Cylindrical RSO Signatures, Spin Axis Orientation and Rotation Period Determination

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Abstract

Spin axis orientation and sidereal rotation period determination of unresolved tumbling cylindrical RSOs has the potential of significantly advancing the understanding of the dynamics of non-operational satellites such as Boeing/Hughes 376 communications satellites and SL-6 rocket bodies. Cylinders produce very predictable specular and near-specular flashes and brightness peaks in patterns that are unique to every combination of spin axis vector, phase angle bisector vector and sidereal rotation period for that particular object. The observed flash periods are not constant and differ in defined patterns from the sidereal flash periods. The differences in these periods are very small and difficult to measure accurately enough to accurately discern the required patterns. However, the times of occurrence of the flashes or peaks are much easier measured to the required accuracy to identify the unique patterns. This paper reports on the further development of a technique of determining the spin axis vectors from the observed flashes reported by De Pontieu [1] for tumbling LEO objects. This new approach first measures the average observed flash period and calculates the possible range of sidereal rotation periods that could be producing the observed period. Then the flash times for this range of possible periods are modeled together with all the possible right ascensions and declinations (in increments of one degree) of the spin axis vectors for the changing observer-target-sun geometry for the time period of interest. The modeled flash times are compared with the observed flash times to find the best fit and thus the best candidate spin axis vector. Later observations and analyses with different 3D geometry are then used to eliminate ambiguous solutions and to confirm good candidate vectors. This paper describes the experimental methods and analyses, and presents the candidate spin axis vectors for several 376 and SL-6 objects. Because there is very little "ground truth" data available with which to compare these results, the paper invites observations and analyses from other researchers to validate these experimental methods and to verify or eliminate the spin axis vectors and sidereal rotation periods determined to date. The paper also describes the planned on-orbit experiments to extend this research to observations using NEOSSat when it is launched.

1. Introduction

The United States Space Surveillance Network (SSN) has, for many years, tracked satellites and maintained a comprehensive database of satellite orbital elements. However, less emphasis has been placed on the systematic collection and analysis of optical signatures to specifically address identifiable signatures, axis orientation and rotation periods. Some analysis has been done, and continues to be done, to determine rotation periods of tumbling satellites, including very accurate Fourier analyses. Less attention has been paid to spin axis orientation of satellites but considerable related work has been done to determine the spin axis orientation of asteroids. Some published papers [1] [2] have addressed the determination of satellite spin axis orientation based on an analytical derivation from specular reflection measurements. Most of the published work to date has been done on LEO objects plus some work on Molniya satellites, and other spinning satellites [3]. This current research began with a short review of spin axis determination of some LEO objects based on ground-based observations, but has concentrated on high-earth-orbit SL-6 rocket bodies in highly eccentric orbits and uncontrolled Boeing/Hughes 376 cylindrical satellites in GEO orbits.

The main immediate purpose of this analysis is to contribute to an improved capability to correctly and unambiguously tag observations to the correct catalogued resident space objects (RSOs) through knowledge of the signatures of individual objects. Secondary and related benefits include determination of RSO attitude characteristics including 3-axis stabilisation, spin stabilisation and uncontrolled tumble. Such a determination would support assessment of active, inactive or dead payloads. It would also support prediction of future orbit manoeuvres or orbit change or decay, and could assist in de-orbit operations. Long-term analysis could identify orientation and tumble coupling to environmental factors such as atmospheric drag, solar radiation pressure and gravitational field variations. Knowledge of unique temporal signature shapes and magnitudes could potentially contribute to more effective streak observations, streak end-point determinations and observation planning.

