ORGANIZATION OF THE ORBIT AND RE-ENTRY PREDICTION COMPUTATIONS AT CNES FOR SKYLAB AND COSMOS 1402.

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ABSTRACT

The risks of satellite impact over ground, when re-entering, are not excluded. Whenever it was the case, the French Government assigned the Centre National d'Etudes Spatiales (CNES) for implementing the appropriate capabilities for predicting the impact date, in order that the concerned french agencies are able to take any actions, safeguard useful, as in France as in French overseas territories. In this paper, we present the CNES' operational activities which were set in two circumstances : SKYLAB in 1979 and COSMOS 1402 in 1983. Each of them has its own caracteristic and we emphasize differences and difficulties we encountered in both cases. We successively, examine orbital predictions for information purpuses or antena pointing, then orbit improvement with tracking data and finally computations of re-entry windows.

1. ORBIT PREDICTIONS

1.1 The "NORAD" elements

These orbital elements named "2-lines" are one of the most efficient way to initiate satellite orbit : they are available for a tremendous number of satellites and frequently updated.

If needed, NASA provide them through teletype channel; this was the case for SKYLAB as well as the parts A and C of COSMOS 1402 satellite.

As for as the "2-lines" accuracy is concerned, their use cannot satisfy all the purposes (e.g. pointing of antenna with narrow beam). For SKYLAB and COSMOS, the "2-lines" elements were extrapolated with a different model from the one which is used by NORAD to compute the elements themselves. A systematic evaluation is made at CNES by comparing successive bulletins in order to eliminate spurious sets and estimate the precision (Fig.1)

One can note that this evaluation is made on converted elements (semi major axis and its drifts) which are not in the "2-lines" sets.

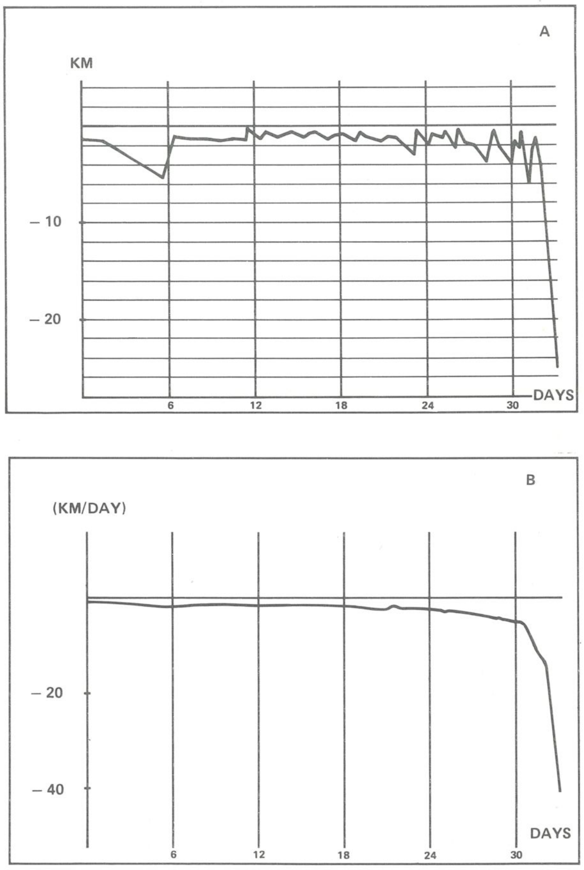


FIGURE : 1 lines evaluation of COSMOS 1402A

A Semi major axis
B Semi major axis drift

Since COSMOS 1402, CNES has the possibility of using the same model as NORAD [Ref. 1] . It does not improve the instrinsic accuracy, but it remove the errors when converting the elements.

1.2. Long term predictions

These types of predictions are mainly based on analytical development of the evolution of the orbital parameters or methods of averaging.

Proc. Workshop on Re-entry of Space Debris, Darmstadt, 24-25 Sept.1985 (ESA SP-246, Feb.1986)

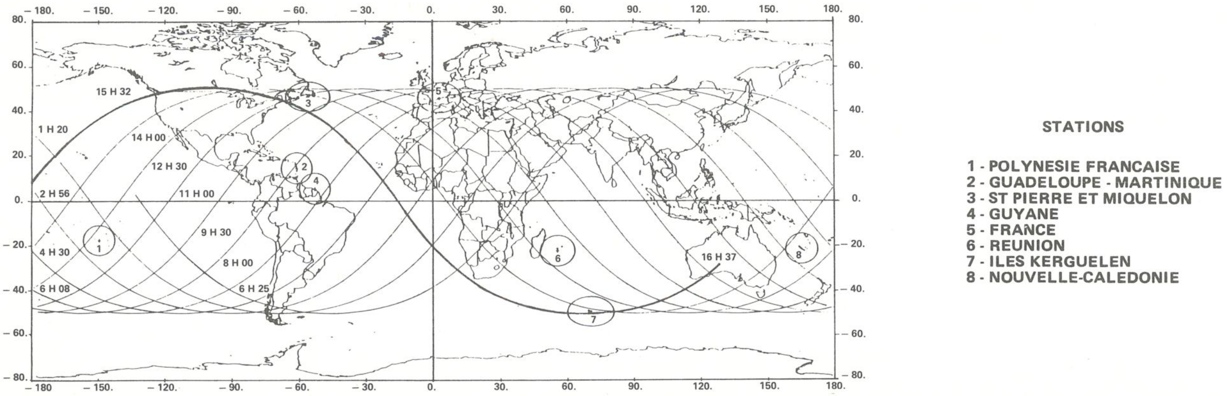


FIGURE 2 : SKYLAB GROUND TRACK OVER FRENCH OVERSEAS TERRITORIES JUL 11,1979 PASS

The long term predictions at CNES are intended to provide tracking site with pass predicts, at least on a weekly basis for planning of activities. They give also informations on the satellite ground-tracks. The models available at CNES are based on KOSAI or BROUWER elements when drag is not so important compared to gravity field perturbations. Algorithmes of theories were the coupling of drag and zonal Earth potential perturbations is included are under implementation at the computing center.

