Working the celestial sight in flight

[This paper assumes that the reader is familiar with celestial navigation as practiced on ship board..]

Before I can give an example of how celestial navigation is done in flight I must explain how some things are done differently in flight than on board a ship.

The first thing to discuss is the "Motion Of the Body" adjustment (MOB.) The marine practice is to take the sight, consult the almanac for the Greenwich Hour Angle (GHA) of the body (or Aries) for the even hour before the sight and then add an increment for the minutes and seconds after the hour. The navigator then chooses an assumed longitude to make the Local Hour Angle (LHA) used in the computation a whole number of degrees.

It is done differently in flight. The flight navigator plans a fix time, usually on the hour or at even ten minute intervals after the hour (the Air Almanac publishes data for every ten minutes, see Air Almanac, page 246 as an example) and takes out the GHA without any interpolation. He then chooses an assumed longitude to make a whole number of degrees of LHA and calculates his Computed Altitude (Hc) based upon this. Since two out of the three sights will be taken earlier than the fix time it is necessary to make adjustments to allow for this and this is what the MOB adjustment is all about and this is how it works. Think this one through. Imagine you are on the equator and you are shooting a star directly west of your position, azimuth 270°. Since the earth turns 15' of arc per minute of time, (15 nautical miles at the equator) the altitude of that star will get lower at the same rate, 15' per minute of time and 60' , one full degree in four minutes. Attached are pages from H.O. 249 to illustrate this (H.O. 249 excerpts .) Look at the first column on page 8 of the H.O. 249 Extracts PDF file (files are attached at the bottom of this page) which is the 0° latitude page of H.O. 249 volume 2 which is an azimuth of about 90° (or 270°) and you will see that the altitude decreases exactly one degree (60') for each one degree increase of LHA which takes four minutes of clock time. This also works with H.O. 249 volume 1, see page 11 and look at Procyon at LHA Aries of 45° to 48° which also have azimuths of about 90° (or 270°.)

What happens at a different latitude? The earth still turns at the same rate but the minutes of longitude become smaller as you move away from the equator based on the cosine of the latitude.

For example, at a latitude of 60° a degree of longitude is only half as long as it is at the equator since the cosine of 60° in .5 (30 nautical miles) and the change of altitude for a sight on an azimuth of 270° should also be one half or 30' per degree of LHA change. Look at the 6° declination column on page 10, which is the 60° page, at LHA 85° to 90° which results in a 90° (270°) azimuth and you will see that the altitude changes at the predicted rate, 30' per degree of LHA change. Also look at Capella for LHA 18° to 32° on page 13 to see that this also works for selected stars.

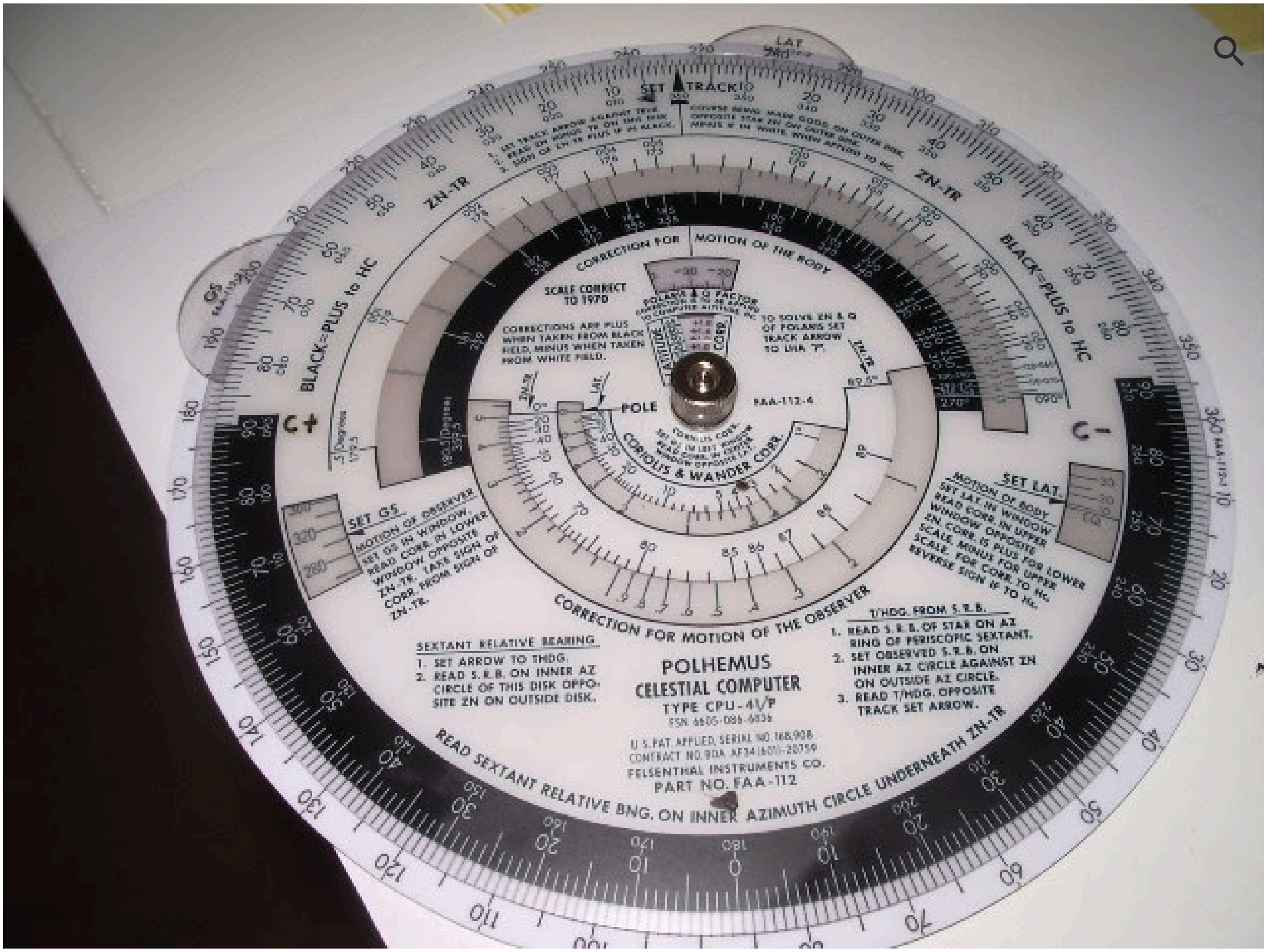
But what happens if the azimuth is not straight east or west? In this case the change of altitude is related to the cosine of the difference in the azimuth from east or west (which just happens to be the same as the sine of the azimuth) times the rate of change for the straight east and west cases. Using, for example, cases where the body is 60° (cos is .5) from east making an azimuth of 30° (or 150°, 210°, 330°, where the sin is also .5), the change in altitude should be at half the rate of the direct east case since the cosine of 60° is .5. Look at page 8 for 0° latitude, LHA 6° to 7° and declinations of 11° to 12° (producing azimuths of 30°) which shows changes of altitude at a rate of 30' per degree of LHA change, just as expected, one half the rate for the straight east case. Look at page 9 for 60° latitude, LHA 25° to 28° and declination zero which produces a 150° azimuth gives a rate of 15' per degree of LHA change (one half of one half of 60') and look at page 11 , Capella LHA 115° to 117° on and page 13, Betelgeuse LHA 64° to 65° for examples for selected stars.

