STUDY OF POTENTIAL USE OF SPACECRAFT AS REFLECTING OBJECTS

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Abstract- The authors of the article analyze distribution of artificial space objects in Earth orbits according to the main parameters, such as altitude, inclination and eccentricity. The algorithm of constructing ground track of specified spacecraft orbit has been developed. Potential use of artificial spacecraft as reflecting objects which can scatter or reflect radio waves has been studied.

Keywords- Space Objects, Radio Communication, Ground Track, Reflected Radiation.

I. INTRODUCTION

About 60 years have passed since the first spacecraft was launched into space by the Soviet Union in 1957. Since then more than 7000 (7142) space objects have been successfully launched in the world. At present more than 60 countries are actively exploring space, the leaders among these countries are the USA, Russia and China. According to the American organization Union of Concerned Scientists as of May 2015there are 1265 objects in Earth orbit that are operational spacecraft [1]. Distribution of operational spacecraft in near-Earth space as of May 31, 2015 is the following: there are 669 low earth orbit (LEO) AES at an altitude of 160 km to 2000 km, 94 middle earth orbit (MEO) AES at an altitude of 2000 km to 35786 km, 465 geostationary (GEO) AES, altitude is about 35786 km, 37 AES in elliptic orbit.

II. SPATIAL DISTRIBUTION OF SPACE OBJECTS

At present the North American Aerospace Defense Command (NORAD) catalogue has the biggest database of artificial space objects [2]. Visual display of space objects based on the NORAD catalogue data is given in GoogleEarth application (Figure 1).

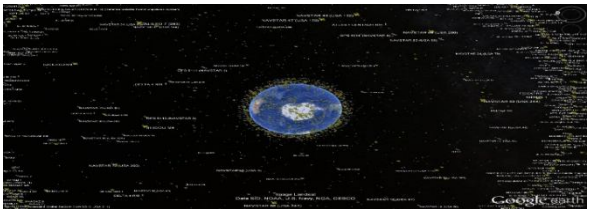


Figure 1 – Artificial space objects in GoogleEarth application

Accessible part of the NORAD catalogue contains data on more than 40640 objects in Earth orbit with the size of more than 10 cm (Figure 2). NORAD catalogue contains the following information: NORAD number, COSPAR number, object name, source, period, inclination (degree), apogee, perigee, eccentric, etc.

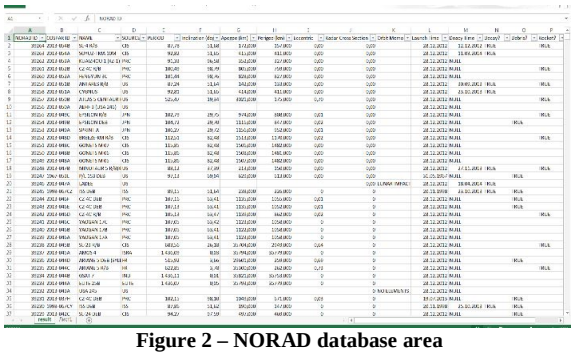


Figure 2 – NORAD database area

Among artificial space objects in near-Earth space there are operational satellites, parts of destroyed satellites, used-up spacecraft, rocket upper stages and objects which were lost during space activities. About 6% of trackable space objects are operational ones. More than 22% stopped their functioning, 17% are used-up upper stages and boosters of launch vehicles and 55% are debris, engineering elements which accompany the launch, explosion pieces and fragmentations. The number of objects bigger than 1 cm is estimated at 600 thousand.

Spacecraft parameters presented in NORAD database give an opportunity to estimate the distribution of space objects in space. Apogee and perigee of every space object are maximum and minimum distances between satellite and Earth accordingly. Semi-major axisis one of the 6Keplerian elements of the orbit which gives us information about satellite orbit. It determines the average distance from the Earth center and it is used for analysis of space objects listed in NORAD database by altitude:

$$a = (\text{Apogee} + \text{Perigee})/2.$$

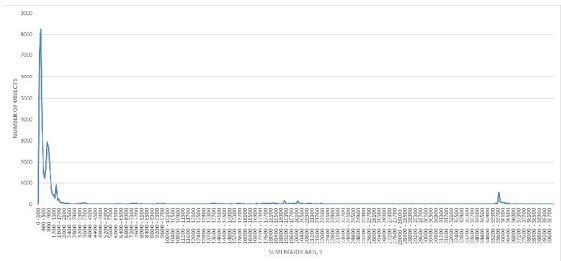


Figure 3 – Altitude distribution of space objects

As can be observed in the chart of altitude distribution of space objects, shown in Figure 3, the most crowded are those regions of the orbit near the Earth which are mostly used for space activities. These are low earth orbit (LEO), middle earth orbit (MEO) and geostationary orbit (GEO). Thus, 90% of space objects orbiting the Earth are located at the altitude of 2000 km (Figure 3). Most space objects in low Earth orbit are located at three basic altitudes: 300 km, 800 km and 1500 km (Figure 4).

