A CRITICAL DETERMINATION OF THE LATITUDE AND LONGITUDE OF THE CRANE OBSERVATORY, TOPEKA, KANSAS BY ASTRONOMICAL TRANSIT MEASUREMENTS

by

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INTRODUCTION

This investigation was undertaken to obtain a definitive value of the latitude and longitude of Crane Observatory for the purpose of publication in the American Ephemeris and Nautical Almanac. The position of the observatory, built in 1903, had not been determined by astronomical methods.

In 1904, G. Bruce Blair determined the geodetic coordinates of this observatory by triangulation, using two secondary stations of the U. S. Coast and Geodetic Survey of 1902. He reported the latitude to be $39^{\circ}\ 02'\ 04''.532$ and the longitude $95^{\circ}\ 42'\ 05''.694$. It should be pointed out that the latitude and longitude of the secondary stations were given only to the nearest hundredth second of arc, yet the final results were reported to the thousandth second of arc. Probable errors of the secondary stations or the final results were not given. The geodetic coordinates of primary base stations are constantly being checked and values revised from time to time to improve the accuracy of these positions.

Since astronomical methods are capable of giving a higher degree of precision, it was decided to check the above results. A systematic program of observing was instituted and carried on during the summer of 1955 to obtain the necessary data for this computation. The reduction of these observations was a very lengthy and time consuming task, hence the delay in reporting the final results of this investigation.

EQUIPMENT

The following items all permanent equipment of the observatory, were used to pursue the investigation: (Plates I, II)

(1) Fauth combined zenith and transit telescope

(2) Warner and Swasey chronograph

(3) E. Howard and Company mean solar and sidereal clocks

(4) Hallicrafters Model S-38 short wave radio

DETERMINATION OF LATITUDE

Theory of Measurement

The declination (δ) of a star is its angular distance north or south of the celestial equator and is given for certain stars in various star catalogues. Declination is considered positive if the star is north of the celestial equator and negative if south. The zenith distance (z) of a star is the angular distance from the zenith to the star, measured along a vertical circle through the star. The meridian zenith distance of a star can be measured with a zenith telescope and will depend on the declination of that star and the latitude (ϕ) of the observer according to the equation $\phi = \delta \pm z$. The positive sign is used if the star is north of the zenith and the negative sign if the star is south. The celestial meridian, often simply called the meridian, is a great circle on the celestial sphere passing through the celestial north and south poles and the zenith, a point directly above the observer.

EXPLANATION OF PLATE I

Fauth combined zenith and transit telescope.

Crane Observatory, Topeka, Kansas.

PLATE I

EXPLANATION OF PLATE II

Left - Warner and Swasey chronograph

Right - E. Howard and Company mean solar clock

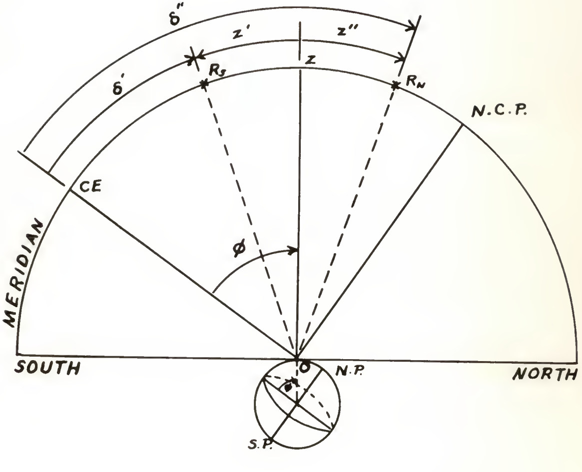
Crane Observatory, Topeka, Kansas

PLATE II

EXPLANATION OF PLATE III

O	Position of observer on the earth
Z	Zenith of the observer
NP	Earth's north pole
SP	Earth's south pole
NCP	North celestial pole
CE	Intersection of celestial equator with meridian
R_N	Position of star on meridian north of zenith
R_S	Position of star on meridian south of zenith
z'	Zenith distance of star south of zenith
z''	Zenith distance of star north of zenith
δ'	Declination of star south of zenith
δ''	Declination of star north of zenith
ϕ	Latitude of the observer

