DETECTION OF THE MALFUNCTION OF COSMOS 954 AND COSMOS 1402 AND THE SUBSEQUENT PREDICTIONS OF THEIR RE-ENTRIES

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ABSTRACT

The graphical detection of the malfunction and natural decay of Cosmos 954 is described briefly. The Cosmos 1402 incident and the techniques employed to follow the decays of its fragments are reported as extracts from a personal diary written at the time.

1. COSMOS 954

The launch of Cosmos 654 two days after that of Cosmos 651 in May, 1974, prompted the immediate assumption that it was a replacement for the earlier satellite which had experienced electrical failure. When more data became available it was clear that both satellites were co-planar, with Cosmos 654 leading Cosmos 651, and the possibility of the pair working in conjunction was recognised.

Members of the Kettering Group began receiving the NASA two line orbital elements in the autumn of 1974. Selected pupils at Kettering Grammar School concentrated on particular satellites or sub-sets of satellites as personal projects and the next pair in the series, Cosmos 723 and 724, were allocated to Stuart Ganney and John Kellett. By plotting the mean orbital period between consecutive epochs against mid-epoch they were able to demonstrate that the satellites made micromanoeuvres to maintain orbital period and, moreover, they manoeuvred in sympathy as if station-keeping. After 43 days, Cosmos 723 was raised to a higher, circular orbit to be followed 22 days later by Cosmos 724.

Ganney and Kellett later studied Cosmos 860 and 861 and Cosmos 952 and 954. Cosmos 952 was raised to the higher orbit after three weeks whilst the Cosmos 954 remained in the lower orbit. Andrew Driver took over the monitoring of Cosmos 954 as a short-term project, expecting it to be raised by mid-November, 1977, at the latest. However, at the end of the first week in November, he noticed that the satellite was no longer making micromanoeuvres and had entered a régime of natural decay. At that time it was by no means certain that the orbit would not eventually be raised but, as time went by, this seemed less likely and it was expected to decay in the atmosphere in the spring.

On January 6, 1978, the rate of decay changed dramatically and the graph of mean orbital period against epoch pointed to a re-entry on or around January 25. Consequently, it came as no surprise when, in the afternoon of January 24, UPI phoned the School to ask if we "knew anything about this satellite that has fallen over Canada." A Tass announcement issued following the decay stated, "In the course of the satellite's flight outside the zone of radio visibility of the Soviet tracking facilities it was sharply depressurised for reasons yet unknown on January 6, with the result that the satellite began to come down in an unplanned régime". The announcement claimed that the energy unit was designed in such a way as to be fully destroyed and burnt in entering the dense layers of the atmosphere.

2. COSMOS 1402

2.1 Introduction

At the end of 1982, the Kettering Group were particularly interested in trying to locate transmissions from Cosmos 1426, which had a unique orbit. Due to New Year's Day falling on a Saturday, Monday, January 3 was a public holiday and there was no mail delivery.

All times given in the following diary extracts are Greenwich Mean Time (GMT).

2.2 Diary

Jan 4 - Phoned the Earth Satellite Research Unit (ESRU), Aston, at 0928. Chris Cooke promised to call back when he had sorted the teleprinter traffic.

He called at 1030 and gave me data for 83-84B & C, which I should have recognised immediately as fragments from the raising of Cosmos 1402 to the "safe" orbit.

Craig Covault, Aviation Week, phoned at 2126. He had nothing new about Cosmos 1426 but, in asking around, he had been told that the "RORSAT was ready to come in like Cosmos 954."

Checked my two line elements and saw that, as of December 26, it was still behaving normally.

Jan 5 - On waking, immediately realised that 84B & C were fragments of Cosmos 1402. I should

have spotted that yesterday morning but even then, without current data on 84A, I would not have been able to tell that anything was abnormal.

Mail contained two lines for December 28 with nothing for 84B or C. On checking I determined that they were catalogued between the launches of Cosmos 1426 and 1427 on December 28 and 29.

Recalling that Sven Grahn had told me that he had received two lines for December 29, I telephoned him in Stockholm at 0856 and asked him to look out the data for 84A, B and C. He called back at 0905. The first elements for 84C were for Dec 28.32 and those for 84B were for Dec 28.57. There was a two line for 84A with the same epoch as 84C, a negative rate-of-change, and a mean motion, n, of 16.0622 rev/day, implying separation of components in the early hours of December 28. BUT there was another two line for 84A on Dec 29.13 with n = 16.067 rev/day, showing that it had not moved to the "safe" orbit. He also told me that Jan-Ola Dahlberg, at Malmö, had received 19.954 MHz signals "a few days ago" when trying to locate transmissions from Cosmos 1426.

