A TRANSFORM OF ORBITAL ELEMENTS TO DETECT SPECIFIC CLUSTERS OF OBJECTS IN A DRIFT ORBIT

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ABSTRACT

More than 8000 catalogued objects are now in geostationary orbits (GSO) and approximately 95% of them (inactive satellites, last rocket stages etc.) are not operating, i.e. they are in the list of space debris and their presence in GSO is not necessary. Therefore a significant risk exists any future launching not to be successful. In previous works of the authors [4,5] the linear regression analysis was used to select those of the 323 geostationary objects in a drift orbit catalogued in the ESA's DISCOS Database [1,2,3], which are closely located around a straight line in the plane of two of their orbit parameters - the perigee and the apogee mean deviation from the geostationary orbit for example. Such type of clustering may contribute to reveal common technical and exploration conditions which have caused deviations in their orbit parameters.
In this work the same set of objects as well as updated data referred to year 2001 were examined, making use of a transform known as the contrast coefficient-ND (normalized difference) and named herein the apogee-perigee contrast coefficient (APCC) . It was shown that the usage of APCC may reveal new clusters in comparison with the linear regression line.

1. INTRODUCTION

More than 8000 catalogued objects are now in geostationary orbits (GSO) and approximately 95% of them (inactive satellites, last rocket stages etc.) are not operating, i.e. they are in the list of space debris and their presence in GSO is not necessary. Therefore a significant risk exists any future launching not to be successful. The control of such objects becomes indispensable. One of the tools to minimize the risk of space collisions with these space debris is to examine the distribution of their orbital parameters.
In previous works of the authors [4,5] the linear regression analysis was used to select those of the 323 geostationary objects in a drift orbit catalogued in the ESA's DISCOS Database [1,2,3], which are closely disposed (278 cases) along a straight line in the plane of two of their orbit parameters - the perigee and the apogee mean deviation from the geostationary orbit for example. It was suggested that the examination of such type of clustering may contribute to reveal common technical and exploration conditions which have caused deviations in their orbit parameters. It is worth noting that the slope of the straight regression line is very close to 1 and the intercept is many times smaller than the ellipse axes which corresponds to debris orbits very close to circles, shifted with respect to the geostationary orbit.
In this work the same set of objects was examined making use of a transform known as the contrast coefficient-ND (normalized difference) and named herein the apogee-perigee contrast coefficient (APCC) Additional processing was performed of data taken from the updated ESA's DISCOS Database (2001) [6] concerning the same category of objects in a drift orbit: Table 1. 3.3, pp. 41-61.

2. MATERIALS AND METHODS.

The linear regression analysis was used in [4,5] to select objects with similar changes in their orbital elements.
To extract which of the objects are to be subjected to linear regression analysis in the plane of two orbital parameters, the perigee and apogee mean deviations for example, we used two criteria:
- having in view that a determination coefficient R^2 of approximately 0.95 is usually desired in the linear regression analysis to consider the linear model as adequate enough, we accepted this value as a proper objective criterion for selection;
- the subjective criterion was based on a visual review of the whole set of points in the regression plane and on taking decision which of the points are to be removed in order the rest of them to satisfy the first criterion; after the visual criterion is applied, the determination coefficient R^2 is to be calculated (several times if necessary) to verify the proper choice of objects); it is obvious that such a set should content more than 5-10 objects because a straight line drown between two-three points is of no use in our case;

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theoretically the number of the proper sets which would satisfy these criteria is more than one.

It turned out that 278 from 323 geostationary objects in a drift orbit catalogued in the ESA's DISCOS Database ([3] -Table 1, 3.3) were grouped along a straight regression line (Fig. 1) with correlation coefficient R=0.985 in the plane of the apogee mean deviation Δr_a from the geostationary orbit and the perigee mean deviation Δr_p from the geostationary orbit. Similarly the same orbital elements of 62 from 84 spacecrafts in near GSO with Δr_p between 0-300 km above the geostationary satellite orbit (Table 3, [3]) showed R=0.968. The existence of such a close clustering of the objects would possibly contribute to reveal common features in their construction and exploration conditions or to estimate the risk of space collisions which they generate.

A clearly separated cluster (Fig. 1) of 11 objects (from No 313 to No 323 in [3], Table 1, 3.3. - objects in a drift orbit) was observed [4] located closely to the straight line and the orbits of which were characterized by the largest and negative Δr_a and Δr_p. within the subset of the linear regression.

