ON THE POSSIBILITY OF LONG TIME EXISTENCE OF MAN-MADE MICROPARTICLES INJECTED ON OBLONG ELLIPTIC ORBITS WITH LOW PERIGEE ALTITUDE IN THE NEAR EARTH SPACE

Evgeny K. Kolesnikov (1), Sergey V. Chernov (2)

(1) St. Petersburg State University, Universitetsky prospekt, 28, 198504, Peterhof, St. Petersburg, Russia, Email: kolesnikov_evg@mail.ru

(2) St. Petersburg State University, Universitetsky prospekt, 28, 198504, Peterhof, St. Petersburg, Russia, Email: beam2000@mail.ru

ABSTRACT

Basing on the results of numerical experiments a possibility in principle of long time keeping (more than 1 month) and very long time keeping (about or more than 1 year) of man-made particles of aluminium and aluminium oxide with radii more than 1 micron and less than 0.1 micron injected on oblong elliptic orbits with low perigee altitude in the near earth space is shown. Estimates made earlier that clouds of man-made particles with long time life which are observed by space vehicle on low altitude orbits consist of particles moving in the Near Earth Space on oblong elliptic orbits have been confirmed by obtained calculated data.

1. INTRODUCTION

Problems of fine-dispersed particles dynamics in the Near Earth Space (NES) attract fixed attention of researchers over a period of last two decades [1-5]. The urgency of these studies relates with a problem of anthropogenic pollution of the Near Earth Space by man-made microparticles (MP) that exert negative influence on spacecraft structurals which are sensitive to shock loading (solar cell panels, windows, optical reflectors and others). Especially strong influence on spacecraft functioning occurs when spacecraft passes across clouds of man-made microparticles (they are named astrosols) in which a particles flux density is equal 10^4-10^5 background one. Astrosol clouds with sizes from some hundreds kilometers to some thousands kilometers and with life time of some weeks in the NES was revealed as result of onboard measurements by many spacecrafts on low altitude orbits: LDEF [6, 7], Salut and Mir [8, 9], Space Shuttle [10] and others. Methodical investigations of astrosol complexes character in the near space essentially begins just only. In particular important question about orbital parameters of astrosol complexes particles which signifies in principle to attribute possible sources of MP clouds and theirs formation mechanism is left in abeyance up to date. A series of facts enables to suppose that MP clouds which are observed by spacecrafts on low altitude orbits consist of particles moving on oblong elliptic orbits with low altitude perigee. Firstly as result of strong resistance of high atmosphere residual gas a long time orbital existence of even the largest man-made microparticles with radii of about 100 microns that are injected on circular orbits and elliptic orbits close to circular ones and move on altitudes of low altitude orbital spacecrafts mentioned above is practically impossible [4]. For example the results of numerical modelling show that the orbital existence time of aluminium microparticles with radius of 100 microns injected in the NES on the circular orbit with altitude of 450 km (it is the altitude of LDEF) for conditions of low level of the solar and geomagnetic activities is 8.6 days, and if MP is injected on low circular orbit with altitude of 250 km (it is typical altitude of Salut and Mir) the time is only 1.6 hours. In addition some results of onboard experiments mentioned above (distribution of percussive craters at spacecraft surface and their morphology features) indicate that the astrosol complexes seemingly consist of particles moving along oblong elliptic orbits with low altitude perigee and high altitude apogee [6, 10]. As possible sources of particles mentioned above in papers there are considered particles which are born on oblong elliptic orbit similar Molniya orbit and also fine-dispersed products of ejection of solid rocket motors (SRM) [9].

The aim of this paper is to carry out numerical experiments which enable to find out principle possibility of long time keeping of man-made particles of aluminium and aluminium oxide with radii from 0.01 to 100 microns which are injected in the NES on oblong elliptic orbits with the low altitude perigee.

