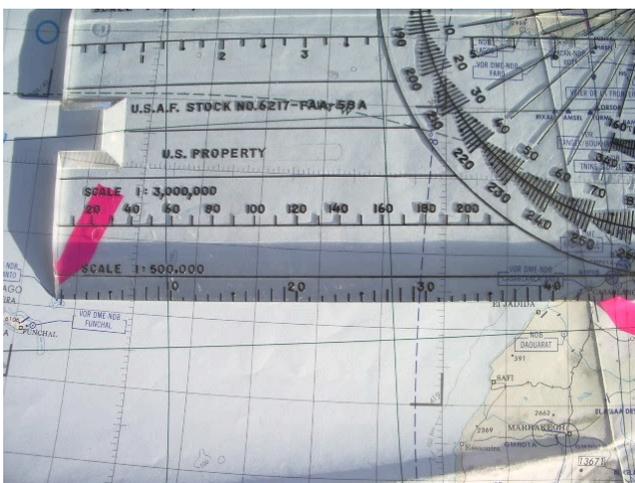


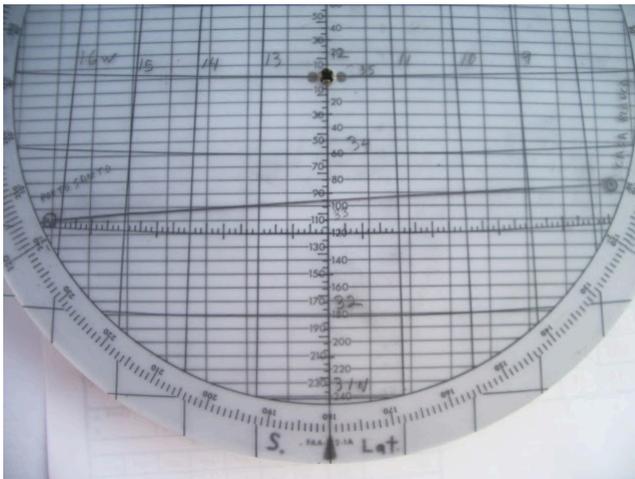
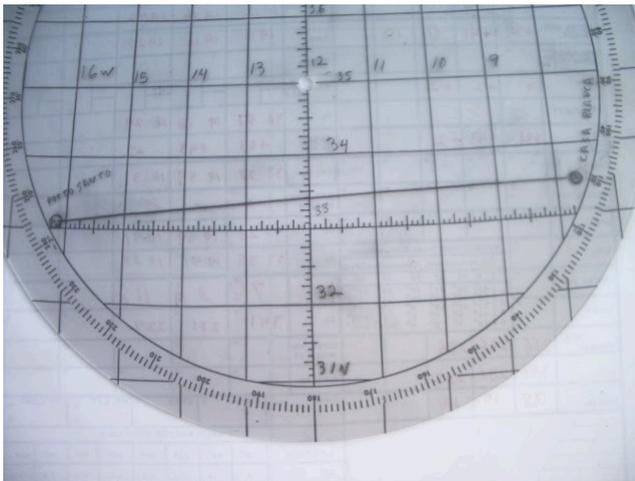
Example of in flight celestial navigation

Now that we have discussed the technique of flight navigation we can look at an example of how it is actually done. I will use the Polhemus computer to illustrate this process which will also show how handy this device is but it can also be done on a plotting sheet though not so conveniently. (If you have not already read [Working the celestial sight in flight](#) you should do that before reading this page.)

