Analysis of Orbital Lifetime Prediction Parameters in Preparation for Post-Mission Disposal

Ha–Yeon Choi¹, Hae-Dong Kim²†, Jae-Dong Seong¹

¹Aerospace System Engineering, Korea University of Science and Technology, Daejeon 34113, Korea
²IT Convergence Technology Team, Korea Aerospace Research Institute, Daejeon 34133, Korea

Atmospheric drag force is an important source of perturbation of Low Earth Orbit (LEO) orbit satellites, and solar activity is a major factor for changes in atmospheric density. In particular, the orbital lifetime of a satellite varies with changes in solar activity, so care must be taken in predicting the remaining orbital lifetime during preparation for post-mission disposal. In this paper, the System Tool Kit (STK®) Long-term Orbit Propagator is used to analyze the changes in orbital lifetime predictions with respect to solar activity. In addition, the STK® Lifetime tool is used to analyze the change in orbital lifetime with respect to solar flux data generation, which is needed for the orbital lifetime calculation, and its control on the drag coefficient control. Analysis showed that the application of the most recent solar flux file within the Lifetime tool gives a predicted trend that is closest to the actual orbit. We also examine the effect of the drag coefficient, by performing a comparative analysis between varying and constant coefficients in terms of solar activity intensities.

Keywords: KOMPSAT-1, KOMPSAT-2, solar activity, drag coefficient, lifetime

1. INTRODUCTION

Currently, the United States, France, and Japan that are advanced in space exploration enact the Space Debris Mitigation Guidelines (NASA 1996; U.S. Government 2000; CNES 2011). These guidelines are a set of regulations that aim to deter the generation of fragments during the normal operating period of satellites and to minimize the risk of potentially hazardous situations in the space environment, such as during post-mission disposal. As such, the guidelines require compliance even during the development stage of satellites, to ensure steps are taken to protect the space environment. With this in mind, preparations for the post-mission disposal of a satellite require accurate prediction of that satellite’s remaining orbital lifetime. For example, the orbital lifetime of Low Earth Orbit (LEO) satellites after a mission has been recommended to not exceed 25 years, and therefore predictions of the precise orbital lifetime must be made with care (IADC 2007; United Nations Office for Outer Space Affairs 2010).

LEO satellites are strongly affected by solar activity, which could be observed in a comparison between the orbits of Korean Multipurpose Satellites 1 and 2 (KOMPSAT-1 and KOMPSAT-2), which were respectively operated during high and low solar activities. While KOMPSAT-1 experienced a daily orbital decay of 5-37 m day⁻¹ due to solar flux, KOMPSAT-2 showed a much smaller decay of 0.4-1.4 m day⁻¹ (Kim et al. 2010). Among the atmospheric drag parameters, the drag coefficient depends on the interrelationships among the satellite body surface material, the chemical composition of the atmosphere, and the temperature of colliding particles, making satellites especially sensitive to atmospheric changes caused by solar activity (Kim et al. 2002).

Lee & Cho (1996) performed an orbital lifetime analysis of LEO satellites using equations of motion, which consider the variable orbital elements and the results showed that atmospheric drag is major factor affecting the lifetime of
satellite orbits (Lee & Cho 1996). In another study, variable solar flux and geomagnetic index were considered to determine accurate orbital lifetimes, and lifetime analysis simulations were performed under worst case of +2σ solar flux (Lee & Lee 1997). In addition, a study into the effects of solar and geomagnetic activity on KOMPSAT-1 revealed that the atmospheric density of the Earth is affected by large-scale solar activities, such as coronal or mass ejection (Park et al. 2007). The results showed that atmospheric density of earth is affected by solar activity, such as coronal mass ejection. Another work has been carried out to increase the accuracy of orbit determination for KOMPSAT-1, by estimating the satellite drag coefficient and the solar radiation pressure coefficient (Lee et al. 2001). This paper stressed the need for an accurate estimation of the drag coefficient and solar radiation pressure coefficient because they cannot be modeled. A further study derived an equation to calculate fuel consumption, based on variations of orbital elements due to continuous changes in atmospheric drag (Jung & Song 1999). In this study, the necessary corrections to orbital speed due to atmospheric drag and the required fuel consumption were effectively predicted and applied to the orbital analysis of KOMPSAT. It should be noted that LEO satellites consume large amounts of fuel to respond to atmospheric drag, and therefore accurate drag prediction is crucial because fuel consumption has a direct influence on mission lifetime and weight at launch. In addition, an analysis of the variations in drag force and drag coefficient with respect to mission altitudes and attitudes of LEO satellites that had a parabolic antenna mounted upon them has been carried out, using a direct Monte Carlo simulation (Shin et al. 2014). In this, variation in atmospheric drag is seen as an important element in the operation of such satellites. Finally, research has been conducted to calculate the atmosphere drag and lifetime of the kick motor of KSLV-1 (Korea Space Launch Vehicle-1) using System Tool Kit (STK®) (Park et al. 2006).

