Experience of modeling relief of impact lunar crater Aitken based on high-resolution orbital images

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Abstract. The paper presents the author’s results of modeling the relief of lunar Aitken crater on the basis of high-resolution orbital images. The images were taken in the frame of the “Apollo” program in 1971-1972 and delivered to the Earth by crews of “Apollo-15” and “Apollo-17”. The authors used the images obtained by metric and panoramic cameras. The main result is the careful study of the unusual features of Aitken crater on models created by the authors with the computer program, developed by “Agisoft Photoscan”. The paper shows what possibilities are opened with 3D models in the study of the structure of impact craters on the Moon. In particular, for the first time, the authors managed to show the structure of the glacier-like tongue in Aitken crater, which is regarded as one of the promising areas of the Moon for the forthcoming expeditions.

1. Introduction
Moon craters, along with the lunar seas and mountains, make up one of the main elements of the relief of the lunar surface. The structure of the craters of the Moon has been studied since their discovery by Galileo more than 400 years ago. The very name of the “crater” is also introduced by Galileo. This term is often translated from Greek as a “cup”, but many lunar craters are far from cupped in shape, but more like tea plates. Nevertheless, almost all lunar craters, despite their size, are called craters. Diameters of craters on the Moon vary over a wide range. The lower boundary is meters and tens of meters; the upper limit of the range is hundreds or even thousands of kilometers. Craters of the largest size were called “basins”. So in the central part of the western hemisphere of the Moon there is a multi-ringed Orientale basin. The diameter of its outer ring reaches 930 km. On the far side of the Moon in its southern half there is the center of a huge impact multi-ring basin with an outer ring diameter of more than 2000 km (!), which for a long time was considered the largest impact basin in the entire Solar System.

2. Orbital images of high-resolution
Among the many orbital photographs of the lunar surface, it is necessary to single out images delivered to the Earth during the performance of two historical missions. These are spacecrafts series “Zond” (USSR, 1968-1970) and spacecrafts of the “Apollo” program (USA, 1971-1972). A distinctive feature of the photographs of these missions is that for the orbital survey, film cameras were used, and the film itself was delivered to the Earth. Images of the “Zond” were delivered in automatic mode, and
the “Apollo” images were brought to Earth by the crews of the spacecrafts. The survey cameras had a high resolution, a large field of view, and were carefully calibrated during pre-flight tests.

For a long time (about 40 years), the materials of these missions were available to a limited number of specialists. More recently, 8-10 years ago, it was possible to digitize film images with the help of photogrammetric scanners. After that, the described images in the form of the graphic files became available to many researchers [1]. Over the past 40 years, computer and information technologies have gone far ahead. For this reason, some scientists believe that with the advent of digitized copies, the images of the Apollo spacecrafts acquired a second life. The validity of such assertion can equally be attributed to the images of the “Zond” spacecrafts.

In this paper, the authors used mostly digitized images of the “Apollo-17” spacecraft. On the selected images, the territory of the equatorial belt of the far side of the Moon was photographed. For the construction of digital models, Aitken crater was chosen. Aitken is a young impact crater, with a diameter of 130 km (17 degrees South Latitude, 173 degrees East Longitude). Information about the selected images and cameras is shown in Table 1.

Table 1. Characteristics of high resolution orbital images

| Camera            | Focal length (mm) | Shot size on a film (mm) | Scannings resolution (px/mm) | Image size (px) | Resolution on the Moon in meters | One picture file size (Mb) |
|-------------------|-------------------|--------------------------|-----------------------------|----------------|-------------------------------|--------------------------|
| Apollo -17 (Metric) | 76                | 120 x 120                | 200                         | 24000 x 24000 | 6                             | 1039                     |
| Apollo -17 (Panoramic) | 699             | 127 x 1219               | 200                         | 25400 x 244000 | 1-2                           | 11821                    |

3. Formulation of the problem of the lunar relief modeling

Photographing the Moon from orbit has a number of characteristic features, in contrast to Earth-based telescopes. Firstly, there are essentially other geometric conditions for photographing. Secondly - significantly different parameters of the shooting cameras. Thus, the scale of the images is larger, the extra-atmospheric quality of the images is higher, and the resolution becomes much higher.