2. Background

A considerable number of observations have been taken, by various observers, of LEO satellites that flash due to specular reflection of sunlight. These flashes are occasionally visible to the naked eye, or are easy to see with binoculars, small telescopes or wide field-of-view cameras. The observations tend to be from amateur astronomers or satellite observers, using a variety of equipment and a variety of means of determining the flash periods to varying accuracies. These flash periods are normally the apparent flash periods as seen by the observer. They usually do not take into account the varying geometry of the observer-satellite-sun angle during the observations caused by the movements of the observer and the satellite due to earth rotation and orbital motion. This variation is called the synodic effect. This difference between the apparent flash rate and the rotation or tumble rate of the satellite is not constant but typically varies with time as a function of the changing geometry. The magnitude of this variation for a given changing geometry is a function of the orientation of the spin axis of the spinning satellite with respect to the observer-satellite-sun geometry. This varying synodic period can be used to provide an estimate of the orientation of the spin axis of the satellite. A version of this technique is called the "epoch method" by Magnusson [4] and is described as a "most reliable tool" for determining the rotation axis and rotation rate of asteroids. A variation of the epoch method was used successfully and demonstrated by De Pontieu [1] for several cylindrical LEO satellites with apparent flash periods of about 20 seconds. De Pontieu calculated the statistical match between the observed flashes and the expected flashes for all possible orientations of the spin axis, choosing the best fit. Normally, observations from a single set of observations (such as perhaps 20 flash periods from a single pass of an LEO object by a ground-based observer) will produce at least two possible orientations of the spin axis. The less accurate the observation times of the flashes (and thus the apparent periods), the more possible orientations will be calculated. Even with very accurate timings of the observations, normally two possible spin orientations are produced due to geometrical symmetry. One or more additional sets of observations are normally necessary, with significantly different observer-satellite-sun geometry required to solve the ambiguity of the spin axis orientation. De Pontieu's technique for solving these ambiguities is to plot the statistical fits of all the possible spin axis orientations as right ascension/declination pairs on a celestial sphere, and observe the variation of the statistics. The actual statistics used for the De Pontieu plots or used for some other technique to determine the candidate orientations are not that important. The plot or technique simply must determine the two or more best fits of the observed flash periods with the expected flash periods of all possible orientations.

Another approach to the determination of spin axis orientation is to accurately model the tumbling satellite and compare observed spectral signatures to those obtained from rotation of the model around all possible spin axis orientations and observer-satellite-sun angles. This technique could be done for either monochrome visible signatures or for multi-spectral signatures (assuming that the satellite could be observed in colour). Specular reflections would be useful but non-specular signatures are much more commonly and easily obtainable. Modeling requires three dimensional graphic capability such as Java 3D which can model in both monochrome and colour, and can model surface characteristics such as texture, diffuse reflection, specular reflection, albedo, transparency, emissivity and shininess. Such techniques can model direct light from one or more point sources as well as ambient light, with all variations of 3D observer-target-source geometry.

Cylindrical rocket bodies or satellites are fundamentally the easiest shapes for which to determine spin axis orientation based on the observations of specular reflections. The 3D geometry of determining the specular reflection conditions is mathematically straight forward. However, experimentally, the geometry of actual orbits and the accuracy requirements of the required observations suggest that a numerical modeling approach is required to derive accurate spin axis vectors from a limited amount of observations.

The observation geometry for reflections from the sides of a cylindrical satellite is described by eight vectors in the geocentric reference frame:

- Position vectors of the cylinder, the observer and the sun
- Unit vectors sun-to-cylinder and observer-to-cylinder
- Unit body vector of the cylinder aligned along its cylindrical axis
- Unit spin axis vector, assumed to be orthogonal to the body vector
- Phase angle bisector unit vector which bisects the observer-cylinder-sun angle

The necessary condition for a specular reflection from the sides of the cylinder is that the dot product of the phase angle bisector and the body axis equal zero (phase angle bisector and body axis are orthogonal). A cylinder spinning (tumbling) about an axis vector **r** orthogonal to its cylindrical body axis vector **b** will produce specular flashes twice per 360 degree rotation. The condition for the flash to occur is:

$$\mathbf{b} = \mathbf{t} \times \mathbf{r}$$

where **t** is the phase angle bisector, which is the vector that bisects the angle between the observer-object vector $\boldsymbol{\omega}$ and the sun-object vector **s**. (De Pontieu's symbology). Specular reflections as seen by an observer do not occur precisely in phase with the sidereal rotation of the cylinder about its spin axis. The actual times that these flashes occur are a function of the directions of the spin axis vector and the phase angle bisector. The observed flash period is called synotic which refers to the changing three-dimensional geometry that modulates the precise times of the observed flashes. By observing the flashes, the actual sidereal rotation period of the cylinder cannot be directly determined, but must be deduced from the changing geometry. For the singularity condition where the spin axis is aligned with the phase angle bisector, the specular reflection is continuous for the entire 360 degree rotation about the spin axis.

3. Experimental Approach

The fundamental approach to determining the spin axis vector is to model the three dimensional observational situation in software, calculate the flash pattern that would be expected for every possible spin axis vector, and then compare the observed flashes to determine which possible spin axis vector pattern fits the best.

