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

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PROGRESS OF RESEARCH

In the U.S.S.R. investigations of the rotational elements and of the figure of the Moon have been continued.

At the Engelhardt Observatory, Kazan, A. A. Nefediev (**1**) re-reduced his heliometric observations of the Moon (1938–1945), using the cracovian method (**2**), and obtained two sets of solutions:

	for the initial $f_0 = 0{\cdot}73$	for the initial $f_0 = 0{\cdot}50$
λ	$= -5^\circ\,10'\,05'' \pm 11''$	$-5^\circ\,10'\,04'' \pm 11''$
β	$= -3^\circ\,12'\,07'' \pm 08''$	$-3^\circ\,12'\,10'' \pm 09''$
h	$= 15'\,36''{\cdot}14 \pm 0''{\cdot}42$	$15'\,36''{\cdot}04 \pm 0''{\cdot}42$
I	$= 1^\circ\,33'\,26'' \pm 14''$	$1^\circ\,33'\,24'' \pm 14''$
f	$= 0{\cdot}71 \pm 0{\cdot}02$	$0{\cdot}63 \pm 0{\cdot}03$
R_0	$= 15'\,32''{\cdot}44 \pm 0''{\cdot}02$	$15'\,32''{\cdot}47 \pm 0''{\cdot}02$

The Yakovkin term in the Moon's radius was found as $+0''{\cdot}009 \pm 0''{\cdot}008$, which confirms the uncertainty of this term. Moreover, A. A. Nefediev has analyzed the available charts and profiles of the Moon's limb, using a great number of observations made at the Engelhardt Observatory (**3**), in order to investigate the possible influence of Yakovkin's term on these charts.

Sh. T. Habibullin considered a more exact treatment of the differential equation of the physical libration in longitude with a non-linear term, and re-reduced (**4**) the Dorpat heliometric series of Hartwig, confirming the results obtained by K. Kozieł (**2**) in his working out of this series.

H. S. Shakirov (**5**) developed a method for investigating the Moon's physical libration from measurements of the position of a crater by direct reference to the stars. On the basis of 89 transit observations of the crater Mösting A, made at the Greenwich Observatory in the years 1952–1954, he obtained the following libration constants:

λ	$= -5^\circ 09' 16'' \pm 23''$
β	$= -3^\circ 12' 44'' \pm 19''$
h	$= 15' 31''{\cdot}6 \pm 0''{\cdot}8$
I	$= 1^\circ 30' 54'' \pm 30''$
f	$= 0{\cdot}71 \pm 0{\cdot}08$

Using the method of position angles for the determination of libration constants, proposed by A. A. Yakovkin (**6**), A. A. Gorynia (**7**) at the Central Astronomical Observatory of the

Ukrainian Academy of Sciences, Kiev, measured 66 photographic plates of the Moon and obtained the following libration constants:

$$I = 1°33'19'' \quad \pm 16''$$
$$f = 0{\cdot}89 \quad \pm 0{\cdot}13$$

I. V. Gavrilov and A. A. Kuryanova (**8**) worked on several photographic plates, some of which had been taken directly before the beginning of a lunar eclipse, and found that the figure of the full Moon's disk can hardly be described as an ellipse with sufficiently reliable parameters. It was concluded that the irregularities of the Moon's limb should be measured from a circle with the centre coinciding with the projection of the mass centre.

Under the direction of A. A. Yakovkin, astrometric computations were made to give the mean positions of 500 bright stars for 1964·0, as well as an ephemeris of the Sun and Jupiter, as seen from the Moon.

In discussing the star images obtained with the Markowitz Moon camera, A. A. Yakovkin (**9**) developed and described a new camera and expressed the opinion that his camera does not possess the disadvantages of Markowitz's camera.

At the Institute of Theoretical Astronomy, Leningrad, S. G. Makover (**10**) dealt with the problem of integrating the differential equation of the Moon's physical libration in longitude, and expressed the opinion that the peculiarity in the solution for $f = 0{\cdot}662$ could be avoided by using an equation having the form of Hill's equation.

During the period covered by this report 427 observations of lunar occultations (**11**) were made at Soviet observatories.

W. Markowitz, U.S. Naval Observatory, Washington, reports that the right ascensions and declinations of the Moon have been determined from 1200 plates taken with the dual-rate Moon camera at Washington, D.C., since 1952, and from 1700 plates taken at 13 other stations as a part of the IGY programme. The measuring was done at Washington, Greenwich, Paris and the Cape. These positions, uncorrected for irregularities of the Moon's limb, are available both in punched-card form and as a machine listing.

Corrections for irregularities of the Moon's limb by C. B. Watts (**12**) have now been published as Volume XVII of the *Astronomical Papers of the American Ephemeris and Nautical Almanac*. These corrections are being applied to the Moon plates.