These changes are the basis for the Motion of the Body (MOB) adjustment tables attached as pages 5 and 7. Review these tables and you will see they produce the same resulting changes in altitude as shown in the previous discussion.

Now we come to, what might be confusing, the sign to apply to these adjustment. Consider the first example, on the equator looking straight west. Since the altitude is decreasing as time goes by, if the sight is taken before fix time (the time used for the computation) then the measured sextant altitude (Hs) should be higher than that computed for the fix time by the amount shown in the "MOB" table or 15' higher for each minu[illegible] the sight is earlier or one degree if the shot is four minutes before fix time. This adjustment would be added to the Hc for the fix time to compute the Hc for the earlier sight so the sign would be "+" so as to arrive at the same intercept. So for any body observed to the west the sign will be "+" and, by the same logic, the sign will be "-" for any body observed to the east. If a shot were taken after the fix time (which is not normally done) you would reverse the signs of these adjustments.

The MOB table and also the MOO tables have a confusing table specifying what sign to use. You would use the listed sign if the sight were earlier than the fix time and the adjustment was to be applied to the observed altitude (Ho.) Since normal practice in flight navigation, as part of the precomputation procedure, is to make the adjustment to Hc, not to Ho, you must reverse the listed signs. If the shot were taken after the fix time you would reverse the already reversed signs and used the listed signs (whew). But for normal flight navigation cases just remember to reverse the listed signs as you make the adjustments to Hc. The easiest way to keep from confusing yourself regarding the sign of the adjustment is to simply draw a horizontal line across the center of the table and put a big minus sign for the top half and a big plus sign for the bottom half of he table. This will provide the sign for the usual case of a sight taken prior to the fix time and the adjustment being made to Hc.

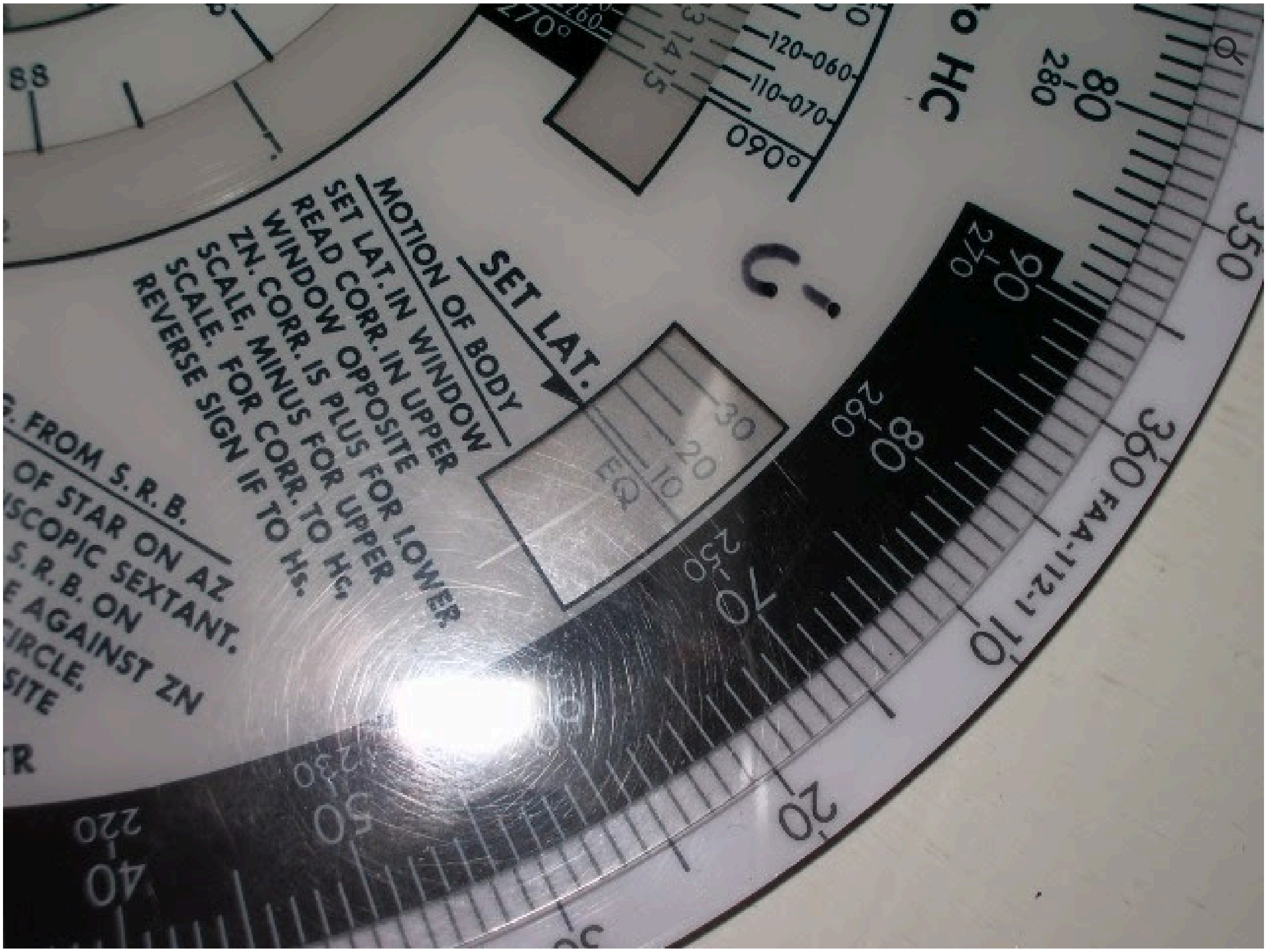
Another way to derive the MOB adjustment is to use the Polhemus computer. At first glance the front of this device looks intimidating (see image 1)



