A SEARCH FOR POSSIBLE BREAKUP FRAGMENTS IN THE GEOSTATIONARY REGION

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ABSTRACT

This paper reports results of an optical survey for the possible breakup fragments of the U.S. Titan 3C Transtage (1967-066G). The target spacecraft 1967-066G might have experienced an energetic breakup because its orbital anomaly can be confirmed in February 1994 in the U.S. Space Surveillance Network catalogue.

Orbits of three uncatalogued objects are acquired by surveying the regions where the possible fragments of 1967-066G may be appeared. As a result of origin identification, it would be concluded that tracklets of all of them are not associated with the 1967-066G's event regarding the motion vectors, however orbits of two of them are associated with the event regarding the orbital plane vectors and the pinch points of their trajectories. Consequently, it might be possible that the breakup scale is quite small or the orbital anomaly of 1967-066G is not an evidence of its breakup.

Key words: breakup; orbital anomaly; the geostationary region; origin identification; optical survey.

1. INTRODUCTION

This paper reports results of an optical survey for the possible breakup fragments of the U.S. Titan 3C Transtage (1967-066G). The final goal of this research is to establish a practical method to identify an orbital anomaly as a spacecraft breakup. The orbital anomaly of the target spacecraft 1967-066G can be confirmed in February 1994 in the U.S. Space Surveillance Network (SSN) catalogue. Some literatures also point out that the orbital anomaly of 1967-066G might be associated with a breakup as in [1, 3, 4, 5]. Thus, 1967-066G is a suitable target for verifying the aim of this research.

We have already investigated that the possible fragments of the parent object 1967-066G will have similar trajectories in the celestial sphere even if there are several weeks uncertainties in the possible breakup epoch [6]. Thus, the objective of the optical survey is to detect the possible fragments and then conduct follow-up observations for precise orbit determination. Once we can retrieve the orbital parameters of the possible fragments, we can verify whether or not the origins are belong to 1967-066G by the origin identification methods to be introduced in this paper. The methods utilize an angular velocity (hereinafter called motion vector) feature and orbital plane features that fragments generated by a breakup event will have. The motion vector feature can be confirmed at an inertial point where the large number of the fragments will pass through. The orbital plane features, which consist of right ascension of ascending node (Ω) and inclination (i), can be confirmed in two projection spaces: one consists of the orbital plane vector ($i\cos(\Omega)$, $i\sin(\Omega)$) where the fragments will form a linear distribution at the breakup epoch, and the other is the celestial sphere, where the trajectories of the fragments of one breakup event will have a pinch point at the breakup epoch. This paper demonstrates the origin identification methods to see if the possible fragments to be detected in the optical survey coincide with the features of the possible breakup of 1967-066G.

2. OBSERVATION PLANNING

The observations are planned around the new moon term in February 2013 at Japan Aerospace Exploration Agency (JAXA) Nyukasa Observatory in Nagano prefecture, Japan. The sensor used at the observatory is the 35-cm aperture telescope Takahashi ϵ-350 equipped with the charge-coupled device (CCD) camera FLI-23042. The sensor has a field of view (FOV) of 1.41 deg by 1.41 deg, and a pixel scale of 15 um/pixel. A readout time per one picture is less than four seconds.

We have to select the observation points suitable for the survey of the possible fragments of 1967-066G. Fig. 1

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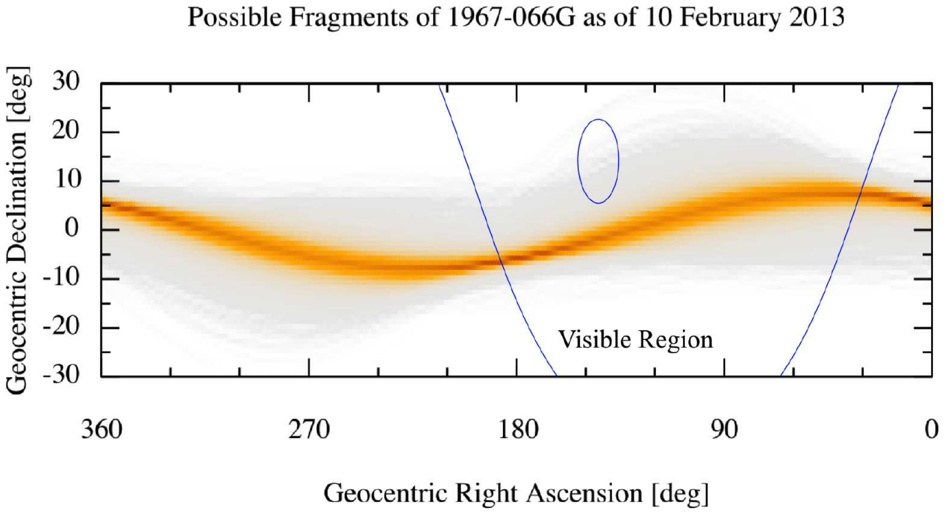

