GEODESY AND CARTOGRAPHY SUPPORT FOR THE MISSION «PHOBOS-GRUNT”

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A new page is opening in the history of Russian cosmonautics. In October 2009 the launch of spacecraft «Phobos-Grunt» is declared. It is also included in the Federal Space Program. That is why it is possible to speak about the revival of planetary directions for space studies in Russia. As a result of preparations for the implementation of the project will be obtain not only the new knowledge about the Mars planet moon, but also be accelerated a new generation of the Solar System researchers building their work on the basis of Russian space technologies.

The main purpose of the «Phobos-Grunt» spacecraft flight is the Phobos soil sample delivery to the Earth, the larger Mars moon study using a set of scientific equipment installed on the spacecraft board. That is why it is required the spacecraft soft landing at a pre-selected area on the Phobos surface. At this stage of the project two organizations (Lavochkin NPO and IPM RAN) have developed a scenario of flight. Russian comparative planetology scientists (GeoKHI RAN), have pre-selected potential landing areas, and Planetary Cartography Laboratory (MIIGAiK) has become responsible for mission geodesy and cartography support. A general view of the spacecraft «Phobos-Grunt» is shown in Figure 1.

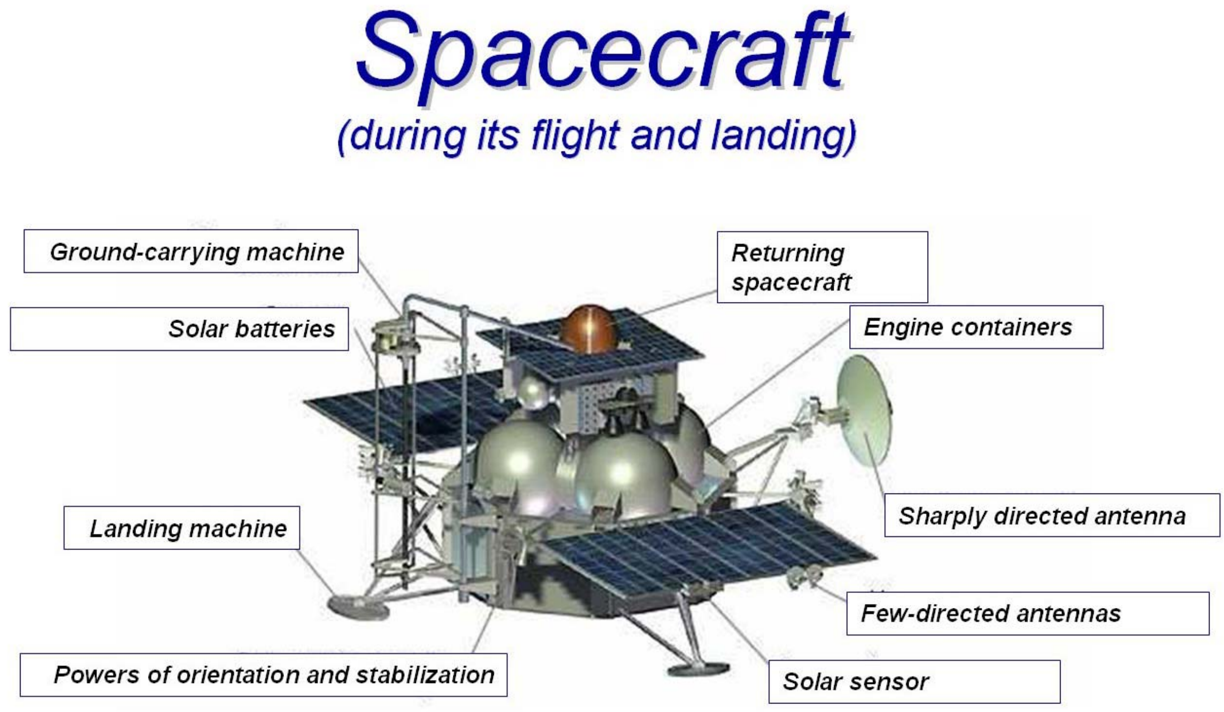

Fig. 1. A general view of the spacecraft «Phobos-Grunt»

