fore and aft, but the only actual provision appears to be Rule 25(d), ss. (ii) of which requires such a vessel (even the Trireme in the open sea!) merely to 'have ready at hand an electric torch... showing a white light which shall be exhibited in sufficient time to avoid collision'. This gives no consideration at all to two or more oared vessels approaching each other and, in the crowded conditions of the Tideway, the conventional method is the only practical way of achieving this.

There was a time when boats were going up and down the river at night with the forelight pointing backwards, in the apparent hope that some of the light might occasionally catch the shirt of the bowman, and enough of that would reflect forwards to be visible to an approaching boat: it is, for about 5 yards! Though not expressly forbidden, flashing lights are becoming more common but (though effective) are a danger to navigation, as they represent a north cardinal buoy: the result could be similar to that achieved by the wreckers of old!

Two eights represent nearly 2 tonnes approaching each other at over 20 knots and, particularly at the turn of the tide, a steersman needs to be able to assess any situation at a glance. In the present 'push-me-pull-you' situation, he can't tell even if the boats in front are coming or going. In the interests of their own safety oarsmen are strongly urged to take advantage of the permission contained in the same subsection to display the same lights as sailing vessels; that is, red/green sectors forward.

If there is a single need for a change in the Byelaws, it is to make such lights compulsory.

KEY WORDS

1. Collision avoidance. 2. Rowing boats. 3. River navigation.

Vertical Sextants give Good Sights

Mark Dixon

Many texts stress the need for marine sextants to be held precisely vertical at the instant that the altitude of a heavenly body is measured. Several authors lay particular emphasis on the technique of 'rocking' the instrument in a small arc about the horizontal axis to obtain a good sight. Nobody, to the author's knowledge, however, has attempted to quantify the errors involved, so as to compare them with other errors inherent in determining celestial position lines. This paper sets out to address these issues and to pose the question: what level of accuracy of vertical alignment can reasonably be expected during marine sextant work at sea?

1. ROCKING THE SEXTANT. When a heavenly body is brought to tangency with the visible horizon it is particularly important to ensure that the sextant is held in a truly vertical position. To this end the instrument is rocked gently about the horizontal so that the image of the body describes a small arc in the observer's field of vision. As Bruce Bauer points out,[1] tangency with the horizon must be achieved *during* the process of rocking and not a second or so after rocking has been discontinued. The altitude is recorded for the instant that the body kisses the visible horizon at the lowest point of the rocking arc, as in Fig. 2. The only other visual clue as to whether the sextant is vertical is provided by the right angle made by the vertical edge of the horizon glass mirror with the horizon. There may also be some input from the observer's sense of balance and his hand orientation.

2. ERRORS OFF THE VERTICAL. From a simple diagram in a vertical plane, Fig. 1, it can be seen that, if an altitude is recorded with the sextant off the vertical, a slant

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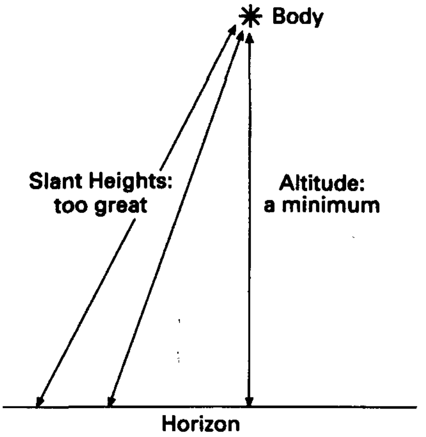

