# FORUM

## Some Refraction Measurements at Low Altitudes


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It may be interesting to report some measurements of refraction which Professor A. N. Black and I made this winter. These were made on the setting Sun, and as the altitude of the observing station was 480·0 ft. it was possible to carry the observations down to the horizontal and, in fact, under clear conditions, to $-20'$.

The observations were made with a micrometer theodolite set on a concrete pillar, and were complete in that the alidade bubble was read after each setting

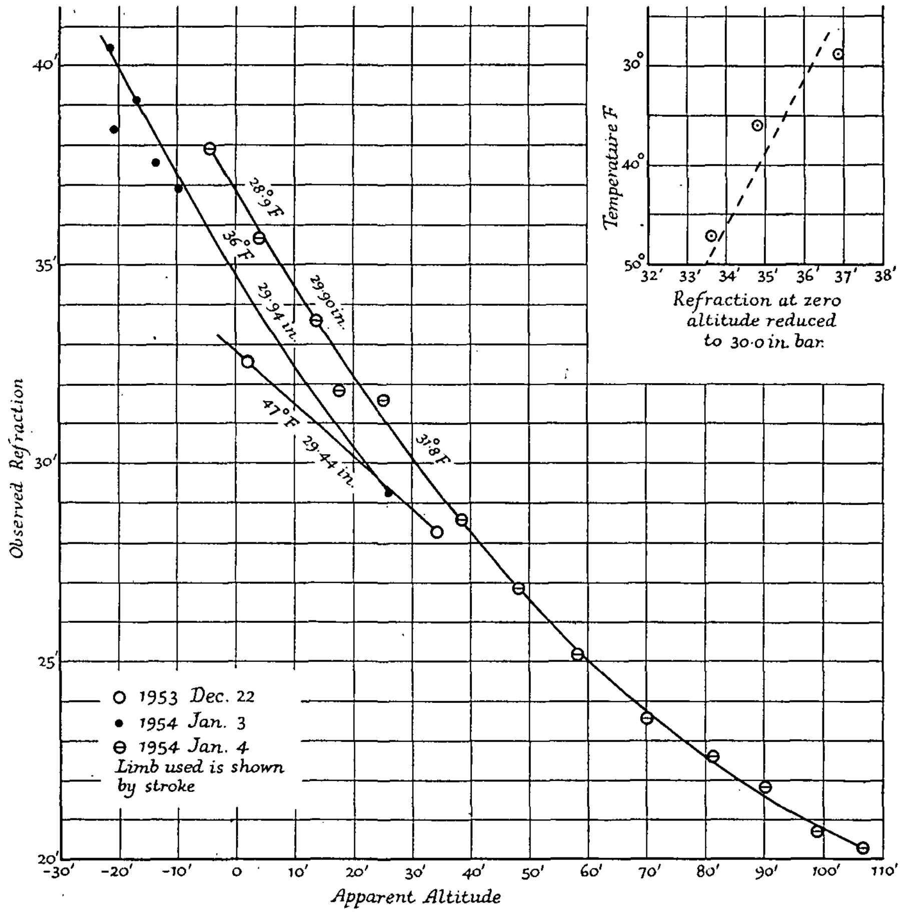


*Fig. 1. Observed refraction of the setting Sun.*

*Station: N. Lat. 55° 42′ 23″. W. Long. 4° 31′ 39″.*


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and the vertical collimation correction was carefully determined and applied. Reliance could be placed on the watch used for timing, and a comparison with the Greenwich time signal was made within an hour or two. The true altitudes were carefully calculated and corrected for parallax. At these very low altitudes the Sun's disk often appears very distorted, and the horizontal projections from the limb on each side give the impression that it is passing through layers of varying density.

The results are shown in the figure. It is suggested that the majority of the irregularities are not due to errors but are produced by the layers of varying density mentioned above. The observation on the upper limb as it vanished into the sea horizon may well be in error, as the Sun was by that time very faint.