The start of the "Phobos-Grunt" spacecraft is scheduled for October 2009. During the approximately one-year continuing flyby to the Mars it will be taken a few corrections of the spacecraft trajectory. Two final corrections, which should provide the spacecraft to Mars elliptical satellite orbit, will be implemented for the 20-30 and 7-10 days correspondingly. They must approach it to the Mars, when the distance to it will be 6 million km and 3 million kilometers, respectively. As a result, the error in the location of the spacecraft at the entrance into the field of Mars attraction must not exceed 100 km. Entering the Mars gravity field, the spacecraft starts moving elongated in the direction of the Sun in an elliptical orbit with two axes, namely 45000 and 5000 km and a rotation period of about three days, which coincides with the plane of the Phobos orbit. After a few corrections on an elliptical orbit the spacecraft using propulsion is transferred to the observation orbit. This circular orbit lies in the plane of the Phobos orbit and has rotation period of approximately 8.3 hours. The height of the observation orbit exceeds the height of the Phobos orbit about 500 km. As far as the spacecraft moves in the observation orbit with some error, then within a few days its parameters should be corrected. The spacecraft orbit observation planned time is 30-40 days [1].

Then the spacecraft should be transferred to the quasi-synchronous orbit with the orbital period, which is equal to the period of Phobos itself. The spacecraft in the Phobos coordinate system turns around the moon of Mars on a trajectory close to an ellipse. Phobos gravity provocates that the center of the ellipse has temporal oscillations resulting in an unclosed trajectory. During this orbit driving the distance to the surface of Phobos will vary - from 30 to 70 km. Transmitting to the final orbit can be done through an intermediate orbit. The satellite will remain at this orbit about 30 days. This time will be used for the Phobos surface imaging with high spatial resolution. After processing the received images a digital terrain model (DTM) will be created and clarified the choice of landing area. Landing on Phobos starts with the distance to the surface about 30 km and takes about 30 minutes. When the spacecraft approaches to the region of landing television monitoring together with laser altimeter, it will be used for selection a landing site size of ~ 10 m without dangerous roughness. In the process of landing it will be sending some images to the Earth. They will be having thr improving resolution. After taking samples of Phobos soil the return module comes back to the Earth. After the flight module to go back the experiments on the surface of Phobos will be continued by the landing module.

MIIGAiK Planetary Cartography Laboratory is responsible in front of solving the following main tasks: calculation of corrections to the coordinates of the landing site and then a variety of cartographic material on Phobos, which should be compiled on the basis of new high resolution images coming from the spacecraft "Phobos-Grunt".

The first step is to briefly describe the study of Mars satellite in relation to geodesy problems. One of the first Phobos digital modeling was established under the leadership of J. Thomas in 1989. This model was the result of the images processing receiving from the American interplanetary stations series Viking and Mariner. The model consists of 98 ground control points and is the greatest achievement of its time. This model was chosen as a base and software embedded in the on-board computer complex of the"Phobos-Grunt" spacecraft. In 1991, the Thomas model was explained by T. Duxbury, using the spherical functions and taking into account the perturbed motion of Phobos (primarily libration). As a result, the network was obtained consisting of 351 points [2]. Most recently the spacecraft Mars-Express has flyby at a distance of just 93 km from the surface of Phobos. Before this spacecraft of the German Aerospace Center (DLR) was on Mars polar orbit and made Phobos surveying at a distance of less than 1000 km from its surface. This allowed to cover ~ 78% of the Phobos surface with high-resolution images [3] (see attached diagram in Fig. 2).