PLATE III



Referring to Plate III, it can be seen that the meridian zenith distance of a star south of the zenith is

$$z' = \phi - \delta' \tag{1}$$

and for a star on the meridian north of the zenith

$$z'' = \delta'' - \phi. \tag{2}$$

Subtracting equation (2) from equation (1) it follows that

$$\phi = \tfrac{1}{2}(\delta' + \delta'') + \tfrac{1}{2}(z' - z''). \tag{3}$$

Equation (3) is the basis of the Horrebot-Talcott method of determining latitude which involves only the measurement of the difference in zenith distances of two stars. With a precision micrometer this difference can be determined very accurately for a "Talcott Pair". A Talcott Pair consists of two stars which transit the celestial meridian within a few minutes of each other, one of which transits south and the other north of the zenith and whose difference in zenith distance is less than the angular field of view of the telescope. Calibration errors of the telescope altitude circle are eliminated since the setting is not altered during the course of the measurement and uncertainties in atmospheric refraction have negligible effect on the results since the zenith distances must be very nearly equal. Since the results obtained by observing a single pair of stars is subject to personal and observational errors, by observing a large number of pairs and combining the results of the independent determinations, a mean value may be obtained that is much more dependable.

Observing Procedure

Prior to making observations with the zenith telescope adjustments of the instrument were made according to the instructions outlined in Nassau (6), p. 209. The following observing list was prepared consisting of five pairs of stars meeting the following requirements: (1) difference in zenith distance less than one degree, the approximate angle of the field of the zenith telescope (2) differences in time of transit (a) over three minutes and less than ten (3) as bright or brighter than +6.0 apparent magnitude for good visibility.

Table 1. Observing list.

No.	Star	Magn.	α			δ		N or S	Alt.		Ave. Alt.		Micrometer setting
			h	m	s	°	'		°	'	°	'	
1.	B4722	0.0	18	35	25	38	44	S	89	42	89	35	6 down
	B4749	4.6	18	42	53	34	34	N	89	28			
2.	B4797	4.7	18	52	57	22	35	S	73	33	73	30	2 down
	B4848	5.7	18	59	50	55	35	N	73	26			
3.	B4948	4.6	19	20	26	65	37	N	63	24	63	39	12 up
	B4963	6.0	19	24	18	12	59	S	63	54			
4.	B5039	5.6	19	41	51	25	39	S	76	38	76	24	12 down
	B5075	5.2	19	49	30	52	52	N	76	10			
5.	B5163	5.9	20	05	03	53	02	N	76	00	76	13	11 up
	B5190	4.9	20	13	21	25	27	S	76	25			

In Table 1 the star numbers are those given in Boss (3). The right ascension (α) of a star is its angular distance east of the vernal equinox on the celestial sphere and is measured either in degrees, minutes and seconds of arc or in hours, minutes and seconds of sidereal time. Since the sidereal day begins at the instant of transit of the vernal equinox, the sidereal time at any instant is equal to the right ascension of a star on the meridian. Therefore, a sidereal clock will enable one to determine when a given star is on the meridian.

In preparing the observing table it was sufficiently accurate to use the right ascension (α) and declination (δ) of the stars as of January 1, 1955. The meridian altitude (h) of the stars were computed by equations (1) or (2), and ($h = 90^{\circ} - z$), using an approximate value of the latitude (ϕ). An approximate initial micrometer setting was obtained by dividing one-half the difference in altitudes of a star pair by the value (R) of one revolution of the micrometer screw, which was found to be $67\overset{''}{.}77$ per revolution (see right hand column, Table 1).

The meridian circle on the telescope was set at the average altitude of the pair and a sensitive level ($1\overset{''}{.}978$ per scale division) mounted on the circle was used to indicate when the instrument was set at the desired altitude. This insured that one star of the pair would transit above the center of the field and the other star below the center of the field. The movable micrometer wire in the field was moved up or down the appropriate number of turns as indicated in the observing list to be near the position where the star would cross the field. The micrometer wire was adjusted to such a position as to bisect the star as it crossed a fixed vertical wire in the center of the field of view, and the micrometer reading recorded as well as the position of the north and south ends of the level bubble. Without changing the altitude circle setting, the telescope was rotated 180° about its vertical axis and the micrometer wire adjusted to bisect the second star of the pair as it crossed the vertical wire in the center of the field of view. Care was exercised to advance the micrometer wire only in one direction to avoid back lash in the threads. The micrometer reading on the second star was recorded and the position of both ends of the level bubble again observed and recorded. This completed the observations for one pair of stars.

Computation

Prior to actual computation of latitude it was necessary to calibrate the meridian circle level to determine its sensitivity. This was accomplished by placing it on a level trier which consisted of a rectangular iron bar of known length with a micrometer head mounted at one end to raise or lower that end of the bar a known distance. The level constant (d_1) was found to be $1.''978$ per scale division.

