Vic-Maui Sextant Sights

Summary: We did sun and moon sights underway and on land using metal and plastic sextants. Each of the average intercepts below represent 4 or more sights. The sun-moon sights were used for running fixes. Details are given below. No special analysis was applied. The averages include *all sights taken*. All can be improved with more careful analysis.

1. Metal underway moon	0.9' T ± 1.7	**2.** Plastic Mk 15 underway sun	6.7' A ± 1.4
1. Metal underway sun	0.1' A ± 1.3	**2.** Plastic Mk 15 underway moon	4.3' A ± 1.4
4. Metal underway sun	1.6' T ± 0.4	**5.** Plastic Mk 15 underway sun	5.1' A ± 1.0
		3. Plastic Mk 3 underway moon	8.4' T ± 2.5
		3. Plastic Mk 3 underway sun	5.8' T ± 2.5
6. Metal on land sun	0.5' A ± 0.6	**7.** Plastic Mk 15 on land sun	4.0' A ± 2.3
		8. Plastic Mk 3 on land sun	1.6' T ± 1.6

Format notes: We use here the StarPilot celestial calculator input format for all angles, since that is the way we did the sight reductions, i.e. Lat 48° 25.6 N = 48.256, and Lon 125° 55.9'W = -125.559 (west is minus, east is positive). For sextant angles, Hs = 33° 02.5' = 33.025, etc. Times are likewise represented as decimals. 13h 23m 44s = 13.2344. If a time has no seconds it is 12.45. We need to be clear on the zones, however, as several were used.

Sights underway

The route was Victoria, BC to Maui HI, on a Beneteau 455f sailboat during a yacht race. We were a crew of 8. Sights were all taken by the author under spinnaker in trade wind conditions, that is surfing in 6- to 8- foot seas with speeds varying from 7 to 14 kts and headings varying some ± 20° or so — not ideal conditions for celestial sights, but still doable, which is one of the points we wanted to make with these data. The motivation for doing them at this particular time was the recent article in Cruising World which raised the issue of cel nav accuracy in general, on land vs. underway, etc. Indeed, one set of sights (first listed below) was taken standing at the boom, directly in the "line of battle" — that is halfway between a food fight from the bow to the cockpit, which occurs in the normal course of events on a racing yacht once a case of spoiled bread rolls is discovered. This involved some dodging of the missiles and the occasional crash of a bread roll on the side of the sextant… again, not ideal conditions for precision work, but at least not boring, even a bonus for the present study of environmental effects on sextant accuracy.

Taking sights on the cabin top. Normally, though, one would stand at the shrouds, or aft near the running backstays. This was to avoid the food fight.

Log of positions

PDT	GPS positions	CMG	SMG
15.44	32.067, -142.246	—	—
17.06	31.594, -142.259	186 T	8.2 kts
17.19	31.555, -142.262	188 T	8.9 kts
17.54	31.489, -142.262	187 T	8.1 kts

Sight notes: At 15.44 PDT on July 5, 2000 our GPS position was 32.067, -142.246. At that time, the indicated SOG was 8.5 kts, and the COG was 185 T. Above we show the averages made good for several intervals that span the sights. Air temperature was 80° F, pressure was 1028 mb. The sun was bright and very hot. Height of eye was estimated to be 11 feet (standing on cabin top, heeled over more often than not), Watch error was 4 s slow. All sights reduced by the Starpath StarPilot cel nav calculator. IC = 0.0 (4 measurements taken after the sights using the horizon: 0.2' On, 0.0, 0.0, 0.0. Note this sextant has historically had 0.0 for IC, checked several ways on land over the past year or more, although in subsequent measurements taken a week later on land in Maui I got 1.0' On as the average of a long series of measurements… so far I do not know the explanation of the latter result. It was applied to the land sights but not to those underway. Sometimes refraction can affect these things as well as psychological effects having to do with the actual colors of sky and ocean, relative brightness, etc.

For an AP or DR position to use for the sight reduction, we will just DR from the 15.44 position using average values made good to a later accurate position recorded at 17.06 of 31.555, -142.255. At this time recent values of SOG, COG were about 8.5 kts at 185 T, about the same as when we started. Unfortunately, these are the only two real positions we recorded in this interval. These two times and positions yield a CMG of 186 T and an SMG of 8.2 kts (from the StarPilot Rhumbline function). Now we choose (arbitrarily, since it doesn't really matter which we use) 16.20 as the "sight time" and our DR position at this time was 32.018, -142.252 from the StarPilot DR-update function.