2. PROBLEM FORMULATION

So we suppose that the microparticle which is assumed to have spherical shape is injected in the Near Earth Space on oblong elliptic orbit with low altitude perigee. Calculations of MP motion are carried out by using of the dynamic model which takes into account that the microparticle is influenced by: the central gravitational field of the Earth and its perturbations caused by the polar compression of the Earth; force of the solar pressure and the resistance force arising due to flow of the background gas and electrodynamics forces (these

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forces are conditioned by influence between MP electrical charge and magnetic and electric fields of the NES). Especially difficult problem is necessity to take account the influence of electrodynamics forces on MP motion. A cause of this problem is difficulty of the definition of microparticle electrical charge which are generated as result of collective influence of MP with charged particles streams from background space plasma to MP surface and secondary charged particles streams emitting of microparticle surface. As a result of spatial heterogeneity of near Earth plasma parameters and MP illumination conditions the microparticles electrical charge are changing along MP trajectory and as a result of a finiteness of MP charging typical time in given moment charge value depends on physical conditions in the Near Earth Space points which correspond to both current and previous locations of microparticle on the trajectory. In general case to sort out the problem of microparticle dynamics it is necessary to solve jointly equations which describe MP charging process in space plasma with microparticle motion equations in the NES.

In a reference system with initial point in the Earth center (the system doesn't spin simultaneously with the Earth) the motion of spherical microparticle in the NES is described by the equation:

$$m\frac{d^2}{dt^2}\mathbf{r} = \mathbf{F}_G + \mathbf{F}_G^{dst} + \mathbf{F}_L^B + \mathbf{F}_L^E + \mathbf{F}_{pr} + \mathbf{F}_{drag} . \qquad (1)$$

In equation (1):

$$\mathbf{F}_G = -G\frac{mM_E}{r^3}\mathbf{r} ;$$

– force of the central gravitational field of the Earth (m – is microparticle mass, G – is gravitational constant, M_E – is Earth mass);

$$\mathbf{F}_G^{dst} = -m\nabla\left\{\frac{GM_E J_2 R_E^2}{2r^3}\left(3\sin^2\theta - 1\right)\right\}$$

– disturbance of $\mathbf{F}_G$, caused by Earth polar compression (J_2 – is second zonal harmonic coefficient of the Earth, θ – is MP latitude measured from equatorial flat);

$$\mathbf{F}_L^B = \frac{q}{c}\mathbf{v}\times\mathbf{B}, \quad \mathbf{F}_L^E = q\mathbf{E}$$

– are correspondingly magnetic and electrical parts of Lorentz force, which are conditioned by the influence of microparticle charge q moving with velocity $\mathbf{v} = \frac{d\mathbf{r}}{dt}$, with magnetic $\mathbf{B}$ and electrical $\mathbf{E}$ fields of the Near Earth Space. In the first approximation geomagnetic and geoelectrical fields can be specified as these expressions:

$$\mathbf{B} = \mathbf{B}_d , \quad \mathbf{E} = \mathbf{E}_{co-rotation} + \mathbf{E}_{cross-tail} ,$$

where

$$\mathbf{B}_d = \nabla\left(\frac{M_d \mathbf{\Omega}\cdot\mathbf{r}}{\Omega r^3}\right)$$

– the magnetic field of central opposed spin-axis aligned dipole with moment of $\mathbf{M}_d$ ($\mathbf{\Omega}$ – the Earth's angular velocity vector);

$$\mathbf{E}_{co-rotation} = \frac{1}{c}\left(\mathbf{r}\times\mathbf{\Omega}\right)\times\mathbf{B}$$