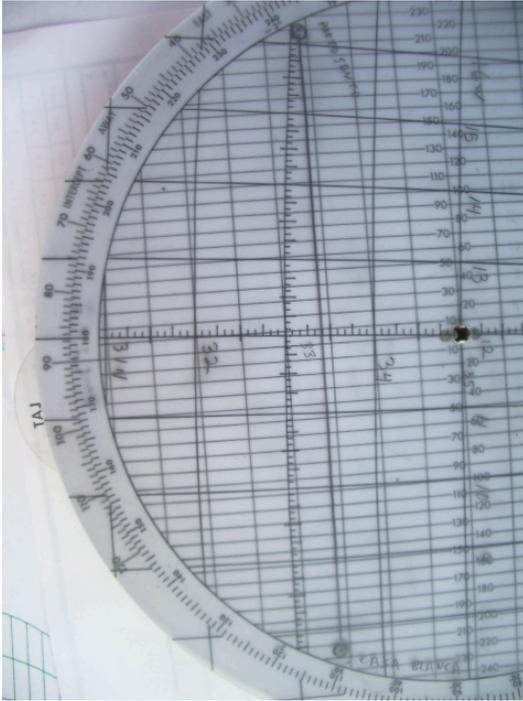
We are ferrying a 1978 Cessna Skyhawk (Cessna 172) from Casablanca Morocco to Porto Santo Island in the Madeira Islands on October 4, 2008 (1.jpg and 2.jpg.) We will be using a Kollsman MA-2 hand held sextant which has a two minute averager but the same procedures would be followed with any bubble sextant.



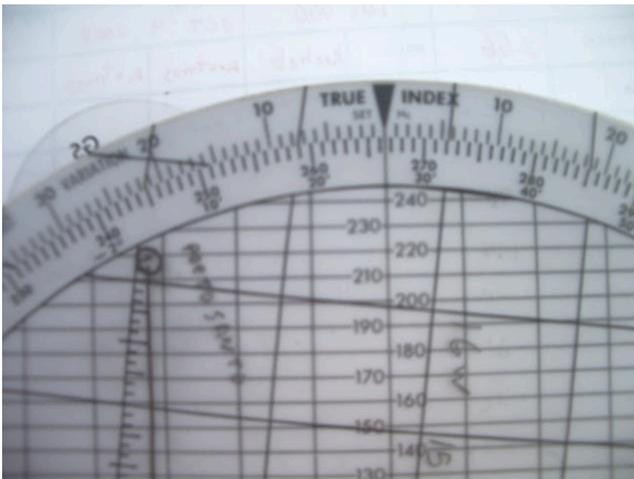
The coordinates of the departure airport are $33^{\circ} 33'$ north, $7^{\circ} 40'$ west. The destination airport is at $33^{\circ} 04'$ north, $16^{\circ} 21'$ west. Using the 35° latitude disk we label the graticule and we then plot the locations of both airports and draw a course line between them (3.jpg) then we place the disk on the base (4.jpg.)



Now, by rotating the disk so that the destination is directly above the departure, we can read out the distance by counting the grid lines between the departure and the destination. Departure is down from the center at minus 215 (visually interpolating between 210 and 220) and destination is up from the center at plus 219 for a total distance of 434 NM (5.jpg.)



We can also read out the true course at the "TRUE INDEX" which is 266.5° , which we will round to 266° (6.jpg.)



Looking at the aircraft flight manual climb schedule (7.jpg), we see that we will climb at an airspeed of about 70 knots and that it will take 21 minutes to climb to our planned cruising altitude of 10,000 feet (Flight Level 100, FL100) using 3.7 gallons of fuel in the climb and covering 27 NM. Since we also used 1.1 gallons taxiing we will have used up 4.8 gallons by the time we level off FL100. After we have leveled off at the top of the climb (TOC) we adjust our throttle to make 2500 rpm and lean the mixture control.

MAXIMUM RATE OF CLIMB

CONDITIONS:
Flaps Up
Full Throttle
Standard Temperature

NOTES:
1. Add 1.1 gallons of fuel for engine start, taxi and takeoff allowance.
2. Mixture leaned above 3000 feet for maximum RPM.
3. Increase time, fuel and distance by 10% for each 10°C above standard temperature.
4. Distances shown are based on zero wind.

WEIGHT LBS	PRESSURE ALTITUDE FT	TEMP °C	CLIMB SPEED KIAS	RATE OF CLIMB FPM	FROM SEA LEVEL		
					TIME MIN	FUEL USED GALLONS	DISTANCE NM
2300	S.L.	15	73	770	0	0.0	0
	1000	13	73	725	1	0.3	2
	2000	11	72	675	3	0.6	3
	3000	9	72	630	4	0.9	5
	4000	7	71	580	6	1.2	8
	5000	5	71	535	8	1.6	10
	6000	3	70	485	10	1.9	12
	7000	1	69	440	12	2.3	15
	8000	-1	69	390	15	2.7	19
	9000	-3	68	345	17	3.2	22
	10,000	-5	68	295	21	3.7	27
	11,000	-7	67	250	24	4.2	32
	12,000	-9	67	200	29	4.9	38