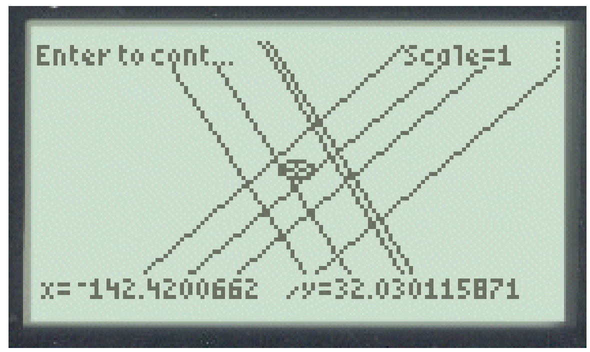
Set 1: Metal Sextant: 15-year-old forerunner of the present day Astra 3b from China. The new models are much nicer, but this one has served us well over the years. First intercepts are for S=0 and constant DR = 16.20 position, second set are advanced to actual sight times using 8.2kts at 186T (set StarPilot DR mode to Speed/time then update DR at each sight).

Upper limb of the moon (16.20 DR)

WT (PDT)	**Hs**	**a -value** (16.20 DR)	**a -value**
16.1220	51.115	1.0' A 115.7	0.6' A 115.7
16.1420	51.370	2.4' T 116.2	2.6' T 116.2
16.1533	51.490	1.0' T 116.5	1.2' T 116.5
16.1710	52.060	0.2' T 116.9	0.4' T 116.9
		avg. =	0.9' T ± 1.7

Lower limb of the sun

WT (PDT)	**Hs**	**a -value** (16.20 DR)	**a -value**
16.1954	64.396	1.2' T 254.8	1.2' T 254.8
16.2114	64.224	0.3' T 255.1	0.3' T 255.1
16.2222	64.072	0.9 A 255.4	1.0' A 255.4
16.2350	63.494	0.7' A 255.8	0.8' A 255.8
		avg. =	0.1' A ± 1.3



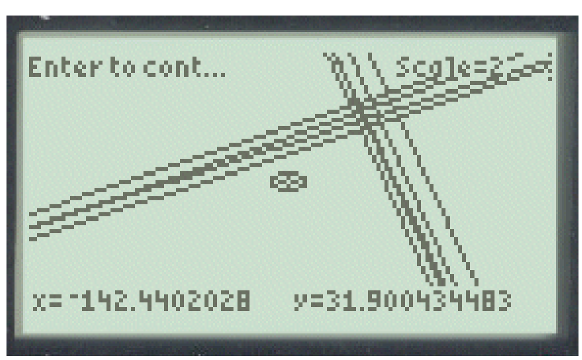
Plot output from the StarPilot calculator. All a-values shown here are relative to the 16.20 DR position, updated with the CMG, and SMG in effect at the time.

If we assume the DR is correct (not too good an assumption in our conditions) then the second set of intercepts is a measure of our accuracy. The average of the moon sights is 3.6/4 = 0.9' T. The average of the sun lines is -0.3/4 = 0.1' A. The spread is about ± 1' in each case, but we can later do better by a careful slope analysis of this data. In the meantime, the running fix obtained at 16.20 *using all the data* is off the DR position by 1.3 miles. Since our DR was likely uncertain by 0.5 mi or so, this is not bad. Later we will see how we can improve on this with the slope analysis to sort out which of the sights were best — or maybe it will get worse, we don't know yet. Note it is a good sign that the sights are a mixture of Toward and Away, which gives hope that the errors are more random and systematic.

Set 2. Mark 15 Plastic sextant. The main issue with plastic sextant sights is the IC. Notes are below, the IC for the sun sights is taken to be 1.6' On the scale ± 2.4'. For these we will just update the DR using the logbook data above for each sight (15.44 to 17.06 for the sun lines, and 17.19 to 17.54 for the moon lines). Temp, Press, WE, HE are the same as Set 1. DR updated at each sight.