A comprehensive orbital mechanics application was built around the SGP-4 version described and detailed in [5], and was used to provide accurate position vectors and angles for the observer, target satellite and the sun for any given time and set of orbital elements. It includes both a flash condition modeling and spin axis determination function for cylindrical shaped objects. It can be used with any arbitrary ground based observer location as well as any space-based satellite tracking platform such as NEOSSat (where its observation vectors are derived from an element set). The application also provides a celestial sphere visualisation function for the position vectors of the observer, target satellite, sun, earth, moon and Venus for use in observation planning.

The software model generates a series of the expected observable flash times for a given time period based on the position vectors and for a given spin axis orientation. The software then cycles through all possible directions of the unknown spin axis vector, from 0 to 360 degrees in right ascension and from -90 to +90 degrees in declination in 1 degree increments. As well, because the actual sidereal rotation period of the cylinder is so far unknown, the software also cycles through the possible sidereal periods which are normally within plus or minus 40 milliseconds of the observed period. These plus/minus limits can be estimated from the changing three-dimensional geometry. This cycle is done at 1 millisecond increments.

The detailed analysis begins at RA = 0, DEC = -90, sidereal period = observed period minus 40 milliseconds, and the time of the first measured flash $\mathbf{t}_1$. These RA, DEC and period values are candidates of the possible actual values for the cylinder. The observer-object's vector is calculated using SGP4, and the sun-object vector is calculated using astronomical equations. From those two vectors, the phase angle bisector vector **t** is determined by the addition of unit vectors. The cross product of the phase angle bisector and the spin axis vector gives the body vector that the cylinder must be aligned with for the observed flash to have occurred. The angle **A** between this body vector ($\mathbf{b}_1$) and the body vector at the reference flash time ($\mathbf{b}_0$) is calculated.

$$\mathbf{A} = \text{angle between } \mathbf{b}_0 \text{ and } \mathbf{b}_1$$

Note: This angle **A** is the difference angle from the reference position for these candidate values of RA and DEC. It is calculated as the difference in vector directions at the two specific instances in time.

The time difference $\mathbf{t}_d$ between the reference flash and the current flash is divided by the sidereal flash period $\mathbf{fp}_s$, which is half the sidereal rotation period $\mathbf{rp}_s$. This is from the sidereal rotation period cycle mentioned above which begins at minus 40 milliseconds of the observed period. The remainder from this division (by an integer flash period) is the time the rotating cylinder has to rotate its body vector from being parallel to the body vector at the reference flash time to the position where it produces a flash. During that time, it is rotating at the candidate sidereal rotation rate, with its spin axis pointing in the candidate RA/DEC direction. It would rotate through an angle **B** during this time.

$$\mathbf{B} = \text{Remainder}\ (\mathbf{t_d / fp_s})\ \mathbf{/rp_s} * \mathbf{360\ degrees}$$

Note: This angle **B** is the difference angle from the reference position for the candidate sidereal rotation period. It is calculated from the rotation of the cylinder for a specific time period.

If the candidate RA, DEC and sidereal rotation period are the actual RA, DEC and sidereal rotation period, then angle **A** will equal angle **B**. The "score" $\mathbf{S_1}$ for how well the candidate values produce a flash time that matches the first observed flash time is the difference between **A** and **B**, zero being the best score.

$$\mathbf{S_1} = \text{absolute value}\ (\mathbf{A} - \mathbf{B})$$

To this point, the score $\mathbf{S_1}$ is the score value for that combination of candidates, for the first observed flash after the reference flash. A score is then calculated for the remaining flash times. The total score **S** is the sum of the scores for all the observed flashes.

$$\mathbf{S} = \text{sum}\ (\mathbf{S_n}),\ \text{where}\ \mathbf{n} = \text{number of observed flashes after the reference flash}$$

The scoring process is repeated for the remaining combinations of RA, DEC and period. The total number of scores calculated is 360 * 180 * 81 (0+/-40). The final solution is represented and saved as a three dimensional array of the total score for each candidate RA, DEC and period. The best score is directly available. Normally a two-dimensional RA and DEC plot is produced for the period with best score, with a colour gradient showing the scores. Due to three-dimensional symmetry of the phase angle bisector and the spin axis vector on the sky, the plots show two "best" regions, one of which contains the RA and Dec with the best score. The best scores for these two best regions are sometimes very close. According to De Pontieu, repeated observations under varying geometry will show one of these two best score directions to remain about the same while the other one will vary, eliminating it.