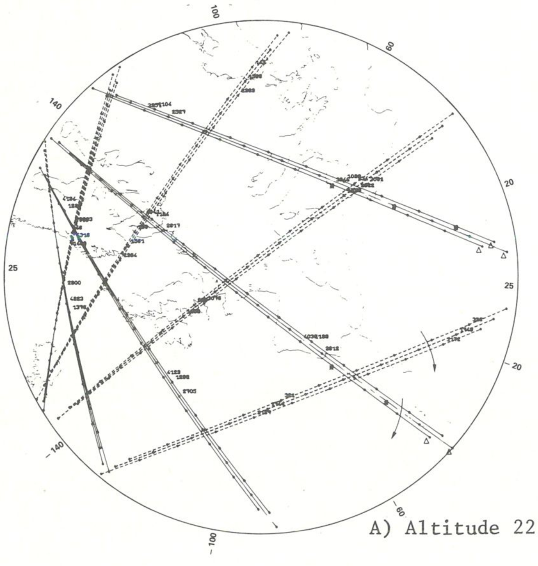
Care must be taken with such predictions because they do not take into account, either manoeuvers made on the spacecraft by the agency(e.g. SKYLAB), or long term behaviour of the atmosphere which is difficult to anticipate.

1.3. Ground - Track Maps

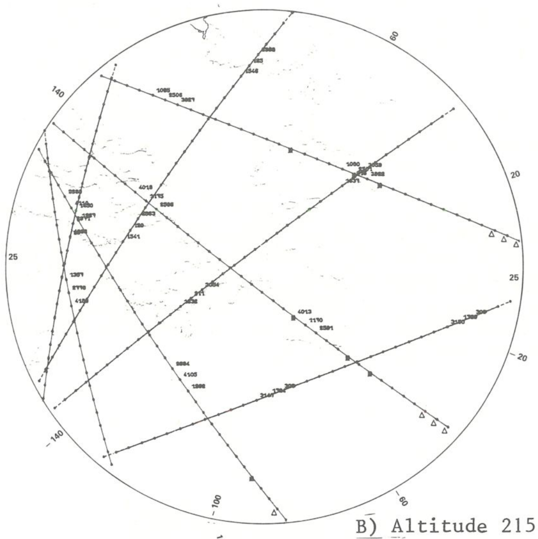
As already mentionned, satellite ground-tracks are to be provided to the agencies which are concerned with safeguard. This is an important part of the operational center. Several ouputs are requested. In order to illustrate this point, we take some samples of what can be done.

In Figure 2, we show the SKYLAB ground-tracks which was issued on the last day with all areas where France has to watch over.

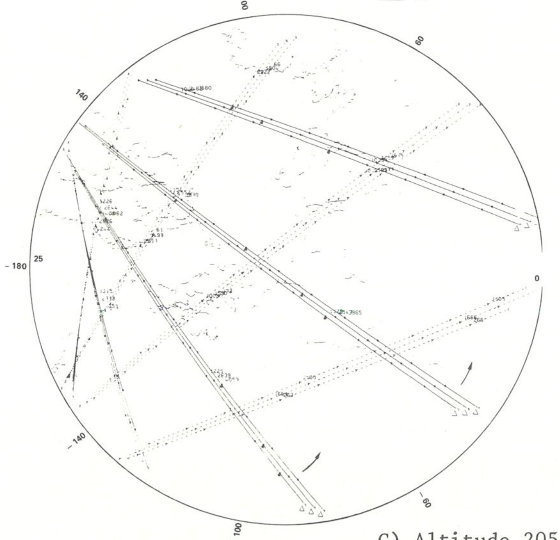
In Figure 3, Ground-tracks of COSMOS 1402 are drawn over EUROPE for periode of three days. On each of the maps, we represent the ascending and descending orbits and one can see the evolution of the tracks according to the altitude of the satellite. At altitude of 221 Km, the tracks are shifting roughly westward, then orbit is phased with Earth rotation for 215 Km altitude, finally the shift is inversed eastward for 205 Km altitude.



A) Altitude 221 Km



B) Altitude 215 Km



C) Altitude 205 Km

FIGURE 3

COSMOS 1402 Ground-tracks over Europe

1.4. Short term predictions

By short term predictions, we speak of two to three days extrapolation; the objectives beeing of provinding tracking ephemerides for radars or more accurate re-entry date. We use numerical integration of the equations of satellite motion, because the altitude is so low that Earth gravity fiel perturbations have to be computed with a Complete model (e.g. Goddard Earth Model GEMIO).Moreover the atmospheric drag effect is taken into account by computing the density at the satellite position The atmospheric model here is a sophisticated one such as DTM or Jacchia.

The initial parameters have to be osculating elements. They are computed from mean elements (iterative method) or whenever possible from an internal orbit improvement throught tracking data.

During SKYLAB, CNES was able to generate every day its own orbital elements and then extrapolate the orbit accurately. For COSMOS 1402 tracking data were not numerous enough to compute an orbit, however we used numerical integration for predictions.

Generally speaking, this activity does not bring any problem as it will be illustrated in the following paragraph.

1.5. Tracking sites and measurements

Optical tracking is provided by :
The BORDEAUX Observatory
The CERGA

The number of optical measurements is limited due to the observing conditions (satellite shining but the optical device being in the darkness).

For example, the part C of COSMOS 1402 was never fullfilling these conditions.

Only the radars being able to work in Skin track mode and with sufficient power were able to acquire the spacecraft. For SKYLAB, Range and range rate were collected successfully on a routine basis, and sent to NASA as well.

COSMOS 1402A, the Radar Equivalent Area was on average of 10 db/m2 with excursions from 6 to 25 db/m2 (due to the tumbling). Part C was worst and could have been detected only once by one radar.

The beamwidth is roughly 1° (Bretagne et Gascogne radars) or 6° (Savoie type).

These radars are located on the following civilian and military launch pads :

- Centre SPATIAL Guyanais (CSG). They are currently used for ARIANE flight sequence follow up.
- Centre d'Essais des Landes (CEL). The sites are in Landes, in Azores Islands and aboard the Henri Poincare ship.
- Centre d'Essais de la Méditerranée (CEM), on the Levant Island.

It is important to emphasize that, even if no valuable tracking measurement is provided, the information of time shift between the predicted time and the observed time represents the only effective mean to verify the quality of the orbital parameters and consequently give confidence to the reentring computations. For COSMOS 1402A, these shifts went from 2 to 5 seconds 10 days before the rentry date, up to 40 to 50 seconds one day before the actual reentry; predictions were made one day in advance.

We can also interpret the time shift in terms of semi major axis drift. This was sucessfully used for SKYLAB for re-computing new predicts for the radar sites.

1.6. Orbit improvement with tracking data

At CNES, a general software package for orbit improvement is available for different kinds of orbit (low, transfer, geostationary,...). The people have participated to several launch operations (french and foreign) and the team has the necessary ability to adapt itself to this type of operation.

The modelization of the forces acting on the satellite can go from elementary models to the most sophisticated ones. In such circumstances, it appears that it is these last ones which have to be used. For example, the software must be able to permanently readjust the drag coefficient because either the area over mass A/M ratio is not well known or changed by attitude maneuver.