Figure 1. Predicted population of the possible fragments of 1967-066G as of 10 February 2013.

predicts a population of the possible fragments of 1967-066G in the celestial sphere as of 10 February 2013. This population represents a time-averaged distribution of the fragments generated by the NASA standard breakup model 2001 revision [2]. The hypotheses applied to the breakup event is the scaling factor of 1.0 that generates 238 fragments down to 10 cm and the two weeks uncertainties of the breakup epoch that can be confirmed in the orbital history of 1967-066G. There are two dense regions where a high probability of detections are expected if the hypotheses are true.

As a result, we select two observation points to maximize a total observation period at each night by considering the region visible from the observatory during observation periods. The visible region from the observatory at the midnight is specified in Fig. 1 for reference. The selected observation points consist of the point A and B, respectively. The observation coordinate for each of them is specified in Tab. 1, where α denotes the geocentric right ascension, δ denotes the geocentric declination, and r denotes the geocentric radius. We observe the point A for the first half night, and the point B for the latter half night. An observation period to take one image sequences is set to 4 minutes, which results in a maximum of 166 observations per one night.

To assess the detection probability of 1967-066G fragments at the selected observation points, this paper predicts a detection rate of 1967-066G fragments in terms of the time-integrated number of fragments in the FOV per one hour. The equation of the time-integrated number of fragments is given by Eq. 1.

$$N = \sum \left(n_k + \frac{T}{P_k} \right) \tag{1}$$

where n_k is the effective number of k-th fragment in the FOV and P_k is an orbital period of the fragment. The summation terms in Eq. 1 represents a detection probability of k-th fragment whose trajectory crosses the FOV when a sensor points at an inertial point during an observation period, T, in a night. One can assume the observation period as a total temporal length of acquired image sequences. Fig. 2 compares the predicted detection rates between the scaling factor of 0.1, 0.6, and 1.0. A data point in this figure represents a detection rate for fragments whose size is larger than a corresponding value in the horizontal axis. The mean value and the standard deviation in the figure are evaluated based on the result of one hundred Monte-Carlo runs of this predictive analysis. It can be guessed from this result that the sensor will detect several 1967-066G fragments at each observation point if the target object 1967-066G experienced a major breakup whose scaling factor is around 1.0 or larger. The same type object 1968-061E experienced a major breakup so that this hypothesis may be also possible for the 1967-066G. In case 1967-066G experienced a minor breakup, the sensor might not be able to detect its fragmentation debris due to the sensor's detection sensitivity limit.

