On December 27, 2008 I posted on the "Brandis Sextant: PAAs or Noonan's?" thread:

"14. Contrary to Ric's premise, there was no way to navigate along the "157-337 LOP" to Nikumaroro (I have written countless posts about this, the navigation is quite simple even though to non navigators it might sound complicated. To a navigator it is no more complex than getting in your car and driving to the supermarket to get a gallon of milk) so they did _not_ end up on that island."

I received this reply from Patrick Gaston:

"14. Guess I'm dense, but I still don't see how it would have been impossible to reach Niku by simply flying down the 137/337 line. Seems to me it could have been done >if and only if< FN was using the offset method, >and< his advanced LOP ran smack through Niku."

The reason I even got involved in the Earhart mystery and started posting on TIGHAR is because of this issue, that it is not possible to follow the 157-337 line of position to Niku. I had read in the April 1992 edition of "Life" magazine that Ric was pushing this theory and I knew instantly that it was wrong. I found the TIGHAR web site in 2002 and starting posting why this was impossible and, needless to say, my postings were not well received by TIGHAR.

Understanding this point is critical is refuting all of Ric's subsequent gambits because the one thing that sets his theory on a pedastal above other theories is that he has
Earhart saying that they are on this 137-337 LOP. No other theory has Earhart's supposed blessing.

I have written extensively in the past trying to make this point clear but if Pat Gaston still doesn't get it then there must be others also who have missed this point. So I am going to try to make it clearer this time so, hopefully, it will be clear to all.

I will start with a different example. Pilots are familiar with a type of on board electronic navigation equipment called Distance Measuring Equipment (DME) which works like radar but in reverse. On the ground there are many navigation radio facilities called VORTACs and VOR-DMEs that have a specialized type of radio equipment that allows the pilot to determine his distance from the ground facility. The aircraft radio sends out a pulse signal that is picked up by the ground equipment and then rebroadcast and eventually received back at the aircraft. The aircraft equipment measures the time it takes for this round trip of the radio pulse and determines the distance that must have been covered based on the known speed of radio waves. The equipment then displays this distance to the pilot on a cockpit display accurate to one-tenth of a nautical mile. One of the things a pilot can do with this information is fly a circle around the ground station maintaining a constant radius. If his display shows him getting further away from the station he can adjust his heading appropriately to get back onto the desired radius circle. If the numbers get smaller he would correct in the other direction.

So let's see how this works. Instrument rated pilots are familiar with a type of instrument navigation procedure called a "DME arc." The airplane is instructed to fly towards the ground DME station until reading a certain distance, say 15.0 NM. (" Electra zero two zero, intercept the one five DME arc, cleared for the approach.") The pilot then tunes in the appropriate frequency in his DME equipment and flies towards the station watching the distance numbers getting smaller. Slightly before reaching 15.0 NM he starts a 90º turn so that at the completion of the turn he is on the 15 NM circle. He then flies along watching his DME display and making corrections left and right to keep the reading at 15.0. (See attached page from the FAA Instrument Flying Handbook.)

So how can this help him find an airport? Let's say he wants to find an airport. He looks on his chart and sees that there is a VORTAC located northeast of the airport and he measures the distance on the chart from the VORTAC to the airport, say 54.0 NM. Now this is important for the analogy. He now knows that if his airplane is directly over the airport his DME will read 54.0 NM. Of course his DME will read 54.0 anywhere else on the circle too so just this information won't allow him to head directly to the airport. But he knows, that if he intercepts the 54.0 DME arc and follows it all the way around he will eventually pass directly over the airport. So our pilot takes up a heading that will take him north of the airport and when his DME shows him on the 54.0 DME arc he turns to go south following the circle and making corrections so that his DME reading, 54.0, will always be the same as what the DME reading would be if he were over the airport at that time. If, by chance, there just happens to be another airport exactly 54.0 NM from this same VORTAC that lies beyond the destination airport, on the DME arc, if the pilot misses his destination (perhaps a cloud obstructed his view at the critical point) if he them continues to maintain the same 54.0 DME reading, this circular LOP will take him over the second airport. This is the analogy to Ric's theory.

