17. COMMISSION DU MOUVEMENT ET DE LA FIGURE DE LA LUNE

PRÉSIDENT: C. B. Watts.

MEMBRES: MM. Atkinson, Boneff, Botelheiro, Brouwer, Eckert, Guth, Hirose, Koziel, Markowitz, Meyer, Nefediev, O'Keefe, Mme McBain Sadler, MM. Ueta, Weimer, Yakovkin.

PROGRESS OF RESEARCH

At the Royal Greenwich Observatory, Murray has made a study of the Moon's latitude as derived from occultations. He examined the term having the period of the libration in longitude and suggests that it may arise through a real ellipticity of the lunar surface. In a paper now in press he has investigated the negative acceleration of the Moon due to the reaction of the lunar oceanic tidal couple. From the eclipse and equinox observations of Hipparchus he derives a value twice as large as that given by the modern observations. He points out that if the acceleration actually does change, Ephemeris Time derived from lunar observations will not be uniform in the Newtonian sense.

Mrs McBain Sadler reports that the British Nautical Almanac Office has continued its routine programme of prediction of occultations for about seventy stations. It has also started to provide approximate predictions of occultations of the twenty-six brightest radio sources in the second Cambridge survey for fifteen radio observatories.

The discussion of reduced observations has been published for the years 1951–52 in *Astr. J.* **60**, 315, 1955, and that for 1953–55 has been submitted for publication. These observations have been reduced without limb corrections.

Many observations are still being received too late for the first discussion. These are being reduced as soon as available and prepared for inclusion in the re-discussion which will be made when corrections of limb errors become available from the results of the Washington survey of the marginal zone.

The combined list of all observations included in the discussion for 1948–53 has been prepared. It will be published as soon as possible and copies distributed to all the observers.

A. Botelheiro, of the Lisbon Observatory, reports that the Observatory continues as routine work the observation of occultations. Since 1938, when the programme was begun at Lisbon, 1023 occultations had been observed up to the end of 1956.

At Sofia, N. Boneff has continued his examination of the distribution of craters on the Moon's surface. Taking into account the circumstance that the eastern hemisphere is always in advance in the orbital motion of the Moon about the Earth, he finds no evidence in the relative distribution of craters between the two hemispheres to confirm the meteoritic theory of their origin.

K. Koziel is continuing his investigations of the Moon's rotation elements at the University Observatory, Cracow, and is about to complete the re-reduction of the Strassburg series of observations by Hartwig, 1877–79. The adjustment of these measures gives for the coefficient of the Yakovkin effect (the relation of the Moon's apparent radius to the latitude libration) the values:

$$\text{without limb corrections, } +0''.019 \pm 0''.013;$$

$$\text{with Hayn's corrections, } +0''.018 \pm 0''.010.$$

These are negligible quantities, as was the case with the Dorpat series of Hartwig. The Kazan series of measures by Banachiewicz, 1910–15, is being re-reduced by J. Mietelski, as is the Bamberg series of Hartwig, 1890–1922, by J. Maslowski and Mrs H. Jasko.

G. Schrutka-Rechtenstamm, at the University Observatory, Vienna, has recently completed a new discussion of the rotation elements of the Moon utilizing observations made at Bamberg and Kasan. He takes into account a discrepancy which he has found

in the *Berliner Jahrbuch* for the years 1883–1922 between the mean longitude of the Moon and its right ascension and declination. His results are for I, $1° 31' 52'' \pm 7''$, and for f, $0{\cdot}625 \pm 0{\cdot}007$. He has also re-reduced the heliometer measures of Franz at Königsberg, involving eight craters, as well as those of Hayn involving four craters. On the basis of these revised results a new reduction of the positions of 150 points measured by Franz on photographs has been made. It is planned to utilize these in forming a chart giving elevations referred to a level surface similar to that of Franz.

At the Paris Observatory, Senouque has continued his measures of photographs to determine the relief of the Moon by stereoscopic viewing.

Following the completion of his *Atlas de profils lunaires* Weimer has sought to obtain a new determination of the elements of the physical libration, and in particular of the value of f. A graphical representation of the residuals seems to confirm the results obtained earlier ($f = 0{\cdot}60$, approximately). The definitive calculations will be made later. He has also undertaken the determination of the selenographic co-ordinates (including the distance from the centre of the Moon) of twenty-four craters, with the purpose of establishing a sound basis for other researches.

At the Naval Observatory, Washington, the survey of the marginal zone of the Moon by Watts has progressed as follows: The measurement and analysis in 1956 of the last of 867 photographs, exposed on 503 nights, made possible the final adjustment of the datum surface. This operation, which required considerable experimentation, was finished in July 1957 and the formation of the libration frame charts was then begun. These charts, to be based on about 480 000 measured elevations, are nearly one-fourth completed. It is hoped that the survey will be ready for publication late in 1958.