4. Required Observational Accuracy

If the software model is used to produce a set of simulated observations for a given set of position vectors and a spin axis vector which are then processed to solve for the spin axis vector, the correct right ascension and declination of the spin axis direction is found. However, the unique variation of the observed flash times from the sidereal flash times attributed to each spin axis vector is quite small. For a typical tumbling cylindrical satellite in the GEO belt over a 24 hour period, the maximum variation of the flash times from sidereal is on the order of 0.4 sec. And that variation occurs over time periods of an hour or more. So the accuracy of the observations and the subsequent measurement and determination of the flash times or peaks in the light curves must be accurate to about 0.1 second or better, very much depending on the geometry and the actual time of the observations. A 24 hour period of hypothetical observations is considered so that a complete picture of the variations can be seen even though the optical observations can only be made during the local night for a ground-based observer. The variation of observed flash times from sidereal rotation shows a complex but well-behaved shape that for each spin axis vector is unique. It is this uniqueness that enables the correct spin axis to be derived. However, for most of the 24 hour period, the amount and rate of variation is very small and in general would be masked by uncertainties in the measurement of flash times. But for each spin axis direction, either once or twice during the 24 hour period, the amount and rate of variation is very significantly more. Where, and to what degree this more rapid variation occurs is a function of the spin axis vector with respect to the phase angle bisector vector, as well as the relative alignment of other pairs of vectors. Examples of this 24 hour variation from simulated flash times are shown in Fig. 1 for two different spin axis vectors.

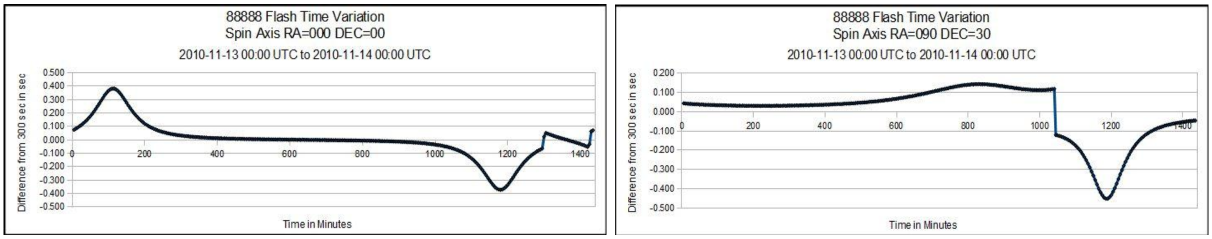


Fig. 1. Variations in expected flash times with respect to reference sidereal rotation

The variation of the flash times from the sidereal rotation shows long periods of the 24 hour period when very little change is happening and it would be difficult to uniquely determine a spin axis vector. However, during one or two short time periods on the order of one or two hours, the variation is much faster and larger. Obviously, observations and measurements during these time periods would be much better suited to produce a more reliable estimate of the spin axis vector. However, because the variations are still quite small, the measurement uncertainty has a big effect and may well obscure the shape and time of the variations to the point that the correct spin axis cannot be determined. Fig. 2 shows simulated flash times with a measurement uncertainty standard deviation of 0.1 second, illustrating the effect that observed flash time uncertainty would have on the quality and usefulness of the observations.