As he follows the circle, first heading south, the circle keeps curving and the pilot must change his heading to stay on it. If he keeps heading south and the circle curves off to the southeast then his DME readings will start getting bigger and he will know to change his heading to correct back onto the circle going from 180 to 170 to 160 etc. Eventually as he follows the circle he will come to a segment of the circle where a straight line tangent to the circle at that point bears 157º. If trying to stay on the circle at this point the pilot's heading will vary slightly to the right and sometimes to the left of 157º.

What we have been illustrating is following a line of position (LOP) that is curved. We can think of this circle as consisting as a collection of short straight line segments connected end to end. For a small radius circle these segments will be short but if the radius is large then we can fly straight line segments for quite a while to approximate the circle.

The concept of an LOP is quite simple, we use them everyday without thinking about. Say a friend calls and says to you "let's meet for coffee at the Starbucks in Simi Valley." You are not familiar with that area so you ask him what the address of the Starbucks is and he says " I don't know exactly but it is on Main street, south of 1st avenue." So you get in your car, confident that you will be able to find Starbucks with only this information. You drive down the freeway and decide to get off at the 1st avenue exit. There are other exits further down the freeway that might take you closer to the Starbucks but since you can't be sure which other one to take you play it safe and get off at 1st avenue. You follow 1st avenue in the direction that your know will cause you to intercept Main street, in this case to the east. You determine that you have arrived at Main street by reading the street signs and you know which way to turn since you know Starbucks will be to the south of where you intercepted the Main street LOP. Yes, Main street is an LOP! What makes this an LOP is that you can determine when you have intercepted it (the street signs) and you can determine that you are staying on it. If you run up on the curb on the right you know that you have to correct to the left. If your run up on the left curb you have to correct to the right. (You can also watch the center line.) You continue to make observations as you drive along making the appropriate corrections to stay on Main street and eventually you spot the Starbucks and have a $4.00 latte with your friend. Note that this method will get you to Starbucks even if Main street does not run in a straight line, it can curve. Also note that the procedure is the same as in the DME example. You continuously compare what your readings are, 54.0 DME in the first example, "I'm on Main street" in the second, with what the reading would be if you were at your destination, 54.0 DME in the first example, "I'm on Main street" in the second.

What sets an LOP off from a mere heading or dead reckoning is that you have the means to determine if you are on the LOP and the ability to make corrections to get back onto it if you wander. _This is the extremely important concept_!

Now let's look at the use of a sextant for following an LOP. Let's say you are downtown standing next to a very high building, say the Sears tower in Chicago.You will be "rubbernecking" bending your head way back to look up to the top of the building. A sextant is simply a device that allows you to measure precisley the amount of rubbernecking that you are doing. It allows you to measure angles between two reference lines and that is all that it does. Using a marine sextant you use the visable horizon as the reference and with a bubble octant you use a very precise bubble level that works on the same principal as a carpenter's level. You use them this way to measure an altitude above horizontal. If you were standing next to the Sears building and used your octant to measure the altitude (the angle above horizontal) to the top of the building you would measure 90º, straight up. Common experience teaches us that as we move firther away from the Sears building that it will look lower and lower, the angle to the top (the altitude as measured with the sextant) will get progressively smaller. You don't have to know trigonometry to understand that a certain angle will be measured at a certain distance from the building, and that anybody measuring that same angle would be at an equal distance away from the building. If you wanted to walk a circle around the building at a 10 mile radius you could (using trig) calculate what angle (altitude) you would measure with the sextant at ten miles from the building. You could then use your sextant to walk a circle around the building maintaining a 10 mile distance. Of course other buildings, cars, hot dog stands, and kids would get in your way so this would work better in the desert, maintaining a constant distance from a mountain peak. So if you are looking for a water hole in the desert that shows on your map as being exactly 10.0 miles from the mountain peak you would first calculate, using trig, what altitude would be measured with a sextant located at the water hole. You can then walk a circular LOP using periodic readings from the sextant and comparing the current reading with what would have been measured at the same point in time if you were at the water hole. You can then maintain the 10.0 mile distance until you find the water hole. This is just like the DME example.