Lower limb of the sun

WT (PDT)	**Hs**	**a -value**
16.3600	61.152	6.3' A 258.6
16.3655	61.020	8.1' A 258.8
16.3743	60.540	6.2' A 258.9
16.3837	60.420	7.0' A 259.1
16.3917	60.350	5.7' A 259.2
	avg. =	6.7' A ± 1.4'



From DR (circle with the cursor in the middle) to the center of the LOP intersections is 10 miles. Slope analysis might improve this by 2 miles or so.

Then we ran for about an hour doing sights with other sextants, and resting from the heat of the sun. Then returned to the Mk 15. We will use these two sets of Mark 15 sights for a running fix. For the moon sights IC = 3.1' On the scale ± 1.0'. See IC notes below.

Upper limb of the moon

WT (PDT)	**Hs**	**a -value**	
17.2557	63.153	4.6' A 139.9	
17.2853	63.372	5.7' A 141.2	
17.3001	63.488	2.9' A 141.7	
17.3150	64.015	4.0' A 142.5	avg. = 4.3' A ± 1.4'

The spread is not at all bad for a plastic sextant: 6.7' A ± 1.4' for the sun and 4.3' A ± 1.4' for the moon, but it is disconcerting that all sights are in the same direction , i.e. Away. This is almost certain proof that there is some systematic error in the data. Note that if the intercept (a) is Away = Hc - Ho, then Hs is too small, which means the 2 or 3' we took off in the IC was too much — or simply the sights are all just too low by that amount. For example, in the last sight if the IC was not -3 but +1 (ie 1' Off) then the a-value would have been about 0. The 17.30 fix obtained *using all sights* is 10.2 miles off of our 17.30 DR. This is a rather poor fix, but we do not have good IC data and the sights themselves were not taken in the proper manner as discussed in Ref [1].

It is fair, however, to say that the sights themselves were only in error by 4.3 miles in one case and 6.7 miles on average in the other, and to stress that the error was in the same direction. This combination of LOPs gives a larger error in the two-body fix, BUT, with a well chosen set of 3 stars, near 120° apart, this near constant error would indeed cancel in large part, and yield a reasonably accurate fix. This is why it is so important to use star sights for fixes, not just running fixes with the sun. Even adding the moon does not help this.

It is interesting to note that the average a-values differed by 6.7 - 4.3 = 2.4 is very roughly the same as the difference in IC's used (3.1- 1.6 = 1.5). In other words, the moon sights would have been 2 miles better using the sun line ICs… but all this is pure speculation, we simply have no better data at present. Later we will do the slope analysis to see if that helps, but we are rather out of range of those corrections.

Notes on the Set 2 Index corrections

The index corrections were measured several times, but unfortunately not following the careful procedure described elsewhere [1]. They were just taken in the Toward and Away (up and down) directions before and after each set of sights. Notation: "A3.2 On" means the IC was measured turning the micrometer drum in the Away direction and the value was 3.2' On the scale. See Celestial Sights with Plastic Sextants (Ref [1]) for more details on plastic sextant IC measurements.

Before the sun sights (16.32) we have 5 measurements:

A 4.2 On	T 0.5 On
A 4.0 On	T 1.5 On
A 3.2 On	

After the sun sights (16.40) we have 7 measurements:

A 2.2 On	T 2.5 On
A 0.0 On	T 2.0 On
A 0.0 On	T 1.0 Off
	T 0.0 On

Since these were not done with the "touch and leave" procedure and the sights themselves were not taken with the "set and wait" procedure (both procedures described in of Ref. [1]), we do not have such nice results to work with. So for now we just do some averaging and note our uncertainty. The average of all 12 is 1.6' On . The average of all 12 minus the highest (4.2 On) and the lowest (1.0 Off) is also 1.6' On. For now let us just say the IC = -1.6' and the uncertainty is ± 2.4' for all the sun sights.

Before the moon sights (17.22) we have 4 measurements:

T 4.0' On	A 4.0' On
T 4.0' On	A 4.5' On

And after the moon sights (17.33) we have 4 again:
T 1.0' On A 3.0' On
T 1.5' On A 3.0' On

Here the average before the sights was 4.1' On and the average after the sights was 2.1' On. For now we will just say that for all moon sights IC = -3.1' and the uncertainty is ± 1.0' Again, we might do better with a more systematic approach but even with this data we are near the limit of plastic sextant accuracy so there is little justification for it.