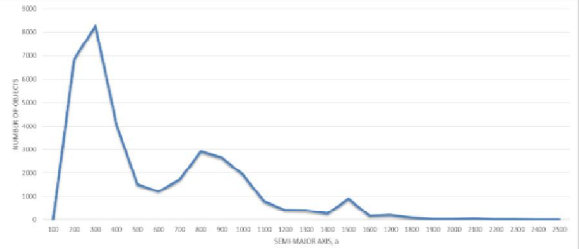


Figure 4 – Altitude distribution of space objects in low Earth orbit

Angle of inclination describes orientation of the orbital plane in space. Inclination of celestial orbit is an angle between its orbital plane and reference plane. The results of the NORAD catalogue analysis shows that inclination angle of 82.2% of space objects lies in the range of 50° - 100°(Figure 5).

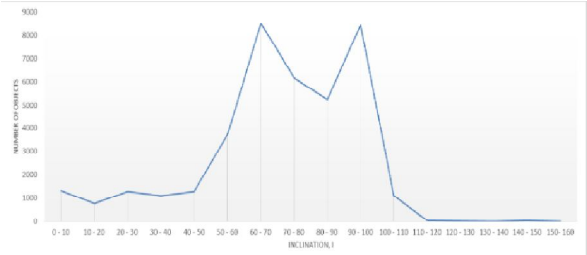


Figure 5 – Inclination distribution of space objects

One of the 6Keplerian elements of the orbit is eccentricity which describes the shape of the orbit. Depending on the eccentricity value *e* the orbit can be circular (e = 0), elliptical (0< e < 1) andparabolic (e > 1).NORAD database analysis shows that eccentricity of 92.4% of space objects lies in the range of 0 – 0.1. This is proved by the chart of eccentricity distribution of space objects shown on Figure 6.

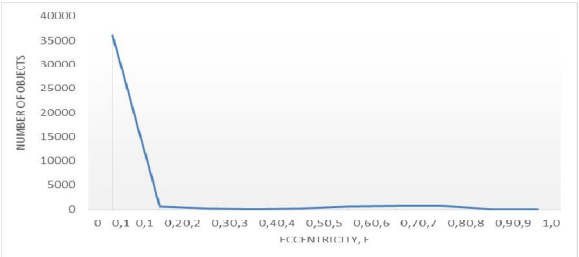


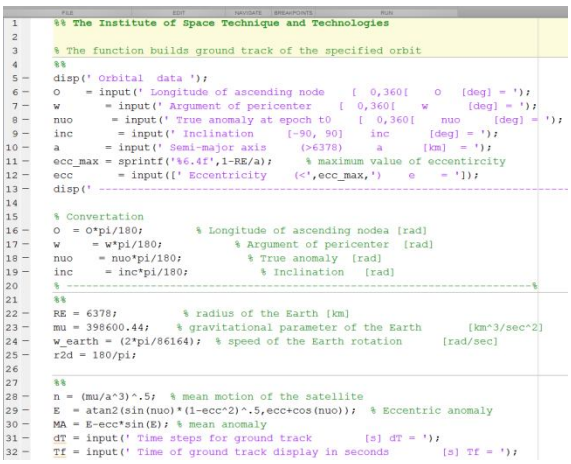
Figure 6 – Eccentricity distribution of space objects

Analysis of distribution of artificial space objects in Earth orbits listed in NORAD catalogue shows that about 35000 of space objects with the size of more than 10 cm are located at the altitude up to 1500 km from the Earth. It is advisable to use space objects at an altitude of 100 km which amount to 7000 as electromagnetic waves reflectors. The altitudes of 300, 800 and 1500 km can be used as distance values of reflecting objects as the most crowded with objects. As most space objects are located in high inclination orbits (50° - 100°) with intersecting planes, average relative speed of their mutual passing is 10 km/sec. From the chart of eccentricity distribution of space objects it can be concluded that the orbit of most artificial space objects orbiting the Earth has circular or elliptical shape close to circular orbit.

III. GROUND TRACK OF SPECIFIED SPACECRAFT ORBIT

Based on the information presented in accessible part of NORAD catalogue, distribution of artificial earth-circling satellites in space can be estimated. But it is impossible to build a track of satellite orbit. This requires additional information which can be retrieved from databases of different organizations. Usually the search of other satellite parameters is performed by NORAD number which represents a unique five-digit identification number of artificial earth-circling satellites. With this number you can get TLE format which is an element set of artificial earth-circling satellite orbit. Two-line format of data TLE was introduced by NORAD and accordingly is used in NORAD, NASA and other systems which use data to determine location of specified space objects.