Solar activity fluctuates with a period of approximately 11 years, as shown in Fig. 1, and the prediction of a satellite’s orbital lifetime depends upon whether solar activity is high or low during and after its mission. Orbital lifetime is therefore closely related to solar activity, and the prediction of orbital lifetime requires the application of parameters that vary according to solar activity. Thus, parameters such as the atmospheric drag coefficient and the solar radiation pressure coefficient must be varied according to the time of their application. However, each parameter has a different sensitivity to the degree of solar activity, and therefore their relevant values must be determined after sensitivity analysis.

In the work conducted by Cojuangco (2007), analysis of the orbital lifetime of a CubeSat with a mass of 1 kg showed that, at the same altitude, changes in parameters such as the solar radiation pressure coefficient and the effective satellite area exposed to the Sun, did not significantly affect the satellite orbital lifetime, despite an increase in solar activity. However, the drag coefficient and drag area were found to be inversely proportional to the degree of solar activity. In addition, predictions of the orbital lifetime of CubeSats ranging from 1 U to 6 U (Quia et al. 2013) revealed that the sensitivity of each parameter showed a similar trend to that shown by Cojuangco (2007) at 100 km intervals between altitudes of 300 and 600 km. Therefore, among the various parameters, we can consider the atmospheric drag coefficient and effective drag area to be most sensitive to solar activity. Thus, application of a fixed parameter value under continuously changing solar activity may result in overestimations or underestimations of orbital lifetime. As such, accurate predictions of orbital lifetimes through parameter adjustments are crucial to post-mission disposal planning. Moreover, these varying parameters are important in planning satellite operation, to account for the fuel consumption over the course of a mission.

In this study, we predict the orbital lifetimes of KOMPSAT-1 and KOMPSAT-2, by comparing actual orbital data collected over a long period of time with differential applications of atmospheric drag values with respect to solar activity. Our results showed that appropriate adjustment of the parameters can increase the accuracy of orbital lifetime prediction. Thus, on the basis of these results, we analyzed the parameters that require adjustment for the accurate prediction of orbital lifetimes, for future KOMPSAT models. In addition, we analyzed the characteristics of the STK® Long-term Orbit Propagator (LOP) and the Lifetime tool and compared the
results. In the Lifetime tool, we examined the effect of varying solar activity predictions on the predicted values, according to the time at which the solar flux file was generated.

This paper is structured as follows. Section 3 presents an analysis of the elements that significantly influence the orbital lifetime predictions produced by the LOP and the Lifetime tool. The following section presents the measured solar flux and the results from the STK® LOP. Subsequently, the results from the STK® Lifetime tool are presented in Section 4.2. Finally, we discuss the main conclusions from this study in the final section.

2. ANALYSIS OF SOLAR FLUX AND ORBITAL LIFETIME

2.1 Solar Flux Analysis

Orbital lifetime prediction using the STK® Lifetime tool requires the input of solar flux data. These data are the SolFlx file, which is named: ‘SolFlxMMYY_Schatten’, where ‘SolFlx’ is the abbreviation of ‘Solar Flux’, ‘MMYY’ represents the month and the year, and ‘Schatten’ is the last name of the writer, K. H. Schatten. This file contains the data that are used in long-term predictions. The renewed Schatten prediction includes data spanning two cycles of solar activity, and is generated approximately every four months. The solar flux values are calculated based on a particular deviation of the F10.7 cm radio emissions within a range of +2σ prediction error (Lim et al. 2013). Prediction analysis was therefore carried out after selecting the file whose generation date was closest to the date of satellite launch.

