Long Lifetime Orbits for the German Lunar Exploration Orbiter

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In the context of the German Lunar Exploration Orbiter mission LEO, one mission objective is the improvement of the lunar gravity field models. Current models are based on tracking data from the very first lunar probes, the Apollo program, and more recently the Lunar Prospector mission. A comparison of the historic lunar gravity models with the more recent models that include the Lunar Prospector data reveals large differences in the zonal harmonic coefficients. The largest errors that are contained in the current gravity field models occur on the backside of the Moon due to missing ranging data.

In order to achieve a significant improvement, a pair of satellites forming a GRACE-like constellation is considered as one element of the LEO mission. Such an approach can significantly improve the orbit modeling on the far side of the Moon. In order to obtain a global coverage for the gravity field, the satellites need to fly in a low altitude polar orbit around the Moon. Due to the asymmetry in the Moon's gravity field, such orbits are known to be highly unstable due to a large disturbance that changes the eccentricity vector and thus leads to a deformation of the orbit which ultimately yields a crash of the satellite into the Moon's surface.

In the context of the LEO Phase 0 and A studies, a range of almost polar orbits with an average altitude of 50 km were identified which exhibit a good stability and long lifetime. Such orbits are known as frozen repeat cycle orbits since their average eccentricity vector is not changing and their ground track is repeating. Due to the very slow rotation of the Moon, the repeat cycle is at least one lunar month (approx. 28 days). As illustrated in Figure 1, the eccentricity vector is changing during this period, but the pattern is closed after one lunar month. The same applies for the ground track. A 3D representation of the orbit is shown in Figure 2 with the altitude scaled by a factor of 40. The orbit is designed for a nominal lifetime of 4 years. It was analyzed in more detail with a Monte Carlo simulation in which the different gravity field parameters were varied according to the reported accuracies in the lunar gravity field model. It turns out that a lifetime of at least 100 days can be guaranteed in the presence of the assumed uncertainties and that a the chances of surviving a full year are around 80% if no orbit maneuvers are applied (see Figure 3).

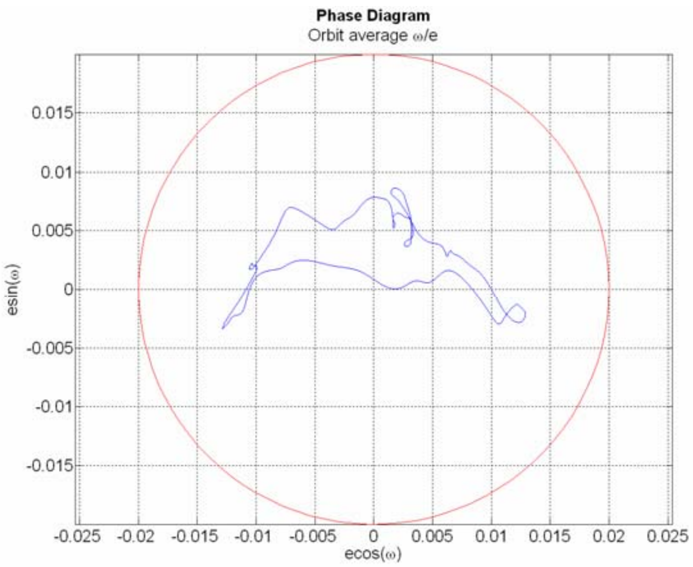

Figure 1: *Eccentricity vector diagram for the baseline reference orbit shown for one lunar month*

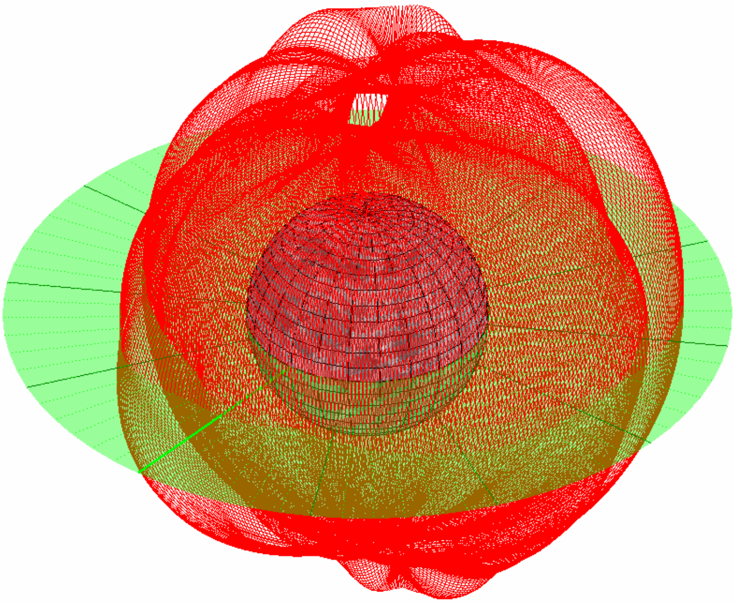

Figure 2: *3D representation of the reference orbit (altitude scaled by a factor of 40)*

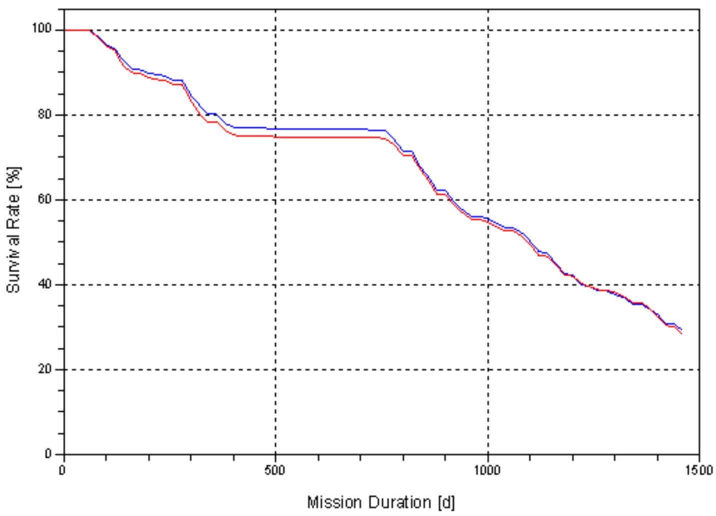

Figure 3: *Survival rate of the LEO reference orbit without orbit maintenance applied*

The mission lifetime can be extended by applying eccentricity vector correction maneuvers at least once per lunar month and an inclination correction maneuver approximately every 10 lunar months. The inclination correction maneuvers become necessary due to changes in the Moon's rotational axis orientation which effectively yields a small change in the ground track and thereby in the inclination w.r.t. a coordinate frame that is fixed to the Moon's current rotational axis. An extensive analysis was carried out for LEO's main satellite for which a lifetime of four years must be guaranteed. This results in a fuel consumption of approx. 1.1 m/s per lunar month. Of course, the lifetime of the sub-satellites performing the gravity field measurements could also be extended by using the same approach, depending on the fuel that is finally available for orbit maintenance maneuvers. However, the number of maneuvers for the gravity mission should be minimized in order not to disturb the measurements too often.

In conclusion, a reference baseline orbit has been found that is suitable for gravity field measurements that allow for a global coverage of the Moon's gravity field and require no orbit maintenance for the first 100 days.

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