On the other hand, tracking data are coming from different radar types; consequently there is always an interface to adapt in order to take these new data into account. These transformations must not induce a complete new software development. The architecture of the program was built in such a way. Even with some difficulties, it was still possible to be ready for reentry activities which were initiated with a short notice.

1.7. Operational Exploitation

In order to illustrate the operating cycle, a block diagram of the links implemented between the different operations participants is provided by Figure 4 in the case of SKYLAB.

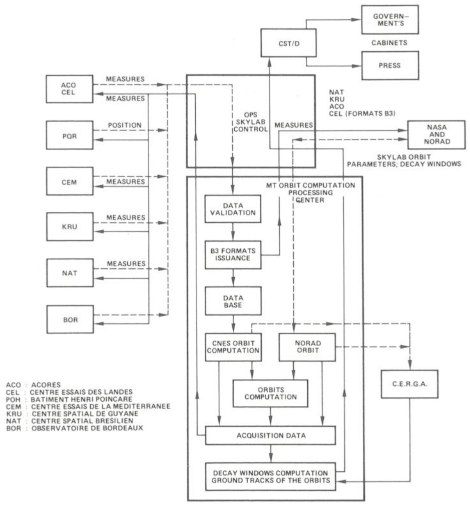
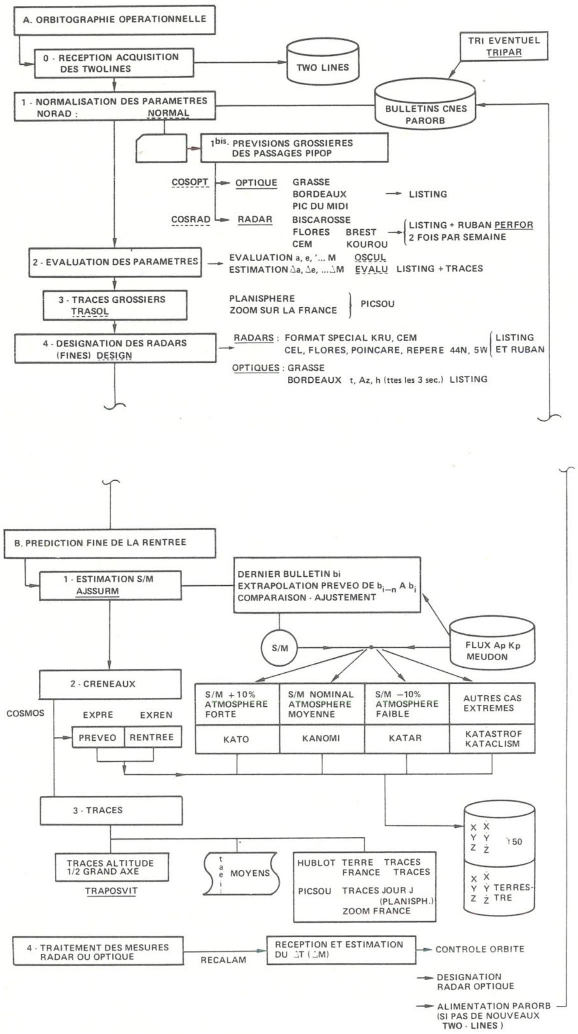


FIGURE 4 : BLOCK DIAGRAM OF THE LINKS BETWEEN THE DIFFERENT PARTICIPANTS

For COSMOS 1402, we show the exploitation of the different packages for (Figure 5)

A - the operational orbit computation
B - the prediction of the reentry (this last part is explained here under in part 2)



N.B. These block diagrams are written in French but words used are universal in most languages

FIGURE 5 : FUNCTIONAL DIAGRAM

2. COMPUTATION OF REENTRY WINDOWS

2.1. SKYLAB

Each orbit determination improves the knowledge of the spacecraft decay and allows to get more accurate reentry predicts. The nominal date for decay is then computed from assumptions on the evolution of a certain amount of parameters function to the altitude and the motion of the satellite. The uncertainty on this evolution allows to define a decay window.

2.1.1. Computation algorithms

SKYLAB decay date was related to the ability to forecast the evolution of the parameters allowing to calculate the aerodynamic (C_x) and geometric (S/M) coefficients.

This forecast being rather difficult, it was believed necessary to direct our study to a global modelization of the phenomena for describing the perturbations of the Keplerian orbit.

The whole orbit determinations is going to be used to identify the mean aerodynamic coefficient (C_a) showing the best the evolution of the semi-major axis of the orbit. This coefficient will have integrated itself the short-term fluctuation : from the altitude (h), the atmosphere density (ρ), the eccentricity (e), the solar activity (Kp) and flux $(F-\bar{F})$, the attack surfaces (S), the drag coefficients (C_x)

Then the aerodynamic force is a follows :

$$F = -1/2\, \rho_{ref} k \frac{SC_x}{M} V^2 \vec{V}/|\vec{V}|$$

V is satellite speed related to the atmosphere

$$V^2 = (V_{Sat} - V_{Atm})^2 = V^2_{Sat} \left(1 - \frac{Vatm}{Vsat}\right)^2$$

$|Vatm| \sim 0{,}5$ km/s

$|Vsat| \sim 8$ km/s

Then $\frac{Vatm}{Vsat}$ ratio is small

$$V^2 = V^2_{Sat} \left(1 - 2\frac{Vatm}{Vsat}\right)$$

The evolution of the semi-major axis is provided by the following perturbations formula.

$$\frac{da}{dr} = -\frac{a\,|\vec{V}sat|}{E}\, |\vec{F}|$$

a orbit semi-major axis

$\vec{V}_{Sat}$ satellite speed

E Orbit energy

This formula is easily transformed :

$$\left(E = -\frac{\mu}{2a}\right)$$

$$\frac{da}{dr} = \frac{2a^2\,|\vec{V}sat|}{\mu}\, |\vec{F}|$$

The result is the equation giving the evolution of a :

$$\frac{da}{dr} = - \rho_{ref} \; k \, \frac{SCx}{M} \quad \frac{a^2 \, V^3 sat}{\mu} \left(1 - 2 \, \frac{Vatm}{Vsat}\right)$$

For a circular orbit :

$$V^2_{Sat} = - \frac{\mu}{a}$$

$$\frac{da}{dt} = - \left[\frac{k \; SCx}{M} \left(1-2 \, \frac{Vatm}{Vsat}\right) \right] \rho_{ref} \sqrt{\mu} \; \sqrt{a}$$

VSat is slightly varying function to the altitude then $\frac{Vatm}{VSat}$ can be considered as constant.