Figure 5-6. Time, Fuel, and Distance to Climb

5-15

Since the air temperature is about standard (15° C at sea level and cooling off about 2° C per thousand feet) this power setting will produce 61% power which will give us a true airspeed of 114 knots and a fuel flow rate of 6.8 gallons per hour (8.jpg)

CRUISE PERFORMANCE

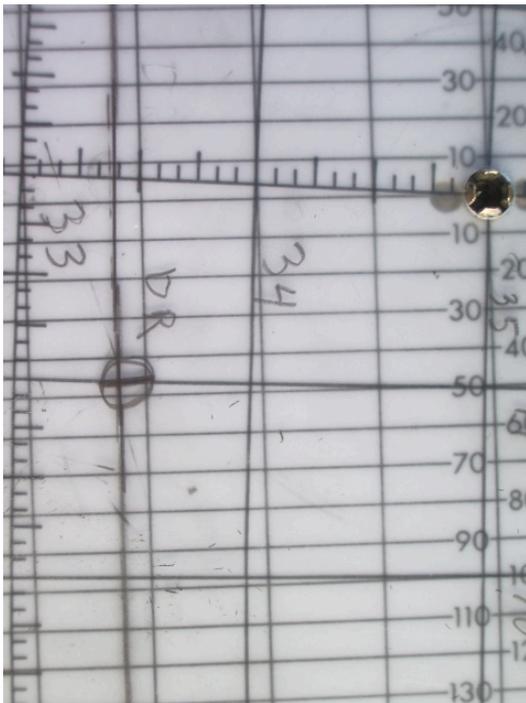
CONDITIONS:
2300 Pounds
Recommended Lean Mixture

PRESSURE ALTITUDE FT	RPM	20°C BELOW STANDARD TEMP			STANDARD TEMPERATURE			20°C ABOVE STANDARD TEMP		
		% BHP	KTAS	GPH	% BHP	KTAS	GPH	% BHP	KTAS	GPH
2000	2500	72	111	8.0	75	116	8.4	71	115	7.9
	2300	64	106	7.1	80	105	6.7	86	110	7.1
	2200	58	101	6.3	85	100	6.1	90	105	6.3
	2100	50	96	5.8	87	94	5.6	93	99	5.8
4000	2550	---	---	---	75	118	8.4	71	118	7.9
	2500	76	116	8.5	71	115	8.0	67	115	7.5
	2400	68	111	7.6	64	110	7.1	60	109	6.7
	2300	60	105	6.8	57	105	6.4	54	104	6.1
6000	2800	---	---	---	75	120	8.4	71	120	7.9
	2500	72	116	8.1	67	115	7.6	64	114	7.1
	2400	64	110	7.2	60	109	6.8	57	109	6.4
	2300	57	105	6.5	54	104	6.2	52	103	5.9
8000	2850	---	---	---	75	122	8.4	71	122	7.9
	2600	76	120	8.6	71	120	8.0	67	119	7.5
	2500	68	115	7.7	64	114	7.2	60	113	6.8
	2400	61	110	6.9	58	109	6.5	55	108	6.2
10,000	2850	---	---	---	75	122	8.4	71	122	7.9
	2600	76	122	8.5	71	122	8.0	67	121	7.5
	2500	68	116	7.8	64	119	7.6	64	118	7.1
	2400	58	109	7.3	61	114	6.9	58	112	6.5
12,000	2850	---	---	---	75	122	8.4	71	122	7.9
	2600	76	122	8.5	71	122	8.0	67	121	7.5
	2500	68	116	7.8	64	119	7.6	64	118	7.1
	2400	58	109	7.3	61	114	6.9	58	112	6.5

Figure 5-7. Cruise Performance

Since we have covered 27 NM in the climb we will have an additional 407 NM to cover in cruise after we reach the TOC. Winds are forecast "light and variable" so using our true airspeed of 114 knots we compute that it will take an additional 3 hours +34 minutes for the enroute phase of the flight for a total flight time of 3+55. We will burn 24.3 gallons in cruise plus the climb and taxi fuel means we will burn a total of 29.1 gallons out of our total fuel on board of 50 gallons leaving us a comfortable 20.9 gallons fuel reserve.