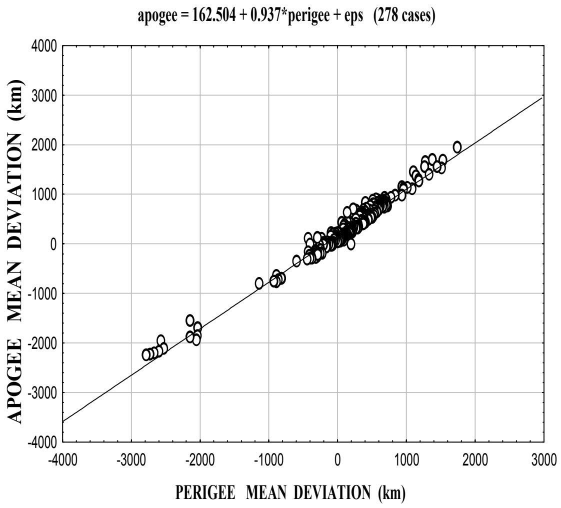

Fig. 1. Linear regression between the apogee mean deviation Δr_a from the geostationary orbit and the perigee mean deviation Δr_p.from the geostationary orbit for selected set of 278 cases of objects in a drift orbit (data updated in 2000)

So the linear regression analysis leads to a type of clustering of the objects in a drift orbit. Herein we used the same set of 278 objects aforementioned but we transformed their parameters Δr_a and Δr_p by means of the normalized difference ND.

The contrast coefficient ND (normalized difference) is a nondimensional coefficient and provides at least the following advantages:

- makes possible the comparative analysis of the distribution of orbital parameters of different dimension or of one and the same dimension but of quite different orders of their numerical values;
- reveals clusters of objects which may be significantly different from those which are observed after the application of the linear regression analysis.

The ND coefficient is usually defined as

$$ND = (a-b)/(a+b),$$

where a and b are two different variables of interest.

By analogy an apogee-perigee contrast coefficient (APCC) is herein defined as:

$$APCC = (\Delta r_a - \Delta r_p)/(\Delta r_a + \Delta r_p). \qquad (1)$$

Assume Δr_a and Δr_p are strictly linearly correlated, i.e.

$$\Delta r_a = k\Delta r_p + m, \qquad (2)$$

where k and m are parameters.

Substituting Δr_a from Eq.(2) into Eq. (1) we obtain

$$APCC = (k\Delta r_p+m-\Delta r_p)/(k\Delta r_p+m+\Delta r_p) = \\ = ((k-1)\Delta r_p+m)/((k+1)\Delta r_p+m). \qquad (3)$$

As the Δr_p values may be negative, the APCC function from equation (3) is a two-arm hyperbola in dependence of Δr_p and has a vertical asymptote at $\Delta r_p = - m/(k+1)$. So if the real mean deviations Δr_a and Δr_p are linearly correlated with a high correlation coefficient then they will be closely disposed along the two arms of the hyperbola defined by Eq. (3).

3. RESULTS AND DISCUSSION.

3.1 Data for objects in a drift orbit referred to year 2000 according to [3].

In Fig.2 the set of 278 objects is shown and their disposition along a two-arm hyperbola with its vertical and horizontal asymptotes is clearly seen. This hyperbolic distribution results from the very close disposition of these objects along a straight line in the plane (Δr_p , Δr_a) (Fig. 1).

The cluster seen in the lower left side of the hyperbola in Figure 2 comprises the same objects in the cluster of 11 objects above discussed (Fig. 1). Additionally the set of 278 cases is divided into two subsets disposed along each of the hyperbole arms. Kernels of some new clusters are seen as well within each of the subsets. This is to confirm that APCC may reveal new clusters in comparison with the linear regression line.
It is easily seen in the left part of Fig. 2 and Fig.5 that the clusters which are clearly distinguished are as well separated as they seem to be, making use only of the perigee mean deviation axis in the interval (-2500 to -500 km). The same is hardly to be said for the objects which are disposed on this axis in the interval (-500 to 1000 km).

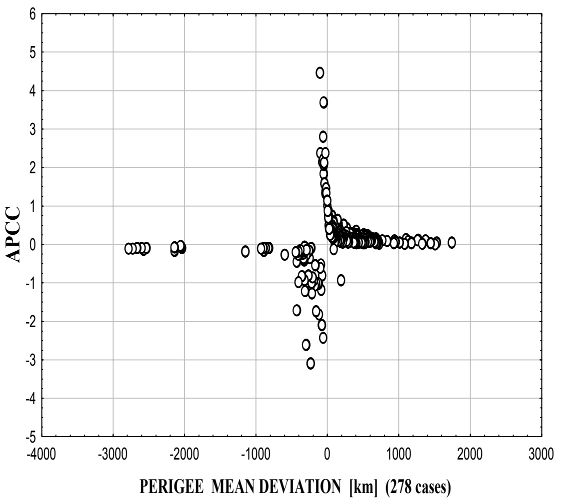

Fig.2. Scatter plot of the APCC transform (normalized difference) vs. the perigee mean deviation Δr_p for selected set of 278 cases of objects in a drift orbit (data updated in 2000)