Integration of this equation for obtaining the evolution of a :

$$\frac{1}{\sqrt{\mu}} \int_{ao}^{af} \frac{1}{\rho_{ref}(a)\sqrt{a}} \, da = - \int_{to}^{tf} k \, \frac{SCx}{M} \left(1-2 \, \frac{Vatm}{Vsat}\right) dt$$

The second term of the equation defines a mean value of little varying terms included in the integral. If $(t_f - t_o)$ is much greater than an orbit (if $t_f - t_o$) is about one day = 16 orbits) this coefficient is really significative. We will call it <u>aerodynamic coefficient Ca</u>)

$$Ca = \int_{to}^{tf} k \, \frac{SCx}{M} \left(1-2 \, \frac{Vatm}{Vsat}\right) dt$$

The integral equation is reduced to :

$$\frac{1}{\sqrt{\mu}} \int_{ao}^{af} \frac{1}{\rho_{ref} \sqrt{a}} \, da = - Ca \; (tf-to)$$

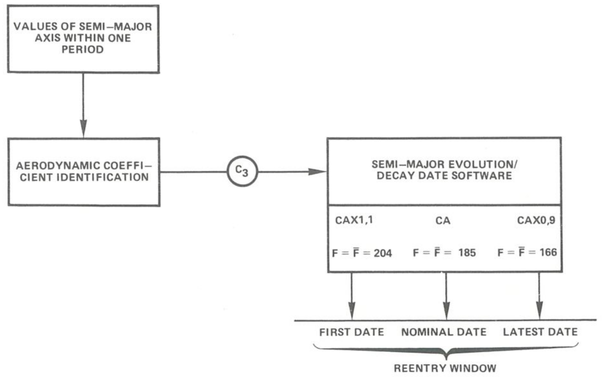
This equation is resolved by numerical integration in order to obtain the semi-major axis value related to the epoch time.

2.1.2. Utilization of the algorithm

The first calculation is used to identify the aerodynamic coefficient C_a, from the evolution of the semi-major axis within several days (value issued from orbit computation).

The C_a coefficient to find is the one minimizing the variations between the computed ant the true values.

Not knowing in advance the evolution of C_a coefficient, the most probable decay date is computed considering C_a constant. The limit values of the window are obtained applying a ± 10% uncertainty on the aerodynamic coefficient and on the knowledge of the scolar flux.



2.1.3. Results

On the figures 6 (a,b,c,d) are shown the reentry windows issued by CNES and NORAD from mid-may. From 15 to june 6 the CNES windows have been issued only with an uncertainty of ± 10% on the aerodynamic coefficient. If we add to this an uncertainty of ± 10% on the flux, all the issued window include the effective reentry date (july 11). This date was announced july 2 by CNES and july 5 by NASA.

On the other hand the effective decay time wasn't in the last window issued by CNES (about one hour shift). This shift could be explained as follows :

- The prediction program was based upon the assumption of a slight and non-secular evolution of different parameters.
- The tumble manoeuver, on the last day didn't allow us to identify the new aerodynamic coefficient.
- The atmospheric density is computed for altitude on the equator, assuming that the errors concerning the altitude variation were included in the C_a aerodynamic coefficient.

The true altitude of the satellite was 12 kms varying between equator and latitude ± 50 deg. Then this variation was not well taken into account by the aerodynamic coefficient C_a at the end of orbital life. To improve the knowledge of reentry date it was absolutely necessary to use the mean altitude (equator altitude + 6 km) with these new assumptions the decay date is 16.51 UT.

On condition that modification, the method used in this decay date predict program, gave during all SKYLAB follow-up, satisfactory results.

The logical following to get more accurate the short-term predicted date, is a sufficient knowledge of the coefficients related to the attitude and aerodynamism of the spacecraft associated with powerful trajectography capabilities. Then it would be possible to completely take into account the atmosphere model which takes of course into account the true altitude.