– is the corotational electric field and $\mathbf{E}_{cross-tail}$ – is the convection electric field which is approximated by uniform electric field. This field is directed from morning to evening side of the magnetosphere and depends on the level of geomagnetic activity;

$$\mathbf{F}_{pr} = Q_{pr}\frac{N\pi R^2}{c}P\left(\mathbf{r}\right)\mathbf{s}$$

– is a solar pressure force (N – is density of the energy flux from the Sun on the Earth orbit; Q_{pr} – is efficiency factor averaged over the solar spectrum; $P\left(\mathbf{r}\right)$ – is "shadow" function which is equal zero inside the Earth shadow region and one outside the region; $\mathbf{s}$ – is unit vector pointing from the Sun). For small microparticle radius the reasonable definition of efficiency factor Q_{pr} is separate and sufficiently difficult problem. At the present time this factor is determined by numerical summation of series which is a formal exact solution of problem of light absorption and dispersion by spherical particle (this solution is provided by Mie theory) [11];

$$\mathbf{F}_{drag} = -C_x\frac{\pi R^2}{2}\rho_a v^2\frac{\mathbf{v}}{v}$$

– is a resistance force arising due to flow of the background gas (ρ_a – is high atmospheric density, $\mathbf{v}$ – is MP velocity relatively Earth (atmosphere), C_x – is the drag coefficient). To define a resistance force for the assignment of the atmospheric density we used the piecewise exponential altitude profile of the atmospheric density, based on the model MSISE-90, averaged with respect to daily, seasonal and latitudinal variations for three levels of solar and geomagnetic activity: low, mean and high [12]. We supposed that the drag coefficient C_x was equal 2; this statement correspond the model of perfectly nonelastic interaction of air molecules with microparticles surface.

In compliance with premises to find MP trajectory in the NES the motion equation has to be solved jointly with MP charging equation:

$$\frac{d}{dt}q\left(\Phi\right) = J_e + J_i + J_{see} + J_{sei} + J_{bse} + J_{ph} + J_a , \qquad (2)$$

where $q\left(\Phi\right)$ – is MP electrical charge, which is determined by the expression $q = R\Phi$ for spherical microparticle of conductive material (Φ – is the MP potential). As the charging currents in equation (2) we take into account: the ion J_i and electron J_e thermal currents from background space plasma to MP surface, currents of secondary electron-electron J_{see} and secondary ion-electron J_{sei} emissions, current of backscattering electrons J_{bse}, current of photoelectron emission J_{ph} by short-wave sunlight, and autoelectronic current J_a. For currents mentioned above analytical expressions was given by us in [13]. For calculation of plasma currents in the Earth's plasmasphere we use the analytical model of plasmasphere which are based on data of [14, 15], for MP motion in the Earth's plasma sheet we use the model of uniform plasma with different electron and ion temperatures (their parameters can be found in [16]). At last for calculation of plasma currents in the Earth's ionosphere we use the ionosphere discrete model which under concrete numerical calculation is provided data of ionosphere model called IRI-2001 (International Reference Ionosphere) [17].

For mathematical modeling of MP motion in the NES in the formulation mentioned above the algorithm of numerical integration of equations (1) and (2) has been developed. The equations are written as the system of seven ordinary differential equations of the first order with right-hand parts which are given as procedures. This algorithm is actualized as the computer program. The program provides construction of trajectories for microparticles made from different materials (aluminium, aluminium oxide, iron and carbon) with real optical parameters that are found by Mie theory. Numerical modeling of MP motion in the NES is carried out by using of different models of Earth plasma sheath and high atmosphere which correspond 3 levels of solar and geomagnetic activities: low, mean and high.

3. RESULTS OF NUMERICAL EXPERIMENTS

Firstly to define orbital existence times of aluminium spherical microparticles of radii from 1 to 100 microns injected in the NES on oblong elliptical orbits with low altitude perigee for conditions of low, mean, and high levels of solar and geomagnetic activity series of numerical experiments has been carried out by using developed computer program. For MP radius values mentioned above electrodynamics forces don't influence significantly on orbital motion of injected microparticles. For this case MP trajectory has to be calculated subject to the influence of: the central gravitational field of the Earth and its perturbations caused by the polar compression of the Earth; force of the solar pressure and the resistance force arising due to flow of the neutral component of background gas. The calculations were carried out for two variants of MP mother orbits which are described by different orbital parameters.