The refraction for zero apparent altitude was read from the curves for the three evenings. These were reduced to a pressure of 30 in. and are shown plotted against the temperature in the inset diagram. Different authorities give varying values for the temperature correction at zero altitude. The values range from 5 to 9 sec. of arc per degree F. Accepting the value of 8, a line has been drawn at this gradient through the points, and it is seen that the slope is not inconsistent with the results.

REFRACTION OBSERVATIONS MADE AT DUNLOP, 480·0 FT. O.D., ON UPPER AND LOWER LIMBS OF SETTING SUN

| Date | App. Alt. | Refraction | Temp. (°F) | Pressure (in.) | Limb |
|---|---|---|---|---|---|
| | ′ ″ | ′ ″ | ° | | |
| 1953 | 34 12 | 28 15 | | | Upper |
| Dec. 22 | 2 18 | 32 33 | 47 | 29·45 | ,, |
| 1954 | 26 8 | 29 8 | | | Upper |
| Jan. 3 | − 9 49 | 36 56 | | | Lower |
| | − 16 40 | 39 9 | 36 | 29·94 | ,, |
| | − 21 24 | 40 28* | | | ,, |
| | − 13 25 | 37 34 | | | Upper |
| | − 20 42(?) | 38 22† | | | ,, |
| 1954 | 107 29 | 20 13 | | | Lower |
| Jan. 4 | 98 54 | 20 40 | | | ,, |
| | 90 35 | 21 50 | | | ,, |
| | 81 13 | 22 33 | | | ,, |
| | 70 21 | 23 34 | | | ,, |
| | 58 34 | 25 8 | | | ,, |
| | 48 6 | 26 50 | | | ,, |
| | 38 20 | 28 31 | 31·8 | | ,, |
| | 25 8 | 31 34 | | | ,, |
| | 17 25 | 31 50 | | | ,, |
| | 3 58 | 35 40 | | | ,, |
| | 13 49 | 33 34 | | | Upper |
| | − 4 25 | 37 57 | 28·9 | 29·90 | ,, |

* Lower limb touches sea horizon.

† Upper limb vanishes below sea horizon but too faint for certainty. Altitude of sea horizon a few minutes earlier = − 21′ 12″.

So it appears that the present observations, thus extrapolated, give a value of $33'.5$ for the horizontal refraction at a pressure of 30 in. and a temperature of 50° F.

Some measurements of dip were also made on 3 January, when a mean value of $21'.3$ was obtained at 36° F. and 29·94 in. At the time of the observation ($16^h$) the tide was probably about 2 ft. below mean sea-level, so that the theodolite was 482 ft. above sea-level.

*Dr. A. Fletcher comments:*

There appears to be a dearth of observations of astronomical refraction which satisfy *both* the following conditions:

(i) they are made with fixed instruments which give greater accuracy than is attainable with a sextant on board ship at sea, and eliminate uncertainties about dip by referring positions directly to the gravity zenith;

(ii) they go down to, or beyond, zero altitude, as distinct from stopping a degree or two above the horizon.

Such observations do exist, but they are neither particularly numerous nor particularly accessible. Thus the observations recorded in Professor Thom's paper are welcome, despite their manifestly limited scope and the absence of meteorological information other than temperature and pressure.

It seems worth while to compare the horizontal refractions indicated by the observations with theoretical values. It is evident from some small tables which I drew up (this *Journal*, Vol. V, No. 4, p. 313, October 1952) that the standard theories of Pulkovo Observatory, Radau (modified or not) and Garfinkel (as calculated by Smiley) are in agreement within one or two tenths of a minute of arc at the temperatures and pressures in question, and in fact that the Garfinkel-Smiley values are sufficiently representative to be used as a good standard of comparison.

Professor Thom sums up his observations as giving a horizontal refraction of $33'.5$ at temperature 50° F. and pressure 30 in. As the Garfinkel-Smiley value is $34'.7$, this means that the observed value is about $1'.2$ less than the standard.