Fig. 1. Altitude and slant heights

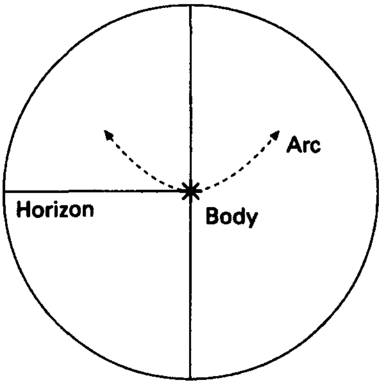

Fig. 2. Rocking the sextant

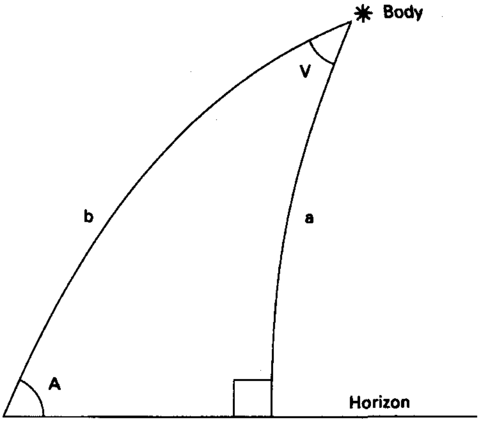

Fig. 3. The right spherical triangle AVB

height above the horizon is in fact being measured. This is always greater than the apparent altitude sought. (It may also lead to small errors in corrections for refraction etc. being applied.)

In order to arrive at a quantitative estimate of the error involved, arcs on the celestial sphere must be compared. In Fig. 3, side b is the slant height measured by an instrument off-vertical by an angle V. Side a is the altitude. Side v is an arc on the celestial horizon. Angle A is an auxiliary angle. The error expressed in units of arc is b-a. In the right spherical triangle AVB:

$$\sin b = \frac{\sin a}{\sin A} \quad \text{where,} \quad \cos A = \sin V . \cos a.$$

From application of the sine rule and Napier's rule (see Fig. 3).

These relationships enable a table of error b-a, expressed in minutes of arc, to be drawn up for illustrative altitudes a and off-vertical angles V: The error, given to the nearest $0'.1$, decreases with altitude in the range 45–90°, exactly mirroring the values

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TABLE 1. ERROR IN MINUTES OF ARC FOR ALTITUDE (a) AND OFF-VERTICAL ANGLE (V)

A\V	1	2	3	4	5	6
10	0·1	0·4	0·8	1·4	2·2	3·2
20	0·2	0·7	1·5	2·7	4·2	6·1
30	0·2	0·9	2·0	3·6	5·7	8·2
40	0·2	1·0	2·3	4·1	6·5	9·3
45	0·2	1·0	2·4	4·2	6·6	9·4

given in Table 1, so that errors for 50° are exactly equal to those for 40°; errors for 60° equal those for 30° etc.

3. DISCUSSION. Error, of course, increases with increasing off-vertical angle V. If the sextant is not held to within 5° of the vertical, large errors of nearly 7 nautical miles in position may result.

Interestingly, the maximum error for a given V is obtained for mid-altitude sights where a = 45°. Sights of bodies low on the horizon or high towards the zenith show only about a half to a third of the error of sights in the 30–60° range. Fortunately for the navigator, bodies at middle altitudes display well-curved rocking arcs that make the vertical easier to judge. Low-altitude bodies display rather flat rocking arcs, but here an error in the vertical has less effect on the observed position as the results of Table 1 show.

Given limits to the powers of human discrimination and the motion of vessels at sea, the author suggests a typical off vertical error of up to about 3° which would result in random position line errors of up to 2·5 nautical miles. Obviously novices, who have yet to master the art of rocking a sextant, and observers in rough conditions, will experience larger errors. It is interesting to speculate that the 'personal error' much discussed in nineteenth-century navigational circles[2] was perhaps nothing more than an individual's tendency to take sights with his sextant cocked slightly to one side of the vertical.

4. VERTICAL ERROR IN CONTEXT. Compared with most of the other errors involved in obtaining a position line from the altitude of a heavenly body, that due to sighting with the sextant off the vertical is potentially very large. It can be kept within acceptable bounds by technique and practice, but never entirely eliminated – the sensory discrimination required, the author suggests, is simply too fine.

REFERENCES

1 Bauer, B. (1986). *The Sextant Handbook*, 2nd ed. Cornell Maritime Press.

2 Cotter, C. H. (1968). *History of Nautical Astronomy*. Hollis & Carter.

KEY WORDS

1. Astronomical navigation. 2. Sextants. 3. Errors and accuracy.