Markowitz has continued his programme with the dual-rate Moon position camera. The work is being arranged for reduction by punched-card methods. Twenty of these cameras and four measuring engines have been constructed for use in I.G.Y. programmes.

C. B. WATTS
President of the Commission

ADDITIONS TO THE DRAFT REPORT

In the U.S.S.R. investigations of the rotational elements and of the figure of the Moon have been continued. At Engelhardt Observatory, Kazan, A. A. Nefediev continued his heliometer measures and made forty observations of Mösting A, which brings the total number of observations since 1938 to 406. S. T. Habibulin obtained 133 photographs of the Moon with the horizontal telescope. At Kiev, a series of 135 photographs has been completed at the University Observatory. I. V. Gavrylov, at the Central Astronomical Observatory of the Ukrainian Academy of Sciences, Kiev, continued his series of photographic observations of the Moon, for examination of figure, and 250 photographs were obtained. Photographic observations by the Markowitz method have been started at Engelhardt Observatory, at Pulkovo Observatory, and at the Central Astronomical Observatory, Kiev. During the period 1955 to 1957 about 100 observations of lunar occultations were made at Soviet Observatories.

At Engelhardt Observatory, Nefediev has drawn maps of the marginal zone of the Moon referred to the general zero level and to the selenographic system of co-ordinates introduced by Hayn. The maps are based on the heliometric observations of the crater Mösting A which have been carried on continuously for nearly half a century at Engelhardt Observatory since Krasnov first began this work. Yakovkin has demonstrated that such maps must satisfy two conditions (*Trans. I.A.U.* **8**, 230, 1952), namely

(i) After the reduction of the measured distances between the centre of the Moon and points on the limb, the value of the Moon's radius obtained when using the maps should be constant for all values of the libration. (It is well known that Hayn's maps do not satisfy this condition.)

(ii) The correction to the latitude of the Moon, derived from observations corrected for limb irregularities, should be sufficiently close to zero to be attributed to accidental errors. A considerable negative latitude correction is obtained from conventional methods of discussion. With Nefediev's new maps it is found that the libration effect on the Moon's radius is practically eliminated. The absolute value of the latitude correction derived from occultations was decreased by $0''.32$ when corrections for limb irregularities were applied.

Habibulin has found from forty photographs (1949 to 1952) the following system of elements for the physical libration.

$\lambda = -5° 10' 08'' \pm 12''$ (m.e.) $\quad I = 1° 33' 06'' \pm 11''$
$\beta = -3° 10' 37'' \pm 8'' \quad R_0 = 15' 32''.59 \pm 0''.03$
$h = 15' 33''.7 \pm 0''.7 \quad f = 0.50 \pm 0.05$

From a discussion of six series of heliometric observations made at Kazan, he has found, using the main term of the physical libration with annual period, the following values of f, the function of the inertial moments of the Moon.

Observer	f
Krasnov	0.58 ± 0.08
Mikhailovsky	0.61 ± 0.09
Banachiewicz	0.60 ± 0.03
Yakovkin	0.63 ± 0.01
Belkovich	0.61 ± 0.03
Nefediev	0.59 ± 0.04

He has also re-reduced the Dorpat heliometric series of Hartwig in order to determine the elements of physical libration. He used a slightly modified method, in which the coefficients of the two largest terms of physical libration in longitude were unknown. He found

$\lambda = -5° 11' 03'' \pm 9''$ (m.e.) $\quad I = 1° 31' 22'' \pm 14''$
$\beta = -3° 10' 04'' \pm 8'' \quad f = 0.60 \pm 0.03$
$h = 15' 33''.28 \pm 0''.35$

At the Central Astronomical Observatory of the Ukrainian Academy of Sciences, Kiev, Gavrilov has completed the discussion of the first series of photographic observations consisting of 100 plates. He confirms the existence of a libration effect in the Moon's radius and finds a preliminary value of $+0''.04$ for the coefficient corresponding to a change of 1° in the libration in latitude.

At Kiev University Observatory, Gorynya and Drofa, from their photographic observations, found a corresponding value of $+0''.06$.

Yakovkin applied harmonic analysis to the determination of the largest term of the physical libration in longitude, the argument of which is the Sun's mean anomaly. Assuming the five large Kazan series to be a continuous series of about 50 years, he found for this coefficient the value $76'' \pm 9''$, from which can be derived $f = 0.69 \pm 0.02$.

J. A. O'Keefe reports that during the past three years, the programme of determining island positions in the Pacific by occultations, observed photo-electrically with electron-multiplier tubes, has progressed to the operational stage. Hirose in Japan and Henriksen and his co-workers in the United States have developed methods of reduction. Positions have been obtained for Palau relative to the Philippines and for Marcus relative to Japan.

