Sensitivity study of radiation pressure models for precise orbit determination

Dominik Stiller

B.Sc. Student, Faculty of Aerospace Engineering, TU Delft, Netherlands

Abstract

Keywords
Radiation pressure, orbit determination

Acronyms: LRO Lunar Reconnaissance Orbiter

1 Introduction

Lunar Reconnaissance Orbiter (LRO)

”SRP is the largest non-gravitational perturbation affecting the LRO orbit and inadequate modeling of SRP is the primary cause of large prediction errors for LRO, particularly during high-beta angle periods” [1]

Operational LRO OD does not use lunar albedo due to computational demand, but used for offline reprocessing. Self-shadowing from Mazarico *et al.* is used [3]

High OD error during full-sun periods with cannonball model, but acceptable with multi-panel model and real attitude for SA and HGA [4]

albedo radiation significant since no atmosphere exists, up to 30 % [5]

model setup: solar array tracks Sun, HGA tracks Earth [6] start at start at 26 June 2010 06:00:00 Earth eclipses Sun during this time Moon does not eclipse Sun (Sun beta angle is about -90 deg, see [6])

mass: 1208 kg (1915 kg loaded mass, 644 kg prop used after mission orbit insertion, then 6.315 kg prop used for each of 10 sk maneuvers till 26 june 2010 [7])

2 Models

every irradiance in the list can be thought of as ray

effect of self-shadowing on LRO orbit is small [8]

no seasonal or diurnal albedo variation on Moon, as opposed to Earth [9]

use angle-based model from Lemoine Constant-emission model from Knocke is not appropriate for moon since it gets very cold Flux from Lemoine agrees with [6, Table 8]

Cannonball area assumptions:

- No self shadowing
- SA and HGA areas are scaled by factor $2/\pi$ (average of $A|\cos\theta|$)

to find equivalent rp coefficient, some authors use raytracing [10], we just use weighted average finding a single rp coefficien is virtually impossible since it changes [11, p 580]

Different values for A and Cr in literature: [3]: 14, 1.0 (for daily/not precision OD, no changing orientation, solar only) [12]: 10, 1.2 (no changing orientation, solar only) [1]: first 1.67, then 0.96 after estimation [13]: 1.03 +- 0.24 (1.04 in sep, 1.4 in jun)

3 Results

beta angle slightly less than 90 degrees leads to sinusoidal acceleration

IAU_MOON is in worst case 155 m off [14] (Special PCK and FK for Earth and Moon, slide 14)

for radiation pressure acceleration, add partial/full eclipse to time axis

absolute acceleration magnitude likely influenced by mass uncertainty rp acceleration magnitude increases as mass decreases

plots for beta = 80 (constant sunlight, Jun 26) and beta = 0 (orbital plane intersects sun, Sep 26)

start at 2010-06-26 06:00:00 UTC, which corresponds to 2010-06-26 06:01:06 TDB

effect of instantaneous reradiation

static vs dynamic performance static number of panels dynamic number of panels per ring

variation in altitude is in part due to assumption of spherical moon (polar radius is 2.1 km less than equatorial)

static vs dynamic have different types of inaccuracy dynamic at low resolution has bias and converges globally towards accurate version static at low resolution looks like noise and noise is reduced when increasing resolution

arc length 2.5 days, which is also used for LRO orbit determination [15]

neglecting self-shadowing overestimates area [2], but minimal self-shadowing in most cases for LRO [1]

Thermal radiation may cause an offset of 1-2 meters over an arclength of 2.5 days [12]

our maximum eclipse time of 48 min agrees with [6]

kink in cross-track SRP also seen in SELENE [16], search for explanation

Email: d.stiller@student.tudelft.nl

References

1. S. Slojkowski, J. Lowe, and J. Woodburn, "Orbit determination for the lunar reconnaissance orbiter using an extended kalman filter," in *International Symposium on Space Flight Dynamics (ISSFD) 2015*, 2015.
2. E. Mazarico, M. T. Zuber, F. G. Lemoine, and D. E. Smith, "Effects of self-shadowing on nonconservative force modeling for mars-orbiting spacecraft," *Journal of Spacecraft and Rockets*, vol. 46, no. 3, pp. 662–669, May 2009. DOI: 10.2514/1.41679.
3. A. Nicholson, S. Slojkowski, A. Long, M. Beckman, and R. Lamb, "NASA GSFC lunar reconnaissance orbiter (LRO) orbit estimation and prediction," in *SpaceOps 2010 Conference*, American Institute of Aeronautics and Astronautics, Apr. 2010. DOI: 10.2514/6.2010-2328.
4. S. E. Slojkowski, "Lunar reconnaissance orbiter orbit determination accuracy analysis," in *International Symposium on Space Flight Dynamics*, 2014.
5. R. Floberghagen, P. Visser, and F. Weischede, "Lunar albedo force modeling and its effect on low lunar orbit and gravity field determination," *Advances in Space Research*, vol. 23, no. 4, pp. 733–738, Jan. 1999. DOI: 10.1016/s0273-1177(99)00155-6.
6. C. R. Tooley *et al.*, "Lunar reconnaissance orbiter mission and spacecraft design," *Space Science Reviews*, vol. 150, no. 1-4, pp. 23–62, Jan. 2010. DOI: 10.1007/s11214-009-9624-4.
7. M. Mesarch, M. Beckman, D. Folta, R. Lamb, and K. Richon, "Maneuver operations results from the lunar reconnaissance orbiter (LRO) mission," in *SpaceOps 2010 Conference*, American Institute of Aeronautics and Astronautics, Apr. 2010. DOI: 10.2514/6.2010-1985.
8. A. Löcher and J. Kusche, "Precise orbits of the lunar reconnaissance orbiter from radiometric tracking data," *Journal of Geodesy*, vol. 92, no. 9, pp. 989–1001, Feb. 2018. DOI: 10.1007/s00190-018-1124-4.
9. P. C. Knocke, "Earth radiation pressure effects on satellites," Ph.D. dissertation, 1989.
10. A. Hattori and T. Otsubo, "Time-varying solar radiation pressure on ajisai in comparison with LAGEOS satellites," *Advances in Space Research*, vol. 63, no. 1, pp. 63–72, Jan. 2019. DOI: 10.1016/j.asr.2018.08.010.
11. D. A. Vallado and J. Wertz, *Fundamentals of Astrodynamics and Applications, 4th ed.* Microcosm Press, 2013, p. 1106.
12. S. Bauer *et al.*, "Demonstration of orbit determination for the lunar reconnaissance orbiter using one-way laser ranging data," *Planetary and Space Science*, vol. 129, pp. 32–46, Sep. 2016. DOI: 10.1016/j.pss.2016.06.005.
13. E. Mazarico, G. A. Neumann, M. K. Barker, S. Goossens, D. E. Smith, and M. T. Zuber, "Orbit determination of the lunar reconnaissance orbiter: Status after seven years," *Planetary and Space Science*, vol. 162, pp. 2–19, Nov. 2018. DOI: 10.1016/j.pss.2017.10.004.
14. Navigation and Ancillary Information Facility, *Spice tutorials*, Jan. 2020.
15. E. Mazarico *et al.*, "Orbit determination of the lunar reconnaissance orbiter," 3, vol. 86, Springer Science and Business Media LLC, Sep. 2011, pp. 193–207. DOI: 10.1007/s00190-011-0509-4.
16. T. Kubo-oka and A. Sengoku, "Solar radiation pressure model for the relay satellite of SELENE," *Earth, Planets and Space*, vol. 51, no. 9, pp. 979–986, Sep. 1999. DOI: 10.1186/bf03351568.