New Opportunities of the Computing–Analytical Complex for Predicting Collisions of the Earth with Asteroids and Comets

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Among new additional possibilities of the complex the computation of a strip of risk on the Earth surface is described. Within limits of a strip a collision with a body can be possible under certain conditions, even if the nominal orbit of the body passes by the Earth. Predicting of collisions of bodies with the Moon is considered. Operation of the complex nowadays is reflected in real time in the form of the dataful table about past and forthcoming approaches of bodies with the Earth and the Moon.

Keywords: Asteroids, comets, collision with the Earth.

Work of the complex and calculation of circumstances of falls of real and fictitious celestial bodies were described in a number of articles [1–3]. In those papers the search of potentially dangerous object (PDO) approaches to the Earth has been considered for two cases: the body on the nominal orbit passes by the Earth; the body in the nominal orbit penetrates into the terrestrial atmosphere up to the certain hight above the surface of Earth spheroid. In present report the boundary case is considered when the body in the nominal orbit does not collide with the Earth, but the probability of collision is great enough (e.g., greater than $10^{-4} - 10^{-5}$). In this case the real body has rather good chance to collide with the Earth. It is necessary to determine passing of a strip of risk along Earth's surface. Besides, in the report the problem of collision of bodies with the Moon is considered. Forming on the website of the IAA RAS the table of the past and forthcoming approaches of PDO to the Earth and the Moon is described.

1 Calculation of strip of risk passing on the Earth surface

The mean daily motion is the most poorly determining element from short-arc observations. On the other hand, the minimum distance at which body passes by the Earth primarily depends on value of the variation of the mean motion relative to its nominal value. If the minimum is less than Earth radius, then collision takes place. All collisions occur in a small neighborhood of the shortest distance between orbits. Therefore calculation for strip of risk points must be started from search of variation of the mean motion which leads to minimum possible distance between bodies. But, first of all, it is necessary to set, whether it is possible to achieve minimum distance lesser than the Earth radius by varying of the mean motion nominal value within acceptable limits of its random errors.

Let for a nominal orbit the minimum geocentric distance is F, defined by a formula: $F = \sqrt{(x-X)^2 + (y-Y)^2 + (z-Z)^2}$, where X, Y, Z are the Earth coordinates, and x, y, z are body coordinates at the time of achievement of a minimum distance, t_E. Let G is a row vector with components equal to coordinates and velocities of body at current moment of time. Then covariance matrix of its components can be written as

$$D = \sigma^2 (\partial G/\partial G_0) Q^{-1} (\partial G/\partial G_0)^T,$$

where σ is the mean error of observations, $(\partial G/\partial G_0)$ is a matrix of partial derivatives of current coordinates and velocities with respect to their initial values, that is isochronous derivatives obtained by integrating the equations in variations together with the equations of motion; Q^{-1} is the inverse matrix of the normal system from which the orbital parameters were found; T is symbol of matrix transposition. The mean error of F at the time t_E can be calculated by a formula:

$$\sigma_F = \sqrt{(\partial F/\partial G) D (\partial F/\partial G)^T},$$

where $(\partial F/\partial G)$ is the row vector of partial derivatives of F with respect to orbital parameters at t_E. Considering that the occurrence of random errors, in absolute value greater than 4.5 times the mean error is highly unlikely, it can be assumed that if $4.5\sigma_F < F - R_c$, where R_c is the capture radius of the Earth, the variation of the mean motion does not make sense, since any variation (any error of mean motion) will lead to minimum geocentric distance which exceeds R_c.

The actual calculation of a strip of risk points comes down to the following. At first the sign of variations of the mean motion which leads at small absolute values of variation to reduction of the minimum distance of a body from the Earth is defined. Then the interval of possible errors (possible variations) of the mean motion breaks into some number of parts of equal length.