The micrometer screw that drives the movable wire across the field was calibrated by measuring the positions of five fixed wires in the field of view which were parallel to the movable wire. The angular distance between the five fixed wires had been determined by observations of the diurnal motion of 115 stars in the longitude determination. The observed interval of time required for a star to move from any one wire to another multiplied by the cosine of the declination (δ) of that star gives the time interval reduced to the celestial equator. The average of the observed time intervals, multiplied by 15, gives the angular separation of the fixed wires. The micrometer calibration (R) was found to be $67\overset{''}{.}77$ per revolution.

The latitude of the observer is obtained by the equation

$$\phi = \tfrac{1}{2}(\delta' + \delta'') + \tfrac{1}{2}(m' - m'')R + \tfrac{1}{2}(b' + b'') + \tfrac{1}{2}(r' - r'') \quad (4)$$

where the "primes" refer to stars south of the zenith and "seconds" to stars north, Nassau (6), p. 215. The term $\frac{1}{2}(\delta' + \delta'')$ is the declination of a fictitious star whose meridian zenith distance (z) is given by $\frac{1}{2}(m' - m'')R$. The letters (m') and (m'') refer to micrometer readings of the two stars. Therefore, according to equation (1) the first two terms yield the latitude of the observer neglecting instrumental errors. The latter are given by the third and fourth terms.

In the first term (δ') and (δ'') refer to the apparent declinations of the two stars of a pair at the instant of observation. Since most of the stars used in the latitude determination were too faint to be listed in the American Ephemeris and Nautical Almanac of 1955 which gave, for a few bright stars, the apparent right ascension (α) and declination (δ) at ten-day intervals, it was necessary to use the Boss Preliminary General Catalogue of 1900 (3) and reduce (α) and (δ) from January 1, 1900 to January 1, 1955 by the equations

$$\alpha_o(\text{epoch } T) = \alpha_o'(\text{epoch } T_o) + (\text{An. Var.})t + (\tfrac{1}{200}\text{ Sec. Var.})t^2 \quad (5)$$

$$\delta_o(\text{epoch } T) = \delta_o'(\text{epoch } T_o) + (\text{An. Var.})t + (\tfrac{1}{200}\text{ Sec. Var.})t^2 \quad (6)$$

where α_o and δ_o are the mean coordinates of the star at the beginning of any year T and α_o' and δ_o' are the coordinates of the star given in the catalogue of the year T_o. $T - T_o = t$, the number of years since the epoch of the catalogue. The value of the annular variation and secular variation are also obtained from the catalogue for each star used.

To reduce the mean declination at the beginning of the year 1955 to the instant of observation, it was necessary to use the formula

$$\delta = \delta_o + \tau\mu' + g\cos(G+\alpha_o) + h\cos(H+\alpha_o)\sin\delta_o + i\cos\delta_o \quad (7)$$

(Nassau, 6, p. 168), where τ is the fraction of the year and g, G, h, and H are independent star numbers found in the American Ephemeris and Nautical Almanac for 1955 (2), p. 263. Correction of declination for the proper motion of the star involves the constant (μ') obtained from Boss's Preliminary General Catalogue (3) and the independent star numbers were used to correct for precession and nutation of the earth's axis.

The third term, $\frac{1}{2}(b' + b'')$, in equation (4) is the correction of the altitude setting of the telescope. With the particular level used, on which the graduations were numbered from one end of the level and increasing towards the objective lens with the telescope inclined,

$$\tfrac{1}{2}(b' + b'') = \tfrac{1}{4}\Big[(n'' + s'') - (n' + s')\Big]d_1 \qquad (8)$$

where n'' and s'' are the readings for the ends of the bubble for the north star, n' and s' the bubble readings for the south star and (d_1) the level calibration constant previously mentioned.

The fourth term, $\frac{1}{2}(r' - r'')$, in equation (4) is a correction for differential atmospheric refraction. The appropriate values of this term were obtained in each case from Nassau (6), Table XXII, p. 284.

Table 2. Independent determinations of latitude

Date	Pair 1	Pair 2	Pair 3	Pair 4	Pair 5
	° ' "	' "	' "	' "	' "
Aug. 17	39 02 01.39	02 02.21		02 05.34	02 04.92
Aug. 29	02 02.95	01 59.90$_2$	02 05.22	02 01.98	02 03.30
Aug. 31	02 25.73$_1$	02 00.71$_2$	02 05.30	02 04.87	02 04.35
Sept. 1	02 05.84	02 04.33	02 05.89	02 05.67	02 08.91$_2$
Sept. 3	02 09.44$_2$	02 02.88	02 04.19	02 05.02	02 08.59$_2$
Sept. 4	02 05.98	02 04.65	02 04.87	02 05.01	02 06.08
Sept. 5	02 09.91$_2$	01 51.25$_1$	02 04.35	02 05.90	02 05.20
Sept. 6	02 01.44	02 03.79	02 04.85	02 05.92	02 04.79
Sept. 7	02 03.48	02 03.94	02 05.10	02 03.83	02 05.69
Sept. 8	02 04.20	02 06.06	02 04.81	02 04.02	02 04.20
Sept.11	02 01.48	02 05.14	02 04.77	02 04.44	02 03.44

($_1$) These two results were eliminated in computing the final value due to obvious errors in reading micrometer.