Now on to celestial LOPs. A celestial LOP is exactly like the ones we have been discussing, there is nothing mysteryous or magical about them. We use the sextant just like in our Sears tower example. Right now there is some person on earth who can look straight up, 90º, to see the sun, it is directly overhead. If he had an octant he would measure 90º to the sun. As we move further away from the point where the sun is directly overhead (we call this the geographic position, GP) the angle we measure with our sextant gets lower and lower. Because our earth is round and because of the way the nautical mile is defined, it works out that for each one degree that the sun is away from being directly overhead we must be 60 NM further away from it's GP. If we measure 89º, one less than the straight up 90º, we must be 60 NM away from the GP. We could draw a circle on our chart of 60 NM radius centered on the sun's GP and we would know that we are somewhere on that circle. At low angles the radius becomes quite large. At the time of sun rise the altitude is zero degrees, ninety degrees less that straight up Ninety degrees times sixty NM per degree equals 5400 NM which means that we must draw or circular LOP at a radius of 5400 NM from the GP. A segment of a circle with such a large radius looks a lot like a straight line for a considerable distance and for convenience a navigator plots this circle of position (circular LOP) as a straight line for a distance on his chart. But he knows that there is a limit to how far he can draw that line and still have it represent the circle of position. A navigator can determine which side of the LOP he is on and make appropriate corrections. If AE intercepted the LOP northwest of Howland and was flying southeast, 157º, she would be following this circular LOP counterclockwise and the sun would be off the left wing tip. Noonan knows if his measured altitude is greater than what would be measured at Howland at the same time then he must be closer to the sun's GP (the Sears Tower example) and must correct to the right. If he is reading less then he is further away and must correct to the left.

This gets us to the legendary 157-337 LOP. At the time of sunrise in the vicinity of Howland the azimuth to the sun was 67º true. A circular LOP based on the sun's GP at that time that passed over Howland would run in the direction of 157-337º true, at a right angle to the azimuth of the sun at that point and time (67 + 90 = 157). (Celestial navigation uses true directions referenced to true north not magnetic directions read off a compass.) This would be plotted on the chart as a line tangent to the circle of position at Howland and would extend 337º true to the northwest and 157º true extending to the southeast. This is the line that Ric extends all the way to Niku, claiming that Noonan knew he would be able to just stay on this line in case he missed Howland and stay on this LOP all the way to Niku and safety.("Send me some more money for my next expedition.")

In fact, this straight line representation of this segment of the circle of position that passes over Howland at the time of sunrise passes close to Niku. But remember what this line represents. It represents the circle of position on which every one with a sextant would measure the same altitude of the sun at the same time. This means that at the time of sunrise at Howland, 1750 Z (1750 GMT, July 2, 1937,) an observer on Howland would measure a zero degree altitude as would everyone else on the circular LOP that ran through Howland . This circle, where the altitude of the sun was zero at 1750 Z, July 2, 1937, passed over Howland, and also near Kamchatka, Russia, over Siberia, over Finland, over Nice, France, close to Dakar, over Cape Horn at the tip of South America before curving up across the Pacific passing near Niku and back to Howland. (See photos of globe.) The circle runs northwest-southeast only near Howland. It runs east - west over Siberia, northeast-southwest over Europe and Africa and again east-west passing between south America and Antarctica. Observers at these other locations would plot a straight line to represent their segment of this circle tangent to the direction of the circle at that point. For example, at Nice France the azimuth to the sun at that time was 288º so the LOP plotted by a navigator there would run 198-018º. It's the same LOP but its direction depends on where you are located in relationship to the sun's GP at the time the sight is taken.