We take off at 1745Z and climb on course on a true heading of 266° and level off 21 minutes later at FL100 at 1806Z and set the power and auto pilot. Our ETA is 2140Z, 3+55 after takeoff. We plan on taking a celestial fix at 1920Z to allow for an enroute leg longer than one hour so as to allow for the determination of an accurate wind vector. We will cover 140 NM during the 1+14 minute cruise from TOC at 1806Z to 1920Z fix time. Since we covered 27 NM in the climb we will be 167 NM from departure at the planned fix time. To plot the 1920Z DR we count up 167 NM on the grid from the departure. Since the departure was at minus 215 on the Polhemus grid we simply subtract 167 from 215 and place a mark on our course line at the minus 48 grid line, visually interpolating between 40 and 50 (9.jpg.)



Rotating the grid to north up by placing 360° at the True Index we can read out the coordinates of our 1920Z DR of 33° 27' north, 11° 00' west (15.jpg.)

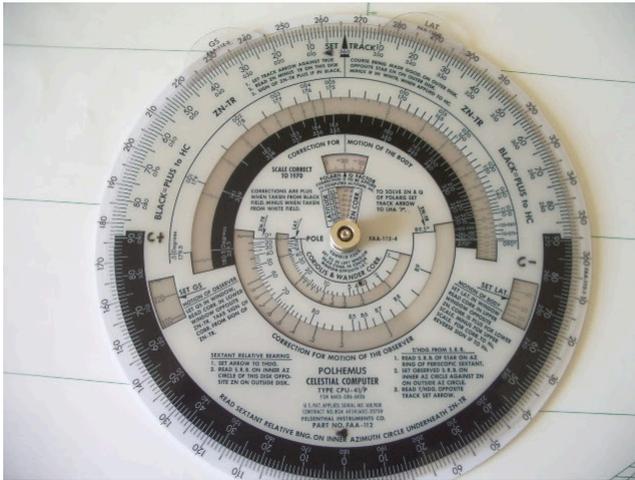


About a half hour before the fix time we start planning our fix. It only takes about ten minutes to do the actual pre-computations for a three star fix but, since we must start shooting the first star nine minutes prior to fix time, we don't want to cut it too close, we want to leave some time for contingencies. We will be using H.O 249 Volume 1, Selected Stars, since it is the most convenient. First we look in the Air Almanac for 1920Z, October 4, 2008 and take out the GHA of Aries without interpolation, 303° 51' (10.pdf.) We select an AP of 33° 00' north and 10° 51' west so that the LHA Aries will be 293° exactly. We use only one AP since we are using H.O. 249 vol. 1 and we are accounting for motion of the observer (MOO) and the motion of the body (MOB) mathematically, not advancing the earlier LOPs to the fix time. We then look at the 33° north page of H.O 249, vol. 1 and looking at 293° LHA Aries we see that the selected stars are Alpheratz, Enif, Altair, Antares, Arcturus, Alkaid and Kochab (11.pdf.) Because the visibility is limited in a Cessna 172 by its high wing we must choose, not the three recommended stars, but Kochab, Arctures and Antares. We take out the Hc's and Zn's for the three bodies, 36° 57' and 341° for Kochab; 19° 16' and 281° for Arcturus; 16° 29' and 222° for Antares. We will shoot Kochab first since it is nearly on the wing tip and so advancing its LOP the most to the fix time will have little effect on its accuracy. We plan our shooting schedule, Kochab at 1912Z (eight minutes before fix time), Arcturus at 1916Z (four minutes early) and Antares at 1920Z. We enter this data our the Celestial Precomputation form (12.jpg.)