3.2 Data for objects in a drift orbit referred to year 2001 according to [6].
The same approach was applied to process data from [6]. The results are shown in Fig. 3,4,5.
In Fig. 3 the choice of a set (marked by squares) that meets the requirements of the criteria aforementioned is shown (293 cases from 341 under consideration). The linear regression straight line for this set is given in Fig. 4 and the APCC transform is seen in Fig. 5. The results in Fig. 5 are in principal similar to those in Fig. 2. Anyway the cluster seen in the lower left side of the hyperbola in Fig. 5 comprises much more objects(from No 324 to No 341, excluding No 340 in

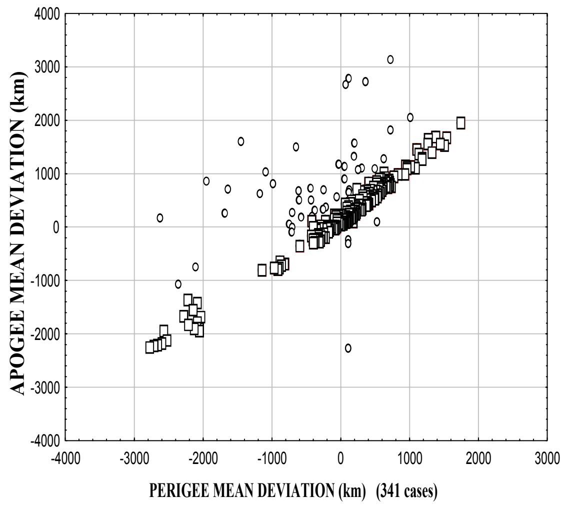

Fig.3. Scatter plot of 341 cases of objects in a drift orbit -data updated in 2001) in the plane (Δr, apogee mean deviation from the geostationary orbit and the perigee mean deviation Δr_p. from the geostationary orbit. The selected for regression analysis objects are denoted by squares.

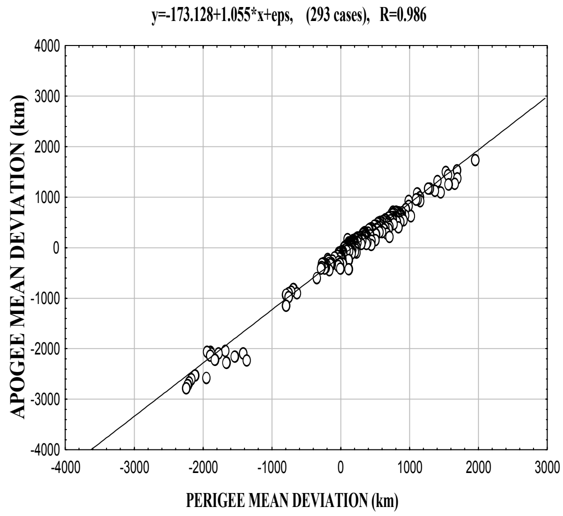

Fig.4. Linear regression between the apogee mean deviation Δr_a from the geostationary orbit and the perigee mean deviation Δr_p from the geostationary orbit for selected set of 293 cases of objects in a drift orbit (data updated in 2001)

Table 3.3) in comparison with the similar cluster in Fig. 2. In the plane (Δr_p , Δr_a) most of the objects are compactly lying along the straight line (Fig.1 and 4) (approximately from -500 km to 1000 km on the perigee mean deviation axis) while almost the same set of objects in Fig 2 and 5 are separated at least into two large groups. A detailed analysis would possibly reveal if this separation is informative i.e. if it is due to some systematic peculiarities of the launching conditions or to the mode of exploration of these objects or it results from the formal mathematical APCC transform. The multidimensional regression analysis would possibly lead to a better detection of other clusters.

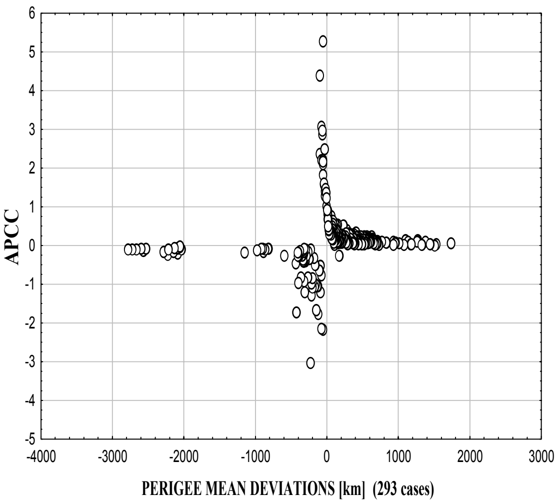

Fig.5. Scatter plot of the APCC transform (normalized difference) vs. the perigee mean deviation Δr_p for selected set of 293 cases of objects in a drift orbit (data updated in 2001)

Our preliminary calculations showed that the correlation coefficient of the linear regression between the semi-axis mean deviation and the perigee mean deviation for the updated values in year 2001 [6] is significantly larger than that obtained with data for year 2000 [3].

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