At the Lunar and Planetary Laboratory, University of Arizona, two major selenodetic problems are receiving attention: (*a*) the Moon's dynamical figure and the constants of rotation; and (*b*) the Moon's geometrical figure.

Some preliminary theoretical work has been done on both these problems, but for some time past attention has been focussed on the practical problems posed by the measurements themselves. These are to be made on photographs taken with the 40-inch refractor of the Yerkes Observatory. Extended experiments with assistants hired for the purpose showed: (i) that the observers must be highly skilled and closely conversant with the varying appearance of a lunar surface object at different phases; (ii) that these variations in appearance are so effective in altering the apparent position of an object that it may be wise to limit the plates to be measured to one phase. In practice this means that the Yerkes plates taken near full Moon will be divided into two series, one of plates taken a day or so before full and the other plates taken just after full; (iii) that manually recorded observations are sufficiently affected by mistakes to give difficulties in the reductions. These mistakes occur even with experienced observers.

In the light of these results the Mann 422-C two-screw comparator is being modified so that the co-ordinate output is digitized. The illumination system is also to be modified to give higher contrast. The machine itself has been placed in a room specially constructed for the purpose in which the temperature is controlled to $\pm 2°$F.

The second of the problems mentioned above is to be attacked by measuring the positions on the photographs of some 400 points on the lunar surface. The reductions, as far as possible, will be based on photogrammetric principles and libration theory will not be used except in a secondary role. The aim is to produce a three-dimensional model of the lunar surface as a set of solid co-ordinates of the measured points. The formulation of this problem is complete and its programming for high-speed computers is now being considered.

The problem of the Moon's constants of rotation is to be approached on the basis of the variation of the relative photographic co-ordinates of a number of well-defined lunar surface features. The measures will be restricted to about 20 or 30 features. Selenodetic measures of the classical type, in which a fundamental point, or points, are referred to the limb are not contemplated at present. Experiments have shown that these cannot be made with sufficient precision on photographs by merely placing the measuring mark on the image of the limb. However, the incorporation of a suitable photometric scanning is being considered, and when this is available limb observations will be added to the measuring scheme.

Moreover, at the Lunar and Planetary Laboratory some theoretical work has been done, but in the main this consists of the verification of Koziel's (**2, 28**) developments for the physical libration in longitude. These were performed with 8-place accuracy using an I.B.M. 650 computer, the final results being rounded to six places. With the exception of some minor changes in the last place, these confirm Koziel's (**2, 28**) results. Therefore, publication is not considered at present.

Mrs F. McBain Sadler reports that the British Nautical Almanac Office has continued its routine programme of predictions of lunar occultations; the number of stations has increased to 85. It also provides predictions of about 160 radio sources for 26 stations.

The lunar occultation observations for 1958 and 1959 were reduced using Brown's ephemeris and analyzed both with and without limb corrections. They were also reduced using the Improved Lunar Ephemeris and analyzed after the application of limb corrections. The reduction and analysis for 1960 and 1961 have also been completed. The discussions for the four years 1958 to 1961 will be published shortly.

The limb corrections were taken from microfilm copies of C. B. Watts' charts, which he kindly provided prior to their publication. Their application has reduced the probable error of a single observation to $0''.3$, and appears to account for the correction to the Moon's latitude which was obtained in previous years. The following values of ΔT and δB were obtained using the Improved Lunar Ephemeris:

	DD only		All phases	
Year	ΔT	δB	ΔT	δB
1958·5	$+31^{s}.25$	$-0''.10$	$+31^{s}.14$	$-0''.06$
1959·5	$+31.72$	-0.05	$+31.63$	$+0.01$
1960·5	$+31.94$	-0.08	$+31.84$	-0.10
1961·5	$+32.23$	$+0.06$	$+32.15$	$+0.02$

It has always been the intention that, when Watts' (**12**) charts became available, limb corrections should be applied to all observations received by the Office since 1943, and in preparation the arguments for entering the charts have been calculated. In the intervening years many observers have re-determined the positions of their stations, particularly during the IGY, and many have supplied other corrections and additional information. In order to make the best possible use of this long series of observations, it has been decided to examine all observations from 1943 onwards in the light of the latest information and to reduce them all using the Improved Lunar Ephemeris before applying limb corrections. So far about 16 000 observations have been examined. The Nautical Almanac Office would like to receive as soon as possible any observations not previously reported.

At the Department of Astronomy, Manchester University, Z. Kopal (**13, 14, 15**) has carried out a certain amount of theoretical work on the internal structure of the Moon and its gravitational field.

Moreover, Z. Kopal (**16**) has organized two expeditions for observations of annular eclipses of the Sun on 1962 July 31, to Western Senegal, and on 1963 January 25, to South Africa, for studies of the exact shape of the Moon.

