# Sensitivity study of radiation pressure models for precise orbit determination

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**Abstract**

Centimeter-scale orbit determination is necessary for satellite navigation and spaceborne geodesy. Orbits are sensitive to perturbations such as radiation pressure (RP) due to solar radiation as well as planetary albedo and thermal emissions. This project investigated sensitivities of orbit predictions to varying complexity in RP models for the Lunar Reconnaissance Orbiter (LRO) at $\beta \approx 0$. We found that solar RP dominates but lunar RP affects secular variations in semi-major axis and argument of periapsis. A constant-albedo lunar model and a paneled LRO model are recommended for precise radial and along-track positioning.

**Keywords**

Radiation pressure, orbit determination

**Acronyms**: LRO Lunar Reconnaissance Orbiter

## 1 Introduction

Lunar Reconnaissance Orbiter (LRO)

Describe LRO mission Describe need for POD

sub-meter accuracy in radial component [1] 50-100 m in total position [2]

figure with magnitudes of perturbations

”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” [3] albedo modeling on moon necessary for selenodetic mapping [4] albedo radiation significant on moon since no atmosphere exists and surface of lunar highlands is rather reflective % [4] High OD error during full-sun periods with cannonball model, but acceptable with multi-panel model and real attitude for SA and HGA [5]

in this paper, only investigate orbital variations over 2.5 day arc -¿ goal is to improve force models for POD Long-term effect of RP would also be interesting (forces could cancel out over time or always act in same direction), but not considered here

Tudat is used and models are used for future research

## 2 General radiation pressure modeling

### 2.1 Mechanics of radiation pressure

### 2.2 Reflectance distributions

Large part of how radiation pressure works is due to reflectance of sources and targets

### 2.3 Radiation sources

extended sources (close enough that rays are not parallel) can be modeles through subsources every irradiance in the list can be thought of as ray

Paneling from [6]

### 2.4 Radiation pressure targets

spacecraft thermal radiation pressure can be high requires thermal model and knowledge of conductivity therefore assume instantaneous reradiation

### 2.5 Occultation

## 3 Radiation pressure modeling for LRO

### 3.1 Lunar radiation pressure

use 5 rings for moon due to convergence analysis and results from [4] [7] also uses 5 rings for LRO Need more with DLAM-1 than knocke due to higher frequency albedo dist or lower altitude?

no seasonal or diurnal albedo variation on Moon, as opposed to Earth [6]

Knocke argues that Earth can be reasonably represented using diffuse albedo reflection only Is this the case also for moon?

find source for how much lunar albedo varies with viewing angle, i.e. if the moon albedo would benefit from an angular distribution model

albedo value used should be for broadband shortwave (0.2 µm to 4 µm, peak at 0.4 µm) [6], which accounts for most of solar radiation albedo used for moon is 0.19 (750 nm, which corresponds to maximum reflectivity [4]), which is mean of DLAM-1, even though 0.12 is commonly cited DLAM-1 is derived from clementine imagery, which is known to overestimate albedo [8] This is to enable better comparison, but if a constant albedo value were used, this amounts to linear scaling

use angle-based model from Lemoine Flux from Lemoine agrees with [9, Table 8]

Constant-emission model from Knocke is not appropriate for moon since it gets very cold -¿ Knocke would result in

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constant emission (only varies by XX% due to change in Moon–Sun distance), will not be investigated further here

### 3.2 LRO target

to find cannonball area and 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: [7]: 14, 1.0 (for daily/not precision OD, no changing orientation, solar only) –¿ use this one [12]: 10, 1.2 (no changing orientation, solar only) [3]: first 1.67, then 0.96 after estimation [13]: 1.03 +- 0.24 (1.04 in sep, 1.4 in jun, but rather a scale factor for paneling than cannonball coefficient)

mass at start of science orbit (15 Sep 2009): 1271.9 kg mass at end of science orbit (11 Dec 2011): 1087.0 kg use end of science orbit mass for all scenarios to get worst case scenario fixed mass to enable comparison also show mass history

effect of self-shadowing on LRO orbit is small [14] neglecting self-shadowing overestimates area [15], but minimal self-shadowing in most cases for LRO [3]

instantaneous reradiation will not be investigated further describe how results change (simple scaling?) Thermal radiation may cause an offset of 1-2 meters over an arclength of 2.5 days [12]

### 3.3 LRO orbit geometry

variation in altitude is in part due to assumption of spherical moon (polar radius is 2.1 km less than equatorial) -¿ leads to change in lunar RP magnitude over orbit sun beta over year + eclipse periods

our maximum eclipse time of 48 min agrees with [9]

### 3.4 Simulation setup

earth albedo + thermal radiation can be neglected for LRO since it is less than 0.1% of solar radiation at moon

solar array tracks Sun, HGA tracks Earth [9] 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 [9])

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 for reprocessing [7]

arc length 2.5 days, which is also used for LRO orbit determination [16] step 5 s, which is also used for LRO orbit determination [13]

MOON_PA frame, IAU_MOON is in worst case 155 m off [17] (Special PCK and FK for Earth and Moon, slide 14)

integrator + propagator params

maybe show figure from poster

two arcs, one for beta = 0 and beta = 90

## 4 Results

no knowledge of true RP accelerations therefore, compare to baseline

Also use [18] as reference for plots and discussion, especially about relation of acc and change in elements

### 4.1 Simulation setups

Solar with/without Lunar with/without Albedo constant/dlam LRO cannonball/paneled Occultation with/without (for solar only?)

### 4.2 Accelerations

thermal vs albedo

kink in cross-track SRP also seen in SELENE [19], search for explanation

Variation with orbital position and time of year (correlate with relative sun position and albedo map)

beta angle slightly less than 90 degrees leads to sinusoidal acceleration

show partial/full eclipse on time axis

absolute acceleration magnitude influenced by mass uncertainty rp acceleration magnitude increases as mass decreases 17% higher mass at start -¿ 17 % lower acceleration magnitude

angle-based thermal behaves quite similar to albedo, but does not vanish in eclipse

### 4.3 Change in orbital element

compare wih Gauss perturbing equations (analytical solution to change of osculating elements based on accelerations), e.g. [20, Sec. 3.2]

### 4.4 Performance

no special setup like cpu pinning or disabled hyperthreading for benchmarking only on one setup Performance may vary in other situations [21] still, a good indication also mention minimum

albedo model can increase computational demand by several hundred pct [7]

## 5 Discussion & Conclusion

"It would seem, therefore, that the influence of the longwave emitted radiation would be almost indistinguishable from a small change in the gravitational constant of the Earth, for low eccentricity orbits. As a consequence, one would expect the shortwave component to have a greater orbital effect than the longwave component, in spite of the comparable magnitudes of their accelerations." [6]

recommendations on which models to use

Future work:

- account for moon topography for occlusion [13], could otherwise lead to large misrepresentation of eclipses for $\beta > 70°$
- Self-shadowing, particularly for SRP, can reduce effective cross section by up to 40 % [13]
- accurate thermal reradiation (e.g. [22])

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