Low Altitude Polar Lunar Frozen Orbits

An Innovative Method for Using Potential Models to Increase the Orbit Lifetimes of Spacecraft after Ascent from the Lunar South Pole

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Objective

- The purpose of the research is to find a low altitude, lunar, frozen orbit in which to launch a spacecraft from the south pole of the moon.

- The orbit should yield the longest lifetime and still maintain a safe altitude above the lunar mountains.
Process

- GSFC’s General Mission Analysis Tool (GMAT) was used to propagate the spacecraft using a 100 x 100 lp165 lunar potential model.

- The Earth, Sun and Jupiter were included in the simulation as point masses.

- Periapsis and apoapsis altitude were varied to cover a wide variety of low altitude, polar orbits.

- The right ascension of the ascending node was changed for each simulation in order to find the optimal launching longitude.

- The potential model of the moon was used to find lunar longitudes that would naturally raise the periapsis to increase the lifetime of the orbit.

- After the optimal orbit was found, a sensitivity analysis was completed to find the performance and pointing errors for the insertion maneuver.
Results for Lifetime vs Lunar Longitude
Results for Lifetime vs Lunar Longitude

- Max propagation time was 45 days
- Periapsis altitude was varied from 5 km to 20 km
- Apoapsis altitude was varied from 50 km to 200 km
- Optimal launching longitudes lie between 0° and 180°
- 31.6° was used for the simulations
- Large range of acceptable lunar longitudes to launch into
- Periapsis has a larger effect on lifetime than apoapsis
- When periapsis altitude is set to 5 km, the orbit has a short lifetime, regardless of apoapsis altitude
Optimal Orbit

The optimal orbit, taking into account longitudes, overall altitudes and lifetimes and trying to minimize fuel used, is listed below.

- Periapsis Altitude = 10 km
- Apoapsis Altitude = 200 km
- Lunar Longitude = 40 degrees

The first orbit around the moon can be seen to the left, as viewed from Earth.
Optimal Orbit

The figure below shows the instantaneous periapsis altitude vs time and the instantaneous altitude vs time over the first day of the orbit. At the point when the instantaneous periapsis is at a minimum (8.95 km), the spacecraft is at apoapsis, and an altitude of 200 km. The instantaneous periapsis altitude drops below 10 km during the first day, however, the instantaneous altitude of the spacecraft does not.
Optimal Orbit

The figure to the left shows how the eccentricity of the orbit changes over time with respect to the argument of periapsis. The line comparing the eccentricity and the argument of perigee revolves around a stationary point or frozen point.
Sensitivity Analysis

- The yaw, pitch and the orbit insertion maneuver performance were varied to see the impact on the lifetime of the orbit.

- Changing the yaw angle is essentially the same thing as changing the launch longitude, and an error of ±5 degrees has little effect on the duration of the orbit.

- Both a reduction in thrust or a change in the pitch angle had a fairly significant impact on the lifetime of the spacecraft.

- The first set of simulations were run under the assumption that the spacecraft did not impact until its altitude over the mean radius of the moon was zero.

- The second case takes into account the possibility of lunar mountains and considers the spacecraft to impact if the altitude comes within 5 km of the mean radius of the moon.
Case I: 0 km Altitude as Impact Condition

Lifetime of a 10 km by 200 km polar orbit at 31.6 deg long
Lifetime limited by 0 km Altitude
Case II: 5 km Altitude as Impact Condition

Lifetime of a 10 km by 200 km polar orbit at 31.6 deg long
Lifetime limited by 5 km Altitude

Thrust (as a percent of ideal thrust) Pitch (degrees)

Lifetime of a 10 km by 200 km polar orbit at 31.6 deg long
Lifetime limited by 5 km Altitude

Pitch (degrees)
Results of the Sensitivity Analysis

• Notice that as expected the life time is shorter for the 5 km altitude impacting condition.

• If the pitch varies by more than about ±1 degree, the spacecraft will impact with the moon.

• If the thrust drops below 97% of the initial thrust, the spacecraft will impact with the moon.

• The lifetimes tend to last longer for the positive pitch angle due to initial argument of periapsis and eccentricity rates.

• A positive pitch angle corresponds to the velocity vector being tipped away from the planet.
Conclusions

• The optimal orbit is a 10 km periapsis altitude by 200 km apoapsis altitude with a lunar longitude near 40 degrees.

• Small pitch or thrust errors can cause drastic changes in orbit lifetime due to the low altitude of the orbit and the presence of the mascons inside the moon.
Questions?
Acknowledgements