The members of the Institute of Space Technique and Technologies have developed an algorithm of constructing ground track of specified spacecraft orbit which allows to estimate the movement of sub satellite point on the Earth's surface. A computer model of spacecraft orbit projection on the Earth's surface has been developed in Mat lab environment. Figure 7 shows a fragment of programme unit of specified orbit ground track in Mat lab environment.



```
%% The Institute of Space Technique and Technologies

% The function builds ground track of the specified orbit
%%
disp(' Orbital  data ');
O    = input(' Longitude of ascending node    [  0,360[    O   [deg] = ');
w       = input(' Argument of pericenter    [  0,360[    w      [deg] = ');
nuo      = input(' True anomaly at epoch t0    [  0,360[    nuo     [deg] = ');
inc       = input(' Inclination     [-90,  90]    inc      [deg] = ');
a       = input(' Semi-major axis     (>6378)     a      [km]  = ');
ecc_max = sprintf('%6.4f',1-RE/a);     % maximum value of eccentricity
ecc       = input([' Eccentricity    (<',ecc_max,')    e    = ']);
disp(' ------------------------------------------------------------');

% Convertation
O  = O*pi/180;          % Longitude of ascending nodea [rad]
w     = w*pi/180;           % Argument of pericenter  [rad]
nuo    = nuo*pi/180;          % True anomaly  [rad]
inc     = inc*pi/180;           % Inclination   [rad]
% ------------------------------------------------------------%
%%
RE = 6378;          % radius of the Earth [km]
mu = 398600.44;    % gravitational parameter of the Earth       [km^3/sec^2]
w_earth = (2*pi/86164);  % speed of the Earth rotation       [rad/sec]
r2d = 180/pi;

%%
n = (mu/a^3)^.5;  % mean motion of the satellite
E  = atan2(sin(nuo)*(1-ecc^2)^.5,ecc+cos(nuo));  % Eccentric anomaly
MA = E-ecc*sin(E); % mean anomaly
dT = input(' Time steps for ground track        [s] dT = ');
Tf = input(' Time of ground track display in seconds       [s] Tf = ');
```

Figure 7 – A fragment of programme unit of specified orbit ground track

The main input data of a computer model of spacecraft orbit track are longitude of ascending node, argument of pericenter, true anomaly, inclination, semi-majoraxis and eccentricity. Orbital parameters of GENESIS 1 spacecraft with NORAD number 29252 were taken as an example when developing the model. (Table 1)

Table 1 – Input data

Orbital parameters	Values
O - Longitude of ascending node, degrees	308.9529
w – Argument of pericenter, degrees	261.2949
nuo – True anomalyat epoch t_0, degrees	10.3494
inc – Inclination, degrees	64.5079
a –Semi-major axis, km	523.5
ecc – Eccentricity	0.00513900

The results of a computer model of specified spacecraft orbit ground track are displayed on the world map (Figure 8).

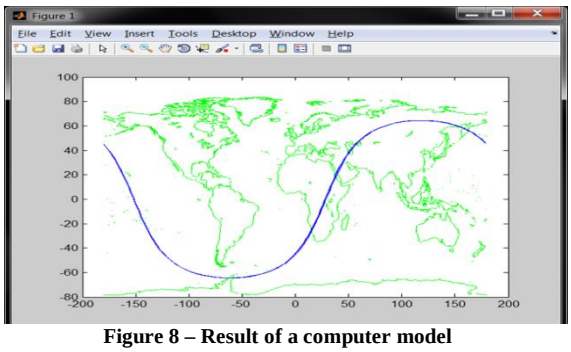


Figure 8 – Result of a computer model

IV. SPACECRAFT AS ARTIFICIAL REFLECTORS

Artificial spacecraft contribute to inhomogeneity of the open space. As $\varepsilon_a$andμ_a parameters of their surface differ according to ε_o and μ_o environments, consistency of radio wave propagation velocity vector is disrupted. As a result the object converts the radio signal: some part of the energy is reflected back, another part is absorbed by the object, and if the object is radar-transparent, the energy is refracted, changing the direction of radio wave propagation. The case when the artificial space object is the source of scattered radiation is interesting for the analyzed system. Spacecraft consist of such materials as iron, steel, copper, aluminium. These metals are radar-reflective materials which can scatter or reflect electro-magnetic radiation. For this reason artificial spacecraft are considered to be artificial reflectors of radio waves.

Primary radio wave induces conduction currents (in conductor) or bias currents (in insulator) on the surface of space objects. These currents are the source of secondary radiation in different directions or scattering of radio waves. Electro dynamic calculation of secondary radiation field is possible only for a limited number of bodies of relatively simple shape (half-wave dipole, sphere, metal sheet, etc.). But most real space objects have more complicated shape. It is advisable to describe their secondary radiation statically.

As some spacecraft are located within one specified volume of space they can be described as a group of objects which consists of separate single objects.

The most important property of space objects is scattering cross-section which is a quantitative characteristic of object's ability to scatter energy in the direction of the receiver. Reflective properties of a group of objects depend on its size (usually there is a strong dependence on the area of object projection onto the plane perpendicular to the radio wave propagation direction), configuration, surface material, signal wavelength, its polarization and radiation direction.

CONCLUSION

The results of NORAD catalogue analysis and conducted calculations showed that at any given time not less than 187 space objects pass over the Republic of Kazakhstan,which area equals to 2 717 300 km^2, at an altitude of 1500 km. These spacecraft can be used as reflecting objects in radio communication.

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