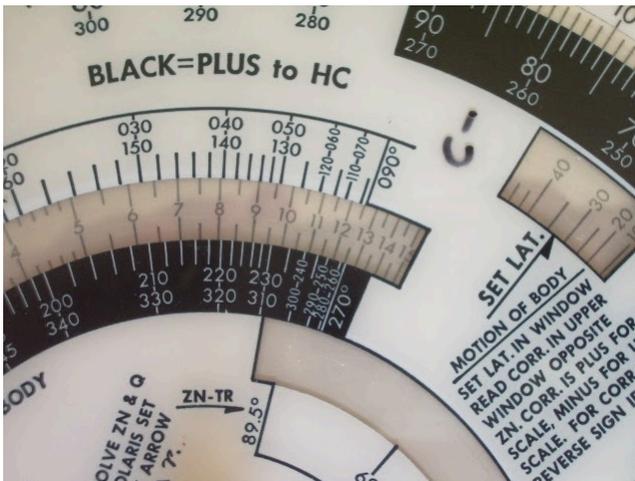
The form is titled "CELESTIAL PRECOMPUTATION" and includes the following sections and data:

- Observer:** DATE: OCT 4, 2008; FIX TIME: 1920 Z
- Star Selection:** STAR SELECTION BY AZIMUTH: 330; STAR SELECTION BY ALTITUDE: 30
- Body Data:** BODY: Kochab, Arcturus, Antares; POLARIS
- Observer's Position:** LATITUDE: 33 00 N; LONGITUDE: 10 51 W
- Sight Reduction:**
 - MOON: 75; SUN: 18; PLANET: 44
 - MOON: +4.2; SUN: +12.3; PLANET: 48.4
 - MOON: -1.5; SUN: -1.9; PLANET: -1.2
 - MOON: 43.7; SUN: 41.9; PLANET: 43.2
 - X Δ TIME: 8; 4; 0
 - TOTAL: 420.6; 442; 0
 - MOON: +1; SUN: +2; PLANET: +2
 - TOTAL: 430.6; 444; 4
- Final Fix:** FIX: 30 51 N; 10 51 W

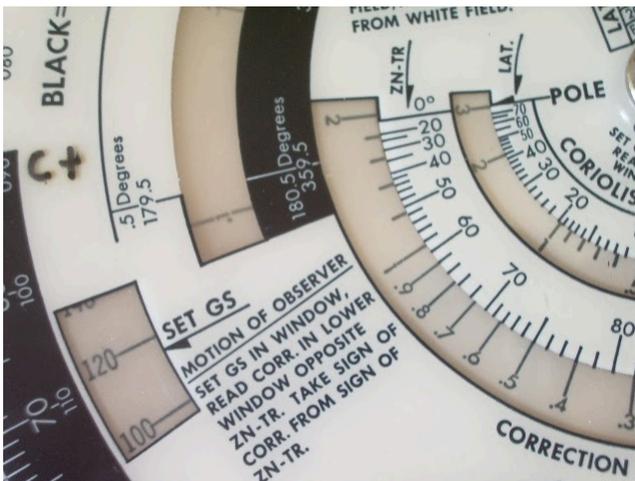
if using the Polhemus computer or the 1 minute adjustment tables from H.O 249 or (13.jpg)



Looking around the outside edge for the Zn's of each body we find the relative Zn's (ZN-TR) and enter them on the form, 75° for Kochab, 15° for Arcturus and 44° for Antares. Using each body's Zn look in the "CORRECTION FOR MOTION OF THE BODY" window and take out the MOB one minute correction and enter it in the appropriate blank (17.jpg , 18.pdf. and 19.pdf.)

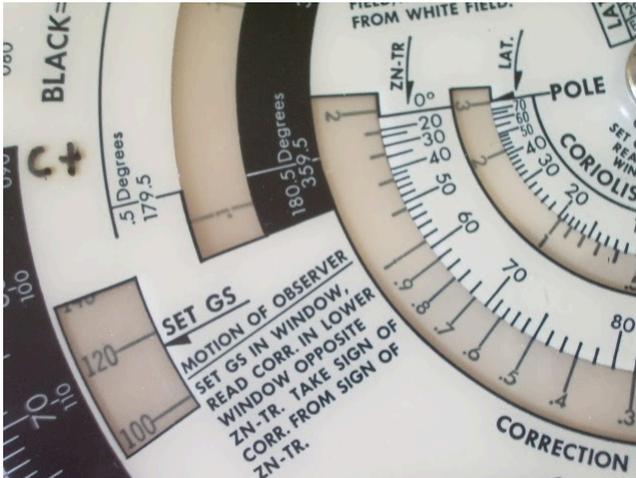


Since all three Zn's are to the west they are all found on the black scale so the signs are all plus. Next, using the relative Zn's (ZN-TR) look in the "CORRECTION FOR MOTION OF THE OBSERVER" window and take out the one minute corrections for MOO (20.jpg , 21.pdf and 22.pdf.)