($_2$) These six values were eliminated from final consideration by Chauvenet's Criterion (Storer, 7, p. 40).

The value 39° was not repeated for each column since it was the same for all results listed.

The weighted mean of these values is

$$\phi = 39^{\circ}\ 02'\ 04''.41 \pm 0''.13.$$

DETERMINATION OF LONGITUDE

Theory of Measurement

The longitude of a point on the earth's surface is its angular distance east or west of the Greenwich Meridian. Since the interval of time between two successive transits of the celestial meridian at Greenwich, or any other assumed point, by a given star is 24 hours of sidereal time, it follows that the difference in sidereal time of transit of a star at any two points may be used to determine the difference in longitude of the two points.

Sidereal time, kept by astronomical sidereal clocks, is local time, that is, the sidereal day begins when the vernal equinox crosses the celestial meridian at a given station. Since the right ascension (α) of a star is its angular distance east of the vernal equinox, the sidereal time of day at any station is equal to the right ascension of a star that is on the celestial meridian at that instant.

By assuming an approximate longitude near the observer's position one can compute the precise time of transit of a given star at the assumed position. The precise time of transit at the observer's position is determined with the astronomical transit telescope. The correction, ($\Delta\theta$), to the assumed longitude is given by the equation:

$$\Delta\theta = \alpha - \left[(\theta_m + i_m C) - 0.021C \cos \phi + (\theta_m - \theta_o)d\theta + Bb + Cc + Aa\right]. \quad (9)$$

In equation (9) (Campbell, 4, p. 132), $(\theta_m + i_m C)$ is the observed instant of transit, the term $-0.021C \cos \phi$ is a correction for diurnal aberration, $(\theta_m - \theta_o)d\theta$ is a correction for clock rate and the remaining terms correct for errors in instrumental adjustment (see p. 26). A, B, and C are coefficients that depend on the observer's latitude and the declination of the star observed. These coefficients are given by the equations:

$$A = \frac{\sin(\phi - \delta)}{\cos \delta}, \quad B = \frac{\cos(\phi - \delta)}{\cos \delta}, \quad C = \frac{1}{\cos \delta}.$$

The term Bb is a level correction for the instrument, where b indicates the inclination, in seconds of time, of the east-west axis of rotation of the instrument. This expression will be positive when the west support is higher and negative when it is lower than the east support. It will be a maximum for stars near the zenith and zero for stars on the horizon. Since the value of the level constant (b) cannot be considered to remain the same for a period of observation lasting as long as one hour, it is advisable to compute it for each observation from readings of a sensitive striding level which is placed across the east and west supports.

The term Cc is a correction for collimation error in the instrument. Since the sign of the collimation constant (c) changes when the instrument is reversed, that is, when the telescope is rotated 180° about its vertical axis, it is customary to reverse the instrument at a time near the middle of the observing period so that errors due to this term will tend to offset each other.

The term Aa is a correction for the azimuth error of the instrument. The value of this correction is greatest for stars near the horizon and zero for stars at the zenith. The azimuth correction changes signs for stars on opposite sides of the zenith. The values of the azimuth constant (a) and the collimation constant (c) will change from day to day, but they can be computed for any particular observing period.

$\Delta\theta$ is most accurately determined for stars near the celestial equator since they will cross the field of view most rapidly and less personal error is introduced due to the uncertainty of the instant that the star is bisected by each of the five vertical wires in the field of view.

Observing Procedure

An observing list of stars was prepared for each nightly observation period from the American Ephemeris and Nautical Almanac for 1955 (2), p. 303-356, which gave the apparent places of 214 standard stars at ten-day intervals. In preparing the observing list for a particular evening, an attempt was made to include some stars near the southern horizon, some near the zenith, some north of the zenith, but more located near the celestial equator since the determination of time, $\Delta\theta$, was the primary objective. The observing lists for different nights did not necessarily involve the same stars since observation often began at a different time. Table 3 on the following page is a typical observing list used. The level readings for that observation period have been indicated.

