Various Orbit Perturbation Effects and Ground tracks for a Burnout Orbit with Desired Target Location

ASE 366L – Applied Orbital Mechanics

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Task 1

Task 1 requires a numerical integrator to propagate 4 different orbits over 5 days: low earth orbit, geostationary orbit, medium earth orbit, and Molniya orbit. The orbit propagator utilizes two-body dynamics with Cowell's formulation to model the accelerations from Earth's gravity and the various perturbations. Accelerations due to effects from J2, J3, atmospheric drag, third bodies such as the Sun and Moon, and solar radiation pressure are considered. The difference in magnitude of the position vectors for each perturbation from a simple two-body dynamical approach are plotted for each type of orbit.

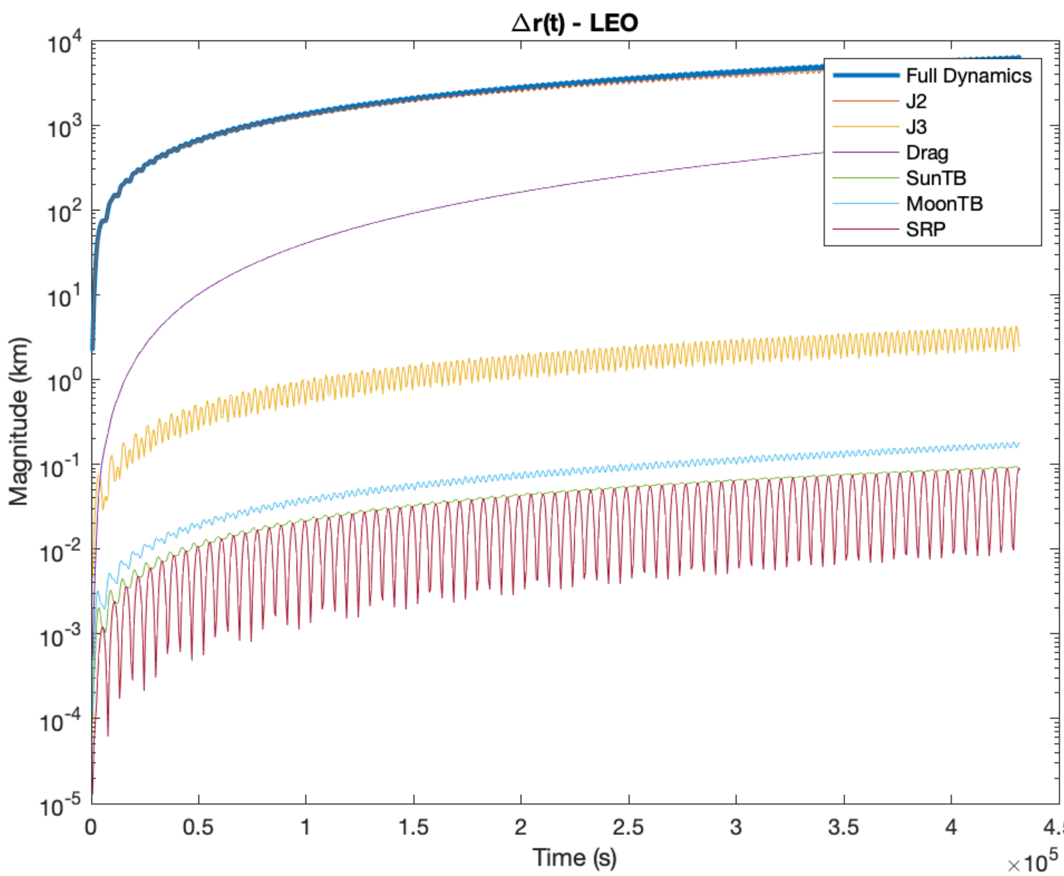

Figure 1: LEO orbit and the effects of perturbations from J2, J3, drag, third-body effects from the Sun and Moon, and solar radiation pressure

The results for a LEO orbit are shown in Figure 1. The J2 acceleration due to Earth's oblateness has the most severe effect on the orbit. At the end of 5 days, the orbit is more than 1000km off, approaching 10000km! Drag has the 2nd most profound effect as this orbit is closer to the atmosphere than others and the secular effect of drag is large, leading to a difference of 100km over the course of the 5 days. The large scale of drag and J2 have on the orbit are due to the proximity to Earth. The effect due to J3 is the 3rd largest factor, however it just barely exceeds a difference of 1km. The effects due to third bodies and solar radiation pressure, SRP, are much smaller. The order of these small effects from largest to smallest influence on the orbit is: Moon third body, Sun third body, and SRP. The overall ranking for the perturbations effects from highest to lowest are: J2, atmospheric drag, J3, Moon, Sun, and SRP.