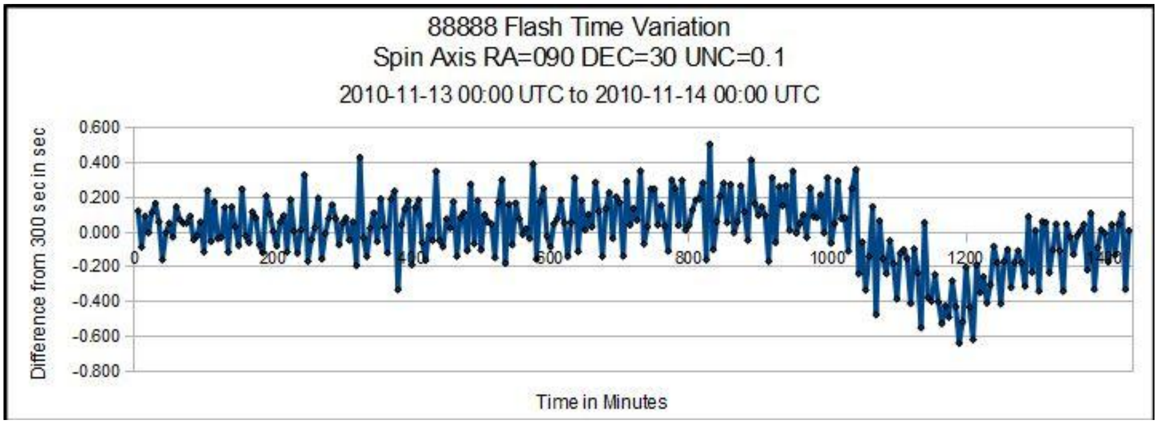


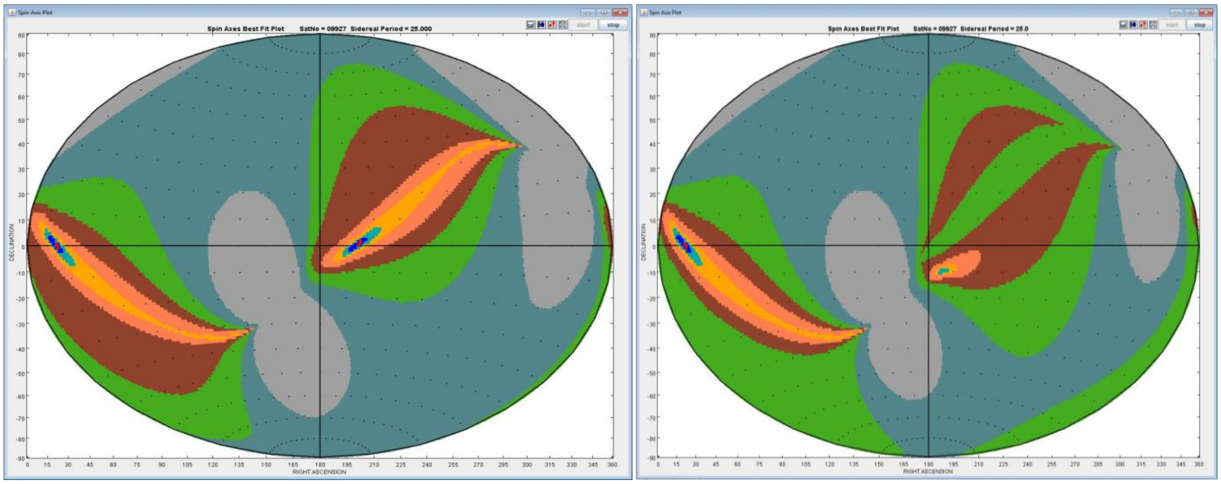
Fig. 2. Comparison of measurement uncertainty of 0.1 sec with variation due to geometry

Clearly measurements made anywhere except between about 1000 – 1300 seconds would probably be of little value, and even during the best times, uncertainties of better than 0.1 seconds would be desired. A series of simulations were done that show that measurements made during the opportune times and for at least 3 hours with uncertainties of 0.1 seconds or better can be used to derive spin axis vectors that are correct to 1 degree in right ascension and declination. For measurements of less than three hours, or with larger uncertainty, or worse, during the non-optimal time periods, the accuracy of the spin axis vector rapidly deteriorates and soon becomes completely incorrect.

5. Simulated Spin Axis Determination

One of the biggest challenges in determining the spin axis vector of an actual tumbling cylinder is to understand when the determined vector is likely to be correct, as described above. There are essentially three main unknown variables: spin axis right ascension and declination, and sidereal spin rate. The relationship of these three variables to the three-dimensional geometry of the observer, target and sun, coupled with the movement of the observer (rotation of the earth) and the more complex orbit of the target satellite, has a very large effect on when useful observations can be made and when measurements are very unlikely to lead to a correct solution. Unfortunately, to know when the best and most productive observing periods are, the RA, DEC and sidereal period have to be known. But they are unknown. So other approaches have to be used to first determine if observations already made are likely to contribute to finding the unknowns and, if not, what are better periods to collect observations. The better the possible spin axis is estimated, the better future observations can be planned to improve the spin axis estimate.

To more fully understand how well the spin axis determination software was able to determine the correct spin axis and the associated sidereal rotation rate, simulations were carried out by first generating the observable flashes that would be observed for various observer-target-sun geometries, spin axis RA/DECs and sidereal periods, and observation time periods and time spans. These simulated flash observation times were then analysed by the spin axis determination software that would provide the spin axis vector and sidereal rotation rate that best fit the input flash times. For "sufficiently" long simulated observation periods, numbers of observations and flash time observations with no uncertainty, the exact spin axis vector and sidereal rotation are easily determined. "Sufficiently" depends on whether or not the observation period fell during a productive and effective time period of the complex three-dimensional scenario. Typically twenty observations with no uncertainty over a two hour time period were sufficient to calculate an exact solution. Fig. 3a, which plots best fit (blue and red) for all possible RAs and DECs, shows two candidate solutions with the left one at RA = 20 and DEC = 0 being the correct one. Normally for one set of observations, a second candidate emerges due to approximate symmetry of the three-dimensional geometry. When a very long observation period is simulated, or two or more observation periods from different nights are simulated, the correct solution stays in place and the second candidate slowly moves and gets weaker, indicating that it is not the correct solution. So the additional observations solve the ambiguity between the standard two candidates that appear initially, as shown in Fig. 3b for combined observations over three nights.