Table 3. Observing list - transit observations August 3, 1955

No.	Star	α h m	δ ° '	Alt. ° '	Refr. '	Setting ° '	Clamp	Level O-East	Level O-West
1.	ε Scorpii	16 47	-34 12	16 46S	+3	16 49S	Direct	24.0/44.0	48.8/24.7
2.	k Ophiuchi	16 55	+ 9 26	60 24S	+1	60 25S		23.5/43.7	45.2/25.0
3.	η Ophiuchi	17 07	-15 40	35 18S	+1	35 19S		23.9/44.1	44.7/24.4
4.	δ Herculis	17 13	+24 52	75 51S	0	75 51S		missed	
5.	β Draconis	17 29	+52 19	76 43N	0	76 43N		24.3/44.8	44.8/24.3
6.	k Scorpii	17 39	-39 00	11 58S	+4	12 02S		24.4/44.9	45.1/24.6
7.	γ Draconis	17 55	+51 29	77 33N	0	77 33N	Reversed	24.2/44.8	44.9/24.3
8.	72 Ophiuchi	18 05	+ 9 33	60 31S	+1	60 32S		25.0/45.7	44.8/24.1
9.	η Serpentis	18 18	- 2 54	48 04S	+1	48 05S		24.8/45.3	44.5/23.8
10.	λ Scorpii	18 25	-25 26	25 32S	+2	25 34S		missed	
11.	α Lyrae	18 35	+38 44	89 42S	0	89 42S		24.4/45.1	44.8/24.0
12.	σ Sagittarii	18 52	-26 21	24 37S	+2	24 39S		24.9/45.6	44.3/23.5
13.	ζ Sagittarii	18 59	-29 56	21 02S	+3	21 05S		24.9/45.7	44.1/23.3

Time signals: 20:35 - excellent; 21:20 - excellent; 22:20 - good.

It was necessary to allow at least five minutes and preferably more time between observations to allow sufficient time to read the striding level, reset the telescope for the next observation and occasionally record time signals.

In Table 3, α is the approximate time of transit in sidereal time. Thus, a sidereal clock enables one to determine an approximate time at which the star will enter the field of the telescope. The altitude at which the star transits is given by

$$h = \phi + \delta \tag{10}$$

for stars south of the zenith and

$$h = 90^\circ - (\phi + \delta) \tag{11}$$

for stars north of the zenith. These values corrected for atmospheric refraction provide the altitude setting for the meridian circle on the transit telescope for each star.

For accurate determination of the time of transit of a star, there are five vertical wires located in the field of view of the eyepiece. The instant at which a star crosses each wire can be determined visually and with a telegraph key a signal can be electrically recorded on the chronograph sheet. Contacts in the mean solar clock provided signals at two second intervals throughout the observing session so that the time at which a given signal occurred was determined by linear interpolation. Only even numbered seconds were recorded except the 59th second, the latter for identification of the minute. Plate IV is a reproduction of a chronograph sheet, reduced to approximately one-half its actual size.

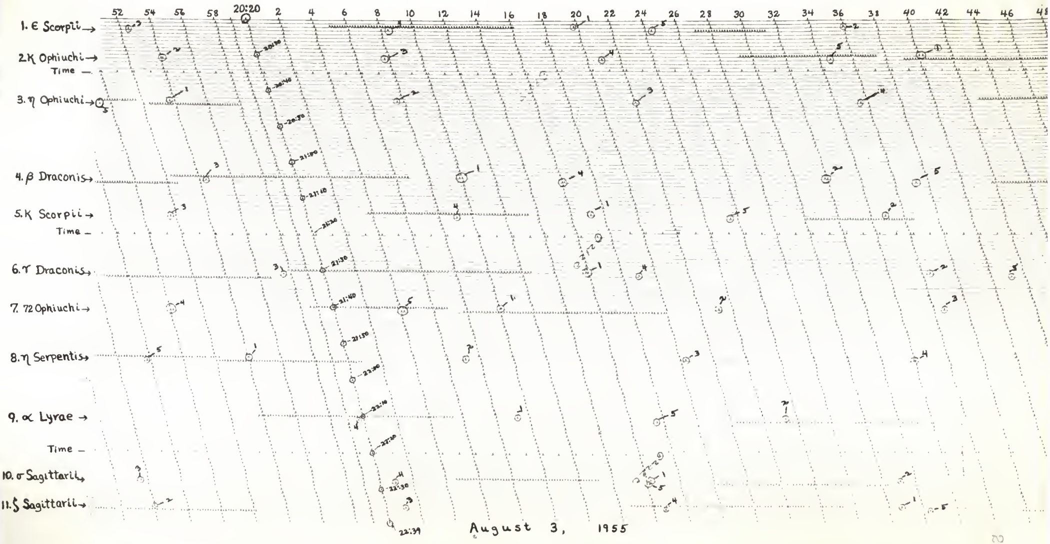
Since the chronograph drum rotated at one revolution per minute, each segment of the record (Plate IV) represents one minute. At convenient intervals between observations, radio time signals from WWV were recorded for the purpose of determining the clock correction. Immediately following each observation of a star, the striding level was placed across the east and west supports and the position of the bubble read, first with the zero end of the scale to the east and then with the zero end west.