Phoned the Ministry of Defence (MoD) to tell them of my suspicions. They indicated that they had heard something to the effect that Cosmos 1402 might be in trouble.

Covault phoned at 1300. I confirmed that Cosmos 1402 was in trouble and gave him the necessary figures.

Gave Frank Miles, of Independent Television News (ITN), a factual statement based on Grahn's two lines and Dahlberg's signals at 1435.

Jan 6 - Grahn phoned the school at 1200. Dahlberg had received signals on December 29 from 1755.57, weak, for 17 s; December 30 from 0631.30 to 0638 - the same "purring" telemetry with short words 1, 6 and 9; and twice on December 31 from 1149.00 to 1154.30 and again from 1223.12 to 1228.00, both weak. The December 31 signals were for a northbound pass over China starting when the spacecraft was south of the Equator.

Don Webster, CBS News, called at 1725 and told me that Kotelnikov's statement had been made at a pre-scheduled press conference for cosmonauts Berezovoi and Lebedev. Questions had had to be submitted in writing and all western correspondents had ignored the record-breaking flight and were asking about the truth of the reports about Cosmos 1402. Kotelnikov had pointed out that such questions should not be directed at the cosmonauts as they were not competent to deal with them and had then made his statement about there being no danger.

Rich Tuttle, Aerospace Daily, called at 1805. He gave me two sets of NORAD data: as of 0853 today, 65°, 89.497 min, 246-244 km; as of 1842 yesterday, 65°, 89.328 min, 247-234 km. I didn't like the sound of that as it looked as if they might still be able to move it a little.

Covault phoned at 1906 and told me that the reactor had been shut down before separation and the spacecraft's batteries were dead. I said that this was in good agreement with Dahlberg's radio obervations.

Jan 8 - Prepared a statement to be read to telephone inquirers whilst I attended the Annual Dinner and Reunion of the Old Cytringanians. Mr. Perry presumes the cause of failure to have been the malfunction of the small rocket which should have propelled the reactor to the 950 km orbit. Neither he, nor anyone else, at this time can predict the final path of the satellite and still less whereabouts on that track and at what time re-entry will occur. If pieces survive re-entry they could be spread along the track over several hundreds of kilometres and for up to 50 kilometres or so on either side of it.

Jan 10 - Cooke phoned from ESRU at 1445. He confirmed that 84B had decayed on December 30 but he had not had a decay note for 84C which must still be in orbit.

John Bransfield, Daily Express, phoned at 1555. I told him that King-Hele, at the Royal Aircraft Establishment (RAE), was much better placed than I to predict a re-entry date.

I then dug out King-Hele's paper (1) which my daughter and I had used with some success for the Skylab re-entry in 1979 and calculated, using $L = Q/\dot{n}$, a life of 12.76 days after Jan 10.06 implying Jan 22.82.

Pierre Neirinck phoned from Dunkerque at 2331. He had calculated the density of the three pieces and had arrived at 1:10.2:24.5 for B:A:C.

Jan 11 - Checked RORSAT launches since the resumption of the programme in April 1980 and found that a piece C always flew for between 20 and 30 days following the separation. Consequently, when I spoke to Covault at 1500, I merely reported Neirinck's density analysis.

Jan 13 - Telephoned Police HQ at Northampton at 1050 and spoke to the Chief Constable. Told him that there was no threat to England from the early evening northbound passes but that the southbound passes after midnight came directly over the country. I felt that, as head of the emergency services for the county, he should be aware of the short duration of the threat periods and their approximate timings, which came 25 min earlier each day.

Jan 15 - Grahn phoned at 0911. He was concerned that 84A was coming down faster than it should if the reactor was still attached. I gave him the durations of the C-pieces for the post-1980 flights and convinced him that C always flew for 20 to 30 days after separation.

Reilly Carver, The Mail on Sunday, phoned at 1956 to say that Tass had announced that the fuel core would burn up in mid-February. I exclaimed, "Oops, we've been concentrating on the wrong piece!"

Phoned Grahn at 1710 and told him. He called back at 1735 and pointed out that 84A was descending at the same rate as Cosmos 954 which had been stable and of low density.

Phoned Covault at 1758 to tell him we had all been concentrating on the wrong piece. He said that he would get on to it first thing on Monday morning.

Radio Moscow's English broadcast at 1800 stated, A Soviet space scientist, Dr. Oleg Belotserkovskiy, has confirmed that the nuclear energy source used in the Cosmos 1402 satellite poses no danger. ...