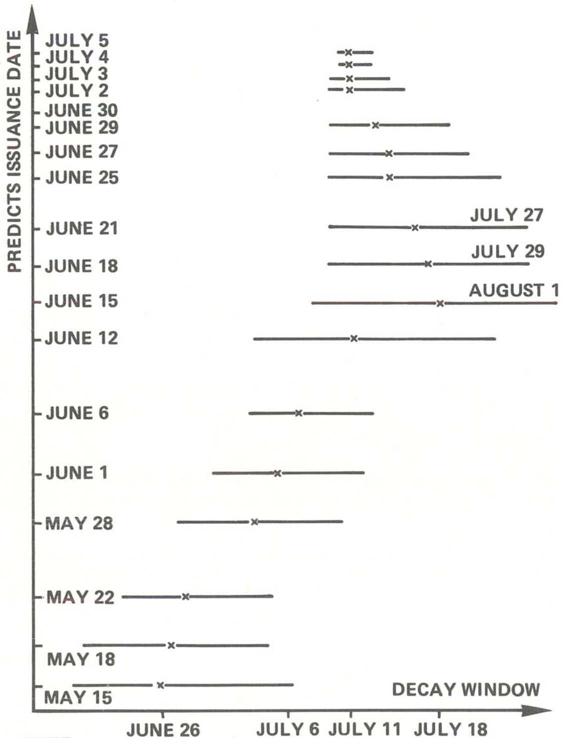


FIGURE 6a. CNES predicts for SKYLAB decay for period may 15 thru july 5

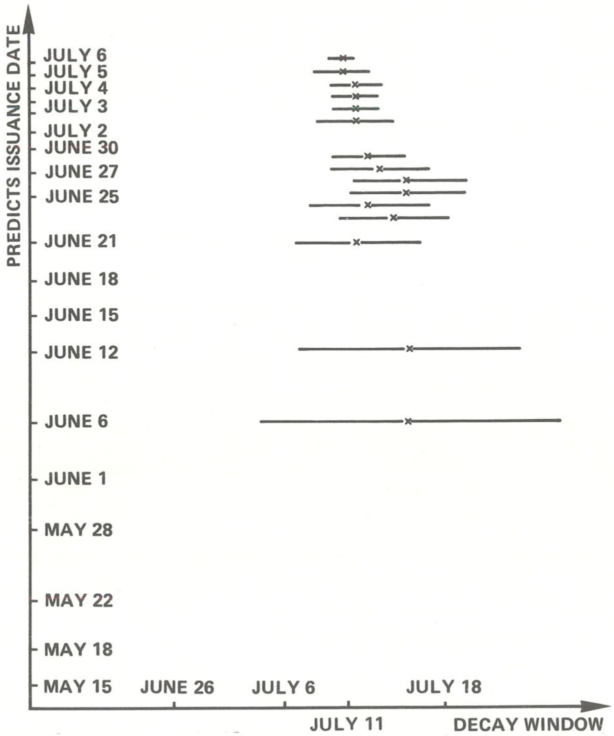


FIGURE 6b. NASA predicts for SKYLAB decay for period june 6 thru july 6 1979

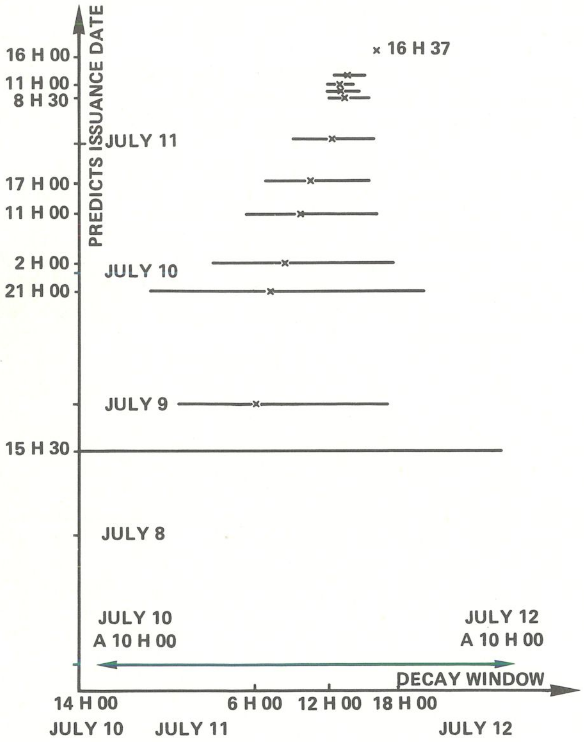


FIGURE 6c. CNES predicts for SKYLAB decay for period july 7 thru july 11

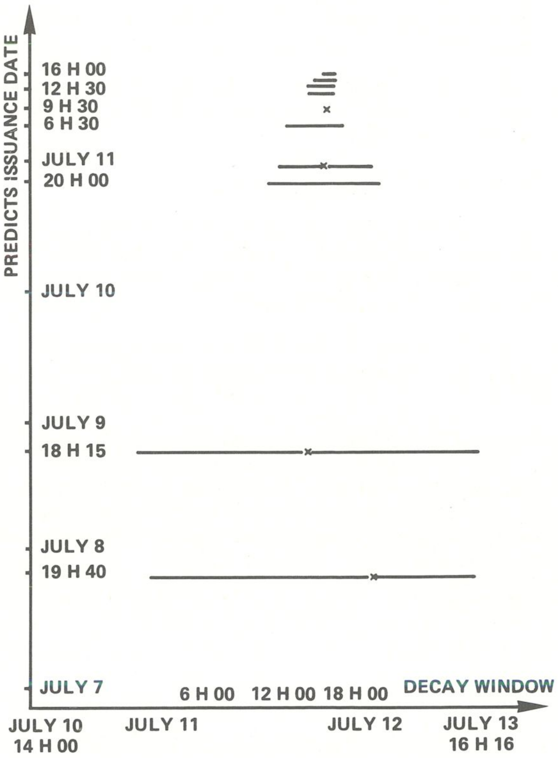


FIGURE 6d. NASA predicts for SKYLAB decay for period july 7 thru july 11

2.2. COSMOS 1402. [3] [4]

2.2.1. FORMULATION OF THE REENTRY PROBLEM

The natural reentry includes two phases :

- a "Keplerian" phase where the altitude of the the satellite is above 120 km. The equations of motion are numerically integrated with COWELL's method. It is supposed that the satellite is under the combined effect of the Earth's gravity field limited to order 8 zonal harmonics and the atmospheric drag force.

- a "Atmospheric" phase below 120 km altitude. Here the trajectory equations take into account the Newtonian attraction with only J_2 perturbation and the drag force where the drag coefficient varies with the Mach number accordingly.

The drag force, when an artificial satellite moves through the Earth's atmosphere, causes an acceleration in the motion equations which is given by :

$$\vec{\gamma}_D = - \frac{1}{2} \rho \frac{A}{M} C_D V \vec{V}$$

where : ρ represents the local atmospheric density
A is the effective cross sectional area
m is the mass of the satellite
C_D is a dimensionless drag coefficient
$\vec{V}$ is the velocity of the satellite relative to the atmosphere and $V = |\vec{V}|$

Numerical integration was choosen so that the joint effect of gravity and drag perturbations are not superposed, but intricately coupled.

The density is given by :

- a standard atmosphere up to 120 km
- the Density Temperature Model (DTM) in the Keplerian phase.

2.2.2. TERMS OF THE REENTRY PREDICTIONS

Reentry window computation is only an extrapolation of an initial orbit, where the physical parameters involved in atmospheric drag have to be modeled, namely :

- the area over mass ratio A/m
- the mean and instantaneous solar flux and the geomagnetic indexes.

In the case we were faced to :

- A/m in an unknown that was evaluated. If changes appear in the estimated value, are they due to attitude or orbital alterations following manoeuvers? They also may come from biaised solar activity predictions which were implied in the A/m estimates.

- The drag coefficient C_D is based primarely on the shape of the satellite and can have variations accordingly to attitude aspect.

In this figuration, long term predictions are hazardous to some extent and require tracking measurements to continuously correct these predictions. Radars and optical tracking were provided to CNES, but not enough data were available to make orbit restitution with adequate accuracy. This deficiency was compensate by reception - in general in a daily basis - of NORAD orbital parameters which were interpreted as measurements.

2.2.3. THE "ATMOSPHERIC" ARC

In this last part of the trajectory (below 120 km) the time decrease of altitude is computed for differnet A/m ratios (see Fig.7). An A/m four times bigger shortens the trajectory of something equivalent to a quarter of a revolution. If the reentry is absolutely natural, the A/m value cannot change as much. Consequently, the last part of the trajectory is not critical to be estimated.
However, no prediction is made on the eventual possibility of spacecraft breaking up in the lower part of the atmosphere although the heat flow can go to 1200 to 2400 KW/m2 depending an A/m and on the wall temperature of the spacecraft

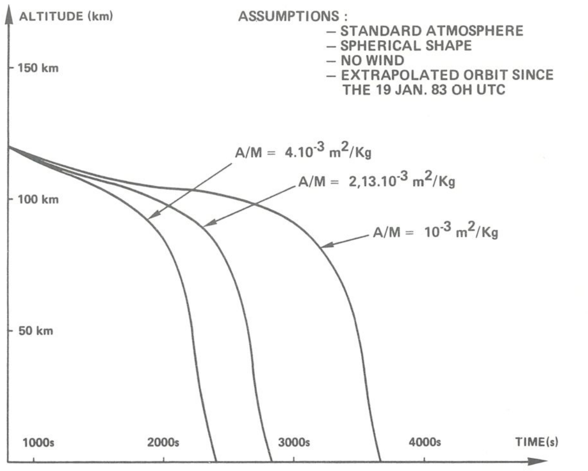


FIGURE 7. ATMOSPHERIC ARC.ALTITUDE DECAY WITH TIME

In order to evaluate the risks of the satellite breaking up an advise about the heat flux received by the spacecraft under some assumptions(standard atmosphere, spherical strape,...) is valuable for the authorities which have to take decision.(Fig.8)