In the first case we supposed that MP injection in the NES are realized in perigee point of oblong elliptic orbits with parameters which correspond Molniya orbital parameters (perigee altitude – 460 km, apogee altitude – 40860 km, angle of inclination – 62.8 degrees). The calculations have been carried out for 4 spatial orientations of mother orbit which are defined by values of longitude of ascending node of 0, 90, 180, and 270 degrees. A node-perigee angle is supposed to be fixed and to be equal 270 degrees.

Calculated dependences of life time of aluminium microparticle on its radius for conditions of low, mean and high activity for examined orientations of "mother" orbit are shown on Fig. 1, 2, and 3 correspondingly.

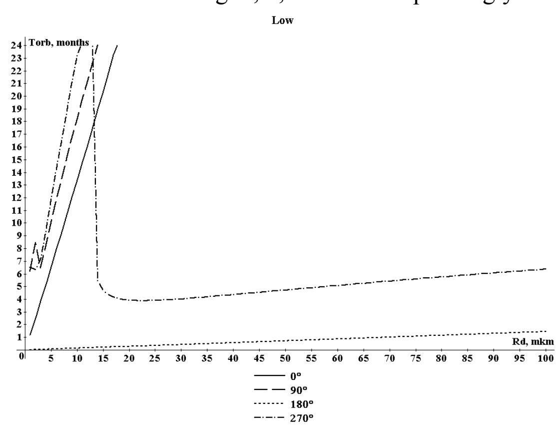

Figure 1

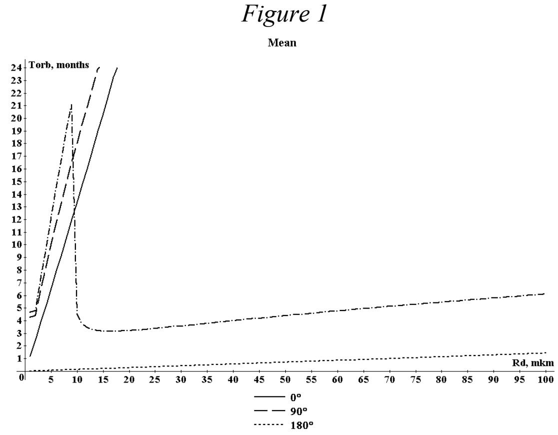

Figure 2

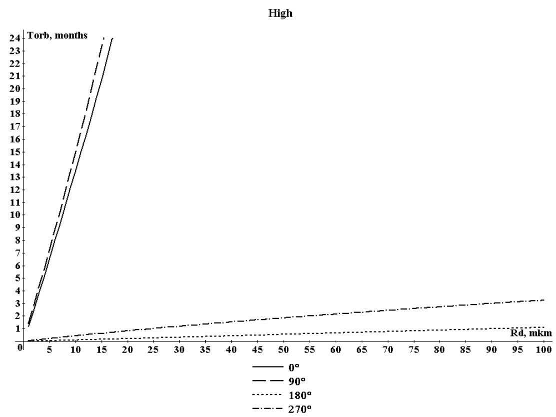

Figure 3

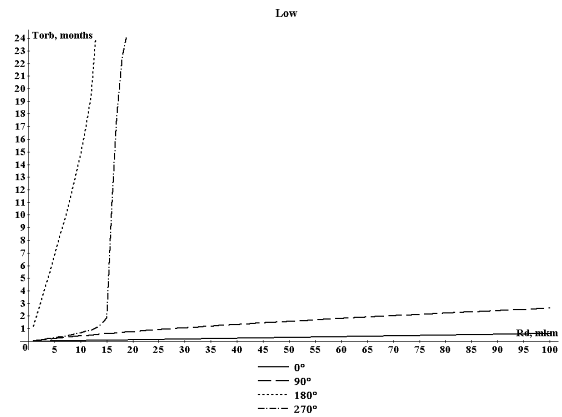

Figure 4

Fig. 1 - 3 show that the microparticles with all radii inside the interval from 1 to 100 microns have long orbital existence time (more than 1 month) if they are injected in the NES for conditions of low and mean activity on orbits with ascending node of 0, 90, and 270 degrees but for conditions of high activity on orbits with ascending node of 0 and 90 degrees. In other cases the life times in the NES more than 1 month occur for microparticle with radii more than some threshold value which depends on activity level and “mother” orbit orientation. In addition obtained calculated data point out the possibility for implementation of modes of MP motion with extremely long times of orbital existence (about and more than 1 year). For example as we can see on Fig. 1 – 3 MP with certain radius values injected on orbits with orientations which are defined by ascending node of 0, 90, and 270 degrees for conditions of low and mean activity can have life times more than 1 year in the NES. Similar result occurs for orbits with ascending node of 0 and 90 degrees for conditions of high activity.