Figs. 3a and 3b. Plots of best fit of candidate spin axes right ascension and declination

It is very difficult to estimate the uncertainty in measuring the time of the peaks of the optical signatures. The observed flashes and light curves from each target satellite are different, and they vary from night to night, and vary with changing geometry. A rough average estimate of this measurement uncertainty is a standard deviation of 0.1 seconds for near specular flashes from SL-6 rocket bodies and somewhat better for the specular reflections from the Boeing/Hughes 376 satellites, provided that the non-specular body signature is also visible. Some experimental observation methods are estimated to improve the uncertainty for some 376 satellites to about 0.05 sec or better. Using simulated flash peak time measurements, pseudo random uncertainty can be introduced and increased to show the effects on the validity of the determined spin axis vectors. For a given number of observations over a given observation period, increasing uncertainty will draw the determined vectors away from the correct value. With enough uncertainty, the determination process will break down completely, as in Fig. 4, where the correct solution is still RA = 20 and DEC = 0. As well, the coupled determination of sidereal rotation period breaks down from the modeled period of 25.000 sec to the determined period of 24.996 sec. This analysis helps determine what amount of uncertainty can be tolerated for defined observation conditions and times.

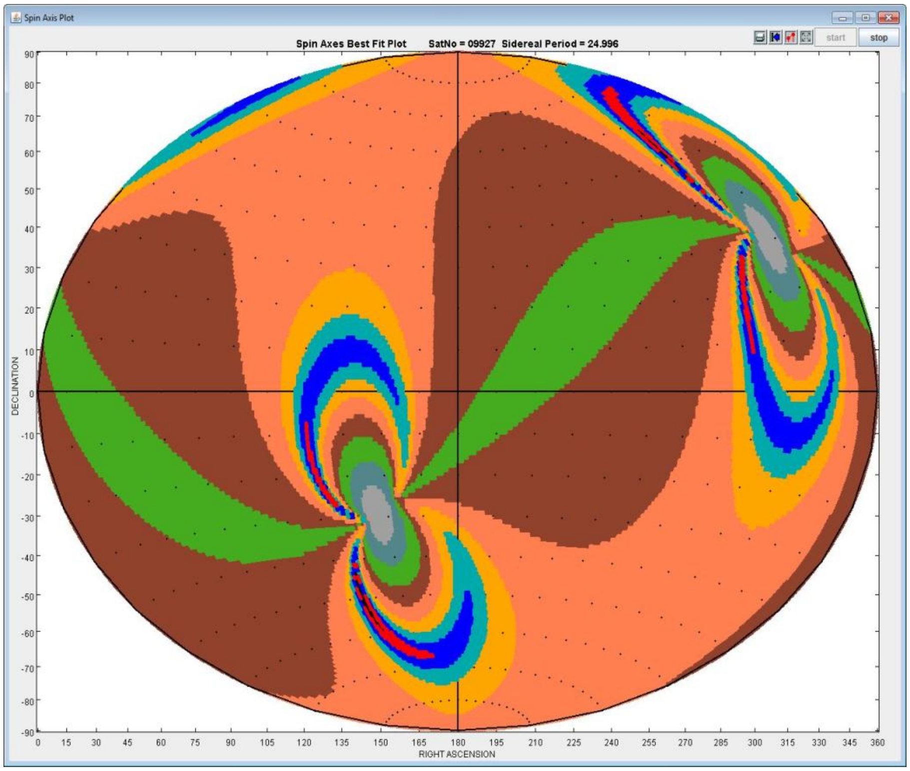


Fig. 4. Analysis breakdown because of increasing uncertainty yields solutions significantly different than those shown in Fig. 3.