Table 1. Observation points

Name	α [deg]	δ [deg]	r [km]
Point A	71.5	7.8	40000.0
Point B	180.5	-5.5	40000.0

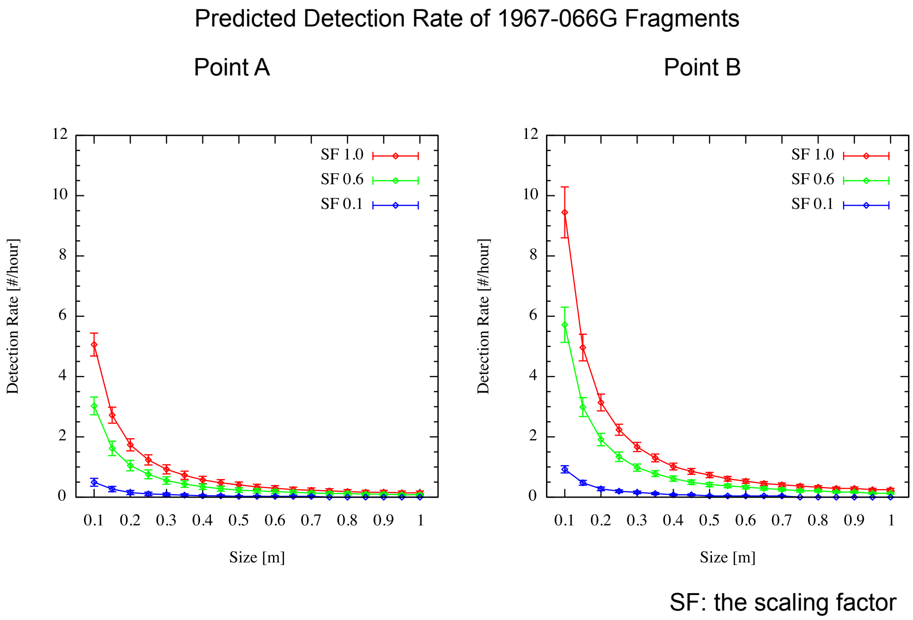

Figure 2. Predicted detection rates at the point A and B.

3. ORIGIN IDENTIFICATION

As a result of the optical survey of 1967-066G fragments conducted during 08-13 February 2013 at JAXA Nyukasa Observatory, the follow-up observations of three uncorrelated targets (UCTs) were performed. These uncatalogued objects, JAXA-UCTs, were identified as JAXA-d0044, JAXA-d0045, and JAXA-d0046, respectively.

In this section, we address the origin identification of JAXA-UCTs detected in the observations. First, tracklets of JAXA-UCTs detected at the survey point A and B are assessed in terms of the motion vector. Second, orbits of JAXA-UCTs are assessed in terms of the orbital plane vector and the pinch points, respectively. To conclude the origin of a UCT is associated with the breakup event, the UCT must be associated with every feature of the event in these assessments.

3.1. Motion vector

The motion vector (dx, dy) and a size of each JAXA-UCT are evaluated in this section. This paper evaluates an object's size in terms of the diameter of the Lambert sphere whose albedo is 0.1. The evaluated properties of tracklets of JAXA-UCTs are summarized in the Tab. 2. In the table, "Point" denotes the observation point where the UCTs are detected, and "V mag" denotes the visual magnitude of a detected object. It may be noted that V magnitude of the faintest object among all objects detected is around twentieth magnitude, though the detection sensitivity might be low for such faint objects.

The motion vectors of tracklets detected at the point A and B are assessed in Fig. 3 and Fig. 4, respectively. In each figure, the detected tracklets are distinguished as correlated targets (CTs), UCTs, and several relevant CTs, respectively. The contours in the right-hand figures represent the possible region where the motion vectors of 1967-066G fragments will exist when assuming the scaling factor of 1.0. At the point A, JAXA-d0044 has weak relevance to 1967-066G fragments. However, the distance between JAXA-d0044 and 1968-081J, which is a fragment generated by the 1968-081E's breakup, is close so that they might have correlations. At the point B, JAXA-d0045 and JAXA-d0046 have weak relevance to 1967-066G fragments, too. Though, they are very close to the CTs, which are launched during the late 70's and the early 80's, so that they might be associated with debris of these CTs.

3.2. Orbital plane vector

We have to conduct origin identification of JAXA-UCTs with the possible breakup event of 1967-066G. To do this, the orbits at observation epochs of JAXA-d0044, JAXA-d0045, and JAXA-d0046 are back propagated to the 1967-066G's TLE epoch 05:09:09.14UT (Universal Time) 1 February 1994 when the beginning of the orbital

Table 2. Properties of tracklets at the observation epochs

Object ID	Point	Epoch [UT]	V mag	dx [arcsec/sec]	dy [arcsec/sec]	Size [m]
JAXA-d0044	A	2013/2/08 13:46:26	14.34	-0.11	1.02	3.03
JAXA-d0044	A	2013/2/13 13:14:27	14.35	-0.08	1.00	3.16
JAXA-d0045	B	2013/2/09 17:58:25	17.26	0.20	3.87	0.53
JAXA-d0045	B	2013/2/13 17:22:26	16.63	0.20	3.79	0.70
JAXA-d0046	B	2013/2/09 17:38:26	16.60	0.36	3.68	0.73
JAXA-d0046	B	2013/2/13 16:30:26	16.64	0.36	3.67	0.72