COMMISSION 17

Report of Meeting. 18 August 1958

ACTING PRESIDENT: A. A. Nefediev.

SECRETARY: Mrs F. M. McBain Sadler.

The meeting, which was attended by over fifty members, was opened by Dr A. A. Nefediev explaining that the Executive Committee had asked him to be Acting President of the Commission, as Dr C. B. Watts was unfortunately unable to attend.

The Chairman called on A. A. Yakovkin to give an account of the work performed at Soviet Observatories during 1955–7 as this report had not been included in the *Draft Reports*; it is included in the additional reports above. The *Draft Report* was then approved.

The first part of the meeting was devoted to the Moon's rotation and figure, and the first speaker was A. A. Yakovkin, who reported on his work on the question of the zero level to be used for charts of the marginal zone. As the centre of mass is unknown, observations made only at the limb, at different phases and latitudes, cannot be represented by a single circle. The radius depends on the libration in latitude and can be expressed empirically by

$$R = R_0 + 0''.05\beta_0^2.$$

A much better representation of the disk is obtained by considering the northern part as a semi-circle, whose centre coincides with the centre of mass, and the southern part by an ellipse whose semi-minor and semi-major axes respectively are R_0 and $R_0 + a$ where

$$a = 0''.96 + 0''.08\beta_0^2.$$

He considers that this effect should be taken into account in the reduction of all observations of the Moon, as, for example, occultations. He emphasized that the result was empirical, but it is obtained from a very large number of observations and gives the best available representation of the figure of the Moon. Although the quantity a represents an additional layer due to craters and mountains, the coincidence of the centre of curvature of the northern part with the centre of mass means that this extra layer must have negligible mass. He is at present making a second approximation to take account of the asymmetry of the east and west hemispheres, so that all other observations such as heliometric and photographic may be satisfactorily represented.

In the discussion which followed, Clemence remarked that the datum surface adopted by Watts has the effect of reducing the value of $\Delta\beta$ from 0".6 to 0".3 which would still leave 0".3 to be explained by the internal constitution of the Moon.

J. Hopmann described the work completed by G. Schrutka-Rechtenstamm at Vienna since the presentation of the *Draft Report* and showed the meeting Schrutka's design for the chart giving elevations referred to a level surface, and also a copy of his catalogue containing rectangular co-ordinates, selenographic longitudes and latitudes, and absolute altitudes. The altitudes are accurate to $\pm$ 1·0 km and seldom exceed 1 km above and 5 km below the mean level, which indicates that the part of the Moon towards the Earth must be nearly spherical. Attention was called to an investigation by K. H. Engel of New York, using Schrutka's chart, which shows that on the average the belt of maria and the continents are about 2 km lower and 2 km higher respectively than the mean level.

W. Markowitz reported that C. B. Watts hoped to complete and send to the printer in July 1959 the charts derived from his survey of the marginal zone of the Moon. His data will also provide details on the figure of the Moon.

In the subsequent discussion Habibulin asked if details were available of Kuiper's proposed investigation. Clemence replied that Kuiper intends to study the librations of the Moon by using small bright specks on the surface in preference to craters, but this work has not been completed.

N. Boneff brought up to date the account of his work as described in the *Draft Reports*. He is preparing for publication the results of his statistical analyses. He emphasized that he had found no evidence in the relative distribution of craters between the eastern and

western hemispheres to confirm the meteoric theory of their origin. Sharonov questioned whether the effect would be appreciable in view of the smallness of the orbital motion. Boneff considered the effect cumulative and that the Moon has existed so long that it would not be negligible.

K. Koziel reported further on the work described in the *Draft Reports*. He has completed his re-reduction of the Strasbourg series of observations by Hartwig. His final values for the coefficient of the Yakovkin effect are

without limb corrections, $+0''.018 \pm 0''.010$;
with Hayn's corrections, $+0''.013 \pm 0''.010$.

These are negligible quantities as had been found with the Dorpat series.

A. A. Yakovkin said he regarded the customary method of combining observations for one hemisphere at a time as not permissible; if observations for the complete circle of the disk were taken at once, the polar diameter would exceed the equatorial by 1". O'Keefe remarked that at the annular eclipse in 1948 the Moon was found to fit the Sun exactly and gave no sign of prolateness.