As is explained in the article referred to above, refraction observations at low altitudes can be corrected with more certainty for pressure than for temperature; the doubt about the temperature correction is rather serious. Thus while the reduction to 30 in. pressure is acceptable, there may be some advantage in avoiding the extrapolation involved in evaluating a result for 50° F. when the observed temperatures lie between 29° F. and 47° F.

The horizontal refractions (at 30 in.) for separate days are:

| Day | Temp. (°F) | Observed | Calculated | O–C |
|---|---|---|---|---|
| First | 47° | $33'.6$ | $35'.0$ | $-1'.4$ |
| Second | 36 | 34·8 | 36·3 | −1·5 |
| Third | 29 | 36·9 | 37·3 | −0·4 |

The observed values are read from the inset diagram; the calculated ones are interpolated from Garfinkel-Smiley. The observations are plainly too few to throw light on variation with temperature. One can sum them up by saying that at an average temperature of 37° F. and a pressure of 30 in. they indicate a horizontal refraction about $1'.1$ less than the standard.

Independent examination of the observations confirms nearly enough Professor Thom's estimates of the horizontal refraction on the first and third days, but

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tends to suggest a reduction by some three-tenths of a minute (to 34'.5) on the second day; it may be noted that his curve for this day passes above both the points which represent the two observations closest to the horizon. Such a change would alter the second residual from −1'.5 to −1'.8, but the average residual for the three days would be altered only from −1'.1 to −1'.2, and the general nature of the result would be unchanged.

Such deviations at the horizon are only to be expected, and are quite insufficient to warrant a deduction that there is anything wrong with the standard values.

# Why not Graphical Sight Reduction?

*from* Robert W. Byerly

MR. J. B. PARKER, in his review of *Sight Reduction Tables for Air Navigation*, published on pages 98–103 of Vol. VII of this *Journal*, states that the time required by him to resolve a three-star fix by means of A.P. 3270 is 10 minutes (p. 100). He comments on the 'errors due to the plotted fix being a hundred or more miles behind the aircraft's position' (p. 101). Later he says: 'An accuracy of sight reduction of anything better than certainly 5 minutes of arc, and more logically 10 minutes of arc, will therefore be wasted on a navigator flying with present-day instruments in a fast modern aircraft in high latitudes' (p. 102).

If Mr. Parker has correctly summarized the needs of an aircraft navigator, which I have no reason to doubt, it would seem that graphical methods of sight reduction should be considered more seriously than they have been in the past. A considerable number of such methods have been devised, all with the object of reducing the time required for sight reduction at the expense of some loss in accuracy. Many of them give an accuracy well within Mr. Parker's limit of 10 minutes of arc and a time of sight reduction well below the 10 minutes required by A.P. 3270.

The simplest and most direct graphical method of sight reduction of which I am aware is one which I devised during the war and brought to the attention of the U.S. Coast & Geodetic Survey. The Survey provided the charts needed in my method. They are known as Equatorial Gnomonic Projection, C. & G. S. Chart No. 3062, and Polar Equatorial Gnomonic Projection, C. & G. S. Chart No. 3063. All that is required, in addition to the gnomonic charts themselves, is an overlay of transparent markable material pivoted at the centre of each chart.

To obtain a line of position from sight and Nautical Almanac data by means of these charts, it is necessary only to plot three points and sketch one short line. With a little practice the time required may be reduced to less than a minute. An example will make this plain:

Figs. 1–3 show part of a 10°-equatorial gnomonic network with a transparent overlay pivoted at its centre, and illustrate resolving a sight from the following data: Observed and corrected altitude, 20°; D.R. position, N. 31° W. 19°; Sun's G.H.A. 85°, Dec. S. 6°.

The first step is to plot the Sun and the dead reckoning position on the transparent overlay, as shown in Fig. 1.

In the second step, shown in Fig. 2, the overlay is turned on its pivot to bring

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