Since all of the relative Zns are ahead of the plane they are all found on the white scale making all of their signs negative. We sum the MOB and MOO adjustments to the "ONE MINUTE ADJ." line keeping track of the signs. Since we are planning the first shot 8 minutes early, the second shot 4 minutes early and the last shot on time, we multiply the one minute adjustments by the time intervals to produce the total motions adjustments. (We get identical values if we use the one minute MOB and MOO tables. If we are using the 4 minute adjustment tables we multiply by 2 and 1 adjustment periods respectively and get the same values.) We look at the refraction table (23.pdf) in the 10,000 foot altitude column and take out the refraction correction for each body and enter it on the form with a plus sign and carry them to the "MISCEL" line. Add the total motion adjustment to the MISCEL line to arrive at "TOTAL ADJ." and carry to the right side of the form into the appropriate columns. Combine the "HA" from H.O. 249 with the total adj. to arrive at precomputed altitude (Hp.)

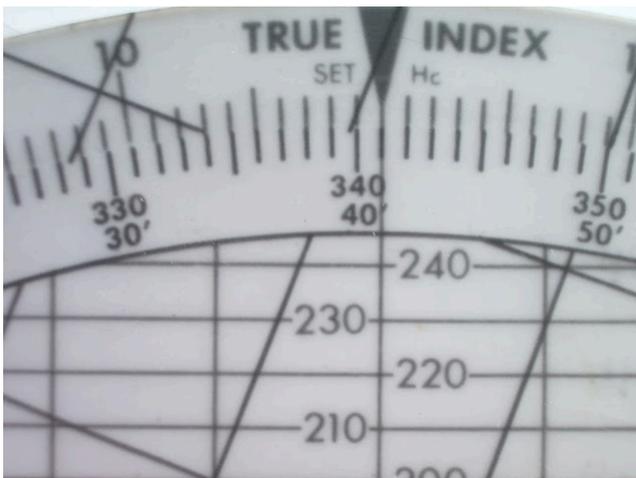
The last bit of information we take from the Polhemus is the Coriolis correction which is found in the "CORIOLIS & WANDER CORR." window. Look at the latitude, 33°, and take out the coriolis correction of 1.7 NM (20.jpg),

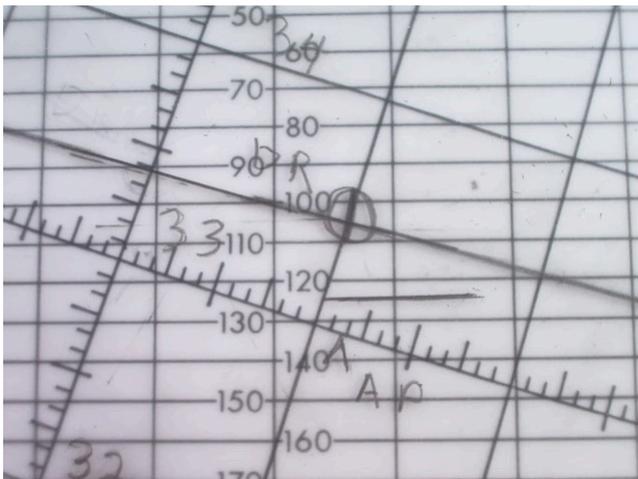


(2 NM if taken from the H.O. 249 table 23.pdf .) We will use this to move the plotted fix 1.7 NM in direction 356° , 90° to the right of the track to account for Coriolis. (Alternatively we could make the same adjustment to to the AP prior to plotting the LOP's, dealers choice. We could also use the Polhemus to derive a Coriolis correction to be applied to each Hp mathematically but that is a needless complication especially at low air speeds.)