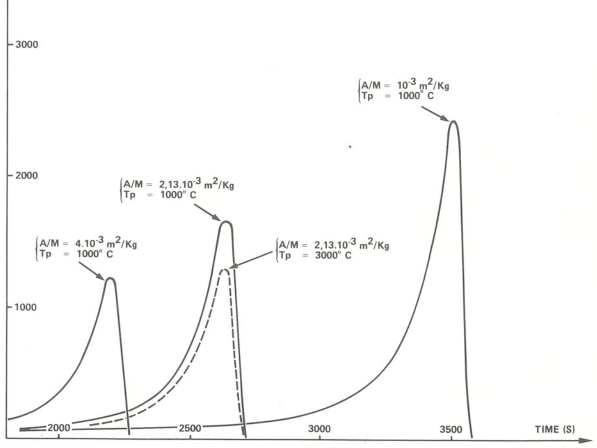
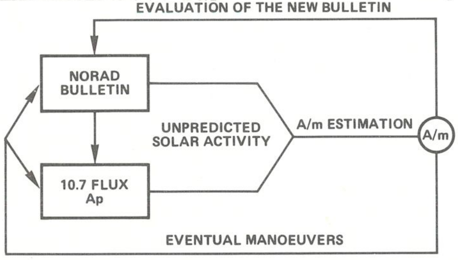


FIGURE 8 : HEAT FLUX RECEIVED BY THE SATELLITE

2.2.4. ESTIMATION OF REENTRY WINDOWS

The applied general procedure is summarized in the following diagram :



2.2.4.1. A/m evaluations

During operations, two differents phases followed one another :

2.2.4.1.1. Initialization phase

A/m was adjusted so that the semi-major axis a evolution on n NORAD bulletins was reconstructed. Under the assumption that the covered period is long enough so that short periodic terms due to J_2 are ignored and that the eccentricity is small enough, we can write for the semi-major axis decay:

$$\dot{a} = \frac{da}{dt} = \frac{A}{m} f(a)$$

and we obtain an expression like :

$$\frac{d(A/m)}{A/m} = \frac{da}{\dot{a}(t-t_o)} - \frac{da_o}{\dot{a}_o(t-t_o)}$$

where t et t_o are two different epochs relatives to two bulletins. When several bulletins are taken, a least square fit is applied.

This adjustment is usual, though it reflects more an "internal" coefficient, that is to say it depends upon the atmospheric model and the C_D variation law used in the integrations of equations.

2.2.4.1.2. The routine phase

With the previously estimated A/m, and with a new bulletin, the coherence of A/m is controled. In general, the semi-major axis prediction was compatible with the new one within 200 meters, for a 15 days period extrapolation. This procedure however can bring to a slight updating of A/m ratio. The nominal predected impact is computed with a "mean" atmosphere (typically 10.7 Flux = 150,Ap=40) The window is then estimated by allowing a percentage of uncertainty in the daily solar flux, the geomagnetic index Ap or the drag coefficient. Generally the used values are illustrated in Table1

COSMOS 1402	(part A) (7 days before reentry)	
VALUES FOR NOMINAL DATE	VARIATIONS	WINDOW
A/m = 0.00217	5%	± 8 h
$F_{10.7}$ = 150	16%	± 1 h
A_p = 40	20 < A_p < 60	± 4 h

- Table 1 -

An evolutive window is however applied as time goes for the following reasons :

- the probability of a magnetic storm
- the A/m ratio can be modified in the lower part of the atmosphere (density is increasing)
- the drag coefficient behaviour is not well defined in the 100-150 km region
- the atmosphere at that altitude is the junction between limits of available models.

2.2.4.2. Solar activity predictions

$F_{10.7}$ and A_p were provided to CNES by the PARIS-MEUDON Observatory Service des Ursigrammes.
The $F_{10.7}$ prediction did not raise problems : the final value beeing generally within a few percent of the predicted one.
From the characteristics and the evolution of an activity center of the solar disk, a large erruption was excepted, starting the 1st of February. In fact, it happened on the 3rd. The Observatory was in the position to predict a magnetic storm on the 4th after 6p.m, which actually took place at 5.15 p.m and lasted up to the 6th at 3 a.m. The A_p grew up to 188 (during the past 20 years, only 10 storms had indexes above 150). At that time the COSMOS 1402 part C was in the part of the atmosphere where this effect is particulary sensitive.

2.2.5. MODELISATION OF THE DRAG COEFFICIENT

C_D and the atmospheric density ρ always occur together as a product. Error models are introduced in order to account for systematic errors in either C_D or ρ.
Some analysis were undertaken in order to tentatively separate the individual factor variations of this product.
C_D varies with the surrounding atmosphere, the shape (which was supposed always sherical), the lighting condition. Up to now, in our software, C_D was considered as a step function of the altitude. According to Cook's model, C_D variations were introduced taking into account :

- a satellite velocity with respect to the mean molecular velocity ratio
- the ratio wall temperature with respect to the external temperature
- the mean molecular mass of the surrounding atmosphere.

When introducing this model, various influences can be displayed : besides the classical atmospheric parameters, one can see the impact of :

- the exospheric temperature and the wall temperature with altitude (see Fig.9). For low altitude C_D has a common value which slightly differs when the altitude increases if the exospheric temperature remains high. But, this difference becomes important with low exospheric temperature up to 20% The general shape is maintained when the wall temperature changes.

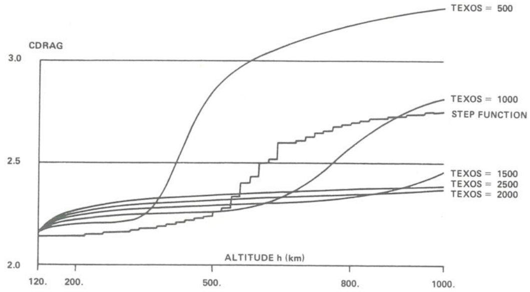


FIGURE 9. TEMPERATURE EXOSPHERIC.TEXO INFLUENCE ON C_D (TW/T = 0,5)

- the season (see Fig.10). Here we show up that C_D has to be modified with the time of the year for a same satellite. If not, the adjusted error model coefficient would be biased.