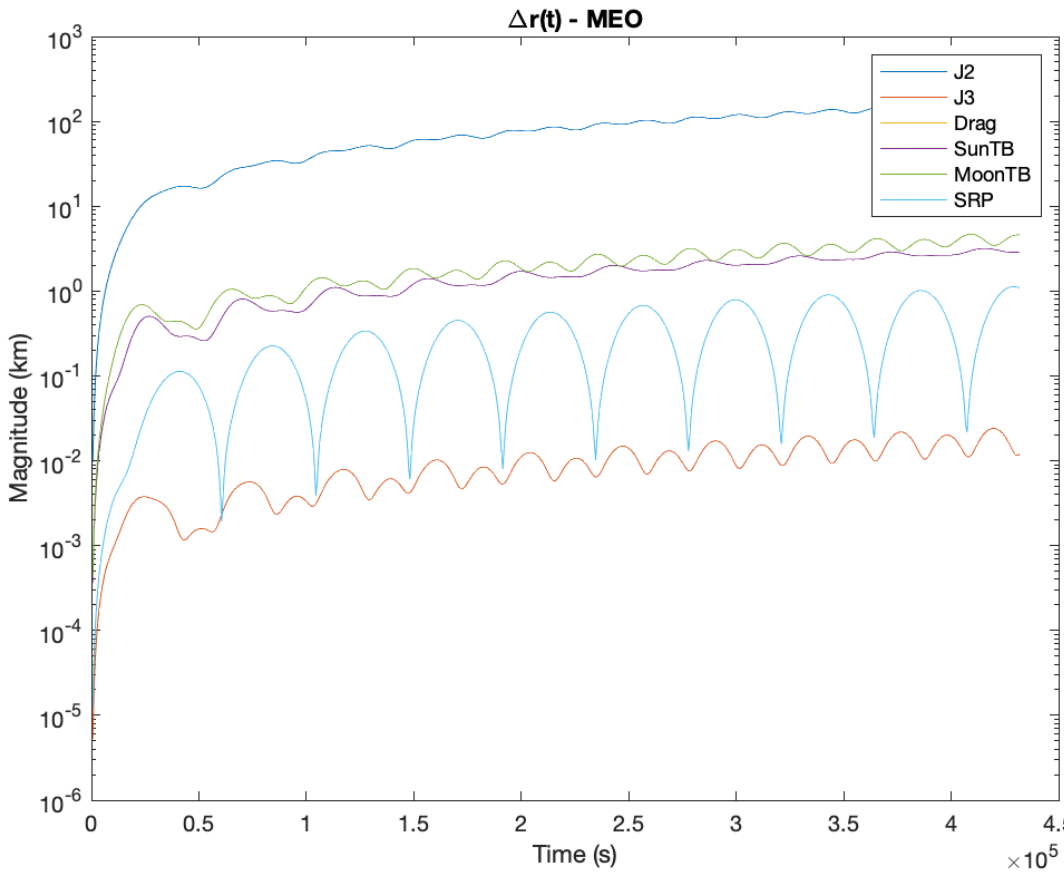

Figure 2: MEO orbit and the effects of perturbations from J2, J3, drag, third-body effects from the Sun and Moon, and solar radiation pressure

In Figure 2, the results for a MEO orbit are shown. The perturbations due to J2 have the highest contribution to the orbit again. The third body effects due to the Sun and moon are the next highest contributors. The moon has a higher effect than the Sun due to its closer proximity to Earth. This is also the reason the effects from the Moon shower higher frequency short period effects, the Moon orbits Earth causing a change in the direction of acceleration more frequently the Sun as it is much further away and relatively stationary.