EXPLANATION OF PLATE IV

Reproduction of chronograph record sheet.

Approximately one-half actual size. Numerals across top indicate two-second mean solar clock signals. Note radio time signals ending at 20:35, 21:20 and 22:20. Star names are on left margin. Signals indicating the crossing of each wire by the star are numbered 1 to 5, preceded and followed by warning signals for identification.

PLATE IV



August 3, 1955

Computation

In the formula given in theory of measurement,

$$\Delta\theta = \alpha - \left[(\theta_m + i_m C) - 0.021C \cos \phi + (\theta_m - \theta_o)d\theta + Bb + Cc + Aa\right], \quad (9)$$

α is the apparent right ascension of the star at the instant of observation. Since the American Ephemeris and Nautical Almanac (2) gave α at ten-day intervals throughout the year, it was necessary to interpolate for the ten-day period and apply a correction for the short period terms, computed by

$$\Delta\alpha = D_\psi\alpha \; d\psi + D_\epsilon\alpha \; d\epsilon \quad (12)$$

as given in the above reference, p. 245.

The expression $(\theta_m + i_m C)$ is the most probable time of transit of the middle wire by the observed star. Let t_1, t_2, t_3, t_4 and t_5 be the times of crossing of the five wires (with the instrument direct, that is, meridian circle level east) and let

$$\theta_m = \frac{t_1 + t_2 + t_3 + t_4 + t_5}{5} \; . \quad (13)$$

θ_m is the most probable time of transit of a fictitious mean wire. Even with precisely accurate values for the five observed times above, θ_m would not necessarily agree with t_3, the time of transit of the middle wire, due to probable unequal spacings of the wires. Let $i_1 = t_3 - t_1$, $i_2 = t_3 - t_2$, $i_4 = t_3 - t_4$ and $i_5 = t_3 - t_5$, for a star on the celestial equator, and

$$i_m = \frac{i_1 + i_2 + i_4 + i_5}{5}, \tag{14}$$

where i_m is the reduction from the mean wire to the middle wire. It will be noted that i_4 and i_5 have negative values for the telescope direct and i_1 and i_2 will have negative values with the telescope reversed. Then $(\theta_m + i_m C)$ is the most probable time of transit of the middle wire by any star, regardless of declination, since $C = \frac{1}{\cos\delta}$.

The time of transit of the five wires by a star were obtained from the chronograph sheet by measurement with a finely divided scale. A simple magnifier was used to measure these values more accurately. The most probable time of transit of the middle wire was computed for each star observed.

Had the value of one turn of the micrometer screw (R) been accurately known, the movable micrometer wire discussed in the section on latitude could have been used to measure the distance between the five wires. Since this was not known, the reverse procedure was followed. The distances i_1, i_2, i_4 and i_5 were determined by observing the transit times of 115 stars, reduced to the equator, and the averages used to determine i_m as follows: $i_1 = 27\overset{s}{.}098$, $i_2 = 13\overset{s}{.}475$, $i_4 = 13\overset{s}{.}213$ and $i_5 = 26\overset{s}{.}127$, so

$$i_m = \frac{(27.098 + 13.475) - (13.213 + 26.127)}{5} = + 0\overset{s}{.}247.$$

The above determined distances were then used in the calibration of the micrometer screw ($R = 67\overset{''}{.}77$) as used in the latitude determination.

As mentioned before, the term $- 0.021C \cos \phi$, is a correction for diurnal aberration. Due to the rotation of the earth, the star is observed slightly east of its true position, hence the observed time of transit is later so the correction is always subtracted from the observed time.

The clock correction, $(\theta_m - \theta_o)d\theta$, was determined according to time signals from radio station WWV. This correction presented a problem in this investigation. Had the mean solar clock used had a sensible rate, $d\theta$, it would only have been necessary to record the time signals once during the observing period, calling this time θ_o, and apply $d\theta$ to the difference in time between the actual observation time, θ_m, and θ_o for each star. It was found that the mean solar clock used was fast and gaining time, that is, $d\theta$ was positive. However, the rate was not constant. On July 6, the first day of longitude observations, the average of the time signals recorded indicated the clock was $06^s.407$ fast. On August 7, the last day, the clock was $19^s.574$ fast, a gain of $13^s.167$, the average value of $d\theta$ being $+ 0.017$ seconds per hour. A minimum value of $+ 0.005$ seconds per hour was noted between July 6 and July 11, while the maximum value of $+ 0.025$ was obtained between August 3 and August 7. The rate did not increase linearly but fluctuated between the above limits.