To find out principle possibility of long time orbital existence of microparticles injected in the NES in perigee point of oblong elliptical orbits for which low altitude part is situated on altitudes of Salut and Mir motion the second series of numerical experiments have been carried out. In this case the model elliptic orbit with perigee altitude of 250 km, apogee altitude of 30000 km, angle of inclination of 51.6 degrees has been considered as a MP “mother” orbit. As a previous case the calculations have been carried out for 4 spatial orientations of “mother” orbit which are defined by values of longitude of ascending node of 0, 90, 180, and 270 degrees. A node-perigee angle is supposed to be equal 90 degrees. Calculated dependences of life time of aluminium microparticle on its radius for conditions of low, mean, and high activity for examined orientations of “mother” orbit are shown on Fig. 4, 5, and 6 correspondingly.

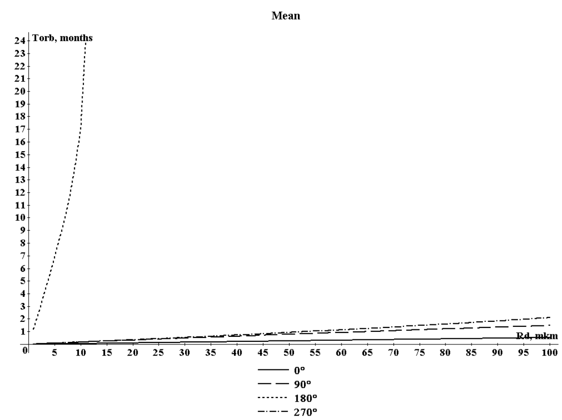

Figure 5

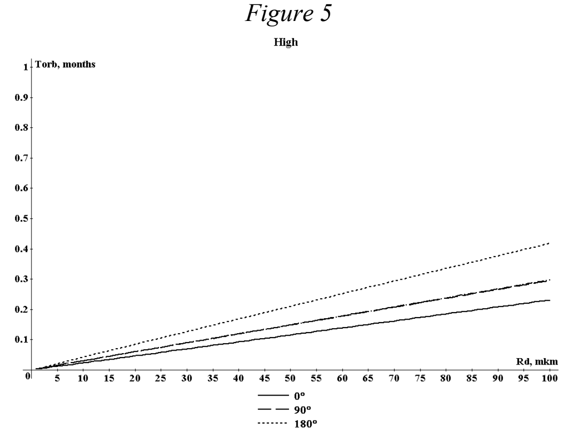

Figure 6

Fig. 4 - 6 show that the microparticles with all radii inside the interval from 1 to 100 microns have long orbital existence time (more than 1 month) if they are injected for conditions of low and mean activity on the orbit with ascending node of 180 degrees. At the same time the long time orbital existence of MP with all examined radius values is impossible if they are injected in the Near Earth Space for conditions of high activity (for all spatial orientations of “mother” orbit) and also for conditions of low and mean activity on the orbit with

ascending node of 0 degrees. In other cases the long life times in the NES occur for MP with radii more than some threshold value which depends on activity level and "mother" orbit orientation. Obtained calculated data point out that for conditions of low and mean activity and for certain orientations of "mother" orbit injected MP can have extremely long times of orbital existence (about and more than 1 year) similar to the case mentioned above. For example as we can see on Fig. 4 – 6 MP with radii more than corresponding threshold values injected on orbits with ascending node of 180, and 270 degrees for conditions of low activity have life times more than 1 year in the NES. Similar result occurs for orbits with ascending node of 180 degrees for conditions of mean activity.

