COSMOS 1402 RE-ENTRY PREDICTIONS: A RETROSPECTIVE ANALYSIS

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ABSTRACT

The orbital decay computations made at CNUCE to predict the re-entry of the space objects Cosmos 1402/A and C have been analyzed to assess the ballistic coefficient variations, the force model appropriateness and the atmospheric model accuracy. From that study some indications on short-term predictions of spacecraft natural re-entry to be used in the future have been deduced. Moreover, the results of a radar tracking network simulation are presented with a few proposals for an European involvement in this field.

Keywords: Re-Entry Predictions, Aerodynamic Drag, Atmospheric Models, Orbital Perturbations, Orbit Determination

1. INTRODUCTION

The number of objects inhabiting the outer space is growing at striking pace. Up today NORAD has classified about 16,000 space objects (Ref. 1) whose about 5,000 still in orbit. With the spread of space activities more and more complex, in particular in low Earth orbit (space stations, military activities connected with the Strategic Defence Initiative, etc...), the hazard of uncontrolled re-entries of potentially dangerous space objects will increase.

Lately, the mass media have payed attention to several undesired re-entries as the ones of Cosmos 954, Skylab and Cosmos 1402. Other uncontrolled re-entries, even if involving very massive space objects, raised less concern, as in the case of the American spacecraft Pegasus I, II and III and of the expended upper stage S-IV-B used to inject into orbit the space laboratory Skylab. Some accidental re-entry has not been covered by the media: for example those of the Cosmos 1625 and the Cosmos 1985-53, injected into orbits too low and then instable.

In any case the problem does exist, and even if the hazard for people and property is still negligible, the phenomenon is much more widespread and frequent than it is supposed to be. On the average one or two space objects per day re-enter on the Earth. The bulkiest ones are generally controlled during the descent, but sometimes fatal failures prevent a safe re-entry.

Such a situation took place at the end of 1983, when a Soviet ocean reconnaissance satellite, the Cosmos 1402, failed an end-of-life maneuver, breaking away in 3 parts that started to decay due to the atmospheric drag (Ref. 2).

Since several years the USSR conducts an extended program of military ocean reconnaissance using two kinds of satellites. The EORSATs (Electronic intelligence Ocean Reconnaissance SATellites) are used to gather information about radar and communications: the typical orbits are circular, 440 Km high and inclined of 65 deg with respect to the equator. The RORSATs (Radar Ocean Reconnaissance SATellites) are used to locate naval groups in open sea through an active radar sensor powered by a nuclear fuel generator. The orbits are circular, 250 Km high, with an inclination of 65 deg (Ref. 2).

Both kinds of satellites are launched from the Cosmodrome near Tyuratam using the F-1 rocket, known in the West as well as SL-11 or Scarp booster. Table 1 shows a list of the ocean reconnaissance satellites launched by the USSR after Cosmos 1402 (until August 1, 1985). As it may be seen, up to now there have been two new aborts.

Table 1.

USSR OCEAN RECONNAISSANCE MISSIONS from Cosmos 1402 launch until August 1, 1985

EORSAT

Cosmos 1405	(COSPAR nr. 1982-088A)	
Cosmos 1507	(COSPAR nr. 1983-110A)	
Cosmos 1588	(COSPAR nr. 1984-083A)	
Cosmos 1625	(COSPAR nr. 1985-008A)	°
Cosmos 1646	(COSPAR nr. 1985-030A)	

°Aborted mission. The spacecraft decayed a few hours after the launch.

RORSAT

Cosmos 1412	(COSPAR nr. 1982-099A)	
Cosmos 1579	(COSPAR nr. 1984-069A)	
Cosmos 1607	(COSPAR nr. 1984-112A)	
Cosmos	(COSPAR nr. 1985-053A)	°°
Cosmos 1670	(COSPAR nr. 1985-064A)	

°°Failed launch: 3 fragments in orbit decayed later.