Time signals were generally recorded at least three times during one observing period, once near the beginning, once near the middle and once near the end. Comparison of these time checks did not indicate a steady rate of change during the single observing period. Generally, but not in every instance, the clock was faster at the middle of the observing period than at either the beginning or the end. This change was of the order of three or four-hundredths of a second.

This variation of rate might be partially attributed to temperature variations. While the clock was supposed to be temperature compensated, it had previously been determined that marked temperature changes affected its rate. Since observations were made during summer evenings, the clock room was generally quite warm at the beginning of the observing period. Opening of windows and the slit in the roof of the adjacent transit room would often lower the temperature appreciably during the observing period.

However, it is quite likely that much of the lack of agreement of clock rate during a single observing period was due to personal errors of the observer. Time signals were recorded by listening to the radio signals and tapping a telegraph key which recorded the signals electrically on the chronograph sheet. While every effort was made to maintain the steady rhythm of the time signals, some personal error was unavoidable and occasiontime signals, some personal error was unavoidable and occasionally poor signals added to the uncertainty. Time signals were generally recorded for a full minute and in some instances longer, then all signals measured to obtain the best average.

Since an observing period seldom exceeded two hours and there were erratic variations obtained in the individual time corrections to be applied, it was felt that the best time correction for a particular observing session was the average of the separate time corrections obtained. A typical example is:

Date: August 7, 1955

At $20^h\ 20^m$	$19^s.528$	fast	(51 signals measured)
$20^h\ 55^m$	19.608	fast	(40 " ")
$22^h\ 00^m$	19.585	fast	(55 " ")
Average	19.574	fast	

Therefore, the clock correction, $(\theta_m - \theta_o)d\theta$, was considered constant for one observing period and equal to the average of the separate determinations of the correction. While this might introduce an error of the order of $\pm\ 0^s.02$ for stars observed at the beginning and end of the period, the sign of the correction would change at the middle of the period and these corrections would tend to cancel each other, resulting in negligible error in the results to the accuracy reported.

In determining the level correction Bb for the telescope, the coefficient B was computed for each star since

$$B = \frac{\cos(\phi - \delta)}{\cos\delta} .$$

For a particular star, δ changed so little during the 32 day period as to affect B only in the fifth significant figure. The value of (b) for the type of striding level used was

$$b = \tfrac{1}{4}\left[(w + e) - (w' + e')\right]d_2 \qquad (15)$$

as given by Campbell (4), p. 80, where w and e refer to the scale readings of the end of the bubble of the striding level when the zero end of the scale was east and w' and e' were the bubble readings with the zero west.

Much difficulty was encountered in determining (d_s), the sensitivity of the striding level. This was undertaken prior to any observations by placing it on a level trier as was used in calibrating the meridian circle level discussed in the latitude determination. Data was obtained and graphs plotted which indicated the sensitivity changed appreciably, apparently near the middle of the scale. After tightening the screws that held the glass capsule in the mount, more consistent results were obtained. The sensitivity was found to be linear for the major part of the scale but increased sharply near the ends. This presented no serious problem, however, since the telescope supports upon which this level rested were very carefully leveled prior to the observing period so all readings taken would be with the bubble near the middle of the scale. Since the level sensitivity did depend on the length of the bubble, it was carefully calibrated for bubble lengths ranging from about 20 to 23 scale divisions and found to have a mean value, $d_s = 2\overset{''}{.}73$ per scale division = $0\overset{s}{.}182$ per scale division. While temperature had a noticeable effect on the bubble length, it was possible to adjust the bubble length between the above limits during the ensuing observing periods. With the instrument carefully leveled, the level correction Bb was generally quite small, that is, less than $0^{s}.1$ but in extreme cases was of the order of $0^{s}.5$.

The values of (a), (b) and (c) do not in general remain constant for very great periods of time. Of these, only (b) can be quickly and accurately measured during the course of observations. However, the values of (a) and (c) can be included as unknowns in the observation equation which, from equation (9), is

$$\Delta\theta + Aa + Cc = m \qquad (16)$$

where

$$m = \alpha - \left[(\theta_m + i_m C) - 0.021C \cos\phi + (\theta_m - \theta_o)d\theta + Bb\right]. \qquad (17)$$

All the terms on the right side of equation (17) can be computed independently for each star of an observing period. An equation of the form of (16) was obtained for each star observed during an observation period, giving a system of six or more linear equations involving three unknowns. These were combined and solved by least squares methods (Storer, 7, Supplement, p. 1).