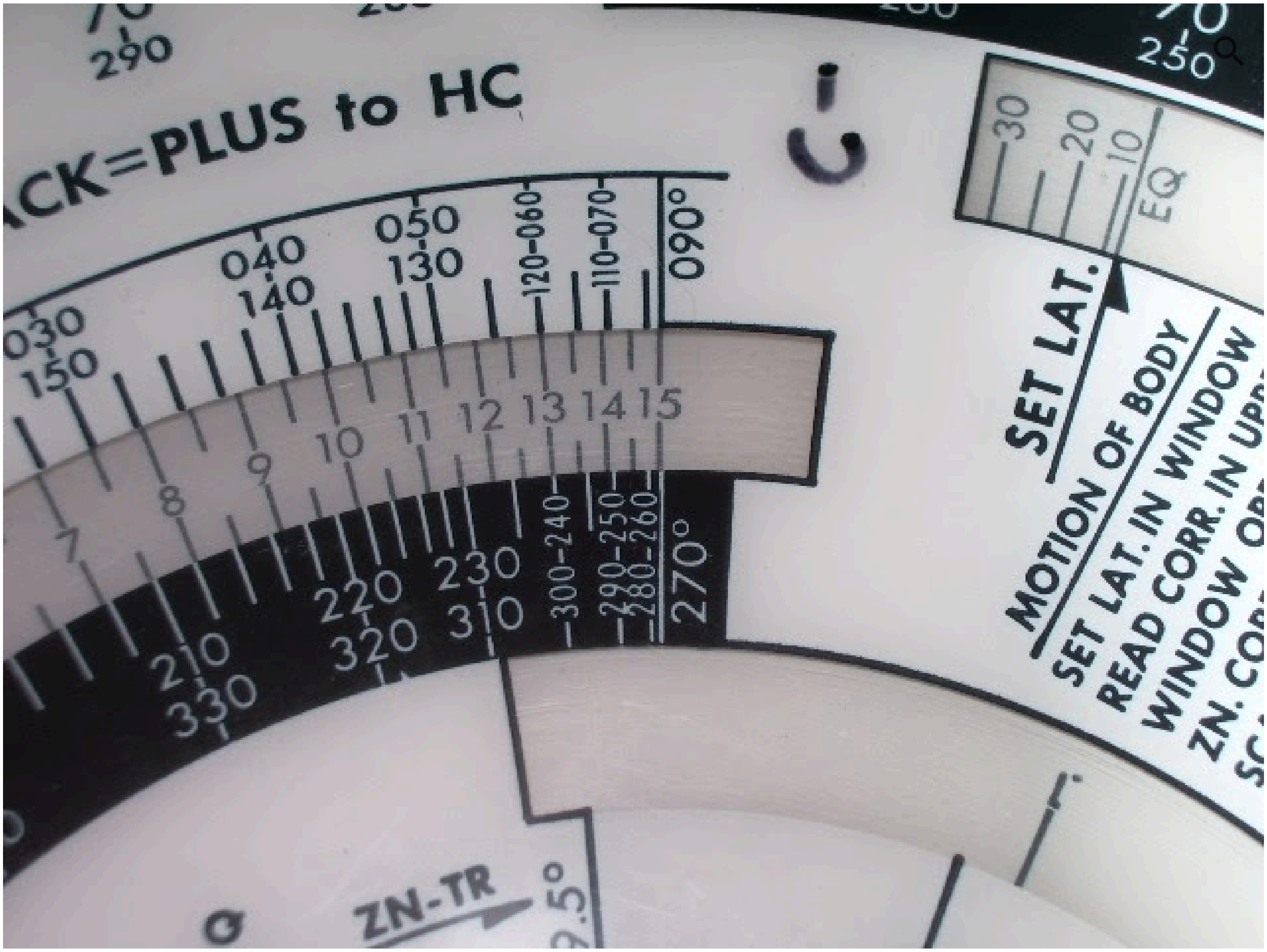
but in fact it only requires setting three

parameters in the appropriate windows and then reading out the MOB adjustment as well as the