In Fig. 2, the ‘True’ curve represents solar flux values that were actually measured by the National Oceanic and Atmospheric Administration (NOAA), while the ‘Predicted’ curve represents predicted values. The predicted solar flux values in December 2001, when the solar activity was high, and in March 2008, when the solar activity was low, comprise the solar flux data of the STK®. The solar flux data generated at the beginning of the prediction period are heavily affected by the intensity of solar activity, and thus solar flux values predicted during periods of high and low solar activities differ considerably. Fig. 2 illustrates that the values predicted in December 2001 are very different to those predicted in March 2008, demonstrating that the flux values vary with the intensity of solar activity.

2.2 Relationship between Basic Parameters and Solar Flux

The intensity of solar activity varies within a solar activity cycle, and therefore basic parameters such as the atmospheric drag coefficient and the solar radiation pressure coefficient can be adjusted, and the precise exposure area of the satellite can be determined, in order to reduce prediction errors. Among the non-gravitational perturbations of LEO satellites, the atmospheric drag force has the greatest influence, and therefore constant values were adopted for the solar radiation pressure coefficient and effective exposed area in this study. This allows the variations in predicted orbital lifetime to be analyzed with respect to adjustments in the atmospheric drag coefficient. The basic parameters generally used in orbital predictions are listed in Table 1. The mass decreases over the operating period, due to fuel consumption, but does not have a significant effect on long-term orbital lifetime predictions, and so a default value is used. Further, although the exposed area varies with the angle with respect to the Sun, a fixed value is used for long-term predictions.

The points in time at which different drag coefficients were applied, according to the solar activity intensity based on the solar flux data of STK®, are listed in Tables 2 and 3. In this study, solar fluxes of 100 or below define a ‘low solar activity period’, while those of 200 or above define a ‘high solar activity period’. The periods in which extreme solar fluxes were recorded differed between KOMPSAT-1 and KOMPSAT-2, because different SolFlx files were used for the

Table 1. Default parameters

| Parameters                      | KOMPSAT-1   | KOMPSAT-2   |
|--------------------------------|-------------|-------------|
| Weight                         | 448.83 kg   | 744.14 kg   |
| Atmospheric drag coefficient   | 2.2         | 2.2         |
| Solar radiation pressure coefficient | 1.5         | 1.5         |
| Drag area                      | 5.871 m²    | 7.934 m²    |
| Area of exposure to radiation  | 6.070 m²    | 7.934 m²    |

Fig. 2. NOAA true data versus STK predicted data.
respective orbital lifetime predictions. The solar flux data predicted in 1999 were used for KOMPSAT-1, while the data predicted in 2006 were used for KOMPSAT-2. The differences between these data sets are shown in Fig. 3, in which the ‘True’ curve represents the data actually measured by NOAA, SolFlx_0199 shows the predicted data from January 1999 to March 2018, and SolFlx_0406 shows the predicted data from April 2006 to June 2007. A comparison between the measured and SolFlx predicted data indicates that the SolFlx_0199 trend is similar to actual values up to 2008, while SolFlx_0406 data are similar to measurements up to 2014. SolFlx_0199 includes solar flux data over the entire period of KOMPSAT-2 operation, since its launch. However, as the values predicted under high solar activity differ from those that prevailed during the operation of KOMPSAT-2, which experienced low solar activity overall, SolFlx_0199 was used for analysis of KOMPSAT-1, while SolFlx_0406 was used for the evaluation of KOMPSAT-2 lifetimes.

### Table 2. KOMPSAT-1 drag coefficients

| Interval     | Solar activity intensity | Cd  |
|--------------|--------------------------|-----|
| 1999–2001    | extremely high           | 2.4 |
| 2002–2003    | moderate                 | 2.2 |
| 2004–2008    | extremely low            | 2.0 |
| 2009         | moderate                 | 2.2 |
| 2010–2012    | extremely high           | 2.4 |
| 2013–2014    | moderate                 | 2.2 |
| 2015–        | extremely low            | 2.0 |

### Table 3. KOMPSAT-2 drag coefficients

| Interval     | Solar activity intensity | Cd  |
|--------------|--------------------------|-----|
| 2006–2010    | extremely low            | 2.0 |
| 2011–        | moderate                 | 2.2 |

### 2.3 Orbital Lifetime Trends

The altitudes of the satellites each month were calculated using SGP4 orbit propagation software from the day of their launch to the time at which the thruster was last used (Table 4), using a Two-Line Element set (TLE). These data are shown in Figs. 4 and 5, alongside the changes in altitude predicted by the LOP and Lifetime tool at the point of last thruster use (Table 4). These results show the natural orbital lifetime trends, and do not include the effects of the initial orbit adjustments and thruster use.

