Keldysh Institute of Applied Mathematics of Russian Academy of Sciences

4. Information about Scientific Projects of the Federal Space Program of the Russian Federation with are at the Development (Working out) Stage

4.1 The “VENERA-D” Project

Development of mathematical models for the analysis of circuits perform dynamic operations in the project "Venera-D" to ensure bringing the lander to the required Venusian areas and for the subsatellite’s injection on the orbit of artificial satellite of Venus.

The analysis of the flight trajectory to Venus in the start windows 2020 - 2025 and recommendations on the choice of options for the orbital and landing scheme was developed. Project "Venus-System" provides that for scientific research in the orbit of the artificial satellite of Venus (WAS) are two spacecraft: the main spacecraft and subsatellite.

The main SC has on-board propulsion system that allows to perform orbital maneuvers and subsatellite is passive flight. Both spacecraft flies to Venus on a hyperbolic orbit in a bundle and then, after inhibition of Venus, separated from the bunch subsatellite.

After separation the subsatellite main spacecraft goes into a circular orbit an artificial satellite of Venus. Next there is a separation of the descent vehicle and performing braking maneuver lander. Developed spacecraft maneuvering circuits in orbit around Venus, providing excretion subsatellite flight and reentry vehicle in the atmosphere of Venus to reach its surface. The analysis of requirements longitude reachable on the surface of Venus in the windows starts in 2020 – 2025. The comparative analysis and rationale for the selection of flight

trajectories of Earth-Venus with the transition into a polar orbit WIS windows starts 2020 - 2025 years. and developed recommendations for choices orbital and landing scheme.

Another approach is to save the characteristic velocity on the flight with the using of a gravity assists. The simplest scheme of flight using gravity assists improves the gravity assist near Earth. Spacecraft after lunch from the Earth goes to the heliocentric orbit that provides a meeting with the Earth in about a terrestrial year. As a result, the spacecraft flyby near the Earth sent SC to Venus. As a result is the reducing of the SC's gravity assist asymptotic velocity to an acceptable value. It is shown that it is possible to gravity assist from Earth, which provides with Venus approaching the asymptotic rate of less than 3 km / c.

The analysis of dynamic circuits realizing landing with:

- class rebounding entry paths into the atmosphere of Venus;
- "weak" gravitational capture.

The above new approaches and techniques were presented as sectional report "Different scenarios of the" Venera-D "mission" at a joint meeting of Russian scientists and leading specialists of ESA and NASA "Venera SDT Meeting", held October 6-7, 2015, Moscow , at the Institute of Space Research:

Grushevskii A.V., Golubev Yu.F., Koryanov V.V., Tuchin A.G., Tuchin D.A. Different scenarios of the "Venera-D" mission. Venera SDT Meeting, 06-07 October 2015, IKI, Moscow).

http://www.kiam1.rssi.ru/index.php?id=pub

4.2 “LAPLACE-P”

The studying of far regions of the Solar system should use natural sources of energy, which primarily include gravitational maneuvers. Using Tisserand-Poincare diagrams based procedure for the synthesis of chains of gravitational maneuvers near the natural satellites of Jupiter Systems to implement space missions, the low-budget expenditure on the characteristic speed, the resulting radiation dose and time of execution.

Developed adaptive synthesis algorithms to overcome ballistic determinism due Tisserand criterion that is inherent in a simplified scenario. It is shown that the diversity of the gravity of the ensemble in the Jovian system, not only complicates the accurate ballistic mission analysis, but, when its effective use, allowing you to tailor algorithms for constructing scenarios of gravity assist at the task-specific space missions, including circumvention of dangerous radiation areas, as well as landing on one of the Jupiter's satellites ("Laplace P") at a reasonable cost, resources and time.

To solve this problem you need to decrease the asymptotic speed of the spacecraft relative to the natural satellite of a planet. Reducing the asymptotic rate is achieved through a large number of passages of the scope of the natural satellites of gravity assist. Restrictions problems caused by high levels of radiation in the Jupiter system and the maximum duration of a space mission.