In response to a command from the ground this system deactivated the reactor and separated the satellite into fragments. Dr. Belotserkovskiy, who is a member of the Soviet Academy of Sciences, said that according to tentative estimates the reactor would re-enter the dense layers of the atmosphere in the middle of next month.

Neirinck phoned at 1832. I told him that he had been correct. He gave me revised density ratios and stressed that the C:A ratio of 2.06 was very precise.

Could not get to sleep for thinking about the least-squares method of finding $\dot{n}$ so got up again at 2200 and wrote a BASIC program to calculate a linear least-squares fit and computed Feb 7.94 for the decay of 84C.

Jan 16 - Issued a statement to UPI, London, which included the following passages.

The Soviet Union announced on January 15 that the fuel core of the reactor had been separated from the main part of the spacecraft and would re-enter the atmosphere in February. It was immediately apparent that we had been concentrating on the wrong object. ...

Our current calculations suggest that piece A will re-enter within the period January 20-25 and piece C between February 4 and 13.

Jan 17 - Max White phoned from the Royal Greenwich Observatory (RGO) at 1000. He had spoken to ESRU. Cooke had not heard the Russian statement until I told him when he phoned soon afterwards at 1013. I urged him to ensure that he got data for piece C as well as A.

Jan 18 - Grahn phoned at 0958. We decided that we would have to agree on the values of Q to be used and so I used a high-power magnifier on figure 4 of King-Hele's paper to obtain values for high and low solar activity whilst Grahn calculated the value 0.6 of the way between low and high. I then ran a linear least-squares fit to these on the CBM 4032 and gave him the slope and intercept.

Covault phoned Mrs. Perry at 1940 and left a message saying that the reactor should return in late January.

Jan 19 - Covault phoned at 1830 and again emphasised that two sources were sticking with A as the reactor. I reaffirmed my doubts.

Grahn phoned at 2033 with second-order polynomial least-squares fits to the Q values and n values. Differentiation of the latter yielded a value for $\dot{n}$ which could be used to deduce a lifetime. This gave Jan 23.38.

Jan 21 - Phoned the MoD at 1123. They told me that they would not be getting data this weekend but would try to see if special arrangements could be made for data to be supplied to me.

They phoned at 1457 to say that there had been no success in making arrangements for me to get data this weekend. The US classify the data for a certain length of time during which they cannot be transmitted over an open telephone line.

Jan 22 - Grahn phoned at 1449. Dick Flagg would phone Ron Parise in Washington DC to see if he had received any more recent two line element sets in the mail today. Pat Vick had told him that the ballistic coefficient (area/mass) for 84A was 0.00433 sq m/kg.

Grahn phoned again at 1719 to say that Flagg had got an orbit from NORAD but only in the form of period and heights.

White phoned with four new element sets at 1848. He had persuaded his friend, the deputy warden at St. Peter's College, to get the data from the teleprinters at ESRU. He said that his friend would go in again tomorrow morning.

Phoned Grahn with the new data which predicted decay for Jan 23.85.

Neirinck phoned at 2247. He had seen 84A in the southeast on January 20 at mag +4, steady. He believed that the Russians might have regained control.

Jan 23 - Grahn phoned at 1158. He had calculated 2030 $\pm$ 1 hour. Phoned the police at 1205 and told them that we expected it to survive beyond the 1730 "danger period".

White phoned at 1234 with two new element sets from ESRU. Phoned Grahn with the new data which pointed to Jan 23.99 and we decided to say midnight $\pm$ 1 orbit.

Saw 84A, mag +1 to invisible, with approximately 15 s between the two maxima as it passed by Capella at 1725.04, nearly one minute early on prediction.

Phone interview with London Broadcasting Company at 1813 in which I predicted decay for 2300 $\pm$ 1 hour.

Jan 24 - The parabolic least-squares program from Grahn arrived in the mail.

Phoned ESRU at 0953 and got two element sets for 84C. Then phoned Grahn at the Swedish Space Corporation.

Jan 25 - Covault phoned at 1711. Gave him details of all "second pieces" in the high orbit since the series resumed. He said that the intelligence community had not been "up to speed" on this and either did not appreciate that there were two pieces in the high orbit since 1980 or had not told the right people!

Jan 26 - Phoned Doreen Walker at RAE at 1520. She told me that they merely differenced two element sets to get n.

Jan 28 - Phoned ESRU at 1455 and got new elements for 84C. Cooke said that he would go in tomorrow to see if there was anything new.

Jan 30 - Phone calls from Grahn. We discussed moving the origin to the most recent data point.