"Motion of the Observer" (MOO) and the Coriolis correction (more about these later.) Image 2



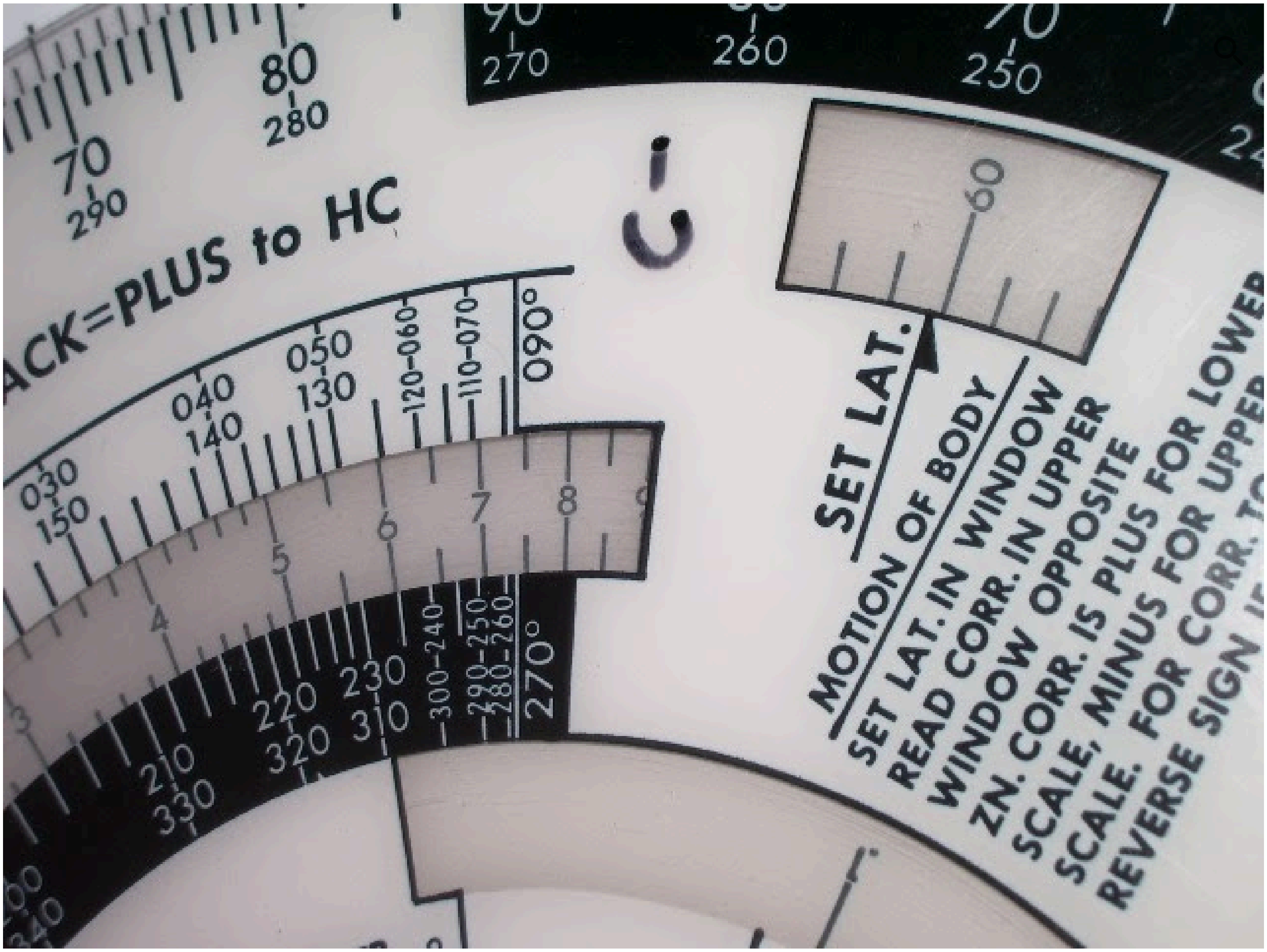
shows a zero degree latitude set in the latitude window which is all you need to do to find the MOB adjustments. Now by looking at the azimuth scale along side of the MOB window you can take the MOB adjustment from the adjacent scale inside the MOB window, see Image 3.



Since

this is set to 0° latitude you will find that the MOB adjustment is 15' for an azimuth of 90° and

7.5' for an azimuth of 30° just the same as on page 7, the one minute MOB table. Image 4


ACK=PLUS to HC
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MOTION OF BODY
SET LAT. IN WINDOW
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shows

it set for a 60° latitude and you find an adjustment of 7.5' for 90° and 3.8' for an azimuth of 30° just like the table on page 7. If you compare the other values on the Polhemus with those tabulated on page 7 you will see that the Polhemus produces identical adjustment factors. In fact, the Polhemus might be able to produce greater accuracy since you can read out the factors for intermediate values instead of mentally interpolating on the MOB table or just simply taking the closest tabulated value. The Polhemus also makes it easy to figure the sign to use for the adjustment, if the Zn is on the white scale, meaning the body is to the east, then the sign is minus and if found on the black scale (the body is west) then the sign is plus when these adjustments are made to Hc, the normal method.