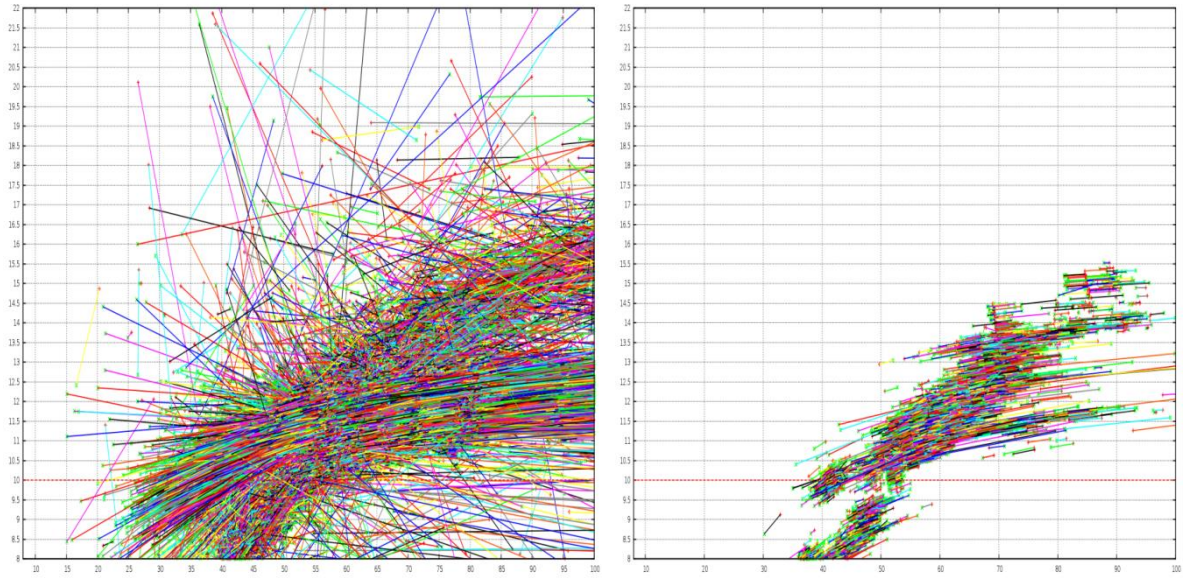

Fig. 5 Primary search possible gravity assist on the Tisserand's graph in "apocentre / pericentre" coordinates (tens of millions of options) as a result of a selection algorithm key growth points for the "reduction" scenarios with simultaneous rise pericenter spacecraft orbit is reduced to just a few thousand monitoring options

The KIAM's implemented algorithm to overcome the "paradox solo disturbances" using real ephemeris of Jupiter and its natural satellites. At the same time the phase is performed bypassing the zone of increased radiation and reduces the asymptotic speed of the spacecraft relative to the natural satellite. The developed methods and algorithms are used to reduce the asymptotic speed of the transition from the model of the restricted problem of three bodies to the conditions of the problem, and four more bodies. As a result, it becomes possible to synthesize comfortable on the accumulated dose of radiation of space missions in the Jovian system.

