FORTUNE EIGHT

Aerospace Industries, Inc.

International Technical Services

Original Lecture: 2002 April 10

MEMORANDUM

To: CMA Class

From: Chauncey Uphoff

Subject: Class Notes for Lecture #12

In Lecture #12, I began a discussion of the Main Problem of the Lunar Theory (Third-Body Perturbation Theory). I discussed the importance of the inputs I received from Professor Michael Lidov in his 1961 (Russian) paper on the long-term effects of doubly-averaged effects of a third body on the motion of a particle (or an artificial satellite). The English version was published in 1963, in the place (AIAA Jrn. Russian Supplement) I was first able to read it. I quickly realized that Lidov's development was a straight-forward double averaging of the same disturbing function written by Kozai in his 1961 paper on 3rd body perturbations. I had been struggling with this disturbing function until I realized that Lidov had simply "thrown away" the terms that depended upon the mean anomaly of the disturbing body in its orbit about the central planet.

I first learned of Kozai's development of the 3rd body disturbing function from Ralph Deutsch's book " Orbital Dynamics of Space Vehicles" (Prentice-Hall, 1963). This was hard to understand for a novice in celestial mechanics, as most of us were in the early 60s. Later, when I read Lidov's paper, PaAngliskii, I understood how to develop a perturbation theory for highly-perturbed lunar satellites. Fortunately, nobody had told me that this was impossible, so I did it anyway. The perturbations were clearly written (in terms of classsical Keplerian elements) in Deutsch's book and were taken from Kaula's (SAO Special Report #22) note from 1959. Here's the Ref. (Deutsch's Ref. [75] :

> **Kozai, Y, "On the Effects of the Sun and the Moon upon the Motion of a Close Earth Satellite," Special Report No. 22, Smithsonian Institution Astrophysical Observatory, Cambridge, Mass. (March 1959).**

Later, through my friend and career-long colleague, Robert J. Vickery Jr., I learned of Professor Lidov's paper in the AIAA supplement and, subsequently, understood Lidov's magnificent simplification of what I now call "The Main Problem of the Lunar Theory." Professor Lidov, and shortly later Williams and Lorell, showed that the "Secular" terms in the old Lunar theory were not secular (linear) but were actually very long-periodic in nature. What is more important is that they showed that the amplitudes of these "Secular" perturbations did not depend upon the semi-major axis of the particle's orbit with respect to the central body (as the old lunar theory implied) but only upon the initial values of the eccentricity, inclination, and argument of pericenter of the "mean mean (doubly-averaged) orbital elements."

Next, I showed an example of an application of this theory to a recent problem that Jason Stauch and I worked on last summer. The application was to find a highly elliptic Earth orbit that would not crash into the Earth or the moon, nor escape the Earth-moon system. Through this mechanism, we were able to show that there are realistic orbits that will satisfy the "Back-Contamination" requirements of a Mars Sample Return mission. The idea is to bring the sample container back to a loosely captured elliptic Earth orbit, with large semi-major axis and low perigee. Most people think such orbits are highly unstable. But there are such orbits that last for decades (perhaps for centuries) if we can select the eccentricity and the argument of pericenter and inclination (wrt. the Earth-moon plane) in such a way as to null the value of Lidov's second integral ($C_2 = e^2\,[2/5 - \sin^2 i \sin^2\omega]$). A couple of short memos were posted on the web-site showing that the technique is both theoretically possible and technically feasible (for, at least, 20 to 30 years).

I pointed out the distinction between this application and the one to which I originally applied Lidov's 2nd integral. That application (IMP-H & J) was to find a nearly-circular orbit, between 30 and 40 Earth-radii, that stayed within that radial range for at least two years. In the MSR application, Jason and I had to show that there are real orbits, with initial high eccentricities and large semi-major axes, that are stable against Earth impact, lunar impact, and escape from the Earth-moon system. In the MSR application, we did not have to suffer the slings and arrows of outrageous resonances that tended to disrupt the IMP-H and IMP-J orbits. My colleagues at GSFC (in those days, Charles Newman, Jim Cooley, and Dan Muhonan) had to thread their way through those resonances to establish the IMP-H and IMP-J orbits. Jason and I didn't have that problem because the MSR Earth Capture Orbit was not close to one of the low-order resonance conditions. If the student wishes to understand this, he or she should think about it carefully. This kind of thinking has nothing to do with your grades (marks); it has to do with your own future.

Other things in this lecture were a reiteration of the distinction between analytical and numerical averaging of the osculating equations of motion (or the perturbations of the two-body equations) and a description of the final homework problem for the Lecture series. The discussion of the distinctions between numerical and analytical averaging included my own explanation of why numerical averaging can "capture" the effects of resonances, while analytical averaging cannot do so without special provisions for the terms that are resonant with the motion of the spacecraft or the osculating orbit.

It is my intention, in this course, to teach the students how I put ideas together, rather than to assemble a bunch of the ideas of others and ask the students to regurgitate that compendium in some kind of "Final Test" of your abilities. Your abilities belong to you; they must be developed and improved by yourgoodselves. Remember, in the long run, the Universe will give you your final exam.

Best regards,
Chauncey Uphoff 2002 April 11