Now let's talk about the "Motion Of the Observer" (MOO) adjustment. Every fix in the air is a running fix because the aircraft moves a considerable distance between the first and last sight. Assuming the normal eight minute spacing between the first and last shot, a slow airplane, say 100 knots, will have traveled 14 NM while a 450 knot plane will have traveled 60 NM. In marine practice the navigator will advance the earlier LOPs to cross them with the last shot when plotting a running fix. The MOO adjustment accomplishes the same thing.

Due to the slow speeds and the short period between the shots, this is not necessary for normal marine fixes,

As an example of how this works, consider a running fix on a ship. A sun shot taken at 1000Z results in an observed altitude, Ho, of 35° 55'. After doing the normal sight reduction the navigator ends up with an Hc of 35° 45' at the chosen “assumed position” (A.P) and an azimuth (Zn) of 130°. This results in an intercept of 10 NM toward the body, 130°. To plot this LOP you draw the azimuth line from the A.P and measure off the 10 NM intercept toward the sun and plot the LOP perpendicular to the Zn.

Then, two hours later at 1200Z you take another altitude of the sun and to obtain a 1200Z running fix you must advance the 1000Z sun line to cross the 1200Z line. There are three ways to advance the LOP. First, you can pick any spot on the LOP and lay off a line in the direction of travel of the vessel, measure off the distance traveled along that line, make a mark there and then draw a line through that mark that is parallel to the existing LOP and label the advanced LOP "1000-1200Z SUN." A second way is to advance each end of the LOP and then just draw a line through these two points, this avoids having to measure the azimuth when laying down the advanced line. The third way is to advance the original A.P and then from the ADVANCED A.P. plot the LOP using the ORIGINAL intercept and Zn. Any of these methods will produce the same advanced LOP.

Now let's consider a simple case. Suppose the vessel's course is the same as the Zn, in this case, 130° and the vessel's speed is 20 knots meaning it has traveled 40 NM in the two hour period. In this simple case we can just extend the Zn line an additional 40 NM and then plot the advanced LOP at that point. So, the LOP is now 50 NM from the original A.P., the original 10 NM intercept plus the additional 40 NM that the vessel has traveled on the same course as the azimuth. Since we have no interest in actually plotting the 1000Z LOP, as we are just planning on having the 1200Z running fix, we can skip drawing the earlier LOP and just plot the advanced LOP by adding the distance traveled to the length of the original intercept to get a total intercept now of 50 NM and using that adjusted intercept to plot the advanced LOP using the ORIGINAL A.P. This method also creates the exact same advanced LOP as the other three methods. This last described procedure is how the MOO table is used.

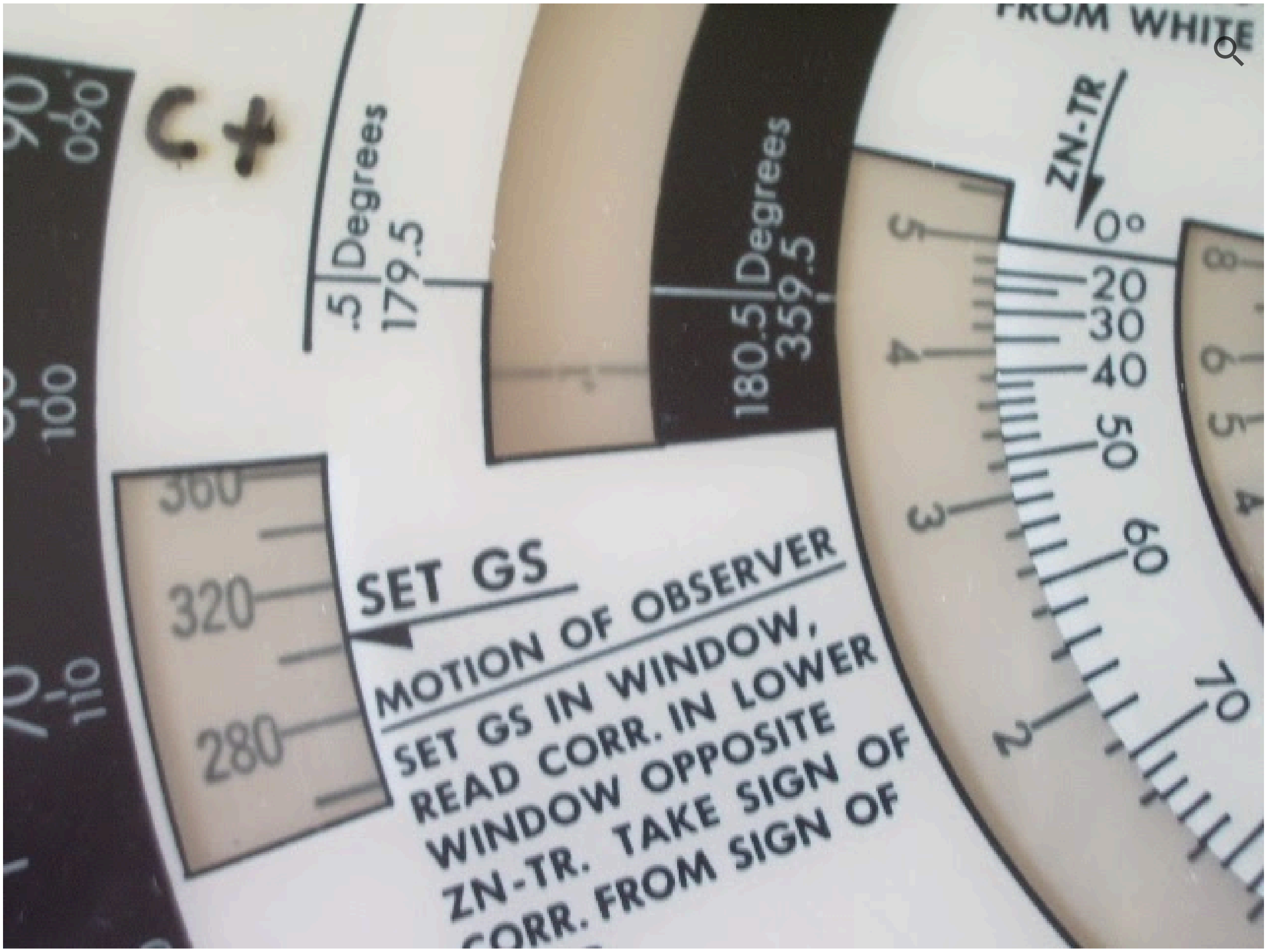
Look now at the MOO table, page 4. Assume now we are in a 300 knot airplane and the first sight is taken at 1152Z, eight minutes prior to the planned fix time. At the top of the column marked "300" knots ground speed you find the number "20" showing that the plane will travel 20 NM (and so the altitude of the body should change by 20 minutes of arc) in a 4 minute period. Also notice that the top row of values are marked for a relative Zn of 000° meaning the body is directly ahead, as in our example. The plane will obviously travel 40NM in the normal 8 minute period from the first to the last shot of a three [illegible] fix. The sign convention is the same as that for the MOB table so simply draw a horizontal line across the center of the table and place a big minus symbol for the top half and a big plus mark for the bottom of the table. If the body is in front of you the sign is minus and the sign is plus if the body is behind you. With these markings we can take out of the table a minus 20' value for our example and double it to have a total MOO adjustment of minus 40' to apply to the Hc.