C. L. Goudas (**17**) has performed a harmonic analysis of hypsometric data by Schrutka-Rechtenstamm using the Manchester University electronic computers *Mercury* and *Atlas*. The main outcome of this work has been a realization that the shape of the lunar surface is quite complicated, consisting as it does of an expansion in zonal harmonics which does not converge any too rapidly with increasing order. In particular, the second harmonic does not stand out conspicuously, thus making it clear that an ellipsoid does not represent a much better approximation of the shape of the Moon than a sphere.

Th. Weimer, à l'Observatoire de Paris, a déterminé les trois coordonnées de 17 cratères fondamentaux de la Lune. Pour ce travail, il a utilisé 39 clichés de la collection obtenue entre 1894 et 1908 au grand équatorial coudé.

Un catalogue de 76 cratères ayant des diamètres de l'ordre de 5 km a été établi; 26 seulement de ces objets se trouvent sur la liste donnée dans *The Moon*, IAU Symposium Vol. no. 14 (**18**).

Ces cratères ont été mesurés séparément par Weimer, puis par Hunt, sur 11 clichés de la collection de Paris. Hunt et Eckhardt en feront la réduction à Boston, U.S.A., afin d'obtenir un système de points fondamentaux sur la Lune.

H. Hirose reports that the Tokyo Astronomical Observatory investigated the Moon's motion by transit observations (**19, 20, 21, 22, 23**), occultation observations (**24, 25, 26**) and observations with a Markowitz camera. Occultation observations have also been carried out by the Hydrographic Office (**27**).

M. Torao and Y. Adachi, Tokyo Astronomical Observatory, determined ΔT = E.T. − U.T. on the basis of meridian transit observations as follows:

	ΔT	m. e.
1952·5	+29^{s}30	±0^{s}60
53·5	30·12	0·34
54·5	30·35	0·24
55·5	30·89	0·21
56·5	31·14	0·42
57·5	30·74	0·28
58·5	30·89	0·30
59·5	+32·09	±0.33

J. Ueta, Kyoto, deals with the discussion of the transoceanic longitude determination by observing equal limb occultations.

At Sophia, N. Boneff dealt with the problem of determination of time by means of observations carried out on the Moon's surface.

A. Botelheiro, of the Lisbon Observatory, reports that the Observatory is continuing as routine work the observation of occultations. Since 1938, when the programme was begun at Lisbon, 1344 occultations had been observed up to the end of 1962.

At the University Observatory, Vienna, J. Hopmann determines with a 8-inch refractor the relative heights on the Moon in order to control the former measurements of Mädler and Schmidt, to determine small terrain elevations and to examine possible systematic errors. Moreover, G. Schrutka-Rechtenstamm is continuing his determination of precise coordinates and absolute heights of selected craters from measurements of twelve lunar photographs from

the Lick Observatory. In addition, some other lunar studies are being conducted, for example the examination of the accuracy of Kuiper's Atlas, the comparison of various lunar charts, etc.

At the Department of Theoretical Astronomy, Cracow University, K. Kozieł has worked out a new method for the adjustment of heliometric libration observations, in which each individual measurement of the crater's distance from the limb gives one observational equation for the main unknowns of the problem. This method, being the simplest from the mathematical point of view, leads also to most convenient formulae for the programming of calculations on electronic computers and which do not require the intermediate, more intricate, cracovian square-root equations, which were essential in the method formerly used in Cracow (**2, 28**).

Using four heliometric series covering the period 1877–1915—i.e., the Strasbourg (1877–1879) and Dorpat (1884–1885) series of Hartwig reduced by K. Kozieł, the Bamberg series of Hartwig, part I (1890–1912) re-reduced by J. Masłowski and the Kazan series of Banachiewicz (1910–1915) re-reduced by J. Mietelski — K. Kozieł determined the libration constants, on adjusting these four series by means of the new method. At the invitation of Z. Kopal, the adjustment was performed on the electronic computer *Mercury* at Manchester University. On allowing for the irregularities of the Moon's limb according to Hayn's charts the following results were obtained:

$$\begin{aligned} \lambda &= -5^\circ\,09'\,53'' \pm 4''.5 \\ \beta &= -3^\circ\,10'\,49'' \pm 4''.3 \\ h &= 15'\,32''.85 \pm 0''.18_5 \\ I &= 1^\circ\,32'\,04'' \pm 7''.0 \\ f &= 0.633 \pm 0.011_3. \end{aligned}$$

Taking into account for the first time the simultaneous determination of the constants of the forced libration together with those of free libration in longitude (A, a):

$$\begin{aligned} \lambda &= -5^\circ\,09'\,50'' \pm 4''.5 \\ \beta &= -3^\circ\,10'\,47'' \pm 4''.4 \\ h &= 15'\,32''.98 \pm 0''.19_1 \\ I &= 1^\circ\,32'\,01'' \pm 7''.1 \\ f &= 0.633 \pm 0.011_5 \\ A &= 18''.7 \pm 4''.7 \\ a &= 334^\circ.3 \pm 15^\circ.7 \quad (1800.0). \end{aligned}$$

At the same time K. Kozieł gave an exact proof for the uniqueness of the solution for f, which lies below the critical value 0·662, and had performed a joint adjustment by eliminating the Moon's mean radius corresponding to each series, as it might be affected by the effect of irradiation. The above work has shown that only a joint analysis of several heliometric series, with a sufficient number of observations and covering a sufficiently long period, may be valuable from the point of view of the requirements of scientific exactitude.