Solar radiation pressure is the next greater contributor to the perturbations of the orbit. The periodicity of SRP is highly evident in the graph; this is caused from the acceleration vector due to SRP switches directions on opposite sides of the Earth. Perturbations due to J3 exhibit the second-lowest contribution. The lowest contribution is drag, which is so near 0 it does not appear on the log scale as we are so far away from the atmosphere to have a significant effect. The magnitudes of the differences in position are lower for MEO than LEO as the distance to Earth is significantly higher, causing all perturbations to have less effect. The overall ranking for the perturbations effects from highest to lowest are: J2, Moon, Sun, SRP, J3, and atmospheric drag.

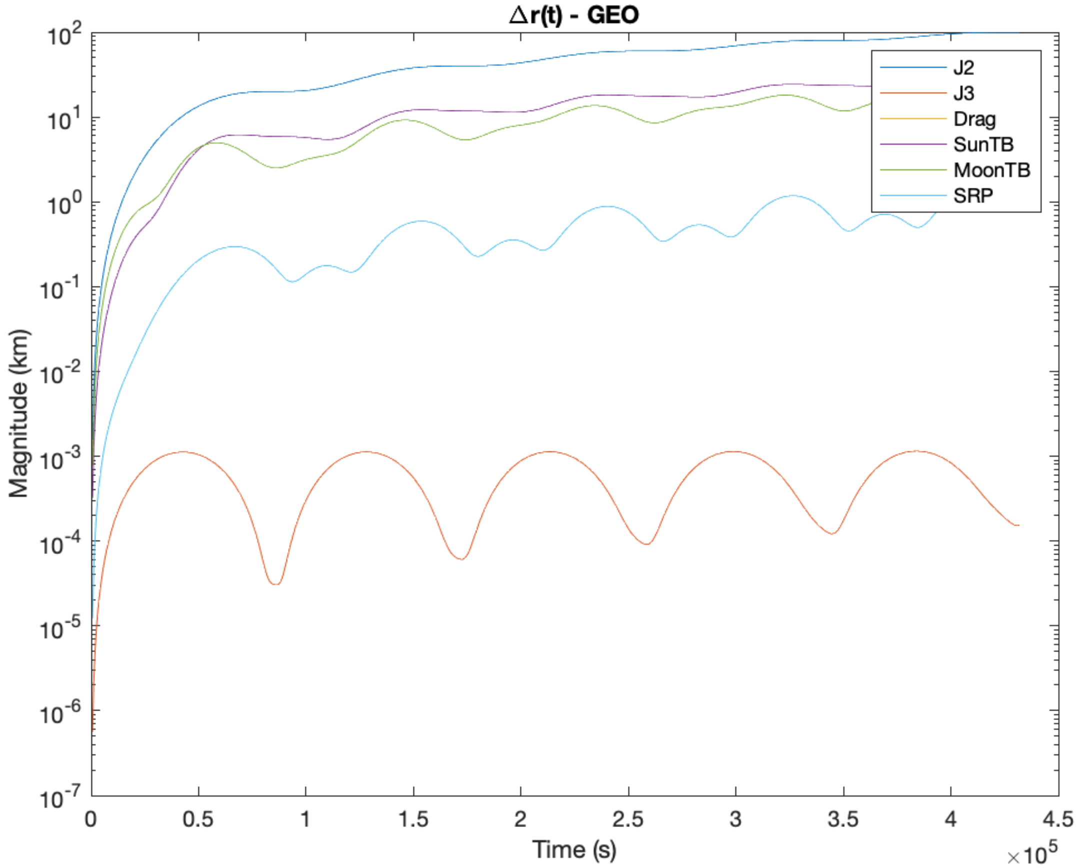

Figure 3: GEO orbit and the effects of perturbations from J2, J3, drag, third-body effects from the Sun and Moon, and solar radiation pressure