[As an aside, I hadn't thought of this before but looking at the LOP on the globe brings this out. The sun was virtually on the tropic of cancer since it was just one week after the summer solstice. The LOP determined by a zero degree sextant reading (the sunrise and sunset LOP) is 90º from the GP which was approximately 23º north and 90º west at 1800 Z. This means that this LOP for an observer straight south of the GP at the 90º west meridian was located 90º south of the tropic of cancer placing it on the antarctic circle approximately 67º south. Going the other way, north, 90º takes you over the top of the world and the LOP then lies over the arctic circle on the other side of the earth at 90º east longitude in Siberia. At both of these points the LOP is running directly east and west, 90-270º.]

The sun actually rose a few seconds earlier than 1750 Z at Howland so at 1750 Z the actual altitude of the Sun as measured at Howland was 0º 13.9' while at the same instant an observer on Niku would have measured 0º 01.2'. Anybody on the LOP going through Howland at the time would have measured exactly the same altitude as at Howland, 0º 13.9'. Since and observer on Niku would not have measured this exact same altitude Niku was not on the 157-337 LOP! but it was close. The difference between the altitudes at Howland and at Niku shows how far off the LOP Niku was. 13.9' minus 01.2' equals 12.7' of arc difference multiplied by one NM per minute of arc (remember how nautical miles are defined, 60 NM per degree and 60 minutes of arc per degree) which places Niku 12.7 NM from the LOP at the time of sunrise. Since the altitude measured at Niku is lower than the altitude measured at Howland, Niku must be farther away from the Sun's GP than the Howland LOP so Niku is southwest of the LOP.

But the earth keeps turning and the sun keeps getting higher in the sky so we need to keep calculating what the new altitude would be if we were at Howland and keep comparing what we are measuring at the time with the computed altitude at Howland. We do this by finding the location of the Sun's GP and do some simple trig to calculate its altitude at Howland. Looking now at page 22 of the Nautical Almanac for 1937, (see attached) we can see the section that applies to July 2nd. Looking down the page for 18 hours G.C.T. (the same as GMT and Zulu time) on July second we see from the second column that the sun's declination (equivelent to the latitude of the GP) is 23º 02.3' north and the third column shows the sun's G.H.A. (equivelent to the longitude of the GP) as 89º 02.5' west about 360 NM south of New Orleans. With the coordinates of the GP and the coordinates of Howland we compute the altitude at Howland at 1800 Z as 2º 31.7' .

{You can do the trig yourself here is the formula:

Sin altitude = sin latitude times sine declination plus cosine latitude times cosine declination times cosine of the difference between the GHA and the longitude.)

Or you can go to the U.S. Navy website at :

http://aa.usno.navy.mil/data/docs/celnavtable.php

and enter the date and time and the latitude and longitude of Howland, 00º 48' north, 176º 38' west and let the Navy do the calculation for you.The column labeled "Hc" is the computed altitude of the celestial bodies and the column "Zn" is the azimuth to the body. You can also enter the location of Niku, 4º 40' south, 174º 32' west, to compute the altitude at Niku to compare with the altitude that would be measured at Howland for the same time. At 1800 Z the altitude at Niku was 02º 18.4' a difference of 13.3' or 13.3 NM. NOTICE the difference has grown six tenths of a nautical mile in just 10 minutes. It had been 12.7 NM at 1750Z and is now 13.3 NM at 1800Z.

If Noonan had been near Niku at 1750Z and taking sights and comparing them to the altitude that would have been measured at Howland at the same time he would have been able to adjust his heading to track the LOP which would take him past Niku which would have been 12.7 NM to his right as he went past it. If he flew by

Niku just ten minutes later at 1800Z using the same standard navigational technique trying to find Howland by tracking the LOP, Niku would have been 13.3 NM to his right, six tenths of a nautical mile farther away if arriving only ten minutes later.