Set 3 Mark 3 plastic sextant. This is the bottom of the line plastic sextant. It does not have a micrometer drum but rather a large vernier scale. It can be read to a precision of only 2’. They sell new for about $50, but are easy to find in swap meets or used marine gear stores for 10 or 15$. We used to have many of these, but they are gone. We bought this one new for these tests.

Notes on Set 3 Index corrections

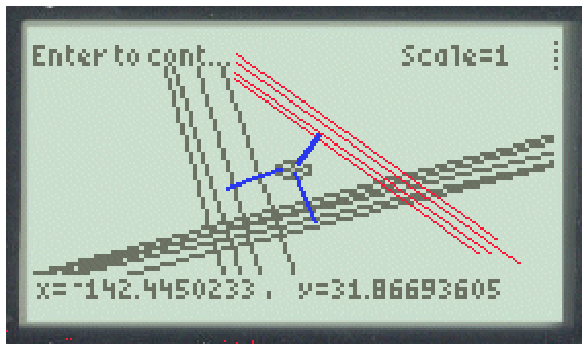
For the sun sights we set the IC to zero before each sight and then immediately proceeded to take the sight without further tests of this setting. During the subsequent moon sights and then later on land in Maui, I discovered that whenever I set it to 0 by eye and then measured it I would get 6’ Off the scale. This result was rather surprisingly consistent and reproducible…which only goes to show that the use of plastic sextants takes time and study… you must learn your “personal errors” — a term described in Bowditch and elsewhere regarding sextant sights. When we did use this type of sextant in class in the early 80’s, we would set them to zero, then paint up all the adjustment screw threads with fingernail polish so they could not turn. It seemed to work well, so we never did do any systematic studies. For now we have this large uncertainty floating around, but it turns out to not make that much difference: first we reduced with 0 for sun lines and +6 for the moon lines, then repeated with + 3 for all sights and got the same answer.

Lower limb of the sun
(DR updated at each sight, IC = 0)

WT (PDT)	Hs	a -value
16.5047	58.18	2.7' T 261.5
16.5419	57.38	7.1' T 262.2
16.5643	57.06	5.3' T 262.6
17.0027	56.22	8.3' T 263.2
		average: a = 5.8' T± 2.5

Upper limb of the moon
(DR updated at each sight, IC = +6)

WT (PDT)	Hs	a -value
17.4106	65.10	7.3' T 147.0
17.4147	65.16	6.2' T 147.5
17.4420	65.35	10.9' T 148.6
17.4750	65.54	8.0' T 150.5
17.4853	66.02	9.7' T 151.0
		average: a = 8.4' T ± 2.5



From DR (circled) to the center of the true LOP intersections (black lines) is 13 miles. The red lines are added to show hypothetically what it might look like if these were 3 star sights with the same approximate constant errors (blue lines) in each set of sights. In this case, the center of the “cocked hat” is a fairly good fix, even though the individual sights were off by some 6 or 7 miles each. This fact is even more important to plastic sextants than to more accurate ones made with a metal sextant.

These sights *all together* give a 17.45 running fix which is 13 miles off the DR at that time. A slope analysis could improve this if it showed that the lower sights were better. Note an intercept labeled T (= Ho - Hc), means the Ho were too big, which most likely means the +6 IC was too big…. If we had used 0 as in the sun lines, each of these moon lines would be 6' lower and the fix much improved. Unfortunately, we did not have enough time to play with this underway.

In short, we did not do very well with these sights, but since they are all Toward it implies there is definitely some systematic error… or the instrument is just off that amount. Later — I do not know the answers yet — we reduce and report on the land measurements made with this instrument and that may shed some light. Note from the plots that the scatter in the sunlines was also larger than with the moon lines which is what we also got with the other plastic sextant. There was a bright glare from the sun during both of these sets so that might have contributed to this.

Set 4 Metal sextant underway

PDT 7/9/00 GPS positions (same sextant as before)
11.37 24.141, -151.290
11.50 24.126, -151.304 CMG = 221 T, SMG = 9.1
12.11 24.106, -151.327 CMG = 226 T, SMG = 8.3

T = 80, P = 1030, HE = 11, IC=0, WE = 5s Slow.. notebook states VERY HOT with much glare…. And my old sextant did not have good horizon shade options (the new models have this corrected) so sights were done without horizon shades with consequently not a very good horizon.