The results for a GEO orbit are shown in Figure 3. J2 effects again show the highest contribution. Third body effects from the Sun perturb the orbit to a greater degree than the moon for this GEO orbit than the MEO orbit. A GEO orbit has a much higher altitude than a MEO orbit and is geosynchronous relative to the Earth. The Sun's gravitational pull is stronger at a higher altitude. Over the course of 5 days, the Sun's position vector relative to the satellite will not change much meanwhile the moon's vector changes to a greater degree while the moon orbits. These changes describe the Sun's higher contribution. Solar radiation pressure exhibits the next highest contribution. The periodicity of SRP is less evident in this GEO orbit than the MEO orbit, caused by the stationary nature of the satellite relative to Earth. Earth's shadow does effect SRP, where the satellite's time in the shadow will be more relatively constant over 5 days compared to a LEO or MEO orbit. J3 has the second-lowest contribution again as we are much further away from Earth than in LEO causing the pear-shaped J3 gravitational perturbation to be less significant. Drag is almost non-existent due to the great distance between the satellite and Earth's atmosphere. The overall ranking for the perturbations effects from highest to lowest are: J2, Sun, Moon, SRP, J3, and drag.

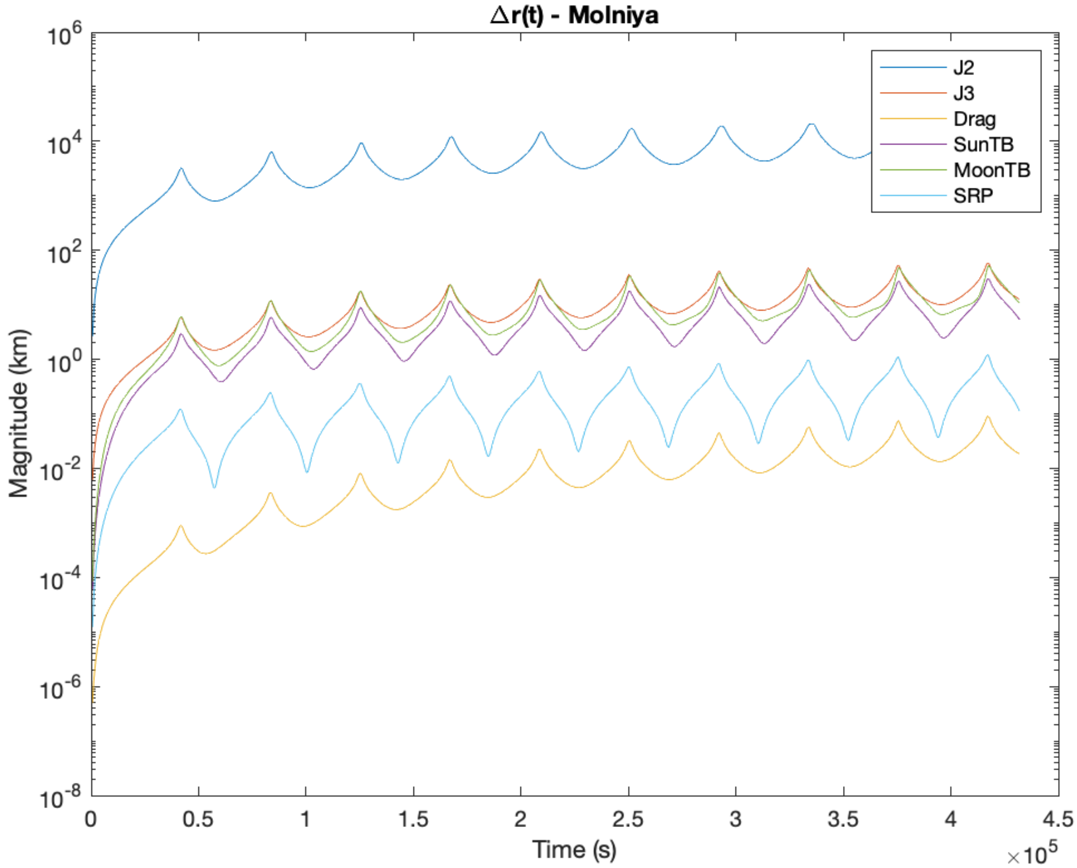

Figure 4: Molniya orbit and the effects of perturbations from J2, J3, drag, third-body effects from the Sun and Moon, and solar radiation pressure