Also the azimuth to the sun at Howland at 1800Z is 67.0 and is 66.7 at Niku, a slight difference due to Niku being further around the circle of position. An LOP calculated at Howland at this time runs 157.0-337.0 while an LOP at the same time at Niku would run 156.7-336.7 and insignificant difference for navigational purposes AT THAT TIME.

Now you be the navigator. Go to the Navy website and do the calculation for 1912 Z when AE reported "must be on you." What altitudes do you find at Howland and at Niku? What is the difference between them? I got 19º 02.6' at Howland and 18º 37.0' at Niku, a difference now of 25.6'. Since Noonan is attempting to find Howland he is comparing his octant reading with the altitude that would have been read at Howland and adjusting his flight path to come up with the same number. Had he actually been near Niku at this time he would have passed by Niku 25.6 NM away, not likely to spot Niku that far away. Also note that the azimuth of the sun at Howland is now 65.8º a 1.2º change from before. Plotting the resultant LOP through Howland would make it run 155.8º-335.8º. Since Niku is actually on a course form Howland of 159º this again shows that the LOP is moving further away from Niku.

Let's move on to time 2013 Z, the time of the last message "on the LOP 137-337" Ric's smoking gun. AE obviously still thought that they were near Howland at the time. Go to the website and find the altitudes at Howland and Niku, I got 32º 48.5' at Howland and 31.º59.3 at Niku. This is a difference of 49.2'. So Noonan using the normal technique of comparing his octant readings with what would have been measured at Howland at the same time would be staying on this LOP that passes through Howland. At this time, however, where the extended LOP passes by Niku it is 49.2 NM to the northeast of Niku. Also note that the azimuth of the sun at Howland is now 62.8º so the LOP would be drawn on the map through Howland on a course of 152.8º again showing that the LOP is moving further away from Niku as the day wears on.

Let's look at one more time, 2240 Z about two and a half hours after the last radio call. This is the amount of time it would take them to fly from Howland to Niku. So assuming they departed the vicinity of Howland after the 2013 Z message they should be arriving in the vicinity of Niku at about 2240 Z. Going to the Navy website we find that the altitude of the sun at Howland at 2240 Z is 61º57.6' and at Niku 58º26.4' a difference of 3º31.2'. Since each degree is equal to 60 NM this makes the distance from Niku to the LOP that runs through Howland 231.2 NM. AE may have eagle eyes but she can't see Niku 231.2 NM away from her position on the LOP. Also note that the azimuth of the sun has changed to 36.3º making the LOP plotted through Howland run 126.3º confirming that the LOP has moved even further away from Niku. Also note from the website that the longitude of the GP of the sun has changed to 159º01.9' (GHA) with no significant change in its latitude (declination.) so now the sun is almost straight north of Howland and much closer than it had been at 1750 Z. The sun is now only 28º 02.4' from being straight overhead at Howland (90º - altitude) so the radius of the circle of position is much smaller, 1602.4 NM compared to 5400 NM at sunrise.
Let's return to our first example using the DME equipment. The plane is following the 54.0 DME arc toward the southeast and nearing the destination airport when the warning flag comes up on your DME indicating that the VORTAC is off the air. You now look at your chart and locate another VORTAC nearby located more northerly from your destination airport. You measure the distance from this second radio station and find that your destination lies 16.0 NM from it meaning that it is on the on the 16.0 NM circle around it. You tune in this second VORTAC and adjust your heading to intercept this new circular LOP. Since the station is more northerly than the first station the LOP lies closer to east at this point than did the previous LOP so you must turn more easterly to follow it. You also note that your previous backup airport that had been on the 54.0 DME arc of the first station is not on the 16.0 DME arc of the new station so following this new DME arc will not take you to the second airport if you should happen to miss your destination.

This is the same situation at Howland. Now that the sun has moved across the sky any LOP derived from it that passes through Howland will go nowhere near Niku so you would not be able to follow this changed LOP to Niku. Noonan was aware of this so would not have