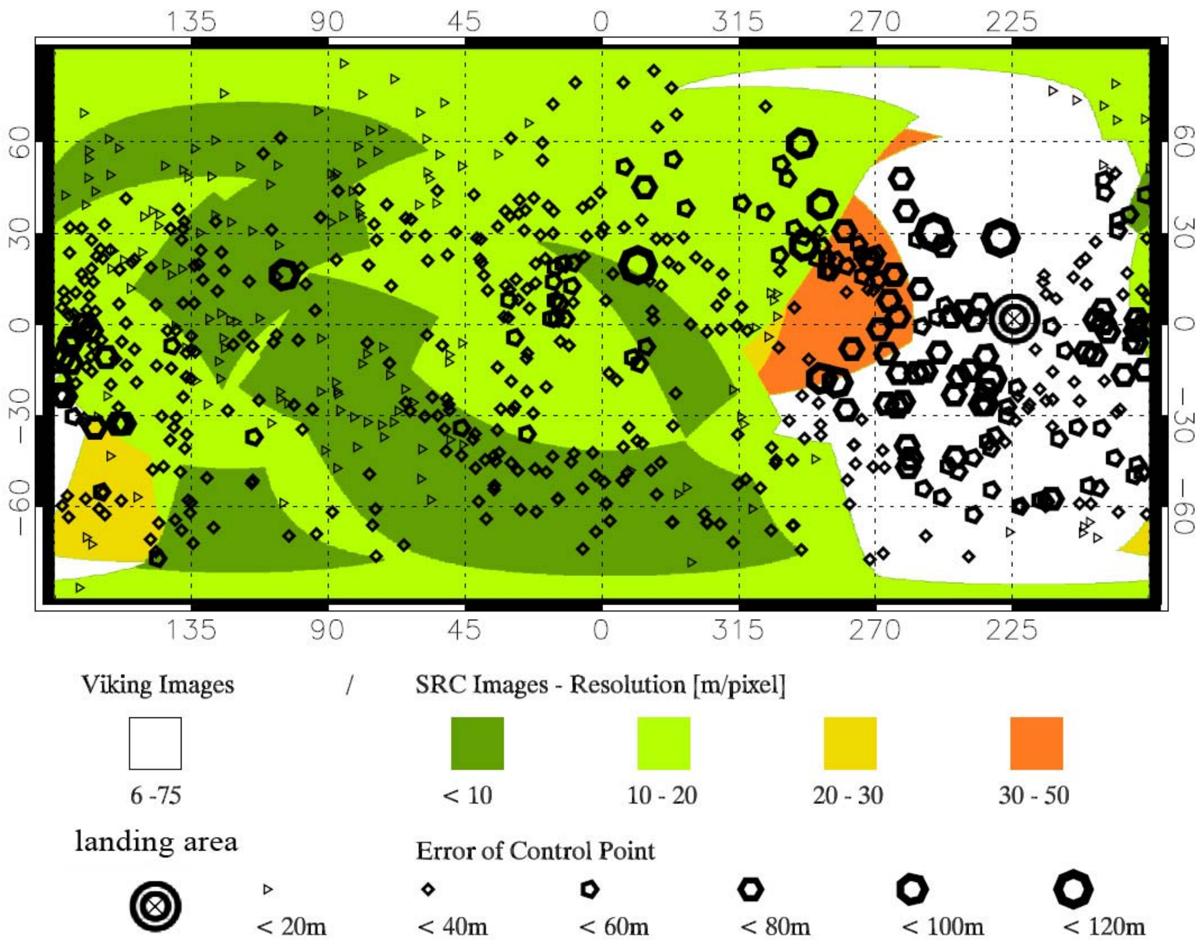

Fig. 2 Phobos spatial resolution images and position of ground control points on the surface.

DLR scientists using the results of these surveys created a new network of 665 ground control points and a digital model of Phobos of high accuracy (accuracy of control points is presented in figure 2) taking into account the revised satellite perturbed motion of Phobos [3].

But the interesting landing area was still not covered by high-resolution images, and Viking spacecraft images was used for this new model in spite of their exterior orientation parameters are known with low accuracy [4].

Summering up, we can to establish a fact that all of the models and their corresponding coordinate systems have a relatively accuracy that does not exceed 100 m. At the same time, the coordinates of the landing point should be determined with an accuracy not worse than 10 m.

Thus, a team of MIIGAiK Planetary Cartography Laboratory has a complicate task: the creation a new coordinate system and the control points network, which should ensure the accuracy of landing at the given point.