6. Observational and Measurement Techniques

All the observations to date have been of either SL-6 cylindrical rocket bodies or Boeing/Hughes 376 cylindrical satellites. Each type presents its own type of optical signature when recorded as a streak in a sidereal stare CCD exposure. SL-6 rocket bodies appear to have white painted cylindrical surfaces that are somewhat shiny and produce a near-specular flash or increase in brightness from the cylindrical surface when the body axis and the phase angle bisector are orthogonal, which happens twice per rotation. Dimmer diffuse peaks usually occur from the ends of the cylinders, between the main peaks from the sides. The side and end peaks are clearly evident in the CCD image in Fig. 5. SL-6 flash periods are in the tens of seconds indicating relatively slower tumbling when compared to the 376s.

Fig. 5. Two body and two dimmer end peaks for SL-6 SSC No 13016

For the Boeing/Hughes 376 satellites, most of the cylindrical surface is covered in solar panels which appear to produce much more specular-type flashes than the painted surfaces of an SL-6. The ends of a 376 usually produce a proportionally much dimmer flash than the ends of an SL-6, probably partly because the 376s are long and narrow cylinders whereas the SL-6s are more short and wide. Often it is difficult to tell if half of the flashes are from the ends or if none of the flashes are from the ends. The 376s tend to produce a series of specular flashes much brighter than the diffuse reflection from the body. Therefore, the optical signatures tend to be a series of disconnected round flashes in a CCD image because the diffuse reflections are often dimmer than the sky background as shown in Fig. 6. Typical SL-6 flash periods are one to two seconds. Because the specular flash tends to create a circular point spread function in a CCD image, the location of the flash can be considered to be the centre of the point spread function. However, this flash also tends to overwhelm and obscure the background diffuse reflection. When the flash occurs near the beginning or end of the time exposure, the location of the end is obscured, making it impossible to accurately assign an accurate time scale to the streak. Because of this, and the fact that the diffuse reflection may be dimmer than the sky background, also making it difficult or impossible to determine the end of the streak, it is often difficult to accurately determine the time of the flash, even though it is a very short specular flash.

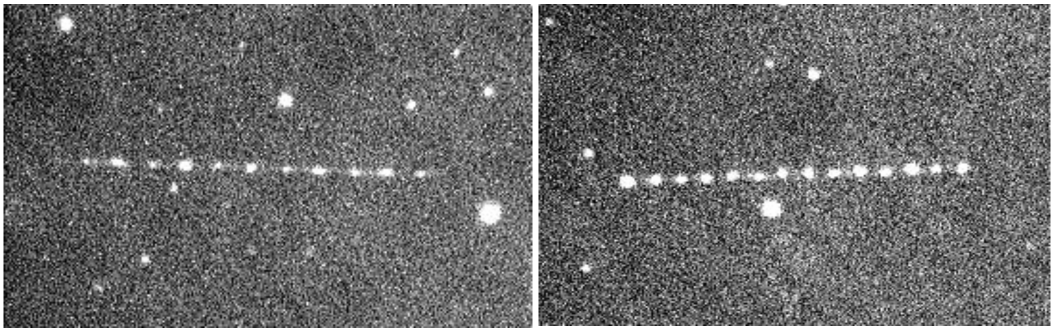


Fig. 6. Boeing/Hughes 376 Anik D1 - SSN No 13431 and THAICOM 1 - SSN No 22931

Successful determination of the spin axis vector and the sidereal rotation rate depends mainly on the accuracy of the measurements of the flash peak times, the relative uncertainty of the flash peak times compared to the flash period, and the number of flashes that can be observed and measured. It also depends on the time span over which the measurements are made, and whether or not these measurements occurred at opportune times when the variation of the peak times is changing significantly from the rotation times.

For the 376s, the specular flashes produce very sharp peaks but the time accuracy is reduced because of the difficulty determining the streak start and stop locations in the CCD image. The relative uncertainty of the peak times compared to the flash period is large because the flash period is short. Many flashes can be observed and measured. Because the 376s are GEO, they generally are visible all night long, depending on how badly their GEO orbit has changed since they were operational, and just where they are located along the GEO belt. The long observation period improves the likelihood that observations are being made during opportune times.

For the SL-6s, the near-specular flashes are not as sharp as the 376s, but usually the exposure end points can be determined accurately. The long flash period improves the relative uncertainty of the flash peak times. The best observations from a measurement accuracy point of view are from about 6,000 km out to about 30,000 km, and the reverse inbound, so the number of observations is limited. If the SL-6 orbit is phased so that the object is at about 6,000 km range and outbound just after evening twilight, and reaches 6,000 km inbound before morning twilight, then the time span is on the order of eight hours or more. The eight hour or more observation time period is a very significant portion of the 12 hour SL-6 orbit so the likelihood that observations are being made during opportune times is good. However, most of the SL-6 orbits are not well phased for the purposes of maximizing the time span and the number of observations.