In points of division of an interval the corresponding values of function, a minimum distance of body from the Earth, are calculated. Among the formed segments two adjacent ones are selected within which the sign of function increment changes. With the selected segments the described procedure is repeated. Process comes to an end when value of a variation in the next point of division leads to collision. Other points of a strip of risk are obtained by a variation of the mean motion with sufficiently small step to both sides from the first value leading to collision.

Fig. 1 shows the strip of risk for a fictitious asteroid whose orbit has been determined from 23 observations of asteroid (99942) Apophis, taken at the time interval from 18.423180 to 27.740170 December 2004. The following table gives some information about time, minimum distance and probability of collision.

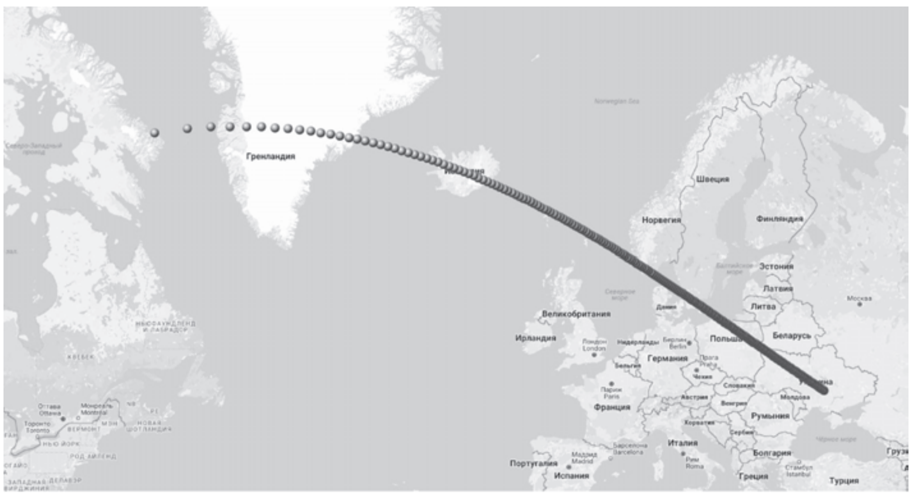

Fig. 1. The strip of risk for a fictitious asteroid

Time of the body passing by the Earth in nominal orbit	JD 2462240.382636, 2029 04 13.882636
The minimum distance from the Earth center	288944 ± 390507 km
The probability of collision	0.0128

2 Collision with the Moon

Predicting of body falls on the Moon differs little from the same problem for the Earth: the Moon's osculating orbit varies stronger than the Earth's orbit and the forecust of the Moon positions should be carried out at shorter intervals as compared with that for the Earth. Hight of entrance in the atmosphere is assumed to be zero above the lunar surface. The selenographic coordinates of the impact point and the Universal time of the event are determinated. All calculations are performed for the Moon after those of the Earth in the event that a collision with the central body is not fixed. Simulation of the collision with the Moon can be organized on the model of the collision with the Earth, of course, taking into account absence of atmosphere.

3 Table of encounters of potentially dangerous bodies with the Earth and the Moon on the website of IAA RAS

During forecasting encounters of PDO with the Earth or the Moon, all essential information about the orbits of PDO, their accuracy, and the circumstances of each approach are shown on the computer screen. To make this information publicly available, easily foreseeable and comparable to encounters of different bodies, on the website of the IAA RAS a table showing past and future encounters of PDO with the Earth and the Moon has been organized. Each row of this table displays the data on one encounter: number or designation of object, the moment of a minimum distance and its value, the probability of collision, the relative velocity, and others. Content of the table reflects the operation of the complex practically in real time. As the complex checks each six minutes updating of information on website of the Minor Planet Center about discovering of new PDO and/or their observations and new data immediately begin to be processed, data in the table correspond to the information which is available in the world at present.

4 Conclusion

Described additional capabilities of the system greatly expand and refine its forecasting ability. The complex now includes search of approaches and collisions also with the Moon. Finally, on the site of the IAA RAS publicly available table of past and forthcoming approaches of potentially dangerous bodies with the Earth and the Moon has been organized.

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