To fix it, the authors propose the following working algorithm:

- Flyby spacecraft “Phobos-Grunt” to Phobos and surveying with high spatial resolution;
- Selection of control points and the photogrammetric processing of images;
- Creation of a new coordinate system and the new control points with a high accuracy in the vicinity of the spacecraft intended landing using the results of processing;
- Creating Phobos digital elevation models (DEM) with the increased accuracy in the vicinity of the expected spacecraft landing;
- Conversion of the old landing place coordinates to the newly established system of coordinates

• Calculation of corrections in the coordinates of the landing place for the coordinate system established in the on-board computer complex and transmitting them on it;
• Landing on the Phobos surface.
In order to follow the proposed algorithm, all the work would be divided into three stages:
1. Preliminary stage
• Research and analysis of existing coordinate systems, the choice of relevance for future DTM;
• Creation of software for processing of stereo images;
• Testing of the created software using images from Viking and Mars Express;
• Debug software;
• Establishment of a coordinate system and the DTM results for validation of software.
2. Work on an quasi-synchronous orbit
• Surveying on quasi-synchronous Phobos orbit, which would create a network of reference points and coordinate system;
• Processing of images obtained on the results of this survey;
• Creating a system of coordinates and Phobos DTM increased accuracy in the place of spacecraft landing site;
• Calculation of corrections to the coordinates of the landing place.
3. Work on the surface of Phobos
• Data from the star sensor module planting;
• Clarify the perturbed motion of Phobos;
• Clarifying the position of the Phobos mass center and the establishment of an appropriate coordinates system.

At the first moment the the interim results of the work (preliminary phase) is summarized, as actively developing software for images photogrammetric processing and creating DTM of Phobos. Type of working window presented in Fig. 3.