The Acting President then discussed his own work on the marginal zone of the Moon and showed copies of his published charts. The compilation was completed at Engelhardt Observatory in 1957. The elevations are referred to a common zero level, which is the surface of a baricentric sphere. The position of the centre of this sphere was determined by using (i) the relation between the Moon's radius and optical libration in latitude as determined by Yakovkin and (ii) the value of the latitude correction derived from occultations by Spencer Jones. The charts were constructed using 5630 elevations of points on the Moon's limb, based on the heliometric observations of Mösting A during the 50 years, 1895–1945. The charts are drawn in the selenographic co-ordinate system introduced by Hayn. For examination of the charts the libration effect on the Moon's radius was computed using heliometric observations made by Hartwig at Bamberg and by Krasnov and Nefediev at Kazan. The results are given in a table published with the charts and they show that, when these observations are reduced with the new charts, the libration effect is practically zero. The reduction, using the new charts, of 199 occultations observed in Poland from 1901 to 1922 showed that the observed latitude correction is considerably less than when using Hayn's charts. The mean error of a limb irregularity with the new charts is about $\pm 0''.22$.

In the discussion which followed Yakovkin pointed out that care must be taken in the reductions by different methods to ensure that the effect of libration is taken into account. The different charts used different fundamental disks. Koziel said that his method had been adapted so that all reductions were made without charts and the necessary corrections, depending on the charts, easily applied.

S. T. Habibulin asked that a recommendation should be made that Commissions 4 and 7 should consider the publication of the ephemeris of Mösting A, subsequent to the cessation of the *Berliner Jahrbuch*, and also the value to be used for the constant f. In the course of the discussion it was pointed out that the ephemeris of Mösting A will be published in the 'Astronomical Ephemeris of the U.S.S.R.' It was considered that the value of f is still too uncertain to warrant a change in the adopted value. It was decided to adopt only the first part of the recommendation, namely that the publication of an ephemeris of Mösting A should be continued.

The meeting then directed its attention to the orbital motion of the Moon. W. Markowitz gave an account of the results obtained from the Moon cameras. Results were first obtained for 1955 and did not give a smooth variation in ΔT. There were differences from lunation to lunation and often marked differences between first and third quarters. From 1956, a new measuring machine was used which should give results freer from systematic error. R. G. Hall had completed a programme for the electronic computer for the 500 plates for 1957 to 1958·5. There are still systematic errors present which are thought to be due to limb effects. Reference was made to the possibility of obtaining from the reductions the term $0''.27 \cos l$, due to the mean anomaly, of the correction derived by Brouwer

and Watts in their paper on occultation and transit observations; a fuller account of this would be given at the symposium on 'The Rotation of the Earth and Atomic Time-Standards'. The final analyses will be made when Watts's results are available.

Some discussion followed in which Sharonov asked about the effects of irradiation. Potter said that experiments were to be made at Pulkovo Observatory to obtain the effects of irradiation, by photographing a sphere under different conditions.

J. A. O'Keefe drew the attention of the meeting to the results obtained on decimetre wave-lengths of the direct measurements of the distance of the Moon. These combined with the dynamical parallax give the best determination of the figure of the Earth. Yaplee has found good agreement with the generally adopted values of the Earth's equatorial radius and the Moon's horizontal parallax.

A. A. Yakovkin reported that he had examined 1500 meridian observations made at Greenwich and has deduced that the effect of libration causes the inclination derived from observations of the south limb to exceed by 0″.6 the inclination derived from north limb observations. This gives a libration effect in radius of 0″.05 β_0 agreeing with the value from general measures.

H. I. Potter reported that the Markowitz type of Moon camera had been used at Pulkovo Observatory since May 1957. The measurement and reduction of the plates is now being made. The Pulkovo Moon camera differs slightly from the Washington one, described by Markowitz in *Astr. J.* **59**, 69, 1954. The Pulkovo camera cannot be called 'dual rate' as it uses the clockwork of the 'Carte du Ciel' type astrograph, to which it is attached. The rotation of the plane-parallel filter is carried out by means of a synchronous motor, the change in the angular velocity of rotation being made, not mechanically, but by changing the frequency. It is well known that the plane parallel glass does not shift the image proportionally to the angle of tilt. The relation is

$$x = d \sin z \left(1 - \frac{\cos z}{\sqrt{(n^2 - \sin^2 z)}}\right) = \frac{d}{3}\left(\tan z + \frac{1}{18} z^3\right),$$

where z is in radians. Tilting the filter as in the Washington camera eliminates only the terms given by $\tan z = \omega t$ and therefore some non-uniformity remains in the shift. In the Pulkovo camera the angular velocity of tilting the filter corresponds exactly to this non-uniformity of the shift and compensates for it. During the exposure time of 40^s the error could otherwise amount to 0″.06. In calculating the Moon's velocity before observation, account is taken of refraction, as its neglect can lead to an error exceeding 1″ at zenith distances of 70°–75° for an exposure time of 40^s. The error depends on hour angle and therefore can distort considerably conclusions about geodetic data derived from Moon observations.