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P4 1 Moonfall: A Criticism of Orbital Mechanics

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Abstract

In this paper we investigate the orbital mechanics at play as depicted in the 2021 film 'Moonfall'. We model the case of a orbital transfer of the Moon from its standard orbit, to one where it just contacts Earth. The required change in the Moon's orbital velocity is found to be between 767.530 ms^{-1} and 856.959 ms^{-1}, with the energy required to move the Moon in this way to be of the order of 10^{28} J. Finally we determine the impact time to be a few days, seemingly in contradiction with the films suggested time span of 'a few weeks'.

Introduction

The 2021 film 'Moonfall' poses a dystopic question, what would happen if the Moon was to seemingly spontaneously start on a collision orbit with the Earth? In this paper we consider two orbits, one that is the Moon's standard orbit and another that has Moon colliding with Earth. Then we consider the velocity change required to make the transfer and the kinetic energy required to cause this velocity change. We also consider the time span on this collisional orbit.

Theory and Modelling

For our modelling of the lunar orbit we made use of the publicly accessible NASA General Mission Analysis Tool (GMAT) [1] software to obtain orbital radii values for a number of points in the lunar orbit under the following conditions; first we modelled the Moon as a spacecraft with mass equal to lunar mass of 7.350×10^{22} kg [2], a semi-major axis of 3.844×10^5 km [2], Eccentricity of 0.0549 [2] and, Inclination of 5.145° [3].

Throughout the GMAT simulation Earth was considered spherically symmetrical and uniformly dense and air resistance was ignored due to the fact that Earth's atmosphere, for practical purposes, ends at the Kármán line at 100 km [4] a comparably small altitude $<<$ orbital radii.

When modelling for a secondary collision orbit we defined the collision orbit as one with a periapsis equal to the combined radii of the Earth (6371 km) and the moon (1737 km), as this would be a 'just touching' case for collision at periapsis, and an apoapsis defined at original lunar orbit radius at time of the orbit change. This required periapsis radius for collision orbit to be 8108 km.

For two bodies in a Keplerian orbit, the relative velocity v can be found using the vis-viva equation [5]

$$v^2 = \mu \left(\frac{2}{r} - \frac{1}{a} \right) \quad (1)$$

Where μ is the Earth's gravitational parameter, r is the centre of mass separation of the two bodies, and a is the semi-major axis of the orbit that can be found by

$$a = \frac{r_{peri} + r_{apo}}{2} \quad (2)$$

Where r_{peri} is the distance at periapsis, and r_{apo} is the distance at apoapsis [5]. We calculate the required velocity for both the unperturbed lunar orbit, and the orbit for collision. The difference of which is the velocity change required to make the transfer. The time period T of the collisional orbit can be determined using Kepler's third law

$$T = \pi\sqrt{\frac{a^3}{\mu}} \quad (3)$$

The factor of two is omitted as the collision only takes half an orbit.

Results and Discussion

We plotted the required change in velocity to transition to a collision orbit against starting lunar orbital radius before the velocity change (Expressed as a fraction of lunar orbit progression).

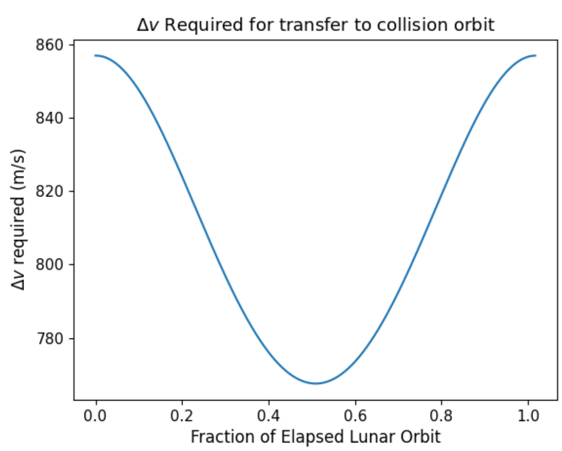

Figure 1: Required change in velocity for collision orbit transition against elapsed lunar orbit fraction, where 0 and 1 represent the periapsis of lunar orbit and 0.5 represents apoapsis. The variation is due to the elliptical orbit of the moon, and we see the Δv required is smaller at apoapsis than at periapsis

The maximum and minimum velocity that the moon would have to be decreased by to 'fall' into the new orbit, Δv was found to be 856.959 ms^{-1} and 767.530 ms^{-1} respectively. The kinetic energy KE required to achieve this can be found by the standard formula [6]

$$KE = \frac{1}{2}m\Delta v^2 \quad (4)$$

where m is the mass of the moon. This sets an upper bound of the energy required at $KE_{max} = 2.698 \times 10^{28}$ J and a lower bound of $KE_{min} = 2.164 \times 10^{28}$ J. As for orbital periods of collision orbits we found the relationship in Figure 2

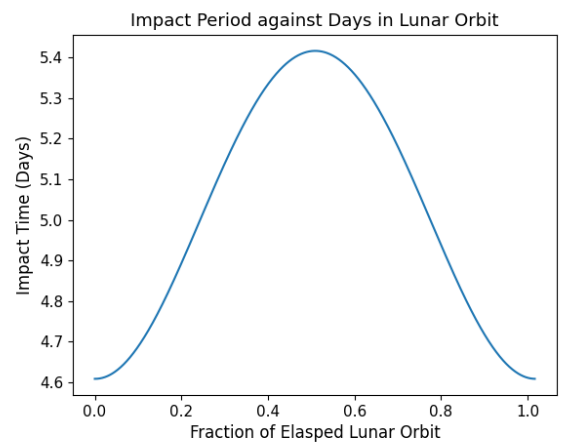

Figure 2: Collision orbit impact time (half of collision orbit period) against elapsed lunar orbit fraction

From here we can see that the collision orbits initiated from closer orbital radii have shorter impact times than those at higher orbital radii, but the range is small $\approx$ one day.

Conclusion

We found the required kinetic energy change to shift the Moon into a collision orbit is at minimum 2.164×10^{28} J. This magnitude of energy is non-feasible, equivalent to about 16,000 years of all human civilization's energy use at current rates [7]. The time periods of collision were found to be considerably quicker than the generally accepted timespan for the films events, a maximum of roughly 5 days compared to a period of 'weeks'. Although in reality the Moon would never actually hit Earth due to the tidal forces on the moon as it passes the Roche Limit [8], and it would be torn apart in the process.

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