Lower limb of the sun

WT (PDT)	**Hs**	**a -value** (DR updated to each sight)
11.4046	41.450	1.5' T 081.1
11.4231	42.084	1.5' T 081.3
11.4359	42.264	0.1' A 081.4
11.4544	42.518	1.8' T 081.5 average = 1.6' T ± 0.4 or so…

The results are not too bad for the conditions, poor horizon and surfing in big seas. The positions used for comparisons cannot be too poor, however, since we only ran for 2 miles during the sights. Here we really must consider the "best sight' (0.1') as an anomaly and more likely the average with the poor horizon was more like 1.6'.

Set 5 Plastic Mk 15 sextant underway

Notes on IC… again, I did not do proper "touch and leave" measurements, so the data are not as good as they could be. Also the sights themselves were not taken in the "set and wait" procedure, so we don't know which to use anyway.

Before sights at 11.56:
T 3.0 On A 7.0 On
T 3.0 On A 6.5 On
After sights at 12:05
T 5.0 On A 8.0 On
T 5.0 On A 7.0 On
T 5.0 On A 6.0 On

Hence we will just average all of them and use: 55.5/10 = 5.5' ± 3 On the scale for all sights. Again, in principle we could do better if we followed the methods of Ref [1]. HE, WE, T, P same as in Set 4. DR using logbook of Set 4.

Lower limb of the sun

WT (PDT)	**Hs**	**a -value** (DR updated to each sight)
11.5846	45.460	4.4' A 082.4
11.5938	45.575	4.6' A 082.4
12.0100	46.154	5.1' A 082.5
12.0443	47.044	6.1' A 082.8 average = 5.1' A ± 1.0

Again, the spread is not bad, but we are fighting an unknown IC in this case with an uncertainty of 3 miles. But we can at least say that the sights are accurate to within about 5 miles without any sophisticated analysis at all…which is one of the points we wanted to make in the letter to Cruising World. And these are underway, in poor but realistic conditions. Not on land.

Set 5 Metal sextant underway

PDT 7/2/00 GPS positions (same sextant as above)
16.04 37.280, -133.574
16.47 37.233, -134.028 CMG = 222 T, SMG = 9.0
All data same as earlier sights but WE = 3s Slow, T = 70, P = 1030.

Lower limb of the sun

WT (PDT)	**Hs**	**a -value** (DR updated to each sight)	
16.3236	54.080	0.2' A 257.1	
16.3404	53.521	0.8' T 257.4	
16.3527	53.356	0.2' T 257.7	
16.3748	53.100	1.7' T 258.2	
16.3943	52.484	2.2' T 258.6	average of all = 0.9' T ± 1.0

This is a good example of where fatigue or over confidence may have entered in. They were going well till the last two. Also, as we will see later, the slope analysis will help sort this out since they are so different — it will definitely reduce the size of the error bar. Again, in any event, one can conclude that the cel nav LOP was right to within 1 mile. Note that these were actually the first sights done underway, but were in the back of the notebook. I am pleased to observe that one does remember how to do this after not having actually done sights in the ocean for more than two years…. But then again, it is not really much different from doing them on land… even surfing around in a seaway.

Set 6 Metal sextant on land

Overlooking the beach on Maui at 20.5753, - 156.4110. July 12, 2000. Very hot. Shade temp = air temp = 85° F, but leaving the thermometer in the sun it heated to 111° F in about 20 minutes. In short, if a plastic sextant is going to go weird in the sun, now will be its time! HE = 17 feet (measured to the foot). Sight times in HST (ZD = +10). WE = 6s Slow. Pressure was 1018 mb.

Note on IC. As mentioned earlier, I found an unusual IC for these sights on land since this sextant has usually had a 0.0 correction. The data were (all On the scale): 1.5, 1.0, 1.2, 1.0, 0.8, 1.0, for an average of 1.0' On the scale, which is what we use here.

WT (HST)	**Hs**	**a -value** (DR = actual position = constant)	
17.4149	18.401	0.5' A 286.8	
17.5323	16.060	0.3' A 287.6	
17.5509	15.426	0.2' A 287.7	
18.2131	9.537	1.0' A 289.6	
18.2256	9.362	0.0' T 289.7	
18.2406	9.196	1.4' A 289.8	average of all = 0.5' A ± 0.6

A better average would be to throw out the last (boredom factor) and get 2/5 = 0.4 ± 0.4. I have not done it yet, but am willing to bet that a slope analysis will throw out the two high ones, leaving a much better fix, which is more typical of careful sextant sights on land.