Fig. 5 shows an enlargement of the measured and long-term predicted orbital trends shown in Fig. 4. It can be

### Table 4. Last use of thrusters

| Satellite  | Date of thruster use |
|------------|----------------------|
| KOMPSAT-1  | July 23, 2007        |
| KOMPSAT-2  | May 22, 2014         |

![Fig. 3](image1.png) Analysis using F10.7 cm radio flux.

![Fig. 4](image2.png) KOMPSAT-1 semi-major axis.

![Fig. 5](image3.png) True orbit, LOP, and Lifetime tool comparison.

http://dx.doi.org/10.5140/JASS.2015.32.4.367
3. CHARACTERISTICS OF THE LOP AND LIFETIME TOOL

3.1 LOP and Atmospheric Density Models

Perturbation modeling is essential for precise orbit determinations and prediction. The perturbations considered by the LOP include Earth’s gravitational fields J2 and J4, the gravitational fields of the Sun and the Moon, the solar radiation pressure, and the effect of Earth’s atmosphere. The atmospheric densities within the Earth’s atmosphere can be represented by two models: the 1976 U.S. Standard Atmosphere Model and the Exponential Density Model, neither of which considers the effects of the solar flux. The 1976 U.S. Standard Atmosphere Model uses a density table for each altitude, while the Exponential Density Model inputs the altitude as a variable and calculates the atmospheric density for the given input altitude, such that:

\[ \rho = \rho_0 e^{\frac{h_0 - h}{H}} \]  

(1)

where \( \rho \) is the density at the user input altitude, and \( \rho_0 \) is the standard density (Kelso 2014); \( h_0 \) is the standard altitude, and \( H \) is the altitude at which the air density is \( 1/e \) of that at the ground, called the ‘scale height’. The scale height is generally around 8 km above the average sea surface.

3.2 Sensitivity of the Lifetime Tool to SolFlx Data

The Lifetime tool requires the input of the solar flux provided by the STK®, and the planetary geomagnetic index as parameters (NOAA, ftp://ftp.swpc.noaa.gov/pub/weekly/RecentIndices.txt) in order to calculate the orbital lifetime of a satellite. Solar Flux and planetary geomagnetic index data are known to vary according to solar activity (Oh 2013; Oh & Kim 2013). Therefore, as they are governed by these parameters, the results of orbital lifetime prediction by the Lifetime tool also vary with solar flux data and the atmospheric density model. In the present study, we observed the sensitivity of the tool to solar flux data.

Figs. 6 and 7 show the varying solar flux over time. Fig. 6 shows the data as given by the SolFlx file, whereas Fig. 7 shows an extrapolation from the launch of KOMPSAT-1 to the time at which the prediction was made using the SolFlx file. The purpose of this extrapolation is to determine whether the prediction made before the solar flux prediction showed a similar trend to that of the existing prediction results. We found that a corresponding trend was indeed present. To determine the sensitivity of the Lifetime tool to the SolFlx data, the orbital lifetime predictions were made several times, all under the same conditions, but with varying SolFlx files. The results shown in Figs. 8 and 9 indicate large differences were present in the predictions made depending on the date of Solar Flux file generation.

Fig. 8 shows that, in the case of KOMPSAT-1, large differences are given by different times of solar flux file generation between

![Fig. 6. Solar flux data according to prediction timing.](image)

![Fig. 7. Solar flux extrapolation.](image)
2020 and 2080. By comparing the information shown in Fig. 8 with the results given by the Lifetime Tool with SolFlx_0307, which were most similar to the actual orbits shown in Figs. 4 and 5, we can see that the application of data generated before SolFlx_0307 resulted in an underestimation of orbital lifetime, while data generated after this point resulted in an overestimation. Similarly, Fig. 9 shows that the lifetime of KOMPSAT-2 showed significant differences between 2030 and 2120.

4. LOP AND LIFETIME TOOL RESULTS

4.1 Solar Flux and LOP Results

This section presents an analysis of the measured solar flux and the results from the STK LOP. The solar flux data consist of actual values measured by NOAA, while the LOP results comprise the values calculated using TLE information in January 1 of each year. The default values listed in Table 1 were adopted as the parameter values in the dynamic model. The LOP performed the orbital predictions without using the SolFlx files provided in the Lifetime tool but instead employed only the 1976 U.S. Standard Atmosphere Model as the atmospheric density model. The atmospheric density model used in the LOP in this study was the 1976 U.S. Standard Atmosphere Model.