So the results of numerical experiments point out the possibility for implementation of modes of MP motion with extremely long times of orbital existence (about and more than 1 year). Motion modes mentioned above can occur both for MP injection on "mother" orbits similar Molniya orbit with perigee altitude of 460 km and for orbits with considerably lower perigee altitude of 250 km. In last case the found possibility of very long existence of MP injected in the NES is rather unexpected because motion modes with extremely long life times in the NES are actualized in spite of strong aerodynamic drag of background gas on low altitude part of the trajectory.

The analysis shows that the basic physical mechanism which leads to the phenomenon of very long orbital existence of MP is disturbing influence of a solar pressure on MP orbital motion. The calculation shows that this influence leads to the increase of MP orbit perigee altitude for significant time interval and weakening of brake influence of high atmosphere resistance force. To illustrate this statement Fig. 7 shows calculated dependence of orbit perigee altitude for MP with radius of 20 microns on time. This MP are injected in the NES on orbit with perigee altitude of 250 km, apogee altitude of 30000 km and ascending node of 180 degrees for conditions of low activity.

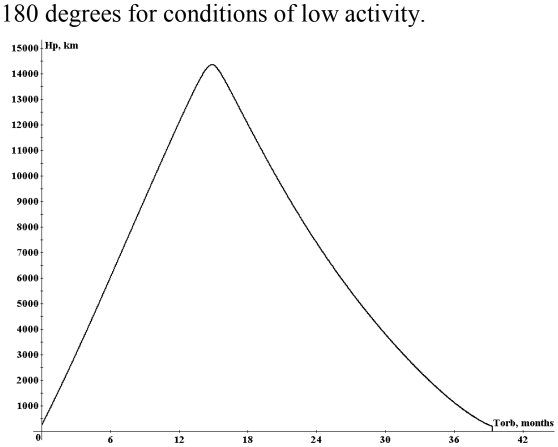

Figure 7

Fig. 7 shows that in the case mentioned above in the course of 15 months after injection moment there is slow increase of MP orbit perigee altitude which then is changed by gradual decrease perigee altitude and stopping of MP orbital existence in 39 months after injection moment. The calculation shows that if solar pressure was absent, in this case atmosphere resistance force would lead to fast decrease of altitude of MP altitude and stopping of MP orbital existence in only 29 days after injection moment.

In addition results of numerical experiments show that the phenomenon of the longest orbital existence of MP is conditioned by combined influence of solar pressure and disturbance of gravitational force caused by Earth polar compression on MP motion. In particular this condition occurs if MP is injected on orbit with perigee altitude of 250 km, apogee altitude of 30000 km, and ascending node of 270 degrees for conditions of low activity. We can see it on Fig. 8 which shows calculated dependences of life time of aluminium microparticles on its radius (these dependences have been obtained if we have taken into account and have left out of account disturbance of gravitational force caused by Earth polar compression). In this case disturbance effect of Earth polar compression have considerable influence on MP orbital existence time for MP radius values more than about 10 microns. For MP radius values more than 15 microns the influence of polar compression effect on MP life time in the NES became rather significant. The physical cause of this phenomenon is conditioned with weakening of dissipative effect of solar pressure force on MP. The weakening is induced by MP orbit precession which is caused by Earth polar compression.

