REENTRY PREDICTIONS OF THREE MASSIVE UNCONTROLLED SPACECRAFT

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ABSTRACT

In just five months, from September 2011 to January 2012, three campaigns of reentry predictions were carried out in support of the Italian civil protection authorities. The objects involved were three massive spacecraft, UARS (NASA), ROSAT (DLR) and Fobos-Grunt (Roscosmos), which received widespread attention for the marginal risk on the ground associated with their uncontrolled reentry, probably exceeding a human casualty expectancy of 1 in 10,000, i.e. the alert threshold adopted by several agencies in the United States, Europe and Japan.

As a matter of fact, in terms of mass and number, the uncontrolled reentries of spent upper stages present a significantly higher risk on the ground with respect to spacecraft and, except for very specific cases as the tragic loss of the Columbia space shuttle orbiter, the bulk of the reentry fragments recovered on the ground come from rocket bodies, not spacecraft. However, the quite more infrequent reentries of the latter typically dominate the media attention, if they are enough massive or peculiar. This occurred also in the cases of UARS, ROSAT and Fobos-Grunt. For example, the spent second stage of the Zenit launcher which put into orbit Fobos-Grunt had a mass (close to nine metric tons) higher than those of UARS and ROSAT combined, but its uncontrolled reentry, on 22 November 2011, did not receive any media attention at all. The same can be said of the Soyuz upper stage used to put into orbit the manned capsule SOYUZ-TMA 3M, reentered over Western Europe on Christmas Eve 2011 with practically the same dry mass, more than two metric tons, of Fobos-Grunt.

Anyway, from the technical point of view, the three above mentioned reentry campaigns offered the occasion to model the orbital evolution, fit the semi-major axis, determine the ballistic coefficients and compare some semi-empirical thermospheric density models under varying solar and geomagnetic activity conditions (Figures 1 and 2), dealing with spacecraft characterized by quite different configurations, shapes, masses and attitude control.

This paper describes the procedures applied to the reentry prediction problem and the results obtained in each campaign, showing the evolution of ballistic coefficients, reentry windows, relative and absolute residual lifetime errors, and ground tracks. For UARS, the average relative residual lifetime error over the campaign was 15%, with a maximum of 28%. For ROSAT the corresponding figures were 3% and 8%, respectively, while for Fobos-Grunt 4% and 8% were found. A detailed discussion of the analogies and differences among the three cases will be provided from the perspective of flight dynamics, drag modeling and spacecraft behavior during the last hours before reentry.

However, in order to provide understandable and unambiguous information useful for civil

protection planning and applications, the nominal reentry time predictions were of no use, while a particular care was devoted to the definition of appropriate reentry uncertainty windows and the computation of the corresponding possible air space crossings and ground footprints on the Italian (and European) territory, in particular during the last three days of satellite lifetime. This piece of information was updated, if needed, but remained relatively stable and accurate until reentry, not much affected by the actual trajectory evolution due to the varying air drag. In other words, it was unambiguous, easy to understand for people not familiar with orbital dynamics and remarkably stable, all qualities that made it very useful for civil protection applications.

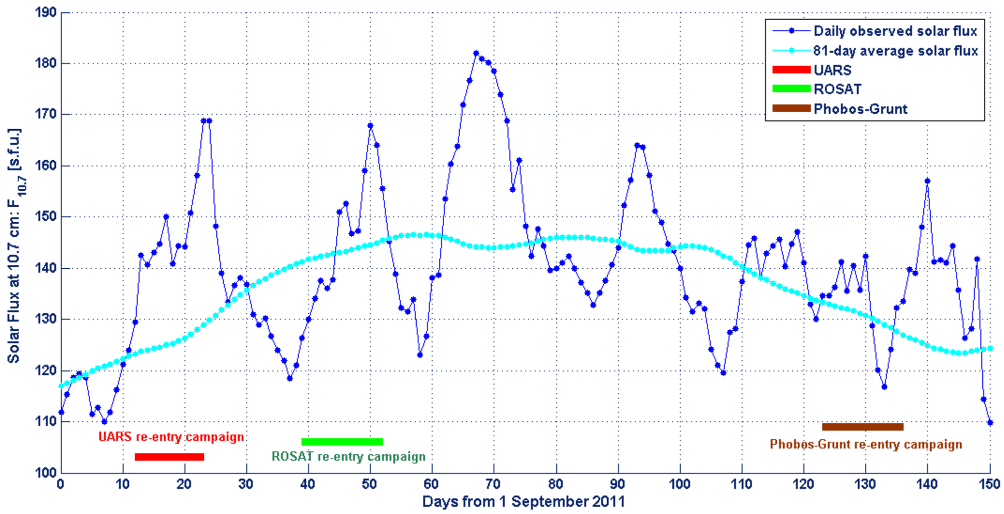

Figure 1. *Solar activity during the three reentry campaigns*

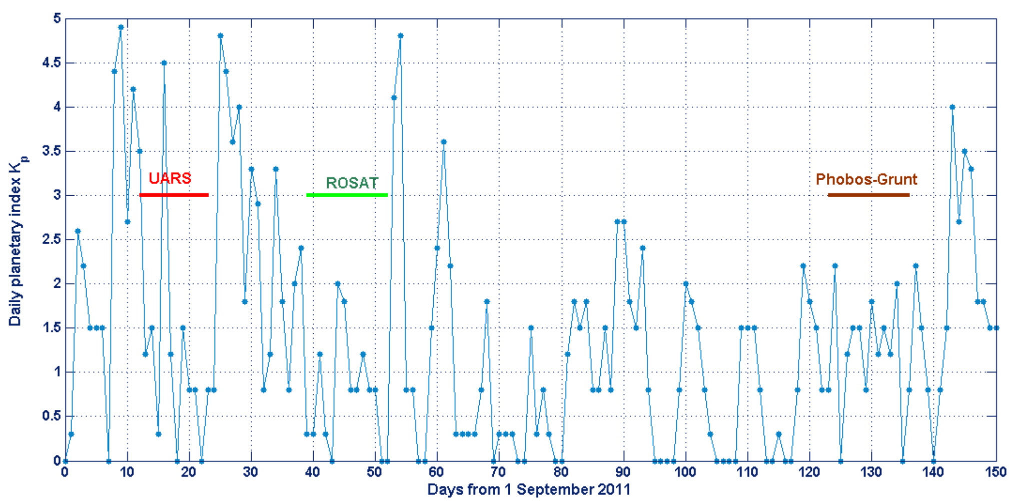

Figure 2. *Geomagnetic activity during the three reentry campaigns*