Figs. 10 and 11 illustrate the results obtained using the LOP alongside the solar flux for KOMPSAT-1 and KOMPSAT-2, respectively. The blue bars denote the predictions made by the LOP using yearly orbital data, while the red curve represents the average solar flux measured by NOAA. Fig. 10 shows the LOP results from the launch date of KOMPSAT-1 to the present. The atmospheric density model of the LOP does

![Fig. 8. KOMPSAT-1 lifetime comparison with different SolFlx files.](image)

![Fig. 9. KOMPSAT-2 lifetime comparison with different SolFlx files.](image)

![Fig. 10. KOMPSAT-1 LOP.](image)

![Fig. 11. KOMPSAT-2 LOP.](image)
not incorporate solar flux data, but when compared with the NOAA’s measured flux data, the results obtained from the LOP do suggest that the orbital lifetime is influenced by the intensity of solar activity. Similarly, Fig. 11 shows the LOP results from the launch date of KOMPSAT-2 to the present, in which the orbital lifetime was more evenly predicted than for KOMPSAT-1, showing a trend that was similar to that seen under low solar activities.

In order to examine the effect of solar flux, the LOP results from the launch date to the official mission completion date for KOMPSAT-1, and from the launch date to the present for KOMPSAT-2, are shown in Fig. 12. As these two satellites have different mission periods, they are shown as sequences, as indicated on the x-axis. In this, sequence 1 was set as the date of launch, while Sequence 10 was set as the final date of the mission or the present; the LOP results for each sequence at one-year intervals were then compared. These results indicate that, overall, KOMPSAT-2 has a longer orbital lifetime, and the intensity of solar activity has a significant effect.

4.2 Solar Flux and Lifetime Tool Results

This section presents the STK® Lifetime tool results. In selecting the SolFlx file of the STK®, the file whose solar flux prediction time was closest to the launch date was chosen. In using the Lifetime tool for orbital lifetime prediction, the results given by the default parameter values were compared with those from the differential applications of atmospheric drag coefficients under each of the solar activity intensities. This comparison was made for each year in the data set.

4.2.1 Flux Sigma Level Adjustment

‘Jacchia 71’ was used as the atmospheric density model in the Lifetime tool. In this section, we present our examination of the change in orbital lifetime with respect to the adjustments in the flux sigma level (Jacchia 1965). Figs. 13 and 14 show that increasing the flux sigma level from ‘Normal’, results in the prediction of an orbital lifetime that is shorter than the overall average. In Fig. 13, the timing of satellite decay for KOMPSAT-1 under a ‘Normal’ flux sigma level is shown to occur around 2040, which is similar to the timescale given by the LOP results. In comparison, an increase in the sigma level results in a small difference, giving an average decay time of 2033 for +1σ, and 2027 for +2σ. For KOMPSAT-2, the average timing of decay is shown in Fig. 14 to be 2094, which is significantly different from the LOP results, although an increase in the flux sigma
level significantly decreases this difference. Estimations for 
+1σ and +2σ resulted in average decay years of 2072 and 2057, respectively, and under a flux sigma level of +2σ, the results were closest to the LOP data.

4.2.2 Application of Different Drag Coefficients to Identical Points in Time

The Lifetime tool was used to calculate the orbital lifetimes of KOMPSAT-1 and KOMPSAT-2 with a starting point in January 1, 2015, and with the atmospheric drag coefficient as variable. Fig. 15 shows the calculation results based on SolFlx files with recent solar flux information, while Fig. 16 shows the results based on SolFlx files generated near the launch dates of the two satellites. The predicted values vary with the different SolFlx files, but Figs. 15 and 16 generally show an inverse relationship between the drag coefficient and the orbital lifetime. Fig. 15 indicates that the average orbital lifetime of KOMPSAT-1 is around 43 years, with a standard deviation of approximately 5 years, while that of KOMPSAT-2 is approximately 70 years with a standard deviation of around 4 years. The recent solar flux data given by SolFlx_Schatten uses the solar activity cycle as the date of prediction, and thus an upward adjustment in the atmospheric drag coefficient does not result in a large deviation. In contrast, Fig. 16 shows that the average orbital lifetime of KOMPSAT-1 is approximately 31 years, with a standard deviation of 1 year, while that of KOMPSAT-2 is approximately 86 years, with a standard deviation of around 6 years. The SolFlx_0199 data that were applied to KOMPSAT-1 were predicted during a period of high solar activity, and therefore the overall orbital lifetime was underestimated and was not significantly affected by the atmospheric drag coefficient. However, as the SolFlx_0406 data that were applied to KOMPSAT-2 were predicted during a period of low solar activity, the lifetime was significantly affected by the drag coefficient, resulting in a large deviation.