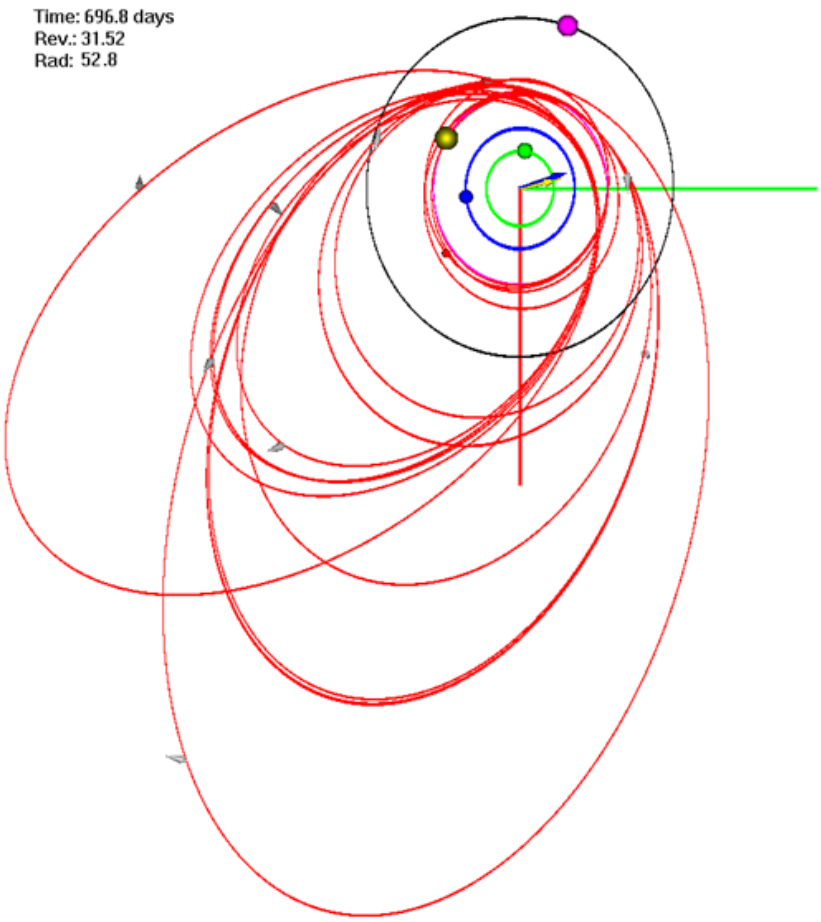

Fig. 6. Typical fragment of the synthesis scripts of SC's gravity assist in the Jovian system, which is very comfortable for the receiving total ionizing dose of radiation

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1. Golubev Yu.Fu, Grushevskii A.V., Koryanov V,V., Tuchin A.G., Tuchin D.A. Bifurcation point during gravity assist in the Jovian system // Reports of the Academy of Sciences. 2015. T. 462. № 2. S. 154-157.
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3. Golubev YF, Grushevskii AV Koryanov VV, Tuchin AG, Tuchin DA Methods of forming large inclination of the orbit of spacecraft using gravity assist // Preprint IPM them. MV Keldysh. 2015. № 64. S. 1-32.
4. Golubev YF, Tuchin AG, Grushevskii AV Koryanov VV, Tuchin DA Sea IM, AV Simonov, VS Dobrovolsky The main methods of synthesis paths for space mission scenarios with gravity assist in the Jupiter system and landing on one of its satellites // Bulletin of Sumy. SA Lavochkin. 2015. № 4. S. 97-103.
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8. Grushevskii A.V., Golubev Yu.F., Koryanov V.V., Tuchin A.G., Tuchin D.A. Advanced methods of low cost mission design for icy moons exploration. // 2nd COSPAR Symposium. Water and Life in the Universe. 09–13 November 2015. Foz do Iguaçu – Brazil. Session 3- Satellite and probe missions for water remote sensing on Earth, planets, and other celestial bodies. Abstracts. URL: http://cosparbrazil2015.org/?page_id=4341#toggle-id-30 [2, 4-5, 8-13].

4.3 “InterhelioProbe”

An analysis of the proposed ballistic NPO Lavochkin schemes flight center of mass of the spacecraft "InterhelioProbe" and the development of requirements for the navigation of its movement, taking into account the disturbing effects of the Earth and Venus on the basis of accurate models of spacecraft motion is developed. The analysis of the flight navigation support "InterhelioProbe" to the disturbing influences on him of the Earth and Venus. The requirements to ensure flight navigation spacecraft "InterhelioProbe".

An analysis of the proposed ballistic Lavochkin NPO spacecraft flight schemes "InterhelioProbe" from the disturbing effects of the Earth and Venus is developed. The analysis is based on accurate models of these flight circuits. It has been shown that it is appropriate to consider the chain on the basis of orbital resonances 1: 1 and 3: 4 (SC’s orbital period relating period to Venus), ending access to the operational orbit (non-resonant gravity assist), which should provide a large amount of the final operational orbit inclination. Consider three schemes combinations of these resonances. Most preferred is the scheme 1: 1, 3: 4.