Observations were made on 12 nights, the minimum number of stars observed being 6 and the maximum 12. For each observation period a value for the correction, $\Delta\theta$, to the assumed longitude was obtained along with its probable error. These results were then combined, weighted according to individual probable errors as given in the results (Storer, 7, p. 53). Table 4 is a resume of the results.

In computing (m) in equation (17), α was the right ascension of the star and numerically equal to the sidereal time of transit of that star. Since the mean solar clock was used to obtain the most probable time of transit of the middle wire by the star, it was necessary to convert the value of the mean solar time obtained to sidereal time by the steps outlined by Alter (1), p. 29.

Table 4. Results of longitude determination

Date	No. stars	Longitude			Probable error
		h	m	s	s
July 6	10	06	22	47.78	± 0.05
July 11	6	06	22	47.75	0.06
July 12	11	06	22	47.65	0.06
July 14	6	06	22	48.01	0.06
July 16	10	06	22	47.95	0.08
July 20	11	06	22	47.88	0.06
July 25	7	06	22	47.68	0.10
July 26	8	06	22	48.12	0.04
July 28	12	06	22	47.54	0.12
July 29	8	06	22	47.67	0.26
August 3	11	06	22	47.88	0.08
August 7	12	06	22	47.86	0.08

Mean weighted value: $06^h\ 22^m\ 47^s.88 \pm 0^s.02$

or $95^\circ\ 41'\ 58''.2 \pm 0''.3$

SUMMARY

The geodetic coordinates of Crane Observatory, Topeka, Kansas, as determined by this investigation were found to be:

$$\text{Latitude } (\phi) = 39^\circ\ 02'\ 04\overset{''}{.}41 \pm 0\overset{''}{.}13$$
$$\text{Longitude } (\lambda) = 95^\circ\ 41'\ 58\overset{''}{.}2 \pm 0\overset{''}{.}3.$$

This latitude determination indicates the observatory is approximately 12 feet south of the position, $39^\circ\ 02'\ 04\overset{''}{.}532$, as reported by Blair in 1904 (See Introduction). It is an established fact that the earth's poles wander slightly, shifting as much as 40 feet from their mean position. Hence, a variation as a function of time, amounting to a maximum of $\pm\ 0\overset{''}{.}4$ is to be expected in latitude determinations.

The longitude determination locates the observatory approximately 580 feet east of Blair's position, $95^\circ\ 42'\ 05\overset{''}{.}694$, which is equivalent to $6^h\ 22^m\ 48\overset{s}{.}380$. It can be expected that the latitude determination might agree fairly well with Blair's 1904 determination since the latitude of any point can be determined independently of any other point by measurement of star altitudes. On the other hand, longitude determinations depend basically upon the measurement of differences of time which can be measured much more precisely with time signals than was possible in 1904.

An analysis of Blair's results indicates clearly that the precision of his results does not warrant reporting the position to the thousandth of a second of arc (which is equivalent to 0.1 foot) since he started with positions known only to a hundredth second of arc. No probable errors were indicated; therefore, an intelligent comparison cannot be made and Blair's results have been given for information only.

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A CRITICAL DETERMINATION OF THE LATITUDE AND LONGITUDE OF THE CRANE OBSERVATORY, TOPEKA, KANSAS BY ASTRONOMICAL TRANSIT MEASUREMENTS

by

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AN ABSTRACT OF A THESIS

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This investigation was undertaken to obtain a definitive value of the latitude and longitude of Crane Observatory for the purpose of publication in the American Ephemeris and Nautical Almanac. A previous determination of the position of this observatory by G. Bruce Blair in 1904, made by triangulation using secondary stations of the U. S. Coast and Geodetic Survey of 1902, was available, but of doubtful value.

The main items of equipment used in this determination consisted of a Fauth combined zenith and transit telescope, Warner and Swasey chronograph, E. Howard and Company mean solar and sidereal clocks, and a Hallicrafter short wave radio.

The latitude determination was made by the Horrebow-Talcott method. This method consists in measuring the difference in zenith distances of selected pairs of stars of known declination with a sensitive micrometer, a measurement which can be made with high precision.

The longitude determination consisted basically in determining the difference in time at the same instant between that computed for an assumed meridian near the observatory and the time observed at the observatory with a transit telescope.

The value of latitude obtained in this investigation was North $39^\circ\ 02'\ 04''.41 \pm 0''.13$, which located the observatory approximately 12 feet south of the previously determined position. The longitude of the observatory was found to be $95^\circ\ 41'\ 58''.2 \pm 0''.3$, about 580 feet east of the determination of 1904.