The Molniya orbit's results are shown in Figure 4. A Molniya orbit is a highly eccentric orbit which passes close to Earth at perigee and has an apogee far away from Earth. The J2 perturbations again exhibit the highest contribution to the perturbations in the orbit. The magnitude of the difference for J2 is just as significant as it is for LEO. While the satellite passes close to Earth at perigee, J2 perturbations influence the satellite's orbit to a greater degree than at apogee. This will cause a big difference during each orbit of the satellite when compared to the simple two-body dynamics approach when the effects of J2 are ignored. The next highest contribution is J3. This perturbation has a more significant effect compared to MEO and GEO for the same reason as J2, the perigee comes close to Earth as opposed to remaining further away from Earth at all times. Third body effects from the Moon rank next in the order of highest contribution. Third body effects from the Sun are almost just as significant as the Moon, but with a slightly lower magnitude. Solar radiation pressure exhibits the next highest contribution to orbit perturbation. Drag is seen as the lowest contributor but is not near zero like MEO or GEO because of the satellite's perigee being closer to Earth where there is much more atmosphere to create drag. The eccentricity of the Molniya orbit explains the periodicity seen in these perturbation's effects due to the perigee and apogee difference as well. The overall ranking for the perturbations effects from highest to lowest are: J2, J3, moon, Sun, SRP, and drag.

Task 2

Task 2 requires a semi-analytic approach to determine the burnout velocity of a satellite such that the ground-track passes over Austin, TX (30.3° N, 97.7° W) after 10 orbit periods. The burnout location is 30.3° N, 120.6° W. The mathematics involved in this calculation is obtained from "T. H. Skopinski and K. G. Johnson, "Determination of Azimuth Angle at Burnout for Placing a Satellite Over a Selected Earth Position", NASA Tech Note D-233, September, 1960". The approach involves only two-body dynamics and the J2 gravitational effects due to Earth's oblateness.

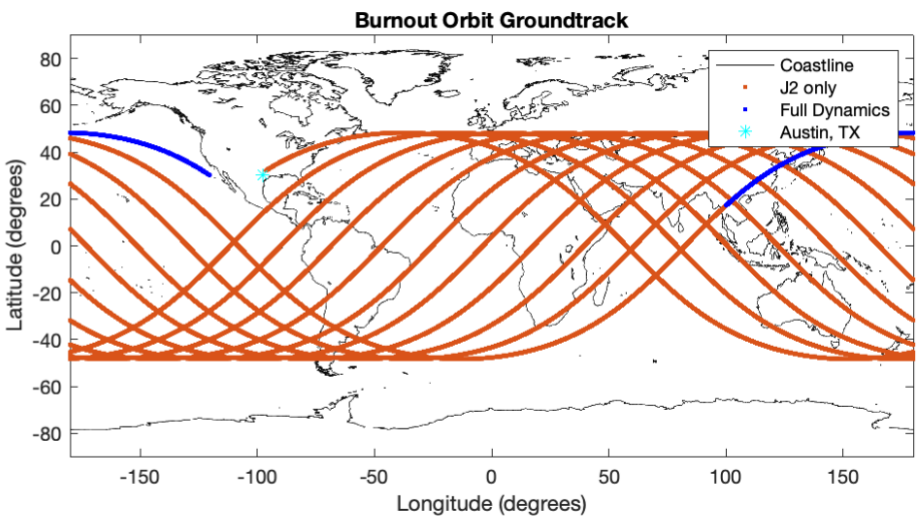

Figure 5: Ground tracks of Satellite Position calculated using two-body dynamics + J2 and two-body dynamics + other perturbations

First and foremost, this is the case for a retrograde orbit. The inclination is greater than 90°, thus our satellite moves across Earth from east to west. Shown in the figure is the ground track for the orbit only considering J2 perturbations and then the ground track considering perturbations from J2, J3, drag, Moon and Sun third-body effects, and solar radiation pressure. The red line which only considers J2 effects shows a correct position after 10 orbit periods passing right over Austin, TX, which is shown in the figure. Using a full fidelity propagator however shows a different story. The satellite's ground track is shown in blue and before one orbit period can be completed, the ground track stops. This is due to including the other perturbations, mainly drag. Atmospheric drag will cause the satellite to bleed velocity at an increasing rate due to the thicker and thicker atmosphere causing a snowball effect to the orbit trajectory and crash in the Pacific Ocean near the West coast of the United States.