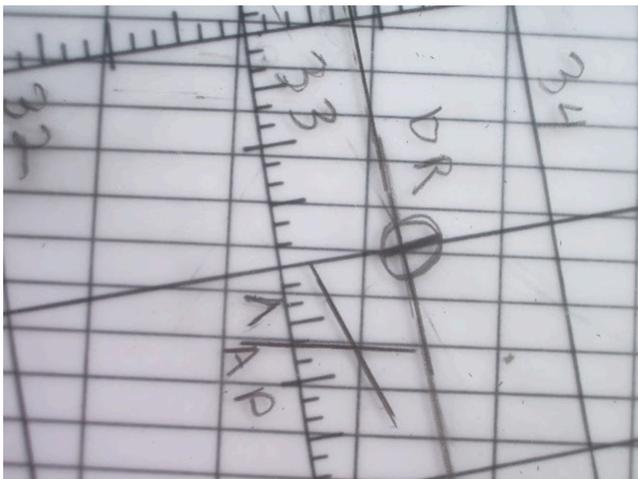
We are now done with the precomputations and can relax until time to shoot Kochab. About 1908Z we get the sextant ready, illumination on, bubble formed, averager set and altitude set to about 37°. We also make sure that the directional gyro is set and that the autopilot is set to heading mode. We look out the window, locate Kochab and bring it into the center of the bubble. At 1911Z we trigger the averager and continually adjust the altitude knob to keep Kochab centered in the bubble. Two minutes later the shutter on the sextant automatically closes ending the two minute shooting period and the average time of the shot is 1912Z. (If using an A-10A and some other sextants you must keep track of the progress of the shot and stop at the two minute mark.) The sextant altitude of Kochab is 37° 35'. We enter this in the form, compare it to the already adjusted and corrected Hp and determine that the intercept is 7 NM TOWARD Kochab, Zn 341°. (No need to correct Hs for refraction as this was already taken care of by applying the refraction correction with reversed sign to adjusted Hp.)

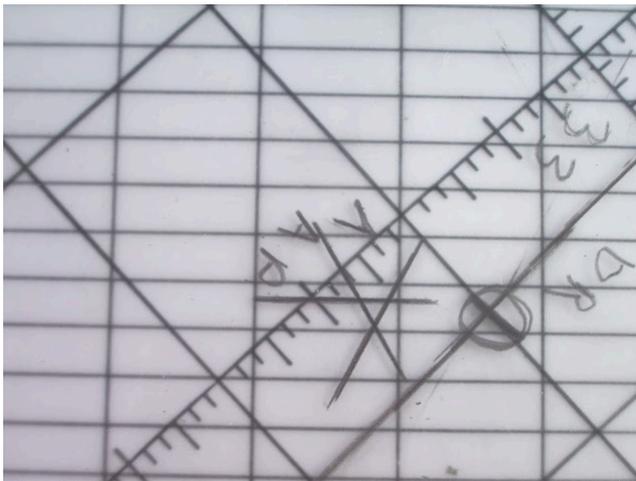
We complete the same steps with Arcturus and Antares and get an Hs of 19° 51' for Arcturus and an Hs of 16° 20' for Antares producing intercepts of 9 NM AWAY and 11 NM AWAY respectively. Using the Polhemus we plot the three LOPs. First we set the Zn of Kochab, 341°, at the TRUE INDEX and then measure up 7 NM from the A.P. since this is a TOWARD intercept. and draw the Kochab LOP parallel to the right-left grid lines on the Polhemus base (24.jpg and 25.jpg .)





We do the same for the Arcturus and Antares LOP's remembering to measure down from the AP since these are AWAY intercepts 26.JPG , 27.JPG , 28.JPG and 29.JPG.)



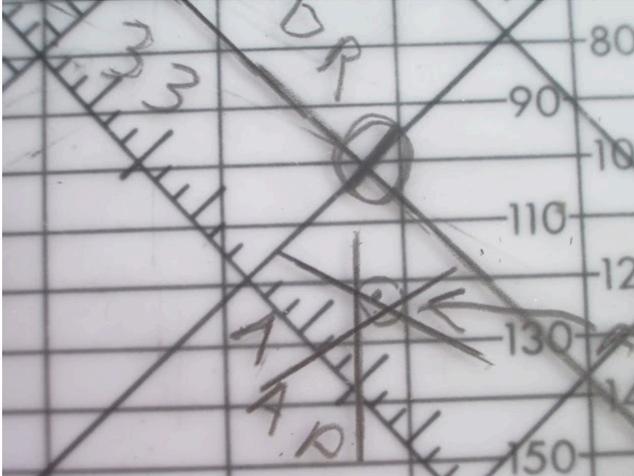


These three lines form the traditional "cocked hat" of a celestial fix. We then move the fix from the center of the cocked hat 1.7 (or 2) NM in direction 356° for Coriolis and then .6 NM in direction 241° for precession and nutation. We do this with visual interpolation since these are small values (30.jpg.)