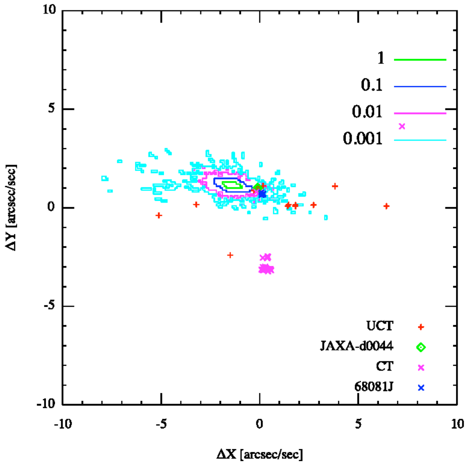

Figure 3. Correlation of the motion vectors at the point A

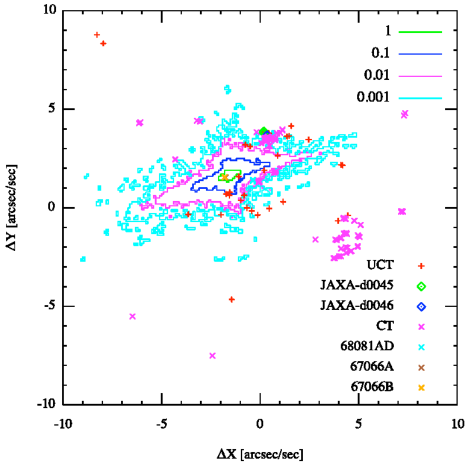

Figure 4. Correlation of the motion vectors at the point B

anomaly can be confirmed in its orbital history. The orbit propagation applies the special perturbation theory including perturbation forces by the J2 term, the third bodies (the Sun and the Moon), and the solar radiation pressure (SRP). The area-to-mass ratio of 0.01 m^2/kg is assumed for each object. Mean orbital elements of those objects before/after the propagation are summarized in Tab. 3.

As previously mentioned, the orbital plane vectors ($i\cos(\Omega)$, $i\sin(\Omega)$) of fragmentation debris of a same parent object show a linear distribution at its breakup epoch. If UCTs and a possible parent object are in a line with at near its breakup epoch, the UCTs may be associated with the breakup. In this study, we assume 1967-066G is the possible parent object.

The orbital plane vectors of JAXA-UCTs and 1967-066G at the beginning of the possible breakup period are shown in Fig. 5. We have to distinguish the features of 1967-066G fragments and 1968-081E fragments because the breakup epoch of 1968-081E is only two years before the possible breakup of 1967-066G and these parent objects have similar orbital plane parameters. Thus, 1968-081E and its 22 fragments catalogued by SSN are also back propagated to the aforementioned epoch and plotted in Fig. 5. In the figure, JAXA-d0045, JAXA-d0046, and 1967-066G are correlated because they are in a line, whereas 1968-081E and its fragments are in another line deformed a little. These lines have slightly different inclinations, thus we can distinguish them. JAXA-d0044 is not associated with any of the lines.

3.3. Pinch point

As previously mentioned, orbits of fragmentation debris of a same parent object share a same intersection, i.e. the pinch point, at near its breakup epoch. The position of the pinch point corresponds to where the breakup occurs. We can also confirm the pinch point in the trajectories of fragments in the celestial sphere. To assess if we can confirm a pinch point between JAXA-UCTs and 1967-066G, their trajectories at the aforementioned possible breakup epoch are drawn in Fig. 6. The trajectories of 1968-081E and its fragments are also drawn in this figure due to the same reason mentioned in the previous paragraph. In this figure, we can confirm a pinch point between JAXA-d0045, JAXA-d0046, and 1967-066G, and also another pinch point between 1968-081E and its fragments (drawn in gray color). These pinch points are a little apart so that we can distinguish them. JAXA-d0044 is not associated with any of the intersections.

The distances between JAXA-UCTs and 1967-066G at

Table 3. Orbits of JAXA-UCTs back-propagated to the possible breakup epoch

Object ID	a [km]	e	i [deg]	Ω [deg]	ω [deg]
JAXA-d0044	42131.233	0.008	14.246	15.044	174.940
JAXA-d0045	42068.045	0.020	11.611	38.139	72.782
JAXA-d0046	41902.138	0.005	11.690	43.532	158.066