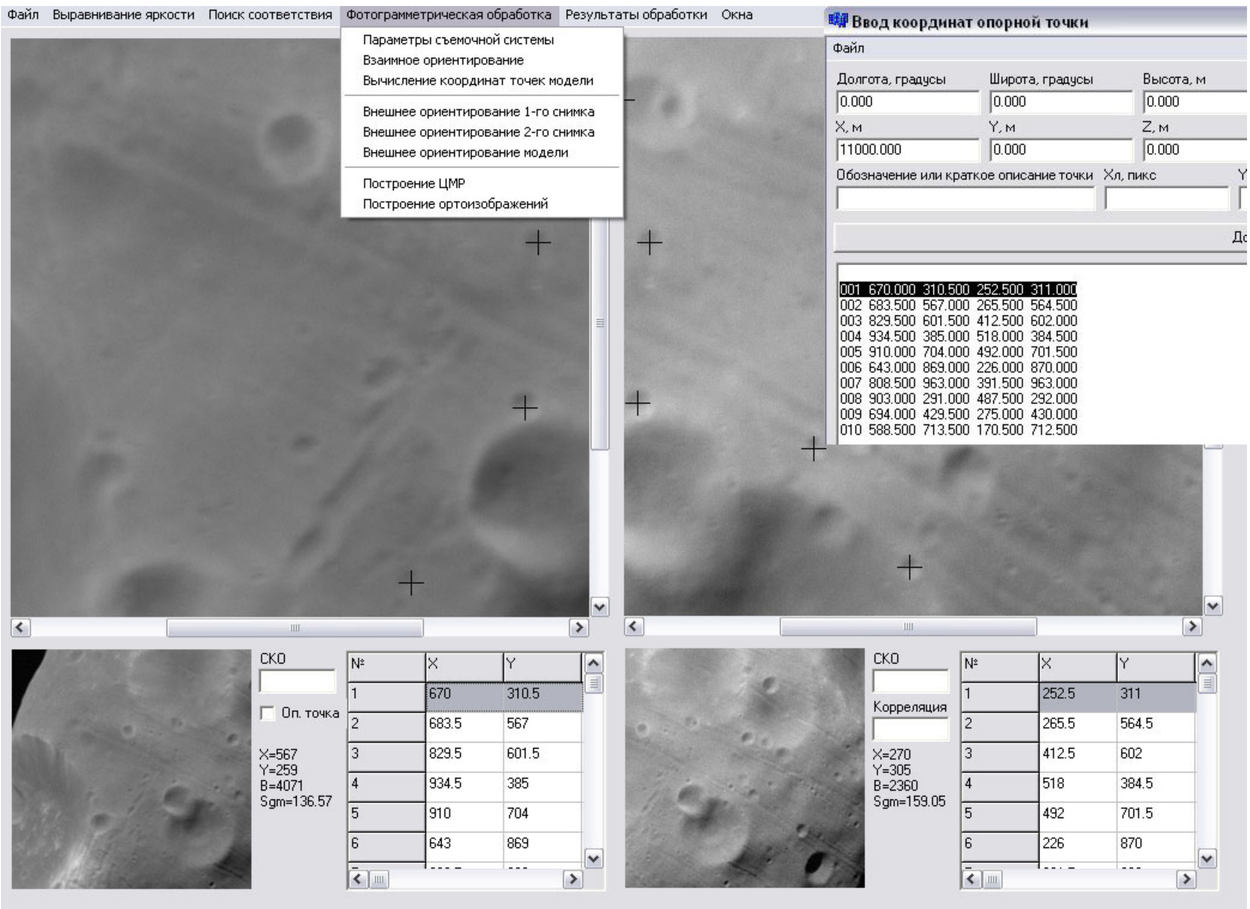

Fig. 3 General view of working window

In parallel with the creation and debugging of the program there is an analysis of existing coordinates systems and the choice of relevance to developing its own system. Phobos was traditionally approximated by triaxial ellipsoid. Recently, however, the practice has been the move to the sphere of equal volume. This approach allows the use of spherical coordinates and to move quickly from spherical coordinates to rectangular and vice versa. This is especially important by working on quasi-synchron orbit.

It was decided to elect a height above the surface of the relevance as a criterion of analysis, since the height of the surface will be important by boarding the spacecraft.The relevance of the different values were taking into account by analyzing today the most accurate Phobos DTM which was created by K.Willner (DLR). Heights presented in Table1were obtained.

It is clear from the Table1 that the closest surface passing to the real surface of Phobos is the triaxial ellipsoid. The average height above the surface of Phobos triaxial ellipsoid with semi-axis a = 13.3 km; b = 11.1 km; c = 9.3 km is just over 107 meters. In relation to The sphere with radius of 11.0 km has an average altitude of 147 meters, but the maximum and minimum deviations are much larger. But further conclusions should be born in mind that the spacecraft provided a rectangular coordinate system and, therefore, some corrections to the landing site coordinates will also need to be in the form of ΔX, ΔY, ΔZ because of the coordinate system difference. Then it is preferable to use spherical coordinates for the transition area, since all the action at quasi-synchronous orbit will require maximum speed giving the possibility of easy and precise result control. In future a tri-axial ellipsoid will be better pass for working out various cartographic products.

However, it should be noted that the current studies are ongoing and using of tri-axial ellipsoid with the calculation of not "geodesic" heights (i.e. perpendicular to the surface of the ellipsoid), but toward the center of the ellipsoid. This option is very useful, because the spacecraft during landing by using a laser altimeter will measure the distance which is not perpendicular to the surface of the reference ellipsoid, but toward the Phobos mass center. The system of coordinates will be chosen in such a way that its center was as close as possible to the center of Phobos masses and, ideally, coincide with it. Then it is obvious that the heights above the ellipsoid defined along the line toward the center of mass would be preferable. In addition, It can be also used a morphographic projection for compiling maps on the surveying results because they have already demonstrated a good quality for mapping celestial body of irregular shape.
In conclusion, it should be noted that the creation of software and the choice of the reference surface have to be finished in time for launch in October this year. For about 11 months the spacecraft will be located on the Earth - Mars flight trajectory. During this period, using images made by Viking and Mars Express spacecrafts, a control point network and a coordinate system will create on carrying out stereo images photogrammetric processing and Phobos DTM simulation. Thus it is possible to test all the work planned for quasi-synchronous orbit. In addition, it is reached an agreement that the DLR German colleagues will provide additional photographic information on Phobos, which would be obtained by Mars Express spacecraft during the “Phobos-Grunt" spacecraft flight on the Earth – Mars trajectory.

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