2. COSMOS 1402 RE-ENTRY PREDICTIONS

In consequence of the warning given by some agencies on the first days of January 1985, CNUCE, an institute of the National Research Council of Italy that maintains and operates several spaceflight dynamics software codes, began to devote itself to the re-entry predictions of the Cosmos 1402 related objects: the section A (Scarp upper stage + spacecraft main bus + nuclear core kick stage) and section C (nuclear core) (Ref. 2).

The institute had at disposal the program EPHEM of the Goddard Trajectory Determination System to compute orbital ephemerides of high accuracy. Then it was decided to use that software for the re-entry predictions. As input orbital data, the NORAD two-line orbital elements were employed.

The program EPHEM povides several orbital theories and perturbing models. In the Cosmos case the luni-solar perturbations, the geopotential harmonics, the solar radiation pressure and, of course, the atmospheric drag were taken into account in the motion equations, solved by the Cowell method.

Two atmospheric models might be used: a modified Harris-Priester model (MHP) and an analytical formulation due to Roberts of the Jacchia 1971 model (JR-71). The second one is more complete, but the first one is simpler to use and less expensive from the numerical point of view.

The determination of the ballistic coefficient to be employed in the orbital propagations was a delicate problem. A possibility could be to obtain it by interpolating with some simple law the semimajor axis evolution on a few days arc. Instead, an iterative method was chosen, in which, starting from the last value used as ballistic coefficient, a new value describing the observed decay after 24 hours, within an allotted tolerance, was determined on daily basis. Each iteration consisted of a short EPHEM run with the same model used for re-entry predictions and taking into account the measured solar and geomagnetic activity.

All the uncertainties considered, the actual re-entry predictions were quite satisfactory. For Cosmos 1402/A, by using the MHP model a mean error of 8.4% was obtained. For Cosmos 1402/C, MHP gave an average error of 10.3%, JR-71 of 10.1% (Ref. 3). Of course, the prediction error was not constant: generally it decreases with the reduction of the lifetime, but presents sudden increases when unpredicted events occur, like a strong geomagnetic storm during the last week of the spacecraft lifetime.

A remark: re-entry here means the descent until an altitude of about 80 Km. To predict with a reasonable level of confidence what can happen at lower altitudes is very difficult, because frequently the space object breaks-up, producing a fragments with different area/mass ratios and then different trajectories. Moreover, a small variation

Table 2.

SUMMARY OF THE RESULTS

NETWORK	SPACECRAFT	OBS. TIME-SPAN	OBS. RATE	ORBIT SOLUTION
TRANET-4	RORSAT	1 DAY	1/60 secs	YES
TRANET-2	RORSAT	1 DAY	1/60 secs	YES
TRANET-1	RORSAT	1 DAY	1/60 secs	NO
TRANET-1	RORSAT	1 DAY	1/30 secs	NO
TRANET-4	EORSAT	1 DAY	1/60 secs	YES
TRANET-2	EORSAT	1 DAY	1/60 secs	YES
TRANET-1	EORSAT	2 DAYS	1/60 secs	YES
TRANET-1	EORSAT	1 DAY	1/60 secs	NO

of the fight path angle around the null value, typical for objects moving in nearly circular orbits, can produce very different down range fragment distributions. Only with detailed data about the spacecraft structure, some realistic prediction could be possible.

3. POST-FLIGHT ANALYSIS

After the Cosmos 1402 re-entry, a study to evaluate the performances of the models and techniques used has been undertook at CNUCE. Some results obtained are briefly resumed in the following.

By using the atmospheric model Jacchia--Roberts 1971 (JR-71) with the a posteriori values of the solar and geomagnetic activity indexes, a more accurate estimates of the ballistic coefficients B fitting the orbital evolution of the objects A and C have been computed. The final values are:

Object A: $B = 0.00681 \ m^2/Kg$ (1)

Object C: $B = 0.00328 \ m^2/Kg$ (2)

If for the drag coefficient the estimate given by Cook in Ref. 4 is assumed ($2.2 \pm 15\%$), using the effective areas computed as shown in Ref. 3, the following mass estimates M have been obtained:

Object A: $M = 9{,}369 \pm 1{,}405$ Kg (3)

Object C: $M = 391 \pm 59$ Kg (4)

A comparison between MHP and JR-71 with a steady solar flux of 150 standard units has shown that the first one reproduces the results of the second when a faint geomagnetic activity (kp planetary index roughly equal to 1) is taken into account in JR-71.