Moreover, K. Kozieł (**28**) published a monograph *The Libration of the Moon*, which appeared as the second chapter in the collective work *Physics and Astronomy of the Moon*.

J. Masłowski and J. Mietelski, respectively, finished in Cracow their re-reduction of the Bamberg series, part I, and Banachiewicz's Kazan series, and obtained the following results:

	Bamberg, I:		Kazan:	
λ =	$-5^\circ\,09'\,26''$	$\pm 5''.2$	$-5^\circ\,10'\,05''$	$\pm 6''.2$
β =	$-3^\circ\,11'\,00''$	± 4.5	$-3^\circ\,10'\,52''$	± 6.3
h =	$15'\,33''.03$	$\pm 0''.18_7$	$15'\,31''.82$	$\pm 0''.28_1$
I =	$1^\circ\,31'\,58''$	$\pm 6''.8$	$1^\circ\,32'\,37''$	$\pm 10''.9$
f =	0·627	$\pm 0.012_0$	0·628	$\pm 0.019_1$
R_0 =	$15'\,32''.98$	$\pm 0''.012$	$15'\,32''.83$	$\pm 0''.019$

taking into account the irregularities of the Moon's limb according to Hayn's charts.

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J. Masłowski and J. Mietelski also dealt in their paper (**29**) with the problem of the integration of the equation for the physical libration in longitude, by discussing the corresponding Mathieu equation, which is similar to Hill's equation. In conclusion, they confirmed the results of K. Kozieł's solution (**2, 28**) and adopted a critical attitude towards Makover's (**10**) suggestions.

The Cracow University Observatory continues, as routine work, the observation of occultations.

PROPOSALS

J. Hopmann, Vienna University Observatory, suggests that on publishing coordinates of lunar objects their numbers should always be given according to the IAU catalogue *Named Lunar Formations* by Blagg and Müller, in addition to their names. This catalogue and the corresponding lunar atlas, so indispensable for the specialist, are, alas, long out of print. Therefore, it is desirable that the Union should undertake a new edition of the above-mentioned catalogue and lunar atlas.

H. Jeffreys, Cambridge, suggests that, in view of the existence of the annual libration in longitude and the possible detectability of a libration with a period near three years, it is desirable that observations should be analyzed by three-year intervals for periods of one and three years; and since it seems possible that the term of period near three years may give γ with as great or greater accuracy than β, results for γ should be given as such; if expressed in terms of f, the value for β, that is taken as standard, should be given explicitly.

The Lunar and Planetary Laboratory, University of Arizona, puts forward the following recommendations concerning lunar photographs:

(*a*) that the measures on each plate be published as soon as completed;

(*b*) that these be published as measured photographic coordinates free of refraction and instrumental errors, and as selenographic coordinates;

(*c*) that the measures be accompanied by all the details of the exposures, measures, and reductions, which are necessary for all possible applications or further reductions of the measures.

Les propositions de Th. Weimer de l'Observatoire de Paris sont les suivantes:

1. Après les résultats obtenus par K. Kozieł (voir ci-dessus p. 217) pour les constantes de la libration physique, il conviendrait d'inviter la Commission 4 (Ephémérides) à utiliser ces nouvelles valeurs plutôt que celles de Hayn ou de Franz pour le calcul des librations physiques.

2. A partir de l'Assemblée Générale de Hambourg, la Commission 17 aura une compétence plus étendue. On pourrait profiter de ce changement pour élaborer, en application de l'article 19 du Règlement de l'UAI, un règlement intérieur. Celui-ci précisera comment se feront les liaisons avec les Commissions voisines (Mécanique céleste, Planètes, Ephémérides); il exigera des membres une participation active à la vie de la Commission, ce qui implique, par exemple, que tout résultat nouveau soit communiqué sans retard au Bureau et au Comité d'Organisation. Ceux-ci pourront ainsi jouer pleinement leur rôle de coordination et d'information et donner chaque année, en plus d'une courte analyse des travaux publiés, quelques indications sur les recherches en cours dans différents établissements.

A. A. Yakovkin, Kiev, finds it desirable that the so-called libration effect in the Moon's radius be taken into account in the re-reduction of heliometric series.

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