4.2.3 Adjustment of Drag Coefficient in Accordance with the Intensity of Solar Activity

This section presents a comparison of lifetime predictions given by constant parameters unrelated to the intensity of solar activity, and those given by drag coefficients that vary according to the intensity of solar activity. In addition, lifetime predictions were made by adjusting the drag coefficients at increased flux sigma levels. The result is confirmed in Tables 5 and 6.

Figs. 17–19 show that the lifetime of KOMPSAT-1 is predicted

Table 5. Mean lifetime

|          | KOMPSAT-1 [years] | KOMPSAT-2 [years] |
|----------|------------------|------------------|
| Normal   | 32.745           | 83.570           |
| Sigma Level 1 | 25.952         | 61.590           |
| Sigma Level 2 | 20.124         | 46.354           |
| Normal and Cd adjustment | 33.134       | 87.248           |
| Sigma Level 1 and Cd adjustment | 25.845     | 63.511           |
| Sigma Level 2 and Cd adjustment | 20.497     | 48.337           |

Table 6. Standard deviations of lifetimes

|          | KOMPSAT-1 [years] | KOMPSAT-2 [years] |
|----------|------------------|------------------|
| Normal   | 3.838            | 2.190            |
| Sigma Level 1 | 3.754          | 2.445            |
| Sigma Level 2 | 2.670          | 1.950            |
| Normal and Cd adjustment | 3.965       | 5.564            |
| Sigma Level 1 and Cd adjustment | 3.009     | 4.261            |
| Sigma Level 2 and Cd adjustment | 3.982     | 3.571            |
to be shorter during extremely high solar activity, and longer during extremely low activity. When the sigma level was ‘Normal’, the average orbital lifetime was approximately 33 years, with a standard deviation of approximately 4 years. Additionally, when the drag coefficients were adjusted according to Tables 2 and 3 for the ‘Normal’ sigma level, the averages and standard deviations of lifetimes were similar to those of the previous results. KOMPSAT-2 had an average lifetime of 84 years with a standard deviation of approximately 2 years under the former conditions, similar to that for KOMPSAT-1. For the latter conditions, the average lifetime was 87 years, with a standard deviation of 6 years. The standard deviations were mostly less than 5 years, which indicates that the TLE information is reliable for long-term orbit tracking.

Compared with adjustments of only the flux sigma level, varying both the flux sigma level and the drag coefficient resulted in a decrease in the average lifetime of KOMPSAT-1, but an increase in the average lifetime of KOMPSAT-2. KOMPSAT-2 is generally operating during low solar activity, and therefore its orbital lifetime is close to or longer than the lifetime of the former, as shown in Figs. 20–22. For both KOMPSAT-1 and KOMPSAT-2, adjustment of the drag coefficients results in an increase of the standard deviation compared with cases in which a constant drag coefficient is applied. This indicates that the adjustment of the drag coefficient with respect to solar activity is reflected in the lifetime predictions.

5. CONCLUSION

The results provided by the LOP for KOMPSAT-1 showed large differences depending on whether the timing of prediction occurred during high or low solar activity. In contrast, the results for KOMPSAT-2 were more consistent under different solar activity levels, because the predictions were made during a period of low solar flux. In contrast, the lifetime predicted by the Lifetime tool varied significantly, dependent on the time at which the solar flux file was generated. In addition, through differential application of drag coefficients, the variable atmospheric drag coefficients and the changes in the flux sigma level were presented. These results showed that KOMPSAT-1 and KOMPSAT-2 differed markedly, and that the drag coefficients must be adjusted in accordance with the intensity of solar activity for accurate lifetime prediction.

In addition, differences were found between the orbital lifetime predictions made using the LOP and the Lifetime tool. For KOMPSAT-1, the prediction results after adjusting the drag coefficient in the Lifetime tool and the LOP showed
trends that were similar to the actual flux intensity. In contrast, for KOMPSAT-2, the solar activity was too low to consider its effects on the results from the LOP and the Lifetime tool. Accurate orbital lifetime prediction is important for post-mission disposal planning. Therefore, the results obtained in this study may be useful for the analysis of long-term orbital lifetime predictions.