If larger, we would set the respective Zn's under the TRUE INDEX and measure up the appropriate amount for each of these corrections. The fix is $33^{\circ} 13'$ north, $10^{\circ} 41'$ west.

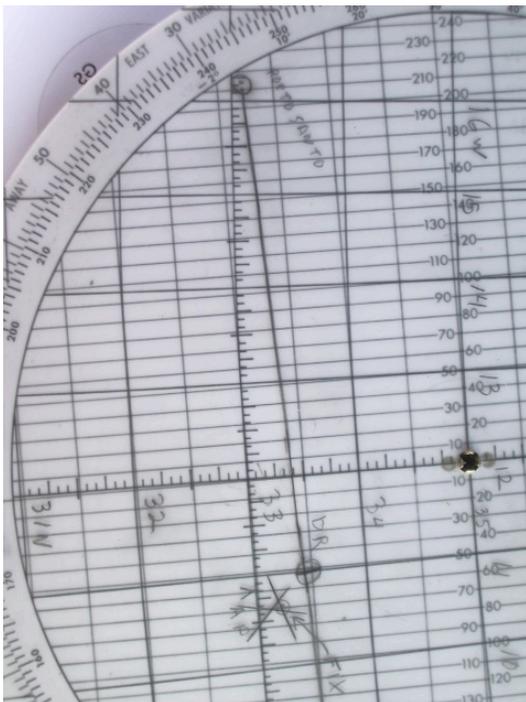
Showing the convenience of the Polhemus even more, we quickly find the wind encountered in flight and the new course and distance to the destination. Since our DR in this case is also our "no wind position" or "air position" where we would be if there were no wind, so any difference between the DR and the fix must be caused by the wind. We now rotate the disk to place the fix directly below the DR and read out the distance between the DR and the fix which shows how far the wind pushed the plane, in this case 21 NM (31.jpg.)



Since the plane flew for 1+14 in cruise we divide this 21 NM by this amount of time and find the wind speed of 17 knots. We now find the direction of true wind as it is already aligned with the "TRUE INDEX" which shows 311° (32.jpg.)



Now we can rotate the disk to place the destination directly above the fix and find the distance and true course to the destination of 284 NM (33.jpg), course 270° (34.jpg.)



Using this new course and the measured winds on our E-6B or MB-2A we calculate a new wind correction angle, new heading, new ground speed, new ETA and new fuel required. Wind correction angle will be 6° RIGHT making the new heading of 276° . The new ground speed will be 101 knots for the remaining distance of 284 NM which means it will take an additional 2+48 to arrive, making the new ETA of 2208Z. This means that we will arrive 28 minutes later than planned, using an extra 3.2 gallons reducing our fuel reserve to 17.7 gallons which is still a comfortable safety margin, more than two hours of extra fuel. We will plan on taking two more fixes at 2020Z and 2120Z to confirm that we are staying on course and maintaining our schedule to ensure having adequate fuel. We may omit the 2120Z fix if we are already receiving radio navigation guidance from the destination which should be only about 80 NM ahead at that time.

Although this is a fairly short flight it is still very useful to get the celestial fixes so that we can be sure we are not running into a strong headwind or getting blown far off course.

Celnav is done the same way in faster aircraft. Since most jets are flight planned at about .7 mach, about 450 knots, this just makes the adjustment for MOO and Coriolis larger but the same methods are used. Using the Polhemus it takes only 40 seconds to plot the three LOP's, about 13 seconds each, and just 30 seconds total to determine the wind speed and direction and the course and distance to destination. Then 25 seconds on the MB-2A gives you wind correction angle and ground speed and another 30 seconds gives you time to destination and fuel required. So by doing precomputations and by using the Polhemus you can have the fix and the new heading, ETA and fuel required, only two minutes after finishing the last shot. Try that with other other computation and plotting method!