The important difference between aerial photography and space photography is that the carrier of the camera moves relative to the object being shot in a fundamentally different way. This movement is not controlled by the pilot of the aircraft. The spacecraft movement obeys the laws of celestial mechanics Therefore, when analyzing space images, it is necessary to take into account the properties of the orbital motion.

Images of the lunar surface, made by cameras from the near-moon orbit, have much in common with aerial photographs of the Earth’s surface. For the processing of both, precise photogrammetry methods are used. When the studied territory is photographed from different sides, the methods of stereophotogrammetry are applied. This allows for the images with mutual overlap to create three-dimensional models of the relief of the lunar surface in the overlapping area. Such models are called discrete digital models, taking into account the fact that the three-dimensional coordinates in this case refer to a certain set of terrain points measured simultaneously on different images included in the model. Such algorithm is used in the construction of topographic maps, photogrammetric coordinate systems. It is assumed that on the investigated territory a priori there are points with the known coordinates. The scale of the model and the orientation of its axes are based on these points, which are called the reference points, and which are recognized in the images constituting the model. The quality of these types of models is determined by the density of the common points of models lying on the surface. The more such points can be found to measure, the more accurately the constructed model will transmit details of the surveyed relief. When such job is performed by a photogrammetric operator, the number of points in the model can be up to several hundreds and is determined mainly by
the laboriousness of the process of identifying points on the images, as well as the time spent on recognition, measurement and processing.

Currently, the “photogrammetric process” described above is improved by algorithms of computer image processing. In particular, the time-consuming operation of identifying the common points on overlapping images is applied using “computer vision” algorithms. To this end, computer programs have been developed that allowed one many times to increase the number of determined points of the model, and the methods of computer graphics made it possible to create a texture model of the studied territory on their basis.

Among these programs, there is the computer program of the firm “Agisoft Photoscan” [3], developed for the analysis of aerial photographs of the terrestrial territory. This article presents an attempt to apply this program to build a model of the relief for lunar impact crater.

4. Some practical tasks of building 3D models for Aitken crater
In the Aitken crater, for a long time attention has been attracted to the anomalies of the albedo of significant areas on the bottom of the crater. The nature of these anomalies is still a mystery. Other objects of the crater are connected with his central peak. First of all it is so called glacier-like tongue, which “crawls out” from the south-western slope of the central peak into the crater floor.

In addition, the floor of the crater Aitken contains another curious detail. To the west of the central peak there are 4 separate peaks, “connected” with the peak by light strips on the floor surface. The origin of these peaks raises many questions, since isolated mountain peaks represent a very unusual phenomenon for the Moon as a whole, and especially on the smooth floor of the crater. By the appearance of the peaks, they could be taken as fragments of a central peak, as is the case, for example, in the Antoniadi crater in the southern circumpolar region. However, with close examination of the “Apollo” and “LRO” images, it is seen that the peaks studied have a different structure and, in their morphology, a different origin.

The listed features of the Aitken crater were detected and studied mainly on single images. In connection with the unusual elements of the relief, it seems important to carry out a more detailed examination of the above-mentioned territories in different angles. For this purpose, 3D models were created for Aitken crater based on high-resolution images taken by metric and panoramic cameras the “Apollo-17”. This allows us to view the investigated areas from different sides together with panoramic “LRO” images.

5. Analysis of the Aitken crater models
It should be emphasized that unfortunately there is no way to show the created models in a journal article in full-fledged mode. Therefore, authors have forced to demonstrate the fragments of models, chosen in such a way as to show the appropriate foreshortening.

Figure 1 shows a fragment of the crater model. It is easy to see the central peak of the crater (view from the south-west), as well as isolated mountain peaks on the bottom of the crater. Digit 5 indicates a glacier-like tongue, “crawls out” from the southwestern slope of the central peak. The structure of the tongue is confidently seen on the pictures of “LRO”. Figure 6 shows a close-up of the frontal part of the tongue. Here, boulders are clearly visible, radially scattered around the epicenter.
Figure 1. Fragment of the 3D model of the central part of the Aitken crater. Numbers from 1 to 4 refer to isolated mountain peaks to the west of the central peak. Number 5 marks the glacier-like tongue “creeping out” of the south-western slope of the central peak. On the other side of the central peak (to the east of it) there are 5 impact craters with which isolated mountain peaks could be connected.