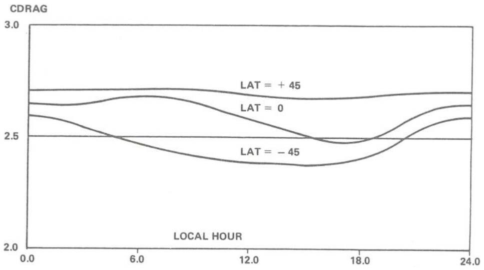


FIGURE 10. SEASON INFLUENCE ON C_D
ASSUMPTIONS : $F_{10.7}$ = 100
TW/T = 0,5
ALTITUDE : 800 km

- the latitude effect (see Fig.11). Over one revolution of the satellite around the Earth, C_D can have variations of 10%.

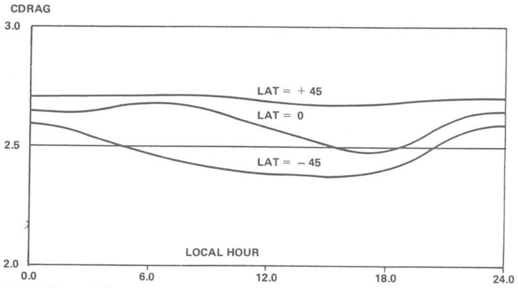


FIGURE 11. LATITUDE INFLUENCE ON C_D
(SAME ASSUMPTIONS AS FIG. 10)

- C_D is dependant upon the atmosphere model since the exospheric temperature is involved, but modes are closed enough not to bring much differences in the corresponding C_D. This C_D analysis was resumed also when making orbit restitution. There are interaction and intersection of the dynamical systems : C_D and the encountered density. If this orbital estimate is made in the purpose of predictions (for pointing of antennas for example), the effect can be important. As a test, on a sun-synchronous orbit, the along track difference in prediction for a period of ten days, has been computed. In all cases, the reference prediction is made with a altitude step function for C_D. The characteristics of the orbit are :

Semi-major axis : 7209 km
Eccentricity : 1.2 10^{-3}
Inclination : 98°

Successively, one can see the effects of :

- $F_{10.7}$ and A_p (See Fig.12 a,b,c)

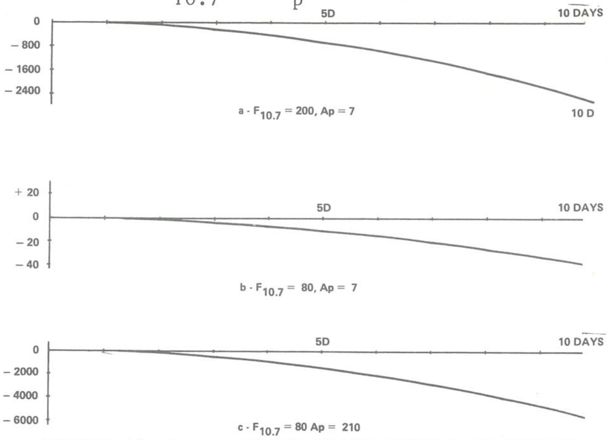


FIGURE 12a,b,c. ALONG TRACK ERRORS IN METERS WITH DIFFERENT SOLAR ACTIVITIES
A/m = 10^{-2}, TW/T = 0,5
Altitude = 500 km

- the local hour of the sun synchronous orbit : 6 hours difference (see Fig.13 a,b)

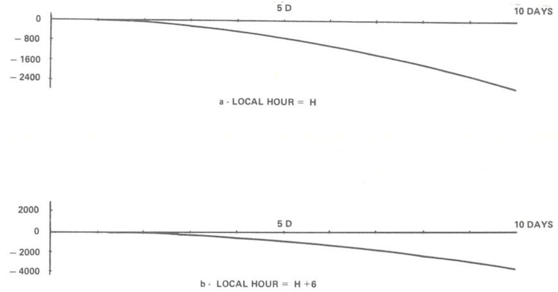


FIGURE 13a,b. ALONG TRACK ERRORS IN METERS : LOCAL HOUR EFFECT on a sun synchronous orbit
A/m = 10^{-2} $F_{10.7}$ = 200 Ap = 7
TW/T = 0.5, Altitude = 800 km

- the lighting where the wall temperature was computed in terms of the actual sun position (see Fig.14a,b)

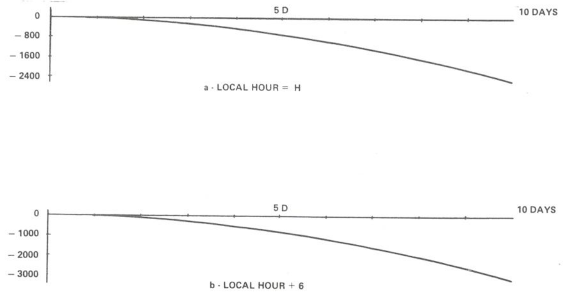


FIGURE 14a,b. ALONG TRACK ERROR IN METERS : LIGHTING EFFECT on a sun synchronous orbit TW/T is function of sun position. light : TW/T = 1. DARKNESS :TW/T = 0 A/m = 10^{-2} $F_{10.7}$=200 Ap=7 ALTITUDE =800 km

Although the C_D impact on orbit restitution is strongly dependant upon the adopted model for it and does not necessarely represent the actual variations, this study brings to a methodology of orbit restitution, where the error model factor can be modified to absorb these types of phenomena.

2.2.6. POST REENTRY ANALYSIS

In this paragraph, we outline the analysis undertaken at CNES and briefly comment them.

For the two parts A and C of the satellite, the corresponding A/m values were approximatively :

0.0022 for A
0.0010 for C

On the last day of each part reentry, as a function of time we plotted the density, the latitude, the geocentric angle between the satellite and the maximum density direction (which is at the sun latitude with a local hour 14 h), C_D, and the geocentric radius of the satellite; (see Fig.13 (part A) and 14 (part C).