Let's do the math. Hc of 35° 45' minus 40' gives us an adjusted Hc of 35° 05'. Since the Ho was 35° 55' we now compute an intercept of 50 NM TOWARD and plot the LOP using the ORIGINAL A.P. and Zn and this new adjusted intercept. You can see that this method produces the same advanced LOP as the previous methods.

In the more normal case the course will not be the same as the Zn so the change in altitude will be less since the maximum change occurs when the body is straight ahead or directly behind the aircraft. The change in altitude due to MOO is computed by the cosine of the difference between the Zn and the course ("track" in the air), the relative Zn multiplied by the maximum change possible, the zero degree relative Zn case. So, in our example, if the track of the plane (course) were 070° then the relative Zn would be 60° (130°-70°=60°) and we would look in the table for that relative Zn in the 300 knot column and take out a value of 10' which we would expect since the cosine of 60° is .5 so the MOO should be one half of the maximum possible for a 300 knot ground speed.

In practice, the MOO and the MOB adjustments are totaled and then multiplied by the adjustment periods covered, (4 minutes on pages page 4 and 5 and one minute on pages 6 and 7) to arrive at the total "motions" adjustments.

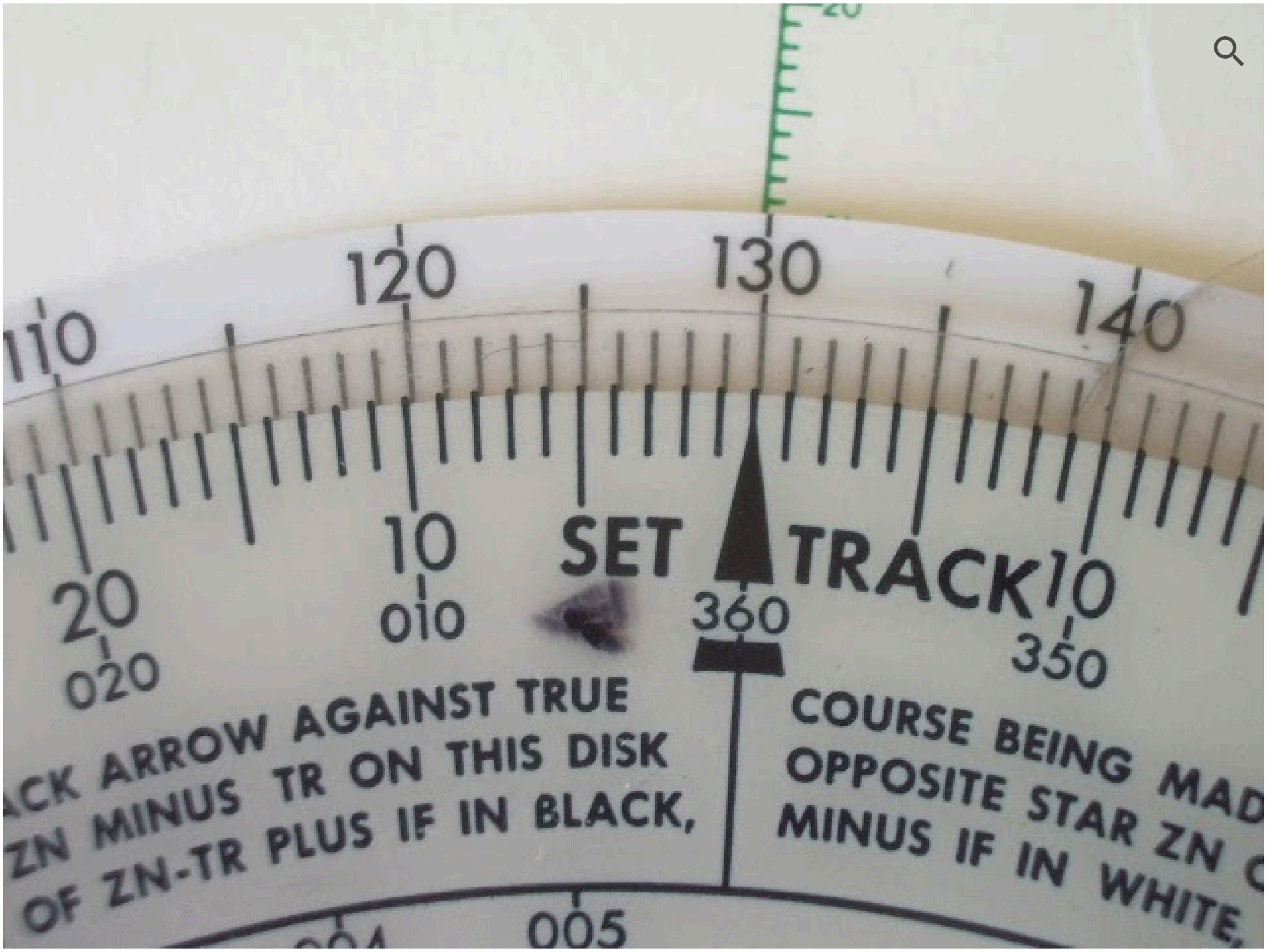
We can also use the Polhemus computer to calculate the MOO adjustment. We do this by setting the ground speed, 300 knots, in the setting window and read out the MOO in the "ZN-TR" window adjacent to the relative Zn. (See image 5.)