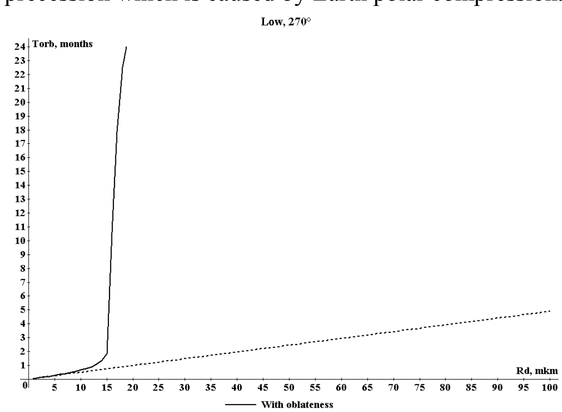

Figure 8

The aim of the second part of paper is to find orbital existence times of aluminium and aluminium oxide spherical microparticles with radii less 1 micron injected in the near Earth space on oblong elliptic orbits with low perigee altitude. The calculations have been carried out subject to disturbing influence of electrodynamics forces which have significant role for MP orbital dynamics in the NES. As a "mother" orbit on which MP are injected the oblong elliptic orbit with parameters similar Molniya orbital parameters has been considered. The orbit has fixed spatial orientation which is described by ascending node of 0 degrees and node-perigee angle of 270 degrees. The calculations have been carried out for conditions of low level of solar and geomagnetic activity.

The calculated data which show that if aluminium oxide microparticles are injected on examined oblong elliptic orbit, disturbing effect of electrodynamics forces has significant influence on orbital existence times of the smallest MP with radii of about or less 0.1 micron in the NES have been obtained. The validity of this statement is illustrated by data of Fig. 9 – 12 on which dependences of orbital existence of MP with radii of 0.2, 0.1, 0.08, and 0.06 microns on true anomaly of MP injection point on “mother” orbit are presented. As we can see from data of Fig. 9 for MP with radius of 0.2 micron disturbing effect of electrodynamics forces practically doesn’t have influence on MP life time in the NES.

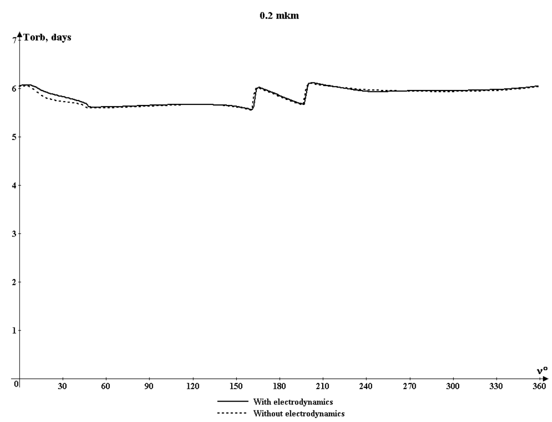

Figure 9

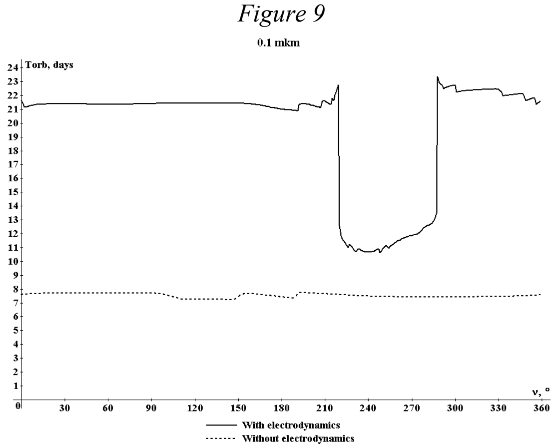

Figure 10

But if MP radius is increasing to 0.1 micron (see Fig. 10), the influence of electrodynamics forces on MP orbital existence times became significant, and for all locations of injection point leads to increase of MP life time in the NES. For MP with radii less than 0.09 micron disturbing effect of electrodynamics forces can lead to both decrease and rather significant increase of MP orbital existence time subject to a location of injection point on “mother” orbit. The calculations show that for injected particles radius values inside the interval from 0.04 to 0.08 microns the implementation of modes with extremely long times of orbital existence (more than 1 year) for aluminium oxide MP orbital motion is possible. Data of Fig. 11 and 12 on which calculated times of orbital existence of MP with radii of 0.08 and 0.06 microns are shown point out to the existence of these motions in particular. As we can see on Fig. 11 and 12 for fixed radius of MP modes of the longest orbital existence are actualized for true anomaly values of MP injection point on “mother” orbit which are situated inside one (see Fig. 11) or a few (see Fig. 12) narrow intervals (their bounds are defined by injected MP radius value).