Concerning the capability of JR-71 to describe accurately the atmospheric density in extreme conditions, a strong fluctuation of the ballistic parameter values has been observed when both space objects were at altitudes from 220 to 235 Km during the geomagnetic storm occurred on 9-10 January 1983. Due to the method used to compute the ballistic coefficients, their strong variations have been interpreted as a discrepancy between the model predictions and the real world density of about 15-20%.

At lower altitudes, where the atmospheric density is higher and the effects of the geomagnetic storms are more limited, no similar discrepancy has been observed.

4. TRACKING NETWORK SIMULATION

To evaluate the possibility for Europe to deploy a radar network able to track space objects, a simulation has been performed assuming the availability of radar devices with the following characteristics:

- Minimum elevation angle: 10 deg;
- Range: 1000 Km for objects with an effective area of 1 m^2;
- Observation rate: 1 every 60 secs;

Table 3.

ORBIT DETERMINATION: TRANET-4/RORSAT		
Observation Time-Span = 1 Day		
KEPLERIAN ELEMENTS STANDARD DEVIATION		
SMA	= 1.94	(m)
ECC	= 0.00000189	
INC	= 0.000163	(deg)
LAN	= 0.000123	(deg)
AP	= 0.0581	(deg)
MA	= 0.0580	(deg)
CARTESIAN ELEMENTS STANDARD DEVIATION		
X	= 13.4	(m)
Y	= 18.4	(m)
Z	= 37.9	(m)
DX	= 4.02	(cm/sec)
DY	= 3.50	(cm/sec)
DZ	= 1.45	(cm/sec)

Table 4.

ORBIT DETERMINATION: TRANET-2/RORSAT		
Observation Time-Span = 1 Day		
KEPLERIAN ELEMENTS STANDARD DEVIATION		
SMA	= 3.69	(m)
ECC	= 0.00000607	
INC	= 0.000216	(deg)
LAN	= 0.000282	(deg)
AP	= 0.209	(deg)
MA	= 0.209	(deg)
CARTESIAN ELEMENTS STANDARD DEVIATION		
X	= 26.1	(m)
Y	= 37.4	(m)
Z	= 65.2	(m)
DX	= 5.83	(cm/sec)
DY	= 6.21	(cm/sec)
DZ	= 3.77	(cm/sec)

- Observation types: range, elevation and azimuth;
- Measurement standard deviations:
  - Range: 40 meters;
  - Elevation: 618 arcsec;
  - Azimuth: 618 arcsec.

Table 5.

ORBIT DETERMINATION: TRANET-4/EORSAT		
Observation Time-Span = 1 Day		
KEPLERIAN ELEMENTS STANDARD DEVIATION		
SMA	= 0.964	(m)
ECC	= 0.000000972	
INC	= 0.000117	(deg)
LAN	= 0.0000802	(deg)
AP	= 0.0371	(deg)
MA	= 0.0370	(deg)
CARTESIAN ELEMENTS STANDARD DEVIATION		
X	= 7.56	(m)
Y	= 12.5	(m)
Z	= 23.1	(m)
DX	= 2.34	(cm/sec)
DY	= 2.07	(cm/sec)
DZ	= 0.923	(cm/sec)

Table 6.