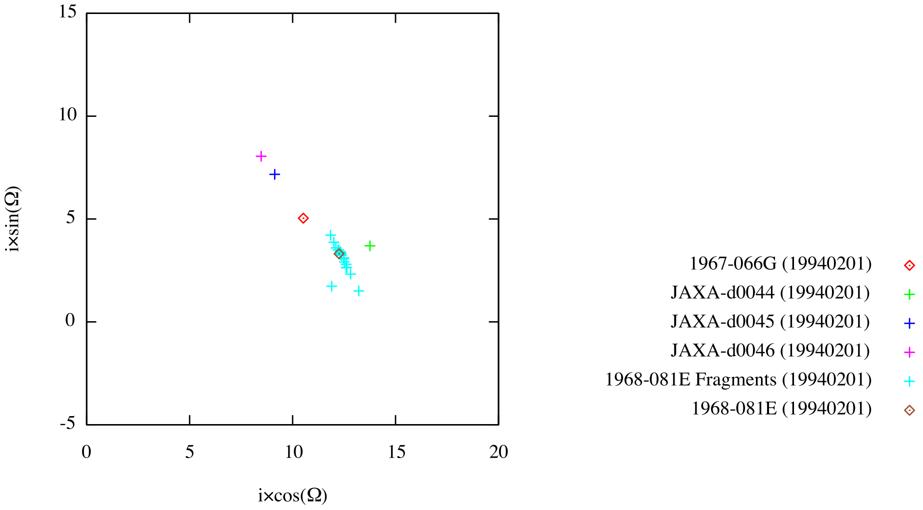

Figure 5. Correlation of the orbital plane vectors.

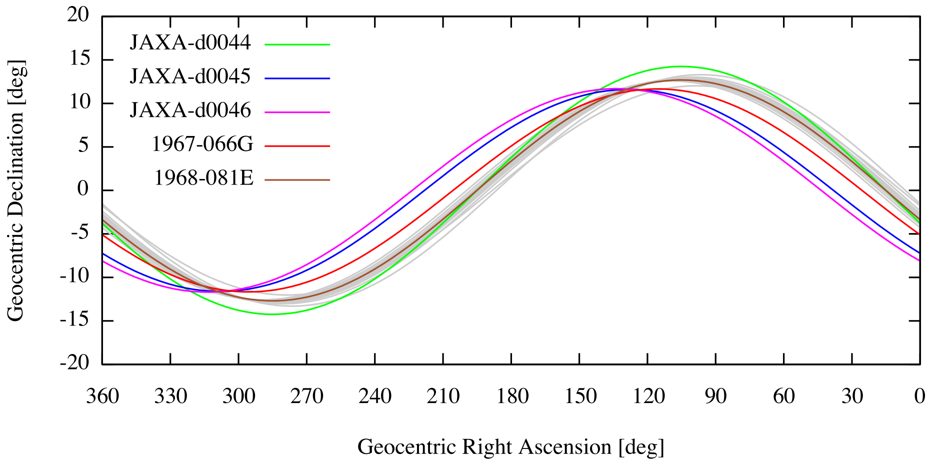

Figure 6. Correlation of the pinch points.

the pinch points are evaluated by using a close approach method. The closest points between each JAXA-UCT and 1967-066G are specified in the Earth inertial frame at the beginning of the possible breakup period of 1967-066G, and then the distance is evaluated in a satellite origin frame of 1967-066G. Distance between JAXA-UCTs and 1967-066G at the pinch points are evaluated as 1934.701 km (JAXA-d0044), 1455.202 km (JAXA-d0045), and 2046.567 km (JAXA-d0046), respectively. It turned out that JAXA-UCTs are so far from 1967-066G at its breakup epoch that they might not have correlations even though the pinch points in the celestial sphere are correlated.

4. CONCLUSION

As a result of origin identification, it might be concluded that tracklets of JAXA-UCTs are not associated with the 1967-066G event regarding the motion vectors, however orbits of JAXA-d0045 and JAXA-d0046 are associated with the event regarding the orbital plane vectors and the pinch points of their trajectories. A breakup fragment that is generated by an event should be associated with each feature of the event, i.e., the motion vector, the orbital plane vector, and the pinch point. Moreover, results of close approach between JAXA-UCTs and 1967-066G show that the distances between each JAXA-UCT and 1967-066G is the order of 1,000 km so that this evidence supports the false of the hypothesis that 1967-066G experienced a breakup.

Though we have surveyed the regions where the probability of detections of 1967-066G fragments are predicted to be high, what we found was not quite associated with the possible breakup event of 1967-066G. Consequently, it might be possible that the breakup scale was quite small or the orbital anomaly of 1967-066G is not an evidence of its breakup. If the latter case is true, a remaining possible cause of the orbital anomaly would be the propellant venting of the Transtage as is inferred by [1].

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