The value of chronometer error can be continually refined by applying the computed chronometer error and re-computing the fix. The chronometer error in each subsequent step is further refined until a chronometer error is computed which results in the moon LOP passing exactly through the point of the star fix. Because this procedure is prone to error and very time consuming, it is best to use a computer. Human error in calculation and plotting is thus easily eliminated. The author used the CN-2000 System for the lunar altitude method calculations described above. The almanac program of the computer as well as its fix computation accuracy is within 0'.2.

The direction of the chronometer error; i.e. either fast or slow is determined from a) the location of the fix position relative to the approximate or estimated position and b) the location of the moon line of position relative to the position of the fix.

If the chronometer fix is to the east (or earlier) the chronometer is slow and the chronometer error is minus (-).

If the moon LOP lies to the west of the star fix, the chronometer is slow and the error is minus (-). This is explained by the fact that the moon moves from west to east among the stars rather than the other way around.

Lunar Distance Observation from an Unknown Position.

Because of the moon's relative motion (between -30' and -40' per hour eastward) among the sun, planets and stars, it is also possible, by direct angular measurement, to compute the chronometer error and the approximate longitude. The procedure is briefly as follows:

The angular distance between the moon and a star (or the sun) is measured with a sextant at the same time as a simultaneous altitude of each of the two bodies is taken. The time of each observation is recorded from a watch of known rate. The observed lunar distance is then "cleared"; i.e., corrected for refraction, semi-diameter and the moon's parallax. The Nautical Almanac is then used to compute the GMT at which the cleared lunar distance occurred. This time is the correct chronometer time of the observation. The chronometer can now be correctly set from the watch times recorded for each altitude and distance measurement obtained during the lunar distance observations.

The lunar distance computations are very extensive and too involved for an example to be presented here. However, those members who wish to obtain a detailed explanation of the lunar distance observation with an example of a solved problem may address requests to the author through the Navigation Foundation.

HISTORY OF NAVIGATION

The Bygrave Position Slide Rule

By John M. Luykx

In 1920 the Air Ministry Laboratory (A.M.L.) in London authorized Henry Hughes and Son, the well-known firm of nautical instrument makers, to manufacture a logorithmic cylindrical navigation slide rule invented by Captain L. C. Bygrave. The "Bygrave" slide rule, as it is now known, was designed to compute the altitude and azimuth of the celestial body from values of:

1. Observer's DR Position or assumed position
2. GMT of the observation
3. GHA and DEC of the celestial body

and to compute the initial Great Circle True Course and Distance in arc/minutes between two points when their LAT/LON coordinates are known.

The Bygrave Slide Rule was the favorite method of celestial sight reduction for post World War I air navigators because it was a mechanical device which was compact, handy and portable. It was only 9 inches long (closed) 2 1/2 inches in diameter and with cylindrical metal case weighed less than 2 lbs. (See Figure 1) Like the Weems Star Altitude Curves, it could conveniently be carried and worked in the close confines of an aircraft cockpit. Although the Nautical Almanac was required to provide the GHA and DEC of a celestial body, solutions accurate to 1 arc minute were possible and could often be completed (with practice) in less than 2 minutes.

The design of the Bygrave Slide Rule is based on the navigation triangle where a perpendicular from the body's Geographical Position (G.P.) is drawn to the observer's meridian forming two right angled spherical triangles with the perpendicular and the right angle in common.

From a Henry Hughes Catalog of Instruments issued prior to World War II, we read that in addition to the housing, the main parts of the slide rule consist of "...two scales which are printed on two cylinders sliding with reference to each other. The inner cylinder on which all results are read is graduated with log tangents and the spiral scale is about 24 feet long divided into minutes of arc. The outer cylinder is graduated with log cosines. Two pointers are provided; one for each scale and are attached to a sliding ring. The pointer which was to be used for each setting is clearly marked and full instructions for dealing with all possible cases are printed on the bottom of the outer cylinder..." On the back of the slide rule are given scales of dip, refraction, moon parallax and an arc to time table. The only other information needed for sight reduction is GHA and DEC data from the Nautical Almanac.

The Bygrave Slide Rule is described, or at least mentioned, in most of the standard navigation texts and was considered by Captain P.V.H. Weems "...as probably the most convenient mechanical computer for obtaining position lines from sextant observations..."

Nine steps (settings) are required to complete the sight reduction process from given values of LHA, LAT, and DEC. Each step requires rotation of either the inner or outer scale and its alignment with either one of the two pointers. At the sixth step azimuth angle (Z) is computed and at the ninth setting computed altitude (Hc) is obtained. With practice the nine steps may be accomplished very rapidly and in many cases in less than 2 minutes. Through experience with the Bygrave Slide Rule in his collection, the author has found that great attention must be given to the alignment of the scales with the pointers but that, with sufficient care, excellent accuracy; i.e., to within 1 arc/minute, can often be achieved in the computation of both azimuth and altitude.

To illustrate the order of accuracy possible with the Bygrave Slide Rule, five sample problems were solved with the rule: four sight reduction problems and one Great Circle problem. The sight reduction problems consisted of given values of LHA, DEC and LAT requiring solution for true azimuth (ZN) and computed altitude (Hc). The Great Circle problem consisted of finding the initial true Great Circle course and Great Circle distance in arc/minutes between two points whose LAT/LON coordinates are given. Table 1 gives the results of the sight reduction computations and Table 2 the results of the Great Circle Sailing computation.

The results in Tables 1 and 2 indicate the inherent accuracy of the Bygrave Slide Rule and the author can personally attest to the rapidity with which computations can be made and to the portability of the instrument and its simplicity of design.

TABLE 1
SIGHT REDUCTION

	1	2	3	4
GIVEN:				
LHA:	77°31'.2	326°41'.8	48°04'.8	297°21'.3
DEC:	N18°06'.2	S09°16'.3	S57°16'.2	N36°42'.3
LAT:	N38°51'.8	N18°31'.2	N04°17'.2	S11°13'.0
FIND:				
ZN:	276°.9T	127°.4T	204°.9T	47°.2T
HC:	20°47'.0	46°57'.0	17°16'.0	14°12'.7

SOLUTION BY TAMAYA NC-2 CALCULATOR

ZN:	276°.9T	127°.4T	204°.9T	47°.3T
(Diff.)	0°.0	0°.0	0°.0	0°.1
Hc:	20°47'.3	46°58'.0	17°17'.9	14°11'.2
(Diff.)	0'.3	1'.0	1'.9	1'.5

TABLE 2

GREAT CIRCLE SAILING

GIVEN:

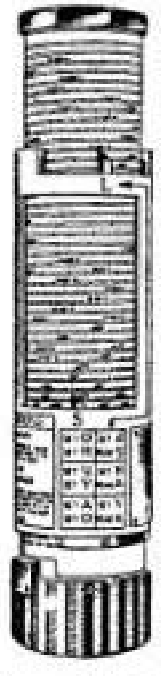
Point A:
LAT: N 38 51'.8
LON: W 76 55'.1

Point B:
LAT: N 50 15'.0
LON: W 08 20'.0

FIND:

Great Circle initial true course
Great Circle distance in arc/minutes

BYGRAVE SLIDE RULE	NC-2	(Diff.)
Course: 052°.8T	052°.8T	0°.0
Distance: 2901'.5	2902'.7	1'.2



Bygrave Slide Rule
Figure 1