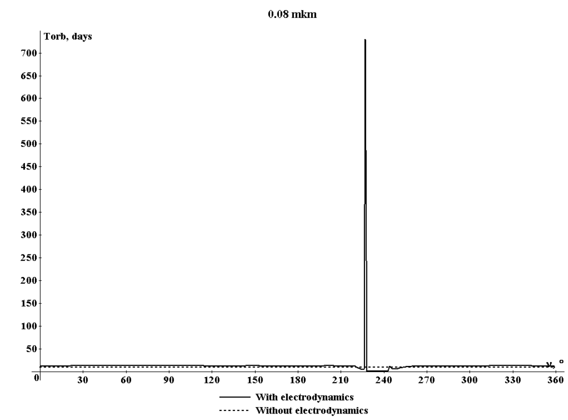

Figure 11

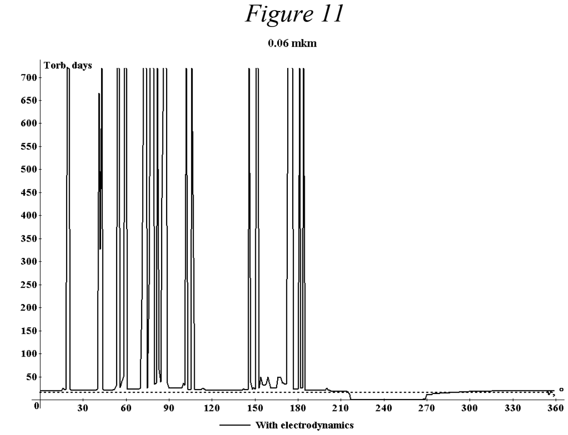

Figure 12

The calculation show that for aluminium microparticles injected on examined oblong elliptic orbit in conditions of low activity the influence of electrodynamics forces on MP orbital existence times in the NES became significant for smaller radii of MP (threshold value is about 0.05 micron). As for aluminium oxide MP the disturbing effect of electrodynamics forces can lead to both decrease and significant increase of MP orbital existence time subject to a location of injection point on "mother" orbit. For example if aluminium microparticle radius is 0.03 micron, maximal life time of MP in the NES is 250 days (this value occurs for the injection point true anomaly of 320 degrees) and is about 50 times of orbital existence time of MP of the same radius which is calculated nonmetering the disturbing effect of electrodynamics forces on MP orbital motion.

Using numerical experiment results there has been shown that the phenomenon of fast increase of life time of the smallest MP in examined case is conditioned with significant decrease of dissipative effect of solar pressure forces on MP. The decrease is caused by precession of MP orbit as a result disturbing effect of Lorentz force. Similar fact of fast increase of life time for the smallest microparticles injected in the NES on circular and slightly oblong elliptical orbits which are situated in Earth's plasmasphere was found earlier by us in [3, 5].

4. CONCLUSION

Obtained calculated data show to principle possibility of long time orbital existence of man-made microparticles made from aluminium or from aluminium oxide (more than 1 month) which are injected in the Near Earth Space on oblong elliptical orbits with low perigee altitude. There is established that the phenomenon of long time orbital existence can occur for both rather large particles with radii more than 1 micron and the smallest particles of radius less than 0.1 micron. This result is serious argument which confirms suppositions made earlier about the fact that long time existence clouds of MP (they are observed by spacecrafts with low altitude orbits) consist of particles that move along oblong elliptical orbits in the NES.

Moreover results of numerical modeling show that in certain conditions microparticles with indicated radii which are injected in the NES on oblong elliptical orbits with low perigee altitude can have extremely long times of orbital existence (about or more than 1 year) and have to be considered as ones of most dangerous possible sources of anthropogenic pollution of the Near Earth Space.

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