The effect of corrections of errors and navigation performance errors on the accuracy of the spacecraft "InterhelioProbe" into a working orbit and costs inherent speed of parry. Acceptable option in which to bring the spacecraft to Venus error does not exceed 0.25 ° for inclination to the equatorial plane of Venus and 25 km in height pericenter.

It is shown that the asymptotic velocity approaching the Venus equal to 17.5 km / s, the maximum value of the inclination of the heliocentric orbit of the spacecraft to the ecliptic plane, which can be obtained as a result of a series of gravity assist is 30 degrees.

"InterhelioProbe" The requirements to ensure flight navigation satellites. In the areas of departure from the planet before the first correction trajectory measurements of the radial velocity and slant range must be carried out by two ground stations every 12 hours in the presence of visibility. In the areas of flight trajectory measurements should be carried out every day two measuring points. In areas closer to the Earth and Venus to 7 days before reaching is the minimum distance to the planet should be carried out VLBI.

In the first six months of the flight path of flight Earth - Venus should be held on the basis of the ground station antenna P-2500 in Yalta, because not ensured the visibility of the station in Bear lakes.

On departure trajectories from Earth elevation for ground stations in Yevpatoriya and Ussuriisk does not exceed 10°. Therefore, they should be provided with the measurement to account for tropospheric component trajectory measurement errors.

A method of forming a large inclination of the orbit of spacecraft using multiob- series of gravity assist. The technique uses real ephemeris Earth, Venus, and other natural bodies of the Solar system.

Proposed methods for the application of a series of gravity assist with real ephemeris Earth, Venus, and other natural bodies of the solar system can be employed as a basis for ballistic designing adaptive scenarios space mission (mission "InterhelioProbe" and others.), Designed to study the outer region of the solar facilities system and inner heliosphere of the sun at close range.

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4.4 A Study of the Asteroid Apophis Artificial Satellite Orbital Motion Dynamics

In frame of a possible Apophis' mission characteristics study, an analysis of the spacecraft orbital motion is performed with taking into account the perturbations from far celestial bodies (Sun, Earth, Moon, Jupiter, and Venus), Apophis' non-sphericity, solar radiation pressure, and the asteroid rotation about its maximum moment of inertia.

It is shown we can take a such spacecraft' orbit around the asteroid that it will be stable for a long enough time: about a month for the main spacecraft' low orbit (with initial radius of about 0.5 km), and several years, till a close approach of Apophis to the Earth in April of 2029, for a small probe's high orbit (with initial radius of about 1.5 km).

This long motion near the asteroid can allow us to improve essentially our information of the Apophis' orbit and make more valid an analysis of its possible impacts with the Earth and Apophis hazard mitigation problem. Figure 1a gives an example of such orbital motion of the probe with a radio beacon from 2020 till April of 2029 in rotating plane that is perpendicular to the line Asteroid-Sun.

The results of this study are presented to IX International Conference "Near-Earth Astronomy" (Russia, Terskol, 2015), published in Proceedings of this Conferences and in the Doklady Physics (2016, Vol. 468, No 4, pp. 403-407).