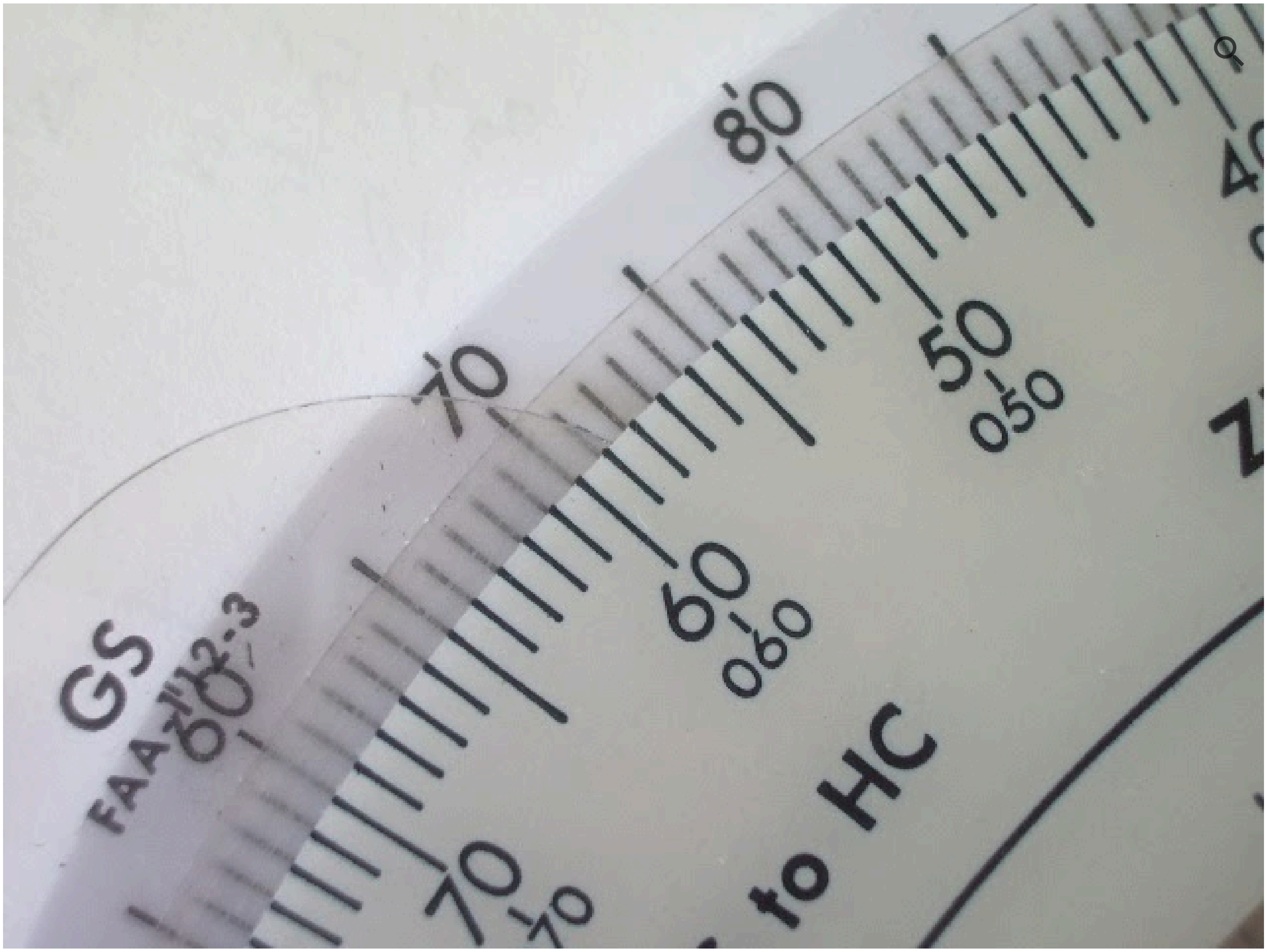
(Zn-TR is another way of saying "relative Zn"

since you calculate relative Zn by subtracting Track from Zn.) Looking at the top of the TR-ZN window where the relative Zn of 000° is adjacent to "5" in the MOO window showing that the aircraft moves 5 NM per minute which causes the altitude to also change 5' every minute when the body is directly ahead of or directly behind the aircraft. This MOO is equivalent to the MOO table at page 6 which tabulates the MOO adjustment per minute. Multiplying this 5' times the same eight minute period gives the same 40' adjustment we got from the MOO table on page 6. You will also find that the adjustment is 2.5' adjacent to the relative Zn of 60° which multiplied by eight minutes gives the 20' adjustment we found in the table on page 6.