7. Spin Axis Vectors and Sidereal Periods Calculated to Date

Observations to determine spin axis vectors and sidereal periods have been done in parallel with the development of an understanding of the requirements for observations to be productive and useful to make these determinations. So the process has been an iterative one. The fact that little or no “ground truth” data is available for the spin axis vectors and sidereal periods of any of these objects makes it difficult to know or determine how accurate the “determined' values are. That is one reason why the analysis of the simulations to quantify the effects of measurement uncertainty and opportune times is so important. So the accuracy of the following derived data cannot be quantified as yet. The data is offered as “candidate” spin axis vectors and sidereal periods in the expectation that they can be either verified or refuted, based on independent observations and analysis, or by further development and understanding of the fundamentals that affect their accuracy. Table 1 provides the calculated right ascension and declination, and the associated sidereal rotation period in seconds of what was estimated to be the most probably spin axis vector for each satellite on one or more observation occasions. In most cases a secondary set of derived data is provided because of the symmetry of the spin axis on the sky that is usually removed by the addition of more observations during one observation period, or later separate observation periods.”

Table 1. Spin Axis Vectors and Sidereal Periods. P indicates primary candidates

SatNo	Date	RA	Dec	360Period		RA	Dec	360Period	Sat Type
07382	2011-07-09	110	-04	1048.0P		Primary axis dominant			SL-6
09850	2010-08-07	119	-23	19.318P		285	21	19.330	SL-6
09850	2010-08-14	114	-27	19.318		289	22	19.316P	SL-6
09850	2010-08-19	113	-20	19.319P		291	25	19.318	SL-6
09850	2010-08-29	160	-25	19.264P		340	25	19.264	SL-6
09850 Combined Observations for 2010-08-07, 14, 19, 29									
09850	2011-08-XX	084	-04	19.326P		Primary axis dominant			SL-6
09927	2010-08-27	138	-34	24.976		319	30	24.976P	SL-6
10949	2010-09-11	334	08	40.261P		154	-08	40.261	SL-6
12855	2010-10-11	185	04	83.264P		005	00	83.264	376 SBS2
12940 Combined Observations for 2010-07-11, 14									
12940	2010-07-XX	251	03	4.484P		123	17	4.484	SL-6
13016	2010-07-17	126	-25	27.380P		306	25	27.368	SL-6
13016	2010-07-26	129	-22	27.446P		281	03	27.440	SL-6
13016	2010-08-07	125	-27	27.527P		300	07	27.529	SL-6
13652	2010-10-08	185	08	4.536P		003	02	4.536	376 Anik C3
14133	2010-11-14	200	01	3.416P		020	04	3.416	376 Anik C2
15223	2010-08-07	151	-26	65.805P		334	26	65.804	SL-6
15383	2010-08-17	296	-14	2.822P		136	45	2.822	376 Anik D2

8. Spin Axis Determination using NEOSSat

The ground-based observations have provided an opportunity to extend the spin axis determination work to space-based observations. A set of experiments is being developed for the satellite-tracking satellite NEOSSat which is planned for launch in 2012. The space-based observations are expected to be more accurate and available over larger portions of an orbit. As well, the more rapidly changing 3D geometry should contribute to more accurate analyses. The experiments are designed to demonstrate how accurately the spin axis vectors and sidereal periods can be determined from space for SL-6 and 376 cylindrical satellites.

9. Conclusions

The objective of this paper was to presents the progress to date of the research project to determine the spin axis orientation and sidereal rotation period of tumbling cylindrical 376-type satellites and SL-6 rocket bodies based on analyses of their optical photometric signatures. Where sufficient observations on individual satellites were possible and where accurate data reduction and processing were possible, a number of the SL-6s and 376 were analysed to provide estimates of their spin axis vectors and sidereal rotation rates. Since no so-called 'ground truthing' is available, it is not known how accurate these estimates are. That is the reason that a considerable amount of effort has been expended to better understand the challenges of this task and to quantify the effects of measurement uncertainty and periods of observations. This research has resulted in the development and use of very practical software tools for use in these types of analyses. The software and the techniques, together with the knowledge gained about 376 and SL-6 satellites, will now be used to effectively prepare for the related experiments to be conducted with the NEOSSat.

Acknowledgements and Contact Information

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