ORBIT DETERMINATION: TRANET-2/EORSAT		
Observation Time-Span = 1 Day		
KEPLERIAN ELEMENTS STANDARD DEVIATION		
SMA	= 1.39	(m)
ECC	= 0.00000219	
INC	= 0.000124	(deg)
LAN	= 0.000100	(deg)
AP	= 0.127	(deg)
MA	= 0.127	(deg)
CARTESIAN ELEMENTS STANDARD DEVIATION		
X	= 11.1	(m)
Y	= 22.4	(m)
Z	= 33.4	(m)
DX	= 3.57	(cm/sec)
DY	= 3.76	(cm/sec)
DZ	= 1.87	(cm/sec)

Being a matter of a very preliminary study, the observation biases, the signal propagation errors, the noise associated to the apparata and the force model errors have been neglected. On the other hand, the attention has been payed to

Table 7.

ORBIT DETERMINATION: TRANET-1/EORSAT	
Observation Time-Span = 2 Days	
KEPLERIAN ELEMENTS STANDARD DEVIATION	
SMA = 1.07	(m)
ECC = 0.00000249	
INC = 0.000523	(deg)
LAN = 0.000992	(deg)
AP = 0.0783	(deg)
MA = 0.0783	(deg)
CARTESIAN ELEMENTS STANDARD DEVIATION	
X = 20.2	(m)
Y = 27.3	(m)
Z = 59.5	(m)
DX = 6.53	(cm/sec)
DY = 6.62	(cm/sec)
DZ = 3.99	(cm/sec)

the geometry of the problem.

As a sites for the tracking stations, the ones of the ESA VHF tracking network (June 1985) have been chosen, i.e: Redu, Kourou, Carnavon and Malindi. Three different network configurations were considered: TRANET-1, including only the Kourou station; TRANET-2, including Redu and Kourou; TRANET-4, including all the stations.

The procedure adopted is the following. For two satellites, an EORSAT and a RORSAT, the ephemerides over a timely orbital arc were generated. Starting from the orbital data, observations with a superimposed white noise, taking into account the standard deviations given above, were simulated for the 4 stations of the network.

Then, for different network configurations and for any spacecraft, a particular observation sets have been sorted out. These sets of data were used by a differential correction computer program to determine the orbit of the objects. Also the ballistic parameter has been considered as a solve-for variable. The results are shown in Tables 2-7.

The TRANET-2 network is able, with a one-day tracking, to get orbital determinations not only useful, but good. On the other hand, the simulation performed is very optimistic and the standard deviations obtained are related more with the inner consistency of the data than with the real world precision. The results, however, give a precious indication on how the orbit determination process is affected by the orbital geometry, the observation time-span and the tracking network configuration.

Moreover, it can be concluded that when quick orbital determinations (based on data gathered in a few hours) of several space objects (a task interesting military organizations like NORAD) are not needed, it is possible obtain useful data from a reduced number of tracking stations. And ESA could use the same locations already employed for satellite tracking.

5. CONCLUSIONS

The problem of the undesired re-entry of space objects will grow ever more important in the near future. Apart from the obvious consideration that the problem must be confronted in order to give an answer to the fears of the public opinion, other motivations urge to pay more attention to the subject.

All space agencies are liable for their space activities and then should track the orbital evolution of the objects launched by them, also after the end of the operative phase. Moreover, the governments,that up today have claimed the security of the skies, will be called to watch over the space as well. And the needed technology come to maturity and the costs are accessible.

If Europe wish to play a role ever more important into space, it cannot ignore that field, depending only on data supplied by other (military) agencies.

ESA seems the ideal juridical and technical body to implement a coordinated network of radars and/or optical sensors able to track those objects selected according to the hazard for people and property. ESOC could be the collecting center of the tracking data and of the information supplied by other sources.

The authorized centers of the Member States could acquire without limitation the data stored in the ESOC archive, perhaps paying a charge fixed by ESA. ESOC could also maintain an historical archives to be used for later investigations.

The possibility to match together national facilities already existent might probably be less expensive, but the security measures that cover many military radar activities would create a situation not much dissimilar from that we have at present: only the data sources would be different.

Instead, it is important to use directly the raw tracking data of a known tracking network. Only in this way it is possible to control the orbit determination process and to solve for the unknown parameters like B. The tracking data transmission, with a standard format, could use the existing computer networks, already operative and quickly expanding in Europe.

6. REFERENCES

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