The origin of glacier-like tongue is of undoubted interest. Let us consider some versions of its origin. First of all, it should be note the similarity of this tongue to the Martian “hourglass”, where the soil contains a significant amount of frozen ice water and comes into motion under the action of solar heating [2]. Another version of the behavior of the tongue can be associated with the still not cooled substance of the central peak, which continues to give out energy accumulated in the process of cratering.

The “driving force” of the tongue of the central peak can also be related to the shock-wave effect from later falls of the impacters in its surroundings. Then separate isolated mountain peaks, located to the east of the central peak, could be considered in the frame of this version (see Figure 1). The sources of the shock wave can be falling bodies (impacters), which led to the formation of small craters on the bottom east of the central peak (Figure 2). The shock wave from the fall places in this case moves to the west directly on the eastern slope of the central peak. In addition, in this place the outlines of the central peak have a concave shape, which should lead to an increase in the effect of the shock wave on the substance of the central peak due to the cumulative effect. This could be enough to eject the material of the central peak in the direction of the shock wave. For more accurate conclusions, it is necessary to model the dynamics of the shock-wave process and to carry out quantitative estimates. It is possible that 5 impact craters lying to the east of the central peak will cause four isolated mountain peaks to the west of the central peak, and the fifth peak is currently being formed in the stage of glacier-like tongue.

The created model allows us to consider the detailed structure of the tongue itself, to reveal details invisible in single images. The glacier-like tongue is presented from two different sides in Figures 3 and 4. The first view shows the tongue from the front part, Figure 3. The second one is the view from the rear side, Figure 4. Finally, Figure 5 shows a close-up view. The first thing that catches your eye is the general structure of the tongue, which on the model is clearly divided into two parts. Let them be conditionally called the front and rear.
Figure 2. Fragment of model created by us for Aitken crater. On the front plane there are 5 small impact craters to the East of central peak, which is located at the figure center. Separate isolated peaks are located behind the central peak. North - to the right.

Both parts are separated by a rather deep gap, while the front part is turned to the rear by almost 90 degrees. The front part contains a significant number of boulders of different sizes, while on the surface of the rear part there are practically none. This can be seen on single images at high magnification.

Figure 3. The view of the glacier-like tongue from the front part on the model created by us on the basis of images of panoramic camera.
Figure 4. The rear part of the glacier-like tongue on the model created by us on the basis of images of panoramic camera. Left side is covered by the slope of central peak.

Low density of impact craters on the surface of the tongue, especially in its rear part, attracts attention. This density is an order of magnitude lower than the density of impact craters on the underlying surface of the Aitken bottom in the immediate vicinity of the tongue. In addition, the surface of the tongue as a whole looks much lighter, as it has not yet been covered with lunar dust. The last two circumstances (density of craters and a light surface) convincingly testify to the fact that the tongue represents a later formation than the surface of the bottom around it.

In general, the view of the described glacier-like tongue is very similar to the structure of the glaciers of the Earth, as well as the Martian soil, which is interpreted as an “hourglass” in the photographs of the “Mars Express” orbital station.

Figure 5. The close-up view. The glacier-like tongue on the model is clearly divided into two parts.
Figure 6. The front part of the glacier-like tongue close-up on a fragment of the image M1095365439RE ultrahigh resolution taken by “LRO” satellite. The place, where from the numerous boulders were thrown out is clearly visible in the central part of the image. (Credit: NASA / GSFC / Arizona State University).

6. Some results
Orbital high-resolution images are the basis for building 3D models. Such models were constructed for the most interesting sections of the lunar territory. Using the example of young impact Aitken crater, it was shown that a detailed survey of relief elements can contribute to the study of the state of matter of lunar craters.

The experience of building three-dimensional models convincingly demonstrated the high requirements that are imposed on the power of the computer. If the model is built on several images of one revolution of the orbit, then to build a 3D-model is a powerful computer with a large operating memory. The inclusion of two or more orbital turns in the model results in a significant increase in consumed resources. Full-scale spatial models with a large number of high resolution images require the use of computing powers of the class of personal supercomputers.

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