ON THE DEVELOPMENT OF OUR KNOWLEDGE OF THE MOTION OF THE MOON AROUND ITS CENTRE OF MASS

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Abstract. This paper presents historical stages of the development of methods concerning observation and theory of the Moon's rotation around its centre of mass from the beginning of the 17th century up to the present day. The accuracy and usefulness of these methods is estimated and a critical attitude is assumed towards the results concerning the values of constants of the Moon's physical libration.

Since the days when Galileo Galilei, after directing the then constructed telescope towards the Moon, noticed that the spots on the lunar disk changed their position, approaching once the eastern, then the western, limb of the Moon, the problem of the mapping of the Moon became strictly connected with the study of our satellite's rotation around its centre of mass. The famous selenographer of Gdańsk, John Hevelius (1647), noted similar oscillations of the features of the Moon from north to south, and Isaac Newton (1686a) explained these librations rightly as possessing an optical character and ascribed to the Moon a uniform rotation around an axis inclined to the plane of its orbit while its revolution about the Earth is uneven. Soon afterwards, J. D. Cassini specified the explanation of the optical libration by formulating three empirical laws named after him, which were published posthumously by his son, Giacomo Cassini, in 1721. The first of these laws stated that the Moon rotated eastward, on a fixed axis, with a constant angular velocity, and the period of rotation was exactly the same as that of the Moon's sidereal revolution around the Earth. The next two laws stated that the inclination of the Moon's axis of rotation to the ecliptic was constant and that the poles of the Moon's equator, of the ecliptic and of the Moon's orbit, were lying in one great circle in the just given successive order. It is perhaps worth noting that according to Delambre (Histoire de l'Astronomie moderne II, 733) the three laws mentioned above were already known to Kepler. Cassini also determined the inclination of the Moon's equator to the ecliptic \( I \), as \( 245' \), which was important from the selenographic point of view.

Tobias Mayer and J. A. Lalande carried out observations, which confirmed Cassini's laws on the understanding that if there existed deviations from these laws, they would have to be insignificant. T. Mayer introduced, moreover, the conception of 'first radius' and 'zero meridian' used to this day both in the theory of the Moon's rotation and its cartography. For the inclination \( I \) he obtained \( 2^o 45' \). In the second half of the 18th century, Lalande carried out micrometric measurements of the position of crater Manilius and obtained for the inclination \( I \) a value not much differing from that determined in modern times: namely, \( I = 1^o 43' \).
Along with these observational researches of the Moon's rotation theoretical studies were also carried out. D'Alembert was the first to discuss the rotation of a rigid body and Euler derived equations for that rotation. But it was Lagrange (1780) to whom we owe a full treatment of the problem of the Moon's rotation – on the assumption that it is a rigid body. Lagrange explained the empirical laws of Cassini on the basis of Newton's law of universal gravitation, for which he was awarded a prize of the Paris Academy. The works of Laplace (1798) and Poisson constitute some supplement to Lagrange's researches. An extraordinarily clear exposition of this theory can be found in the second volume of Tisserand's (1891) celestial mechanics. As late as the year 1880, Hartwig (1880) wrote in his doctoral thesis, which contained a reduction of his Strassburg series of libration observations, that the theory of Lagrange and Laplace was so thorough that "in spite of the rapid development of science, even today [i.e., in 1880] one does not perceive in it drawbacks from the point of view of observational astronomy".

Already Newton (1686b) was speaking of the Moon's physical libration resulting from the attraction by the Earth and by the Sun of the lunar globe deviating from the spherical shape. According to the Lagrange–Laplace theory, the physical libration consists of a forced libration and a free one, the forced libration being a reflection of the periodical terms of the Moon's orbital motion and the amplitudes of its individual terms depending on the inward mass distribution in the Moon. While the free libration, not yet satisfactorily determined, consists of terms possessing a very small amplitude, phase and period depending on the mass distribution within the Moon.

Thus, it was now the first task to obtain from observation the constants characterizing the physical libration. This task was undertaken in 1806 by Bouvard and Arago on the basis of observations of the crater Manilius. Nicollet (1823) supplemented their observations and reduced the whole series of observations thus obtained, which yielded for the inclination \( I \) the value \( 1° 28' 45" \), and for the Moon's mechanical ellipticity \( f = B(C - B): A(C - A) \), the value 0.055, where \( A, B, C \) denote the lunar globe's principal moments of inertia. Soon afterwards Kreil (1837) and Stambucchi, who determined the position of the crater Bode relatively to the Moon's limb obtained for \( I = 1° 35' 48" \), and for \( f = 0.005 \). The values of the inclination of the Moon's equator to the ecliptic \( I \) in the two enterprises do not in principle differ from each other and they are comparable with present-day values, but the quantities of the Moon's mechanical ellipticity wholly remain out of any discussion and do not even constitute a first approximation. In the 1830's Beer and Mädler expressed the opinion that a crater as large as Manilius is unfit for investigation of the Moon's libration and, moreover, the said crater is lying rather far from the disk's centre.

About 140 years ago, the problem was tackled in a promising manner by the founder of modern astrometry, the astronomer of Königsberg, Bessel (1839). For this purpose he used a heliometer, new at the time and improved by himself, which since that time became the standard instrument serving for the determination of the Moon's physical libration constants. Moreover, Bessel prescribed a method of reduction of these observations elaborated in detail, and his disciples Schlüter and Wichmann (1846, 1847) left