Set 7 Mark 15 plastic sextant on land

Note on IC: Unfortunately, again, a careful job in this was not done, but it was these measurements that in part lead to the formulation of proper procedures listed in Ref [1].
Here are the recorded data.

17.45	T 4.0 On	A 1.0 Off	…just after first sight
17.56	T 1.0 Off	A 0.0	… just before 2nd sight
	T 1.0 On		

18.04	T 0.5 On	A 5.0 Off … after last sights
	T 0.5 On	A 5.0 Off

For now, we just average all of these and use that and note the uncertainty. We get 6 On and 12 Off = 6 0ff / 9 = 0.7' Off with an uncertainty of ± about 4'. One can do better as we will show later on doing more sights with good procedures. For now: IC = 0.7' Off for all sights. Else, same data as in Set 6.

WT (HST)	**Hs**	**a -value** (DR = actual position = constant)
17.4435	17.556	6.3' A 287.0
17.5850	14.472	4.9' A 288.0
18.0040	14.244	3.4' A 288.1
18.0251	13.574	1.5' A 288.3 average = 4.0' A ± 2.3'

Note that not only is there clearly some systematic error, i.e. all are Away, but there is also a trend, the a-values getting smaller… in this case it is towards better sights, but that is not significant. The bigger worry is that it does seem to be changing. It is definitely possible that this sextant was not in equilibrium with the local temperature which was extremely hot. In any event, for now, we concentrate on the value itself… 4 miles. Which is not bad for a plastic sextant, even without special care and in the burning sun!

Set 8 Mark 3 plastic sextant on land

Note on IC: The measured IC of the instrument was 6' Off the scale. It was this before the sights and after and it is the same as it was underway. Also as mentioned earlier, I can take this one and twiddle the mirrors and then reset them to what appears to be zero when viewing the horizon, and then twiddle the index arm and measure the IC and get 6' Off again. This is a bit surprising, but we will live with it. Take our small blessings as they come. We call the IC 6' Off the scale. Else data are the same as in Set 6 and 7. Recall this sextant can only be read to a precision of 2' and that requires the use of a vernier scale.

WT (HST)	**Hs**	**a -value** (DR = actual position = constant)
17.5057	16.34	2.4' T 287.4
18.1313	11.40	3.3' T 289.0
18.1419	11.24	1.8' T 289.1
18.1633	10.54	1.2' T 289.3
18.1757	10.34	0.5' A 289.4 average = 1.6' T ± 1.6

This of course is most excellent, and must be considered part luck. One should consider a consistent under 10 miles as good for this device. On the other hand, it is not surprising to us to see the Mk 3 do as well as the Mk 15. We have noticed this in the past. I am not sure it will hold up if we use good procedures with the Mk 15, See Ref [1]. Part of the reason is you must always move the index arm in the same direction. At least with my operation of it, the only way I can very carefully squeeze and push it to a new angle is to push it down. So if I am below the angle, I must crudely set it too high and then carefully push it down. In other words, the very simple design of the instrument forces users to operate it in a consistent way. And — most important — this is the same motion needed to check the IC, so both are done in the same manner. Also, since there are no optics and the arm is so difficult to set carefully, one is forced to use the “set and wait” method discussed in Ref. [1] which is the best way to do plastic sextant sights.

Note in closing: We used the Mk 3 and earlier the Mk 15. But the actual top of the line in plastic sextants is the Davis Mk 25, gray plastic with full view mirror. We did not use it, simply because we did not have one — and we did have this old Mk 15, which turns out to do a fine job.

Hopefully we have made our point about sextant sights. It has taken a lot of time to document what we and many others knew is true without these most elementary examples. With the Internet, we can now archive this and not have to do it again. We do have much data in old logbooks that can be rejuvenated for more examples.

To follow up on this properly, however, we need one more article. Namely a clear presentation that shows how 3 well-positioned stars can provide an accurate fix even when each of the individual LOPs may be off by some constant amount, as is so common with plastic sights. This will clearly show how you can with a plastic sextant get consistent fixes within 5 or 6 miles, even if each of the sights themselves may be systematically off by this amount or even more.