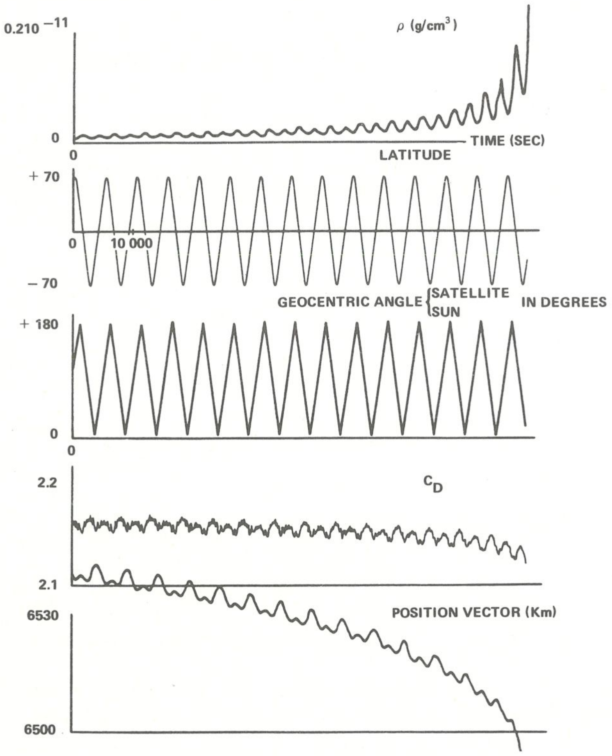


FIGURE 13 . COSMOS 1402 PART A.FROM 0^H (DAY OF REENTRY UP TO 120 Km

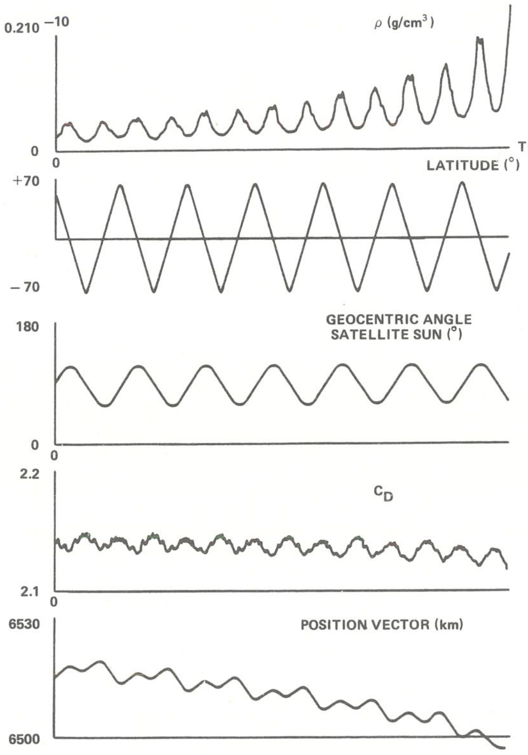
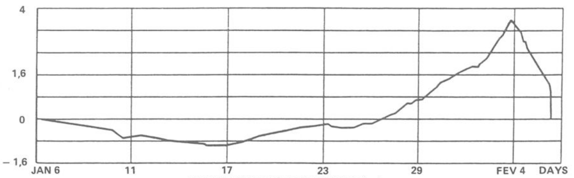


FIGURE 14. COSMOS 1402 PART C FROM 0^H (DAY OF REENTRY UP TO 120 KM)

One can see the predominant effects and how they can be compared to each other. The air density varies by a factor of two between the pole and the equator due to the Earth's asphericity.Consequently the eccentricity beeing small, the general tendency is that satellite meets denser part of the atmosphere in the equatorial region and, if it is around the critical altitude, the down fall is most probable.

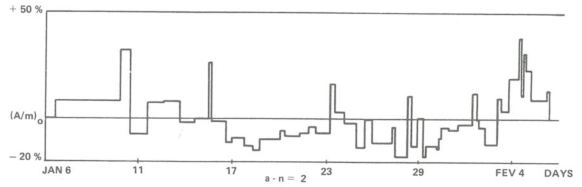
C_D and ρ shows periodic variations of twice the orbital period. Situations such that the satellite enters its final falldown, might be predictable if the coupled effect of variations of C_D, ρ, asphericity and perigee are carrefully looked at. The general history of the decay has been investigated afterwards. Several fits of A/m were made on 2,4 or 6 successives NORAD bulletins and their variations represented (see Fig.15b, 16a).

On other hand, the all trajectory (over one month) was reconstructed with the last A/m value and the evolution with time of the difference between this semi major axis and the one coming from NORAD bulletins was drawn (see Fig.15 a). There is a strong correlation with the geomagnetic activity (see Fig. 15a,b,c) and the important variations of A/m or a.



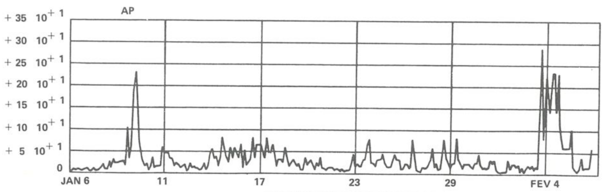
a - SEMI MAJOR AXIS DIFFERENCES (km)

FIGURE 15a. SEMI MAJOR AXIS DIFFERENCES (km)



b - FIT OF A/m WITH 2 SUCCESSIVE NORAD BULLETINS $(A/m)_0$ = 0.0010

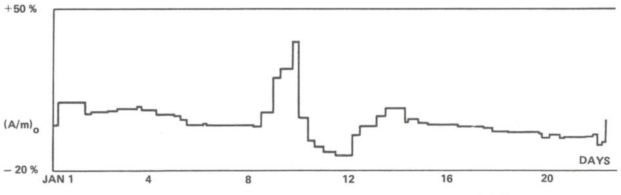
FIGURE 15b. FIT OF A/m WITH 2 SUCCESSIVE NORAD BULLETINS $(A/m)_0$=0.0010



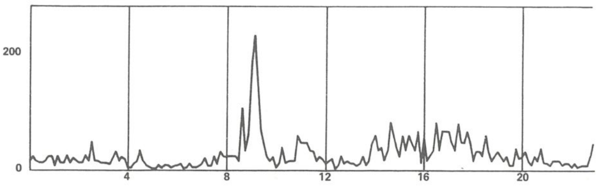
c - GEOMAGNETIC INDEX VARIATIONS

FIGURE 15 c. COSMOS 1402 (PART C) : POST REENTRY ANALYSIS

This shows that the models cannot represent events and are more statistical models. The first peak on Ap (January) has little effect on the part C because the altitude is too high. But on the part A (see Fig.16 a and b) the semi major axis is strongly affected by this event.



a - d(A/m) - LEAST SQUARE FIT OVER 6 NORAD BULLETINS $(A/m)_0$ = 0,0022



b - GEOMAGNETIC INDEX VARIATIONS

FIGURE 16. COSMOS 1402 (PART A) : A/m AND A_p CORRELATION

3. CONCLUSIONS

The past experiences in various European countries show that there is a need of predicting of reentry of Space Debris - More over it is sure that under specified circumstances, these predictions are feasible. When under action we realised that collecting of tracking data are needed. All this suggest that thoughts should be given to a unique computing center where all European informations (tracking data and other types) would be collected.

But first it seems that the aim should be defined precisely (Alarm ? Strategy of computations, regulations ....) Such an activity is episodic and should not require a permanent device ; it has to be shared with computing center involved in orbit determination as full job. All the community could take advantages and benefits of such conception.

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