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Analysis of the Earth–to–Moon trajectories of new type with the temporary capture of a particle by the Moon

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A qualitative theoretical and "exact" numerical analysis of the Earth–to–Moon trajectories of new type [1–3] has been performed. These trajectories have an initial flight from the Earth to a large distance (of about 1.5 million km), the following passive flight to the Moon's orbit, an approach to the Moon with a decrease of an energy of a particle (spacecraft) selenocentric motion to a negative value and the temporary capture in an elliptic orbit of the Moon's satellite.

A qualitative analysis of three principal flight's parts for these trajectories is performed. The effect of the Sun's gravity on a lifting of a perigee of the particle's geocentric orbit — from the Earth to a close neighborhood of the Moon's orbit — during the first part of the trajectory of the particle is analyzed. The analysis has shown that the perigee's passive lifting to the Moon's orbit is possible if there are the initial particle's flight to sufficiently large distance from the Earth and suitable orientation of the Earth–Sun direction relative to the particle's orbit. A qualitative analysis is performed to study the effect of the Earth's gravity on a decrease of the particle's selenocentric energy — from a positive (hyperbolic) value to the zero (parabolic) one and to the capture's beginning — for the second part of the particle's motion during its approach to the Moon. A model of this process is developed, its analytical solution is given. It proves the possibility of such energy decrease for the trajectories under investigation. For the final part of the flight, a qualitative analysis of the effect of the Earth's gravity on the following decrease of the energy of the particle's selenocentric motion — from zero to a negative value for a final elliptic orbit of the Moon's satellite with a high apocenter — is performed.

An algorithm of numerical calculation of the Earth–to–Moon trajectories of this type is developed. The algorithm determines the trajectory by high–accuracy numerical integration of differential equations of the particle's motion with taking into account the gravity of the Earth (and its main harmonic c_{20}), Moon and Sun as the mass points. The coordinates of the Moon and the Sun are taken using the JPL–ephemerides DE403. A stage of the numerical simulation of the particle's motion is carried out. Several trajectories of this type are determined. Their main characteristics are given. It is shown that they are in sufficiently good agreement with the results of the qualitative theoretical analysis. For these trajectories the particle's distance from the Earth reaches $\sim$ 1.5 million km. The perigee of the particle's orbit rises to $\sim$ 0.5 million km by means of the Sun's gravity for the first part of the flight. The velocity at "infinity" relative to the Moon decreases by the Earth's gravity from $\sim$ 0.4 km/s to zero at the particle's selenocentric distance of $\sim$ 180–100 thousand km for $\sim$ 3 days during the second part of the flight. Then, for the final part of the flight, the capture of the particle by the Moon to the final elliptic orbit with altitudes of $\sim$ 75 000 km in apocenter and 100 km in pericenter is performed for $\sim$ 14–30 days. This orbit is unstable and the capture is temporary. An active effect (e.g., a velocity impulse) is required to transfer the particle to a stable orbit with a low enough apocenter. Otherwise, in some time ($\sim$ 14–40 days) the particle transfers to a hyperbolic orbit and escapes from the Moon's vicinity.

Practical efficiency of these trajectories is discussed with relation to their use in astronautics, e.g. for a soft landing on the Moon's surface and for the transfer to an orbit of the Moon's artificial satellite. The problem of navigation for these trajectories is discussed. They use regions of the weak stability of the particle motion in the Earth–Sun and Earth–Moon systems where the small variations of parameters of motion of the particle result in big changes of the trajectory [1]. So, the high–exact measurements and control of motion of the particle are required.

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