ACKNOWLEDGMENTS

This research was supported in part by “A Development of Core Technology for Space Exploration Using Nano-satellite” funded by the Korea Aerospace Research Institute (KARI). The authors would like to thank KARI for its support.

REFERENCES

CNES, Technical Regulations of the French Space Act (2011).
Cojuangco Ai-Ai LC, Orbital lifetime analyses of pico- and nano-satellites, Master Dissertation, University of Florida (2007).
IADC, IADC Space Debris Mitigation Guidelines, IADC-02-01 (2007)
Jacchia LG, Static Diffusion Models of the Upper Atmosphere with Empirical Temperature Profiles, Smithson. Contrib. Astrophys. 8, 215-257 (1965).
Jung DH, Song YK, Fuel Consumption Estimation for Atmospheric Drag Using LEO Perturbation Analysis, J. Korea Navig. Inst. 3, 147-155 (1999).
Kelso TS, Frequently Asked Questions: Two-Line Element Set Format [Internet], cited 2014 May 17, available form: http://www.celestrak.com/columns/v04n03/
Kim HD, Kim EK, Choi HJ, Analysis of the effect on orbit prediction performance according to the solar activity, Proceedings of the Korean Society for Aeronautical and Space Sciences Fall Meeting, 472-475 (2002).
Kim HD, Jung OC, Kim EK, Orbit Analysis for KOMPSAT-2 During LEOP and Mission Lifetime, J. Korean Soc. Aeronaut. Space Sci. 38, 914-924 (2010). http://dx.doi.org/10.5139/JKSAS.2010.38.9.914
Lee IJ, Cho KR, The study of satellite lifetime affected by perturbations, Proceedings of the Korean Society for Aeronautical and Space Sciences Fall Meeting, 431-435 (1996).
Lee BS, Lee JS, Orbital Lifetime Predictions for LEO Satellite, Proceedings of the Korean Society for Aeronautical and Space Sciences Spring Meeting, 436-439 (1997).
Lee BS, Lee JS, Kim JH, Estimation of the General Along-track
Acceleration in the KOMPSAT-1 Orbit determination, in 2001 International Conference on Control, Automation and Systems (ICCAS), Jeju Island, 17-21 Oct 2001.

Lim HJ, Jung OC, Jung DW, Orbital Lifetime Predictions of Operational Satellite, Proceedings of the Korean Society for Aeronautical and Space Sciences Spring Meeting, 790-793 (2013).

NASDA, Space Debris Mitigation Standard, NASDA-STD-18 (1996).

Oh SY, Dependence of Quiet TimeGeomagnetic Activity Seasonal Variation on the Solar Magnetic Polarity, J. Astron. Space Sci. 30, 43-48 (2013). http://dx.doi.org/10.5140/JASS.2013.30.1.043

Oh SY, Kim B, Variation of Solar, Interplanetary and Geomagnetic Parameters during Solar Cycles 21-24, J. Astron. Space Sci. 30, 101-106 (2013). http://dx.doi.org/10.5140/JASS.2013.30.2.101

Park CS, Cho S, Roh WR, Velocity Loss Due to Atmospheric Drag and Orbit Lifetime Estimation, Aerosp. Eng. Technol. 5, 205-212 (2006).

Park J, Moon YJ, Kim KH, Cho KS, Kim HD, et al., Drag Effect of KOMPSAT-1 During Strong Solar and Geomagnetic Activity, J. Astron. Space Sci. 24, 125-134 (2007). http://dx.doi.org/10.5140/JASS.2007.24.2.125

Quia L, Rizos C, Dempster AG, Analysis and comparison of CubeSat lifetime, Proceedings of the 12th Australian Space Science Conference, 249-259 (2013).

Shin S, Na KS, Lee J, Cho KD, Prediction of Parabolic Antenna Satellite Drag Force in Low Earth Orbit using Direct Simulation Monte Carlo Method, J. Korean Soc. Aeronaut. Space Sci. 42, 616-621 (2014). http://dx.doi.org/10.5139/JKSAS.2014.42.7.616

United Nations Office for Outer Space Affairs, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (United Nations publication, Vienna, 2010).

U.S. Government, U.S. Government Orbital Debris Mitigation Standard Practices (2000).