Feb 1 - Kevin Sanders, Cable News Network (CNN), New York, phoned at 1927 and said that the Department of Defense (DoD) were reported in the Washington Post as saying that the decay would occur between 1900, February 6, and 0600, February 10. The mid-point of that window is midday next Tuesday

and then there is a pass right across the centre of the British Isles.

Feb 4 - Phoned the police at 0935 and told them that I had prepared a map of Monday's tracks across the British Isles.

Phoned ESRU at 1528. Caroline would be going in tomorrow but they did not think that anyone would be going in on Sunday.

Marcia Smith phoned from the Library of Congress, Washington DC, at 1914 and told me that the DoD were saying between 1120, February 7, and 1300, February 9.

Feb 5 - Roger Clark, of the Hewitt Camera Team, phoned from ESRU with four new element sets. These pointed to February 8.02.

Feb 6 - Marcia Smith phoned at 1708. The latest DoD estimate was for 1500, February 7, to 1400, February 8. I was pleased that my midnight forecast fell right in the middle of this.

She phoned again at 1825 to say that they had revised their estimate to between 0253 and 1253 on February 7. This caused me some concern as this fell outside their previous estimate.

Phoned NORAD at 1920 and was told that, "as of this morning" the period was 87.506 min.

Experimented with different values of $\dot{n}$ on the 4032 and settled on 0.025 for $\dot{n}/2$ which, with elements for Feb 4.79 gave a period of 87.51 min at 1156 today. This produced an ephemeris which would not be far from the truth over the last 24 hours.

When Gerry Harrington, of CNN, called from Atlanta at 2152, I made the point that the revised times took the ground-tracks right away from the USA. He said that the latest DoD estimate was for between 0628 and 1528.

Feb 7 - Paul Tabart, Independent Radio News (IRN), phoned at 0753 with the latest DoD estimate for between 0905 to 1335.

Antonia Higgs, IRN, phoned at 1045 with a new DoD estimate for between 1006 and 1212.

Frank Miles, ITN, phoned at 1103. AP were quoting the US estimate as between 1042 and 1138. I said that at 1110, the mid-point of that window, it would be east of Brazil over the Atlantic at 20 deg S. I suggested that RAF Fylingdales would be able to say whether or not they had seen it on the pass at 1130.

Antonia Higgs phoned at 1223 to say that it had fallen in the Atlantic at 1100.

Nicola Carslaw, Northampton Chronicle & Echo, phoned at 1245, to say that the MoD were giving the decay time as 1107 and that PA were reporting a Dr. Kennett from the DoD as saying South Atlantic.

Baird phoned from the BBC Monitoring Service to say that the Russians had given 1056 over the South Atlantic. Again an 11-minute discrepancy between Soviet and American times due to the choice of decay time as being either the start of the burn-up (USSR) or impact at the surface (USA).

Feb 8 - Grahn phoned at 2000. He had seen a brilliant aurora on Friday night, February 4, which was rare from Stockholm, and linked this with the increase in atmospheric density which had accelerated the decay.

2.3 Computer program

In its final version, the BASIC program devised to predict decay-time contains data-lines, one for each pair of epoch and mean motion values. These are arranged in chronological order such that the most recent pair are the first to be read when the program is run.

The number of data-points to be used is requested and used to dimension the arrays used in the program. It was found that five data-points spread over a period of one or more days gave consistent results throughout the decay period.

The program computes, by the method of least-squares, the second-order polynomial which includes the most recent data-point together with the standard deviation of the fit. Differentiation of the polynomial provides a value of n to be substituted, with the most recent value of n, in the second-order polynomial previously determined from King-Hele's graphs of Q against $\dot{n}$, interpolated to provide values at 0.6 of the interval between those for low and high solar activity. The resulting remaining lifetime is added to the most recent epoch to predict the decay-time.

When used with the last five NASA two line orbital element sets for 1982-84C, the program gave a decay-time of 1983 Feb 7.461.

2.4 Conclusion

The NASA two line orbital elements are of sufficient accuracy to permit calculation of periods of threat for a given locality in the days prior to re-entry. These periods are of short duration, separated by at least one orbital period, and rarely occur more than twice in one period of 24 hours.

The method evolved predicts the decay-time reasonably accurately several weeks prior to re-entry with increasing accuracy as re-entry time approaches.

The greatest difficulty experienced was in obtaining speedy access to the NASA two line orbital elements and thanks is proffered to the many individuals and organisations who went to great lengths to make this data available.

3. REFERENCE

1. King-Hele D G 1978, Methods for predicting satellite orbital lifetimes, *J Brit Interplan Soc* 31, 181-196.