . Also acknowledged in the paper were inputs from Dr. Buzz Aldrin who, during that time, became a close friend and colleague. Many others were (then) CU students who had taken this course several times because they realized that there was always something new in it. Drew Crouch, Mike Loucks, and Brent Helleckson helped me teach the course several years during the early 90s. Mike and Brent will give a full-day course on use of AGI's STK™/Astrogator next Saturday (2002 April 6). Pay attention; this will be important to your understanding of the main point of this course - the importance of learning to teach oneself.

The "Lunar Cyler" paper is posted under Bonus Handouts on the web-site. As I said, it's a great cure for insomnia because the description of the mechanism is so involved with details as to put one to sleep. But save this paper because you'll like it later. It includes what I call the concept of "Planetary Zugzwang" (from chess and German, meaning, "move compulsion.") Although I had not thought of the "Zugzwang" analogy until after I had the idea, the idea was there before I discovered the "BackFlip." Others had given proof of invention of this concept. For example, Bill Kirhofer, of JPL, discovered the "BackFlip" in the mid-60s, during the Ranger Project days. Breakwell and Gillespie wrote a paper, in 1963, explaining the concept of "Orbits Launched Out of the Ecliptic." Dr. Alex

Kogan, then of IKI, had applied the concept to a 540° moon to moon transfer for a mission that required multiple large-apogee orbits with high inclinations wrt. the ecliptic. Dr. Kogan understood the “BackFlip” concept as soon as I showed it during lectures at Keldisch Institute in Moscow in 1990, just before the demise of Sovietskii Soyuz. What none of us (excepting a few people on the Ranger project) knew was that it is possible to do the BackFlip using a single lunar swingby from a near-minimal energy Earth to moon transfer. Jim Burke (now retired from JPL) told me of the “Kirhofer” orbit during the meeting where I presented the “Restricted 4-Body” paper. I later spoke with Kirhofer and he recalled having discovered the lunar BackFlip in studies of dispersed Ranger trajectories that did not impact the moon. Bill was not able to find his write-up of the BackFlip but told me that it exists in some JPL document regarding Ranger transfer trajectory dispersions.

The BackFlip is an example of what Phil Roberts dubbed “ $n-\pi$ transfers with n odd” in our paper on “Orbit Design Concepts for Jupiter Orbiter Missions.” We had made use of the 180° transfers from one Galilean satellite to another, but we did not realize that it was possible to go from one swingby to another at the same swingby planet in half a revolution. The BackFlip is an example of “ $n-\pi$ transfers” with $n = 1$. (Kogan’s application used $n = 3$). The BackFlip has been executed twice in the real world with the ISTP program spacecraft WIND, using the mechanism to reverse the phase of the highly elliptic cislunar orbit with respect to the Sun-Earth line. Our colleagues at APL (Peter Sharer) , GSFC (David Folta and others), and CSC (Heather Franz) designed and executed the BackFlip maneuver for WIND.

The BackFlip mechanism permits one to reverse the phase of an orbit in cislunar or heliocentric space, by use of a 180° , out-of-plane, transfer from a planet back to itself, without the need for extra propulsion, within a half-period of the swingby planet, except for small navigation maneuvers. It is the dynamical heart of the Lunar Cyclers concept.

In the lecture, as in the paper, I pointed out a mistake I made in trying to go from one BackFlip to another in a single swingby. This “Reflected BackFlip” maneuver (in the Earth-moon system) requires a very high lunar excess speed that is not compatible with low energy Earth-to-moon transfers and is, therefore, not compatible with the objective of the Lunar Cyclers. That objective is to find frequently repeating transfers from Earth-to-moon

and from moon-to-Earth where the trans-moon/Earth transfers have near-minimal energy, with respect to the Earth, so as to permit insertion into (and return from) the trans-moon/Earth orbits with near-minimal energy requirements for the launch vehicles and taxis.

The most important part of the Lunar Cyclor concept is that it allows us to build Cities in Cislunar Space. It is pointed out, in the paper, that the dual Cyclor concept requires both Cyclors to arrive at the moon at the same time (somewhere during the 6-week cycle) in order to provide semi-monthly Earth-return opportunities. Dr. Aldrin recognized, almost immediately, that this "requirement" can be used to join two Cyclors (to build Cities or Hotels), while a third Cyclor is launched from Earth to take the (now empty) place of the one that was joined with the first. Of course, this process can be continued, in affordable increments, to build two (or more) large Cities, with radiation protection, self-sufficient energy sources, hospitals, emergency vehicles, and taxis to take people and supplies from Earth or moon to and from the Cities, or from City to City. The mechanism provides for transfer to the moon in about 5 days, and return to Earth, two weeks later, in another 5 days, in a safe, radiation-protected Cyclor that can truly be made into a City.

I showed the movie of the Lunar Cyclor concept, again, at the end of the lecture with hope that it would make more sense to the students than it did when I showed it in the introductory Lecture #1. I also mentioned that Dr. Aldrin, Dennis Byrnes, Paul Penzo, Jim Longuski (and his students at Purdue), several others, and I are trying to find the same kind of mechanism for continuous transfer between Earth and Mars with no nominal impulse. So far, these efforts have been unsuccessful because of the ellipticity of Mars's orbit and the weak gravity of Mars. But we'll soon find it. Then we'll have a way to build Cities that transfer automatically from Earth to Mars and Mars to Earth, without having to stop at either planet.

Best regards,

Chauncey Uphoff 2002 April 2