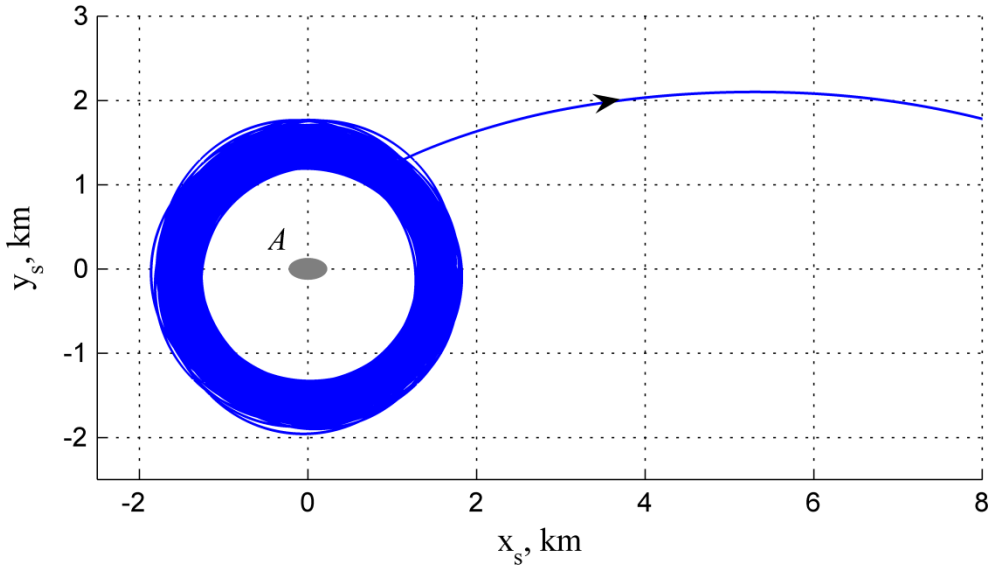

Fig. 1. Orbital motion of the probe with a radio beacon around the Apophis from 2020 till April of 2029

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4.5 An Analysis of characteristics of the astronomical space complex for detecting and determining the orbit parameters for dangerous to the Earth celestial bodies

Now, Russian corporation “Cometa” is designing an astronomical space complex ”Nebosvod” to detect celestial bodies that are dangerous for the Earth and determine their orbit parameters. The

Complex includes one or two spacecraft (SC) on geosynchronous orbits (GSOs) and one SC on the Earth orbit. These SC are proposed to have high-accuracy telescopes for detecting and measuring the celestial bodies. In connection with this Project, an investigation of accuracies for estimation and prognosis of the dangerous body orbit that is close to Apophis one is performed. There were used for this the optical measurements by two SC on GSOs with measurement errors in range 0.02-1″ and some measurement programs on a far from the Earth part of the flight, middle part, and close one. The analysis has shown that the Complex allows having good enough accuracy in the dangerous body orbit estimating. Figure 1 gives an example of the estimating error ellipses for asteroid geocentric orbit aim vector.

There is also performed an analysis of the structure and characteristics of the Information Processing Center that is proposed to be organized in the Complex. The Center will mainly fulfill the high-accuracy and quick processing of large volume of optic-electronic information.

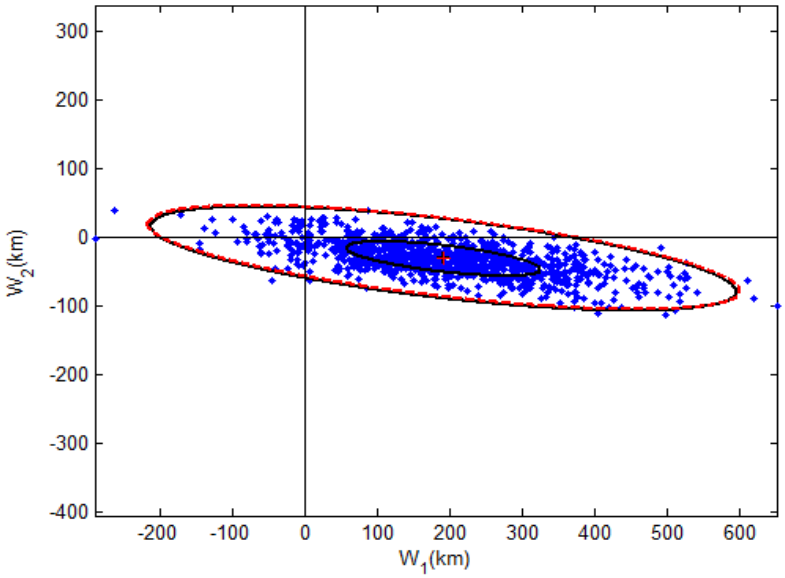

Fig. 1. The estimating error ellipses for asteroid Apophis geocentric orbit aim vector (σ, and 3σ). The model measurements are performed from 01.06.2028 till 14.01.2029, through 12 days. The measurement error is σ_m=0.2″.

The study results are presented to IX International Conference "Near-Earth Astronomy" (Russia, Terskol, 2015), published in Proceedings of this Conference and also presented to XXIII Science-Technology Conference "Complicated automated information-control Systems" (Russia, Moscow, April of 2016).

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