Review of angeo-2020-33

General comments

The paper is dealing with the impact of atmospheric drag on LEO satellites, which is a complex problem. This work does not contain any new ideas and the authors already acknowledge this fact in their abstract! Their methodology and some applications have been already presented in previous work. However, some of the data presented in the paper can be considered as new since the authors examine some specific cases. Overall, the paper does not provide significant scientific contribution, especially when compared with similar work from the literature.

The presentation is mostly clear though some part of the work could be elucidated further:

- It is generally accepted that it is quite challenging to accurate model drag effects on satellites and drag models include many parameters (e.g. drag coefficients, atmospheric density etc.) that are difficult to estimate accurately. The paper makes some assumptions w.r.t those parameters that are not always explained or justified properly (see specific points later).
- No information is provided about the methodology used for the numerical integration of the equations of motion with perturbation due to drag (i.e. coupled equations (1)-(4)).

The authors reach some conclusions that are not really new or substantial. The paper suggests that a model of satellite drag when combined with a high-fidelity atmospheric specification can lead to improved satellite ephemeris estimates. This is true but propagating orbits with high accuracy is complicated and one will also need to consider the aspherical potential of Earth's gravitational field (which is omitted here).

As a final point, it should be noted that all calculations in the paper have been done under the assumption that the satellite orbit is circular. However, real circular orbits of artificial satellites are possible only in the equatorial plane. It has been shown (see E. F. Jochim and M. C. Eckstein, "On the true circular orbit of a satellite, Celestial Mechanics", vol. 21, 149-153, 1980) that an inclined true satellite orbit cannot be circular because the satellite motion is influenced by a perturbing force as a result of the oblateness of the Earth (e.g. J2-term).

Specific comments

Line 26: "Atmospheric drag is the largest force affecting the motion of satellites in Low Earth Orbit (LEO) especially at altitudes below 800 km (Nwankwo et al., 2015)."

It is true that atmospheric drag most strongly influences the motion of a LEO satellite at low altitudes. However, perturbations due to the non-spherical shape of Earth are also important for LEOs and are in general considered for the orbit specification.

Line 41:

When presenting the formula of the drag force it is misleading to refer to the satellite speed (scalar quantity) instead of the velocity. The basic equation for aerodynamic drag shows that the associated force depends on the velocity of the satellite relative to the atmosphere. A simple assumption is to consider a mean motion due to the Earth's rotation. A more general expression could include wind variations (see e.g. D. A. Vallado, “Fundamentals of Astrodynamics and Applications”, 2007). It is not clear what is assumed in the paper (do the authors consider a static i.e. not rotating atmosphere?).

Line 42: “The satellite speed, vs, is a consequence of the balance between an inward-directed (towards earth) gravitational force at the satellite altitude and the outward-directed orbital centripetal force.”

This is a strange statement! In a simple two-body problem (i.e. without perturbations), the gravitational force is the only force acting on the satellite (seen as a point mass). In classical (Newtonian) mechanics, we can define the centripetal force for uniform circular motion (still gravity is the only force acting on the point mass).

Line 121:
The cross sectional area (projected area) might be known for operational satellites but in principle is not so easy to calculate. For high precision studies, the satellite’s attitude determination is employed for its calculation (near re-entry it is extremely difficult to know the satellites altitude accurately).

Line 173: The derivation of coupled equations (1)-(4) is not clear even after looking into the references mentioned in the paper… For example, how do the authors derive Eq. (2) in Nwankwo and Chakrabarti, 2014? In principle, one should be able to derive those equations starting from the general equation of motion for a two-body problem with perturbations (where $\mathbf{a}_{\mathrm{p}}$ corresponds to the perturbing acceleration):

$$\ddot{\mathbf{r}} = -\frac{\mathrm{GM}}{\mathrm{r}^3}\mathbf{r} + \mathbf{a}_{\mathrm{p}}$$

Assuming that the perturbations are only due to atmospheric drag we can write

$$\mathbf{a}_{\mathrm{p}} = \mathbf{a}_{\mathrm{drag}} = -\frac{1}{2}\frac{\mathrm{C_D\,A}}{\mathrm{m}}\,\varrho\,\mathrm{V}_{\mathrm{rel}}^2\,\frac{\mathbf{V}_{\mathbf{rel}}}{|\mathbf{V}_{\mathbf{rel}}|}$$

However, as I have already mentioned the assumptions for the calculations of the relative velocity are not clear. Perhaps the authors could include an appendix in the paper with the derivation of the main equations used for calculating the satellite trajectory. The authors could also discuss briefly the methodology used for solving their set of coupled differential equations in order to obtain the instantaneous positions and velocities of the satellites.

Line 186: “…the radial distance, r, is used to model changes in satellite altitude.”

The authors need to clarify their definition of satellite altitude. Does it take into consideration the oblate Earth or is it for example the radius of the orbit at a specific time minus the mean equatorial radius of the Earth?

Finally**,** NRLMSISE-00 takes as input a location normally provided in terms of latitude, longitude and height (altitude). It is not clear how this location is calculated from the satellite trajectory. The atmospheric density can change rapidly along the trajectory. What is the time step used for the estimation of the atmospheric drag parameters? Finally, the definition of the altitude (see also previous comment) could have an impact on the value of the atmospheric density and therefore on the calculated satellite drag.

Technical corrections

Line 30: Replace "(Nwankwo et al. (2015); and references therein)" with "(Nwankwo et al., 2015 and references therein)"

Figure 1: It should be clarified whether it shows the results of a simulation or it is just a cartoon demonstrating the effects of atmospheric drag on a satellite. If the former, then the parameters used for the simulation should be mentioned and possibly moved to section 3 (could also skip the pictures of the spacecraft).

Line 81: Replace "SunSpot Number" with "Sunspot Number" or "sunspot number" or "Sun Spot Number". You can always use the initials SSN but make sure you are consistent throughout the text (e.g. the caption of Figure 2 mentions Sun Spot Number…)

Line 85: "Figure 2 (after illustrates this cyclic variation in the monthly-averaged SSN along with the related solar-geophysical indices for the solar radio flux (F10.7) and the geomagnetic Ap." I assume that "(after" is a typo and needs to be removed.

Line 131: "Figure 3 is a plot of the 1-hour averaged variations in Vsw, PD, Dst, IMF By and Bz and AE for July 2006." You could consider including a reference for those data in the text and/or Figure 3 caption (e.g. in the Acknowledgment OMNIWeb service is mentioned)? Similar remark for Figure 4.

Consider replacing the word "UltraViolet" with "Ultraviolet" or "ultraviolet".

Figure 10 seems to repeat what is show in figures **3** and **4**… If this is the case, then Figure 10 is redundant.

Line 198: "While a global specification was used to extract the density along the satellite flight path, the atmospheric curves used in Figures 5, 7 and 11 (to be discussed) to represent a general atmospheric response used a reference altitude of 450 km."

This sentence is a bit confusing. Consider revising.

Table 2: There is a typo in the units of Decay (it should be km instead of kg).