The Polhemus makes it easy to figure the relative Zn. You place the "SET TRACK" pointer on the track of the aircraft, 130° as shown in imag



Look at the next image, image 7,


80
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for the

second case, an azimuth of 70° and you find the relative Zn, 60° on the inner scale.

The Polhemus also makes it easy to figure the sign to use for the adjustment, if the relative Zn is on the white scale, meaning the body is ahead, then the sign is minus and if found on the black scale (the body is behind) then the sign is plus when these adjustments are made to Hc, the normal method. This same pattern is revealed in the two MOO tables, the top of the tables show the body ahead and the bottom has the body behind.

After figuring the "motions" adjustments we then need to apply the corrections for errors in the sextant observation itself. We need to apply index error correction, refraction, and, for the moon only, parallax in altitude. Since we are using a bubble sextant we do not apply dip, parallax for the sun or planets or semidiameter (S.D.) In surface navigation you make the corrections to the sextant altitude (Hs) to arrive at observed altitude (Ho) but in aviation we apply the correction to Hc as part of the pre-computation process to calculate pre-computed altitude (Hp) so it is done a little differently.

When applying index error correction we reverse the normal sign of this correction and apply it to Hc. For example, let's say the sextant has an index error of plus 5', meaning that all altitudes measured will be 5' too high. In marine practice we would subtract 5' from Hs so the sign is opposite to that of the error itself. In aviation we add this 5' to Hc so that the sign of the correction is the same as the error itself. Give it some thought and you will see that you end up with exactly the same intercept doing it either way.

We also apply the refraction correction by adding it to Hc instead of subtracting from Hs. The refraction correction table in the Air Almanac and in H.O. 249 looks more complicated than the one in the Nautical Almanac since in must allow for the altitude of the aircraft because refraction is lessened at altitude because there is a thinner layer of atmosphere above the airplane, page 3 .

This table gives the correction rounded to one minute precision which is the norm for flight navigation.

For sea level or low flight heights it is simple to memorize the corrections; 5' above 10°, 4' above

12°; 3' above 16°; 2' above 21°; 1' above 33°; and zero above 63°.

The parallax in altitude correction for the moon is printed on each page of the Air Almanac based upon the horizontal parallax (H.P.) for the moon on that particular day. This parallax varies with the distance to the moon and moves in lock step with the S.D. since they are both related to the distance to the moon. The H.P varies from 54' to 61' during the year. For example, using the page from the Air Almanac, page 246, a day when the H.P is 60', and for an altitude of 36° we find the parallax in altitude correction to be 48' and this would be the correction to use with a bubble sextant. If using a marine sextant and shooting the lower limb we would add the S.D. of 16.0' (also found on Air Almanac, page 246) to produce a total correction (but not including refraction yet) of 64'. Subtract the refraction correction of 1' gives the total correction of 63'. Using the correction table in the Nautical Almanac for the identical parameters you get 63.5'. The Nautical Almanac moon correction table includes a procedure for using it with a bubble sextant and what this does is just backs out the S.D. correction which is included in the correction table and is not needed for a bubble observation. Using this procedure produces a correction for a bubble observation of 47.2' which compares with the 48' from the Air Almanac. In marine practice we add parallax in altitude to Hs but, again, we will reverse the sign and subtract it from Hc which accomplishes the same thing.

Remember to reverse the signs of these corrections and apply them to Hc to produce Hp (pre computed altitude) which you then compare directly with Hs to compute intercept.

Since the sights are taken with a bubble sextant in a high speed vehicle we must apply some additional corrections due to various accelerations to the liquid in the bubble chamber. The main correction is Coriolis which makes altitudes measured to the right of the aircraft (in the northern hemisphere, the opposite in the southern) read too low and those on the left side to read too high. This can be handled in a number of ways. You can move the A.P. to the right (northern hemisphere) at a 90° angle to the course (track) prior to plotting the LOPs by the amount of the Coriolis correction shown in the table in the Air Almanac and in H.O. 249, page 3 file. Or you can move the final fix the same way. Or, the most complicated way, is to make a correction to each Hc by multiplying the Coriolis correction by the sine of the relative Zn, and adding it to altitudes measured on azimuths to the right and subtracting for observations to the left (northern hemisphere), the Polhemus makes this relatively painless.

Rhumb line correction is similar to Coriolis and is caused by flying a rhumb line during the shooting period by flying a compass heading. In high latitudes and high speeds it can exceed the Coriolis correction and can act in either direction depending on the course, either adding to Coriolis or canceling it. But this error can be avoided by steering by directional gyro during the two minute shooting period and this is what is normally done anyway.

Wander error is caused by the heading of the aircraft changing during the observation period. The wander correction is small at low airspeeds and it can be avoided by making sure the heading is the same at the end of the shot as it was at the beginning of the shot. It doesn't matter how the heading changes during the shot (within reason) as the errors will average out.

Ground speed error is caused by the speed of the plane changing during the observation period and this correction can also be avoided by making sure the airspeed is the same at the end as at the beginning, any changes in between will also average out.

Auto pilots do a good job of maintaining airspeed and heading for the two minute shooting period so eliminating the need for the above corrections.

This completes the description of the differences between in flight celestial navigation and the practice of marine navigation. Next read the example involving a flight from Casablanca to Porto Santo Island in the Madeira Islands.

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Air Almanac page 246.pdf	2/8/23 Gary LaPook
HO 249 extracts .pdf	2/8/23 Gary LaPook
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