Module 9

Modern Navigation Systems

Satellite navigation using geostationary satellites

Module 9B

Navigation using geostationary satellites and a plotting board

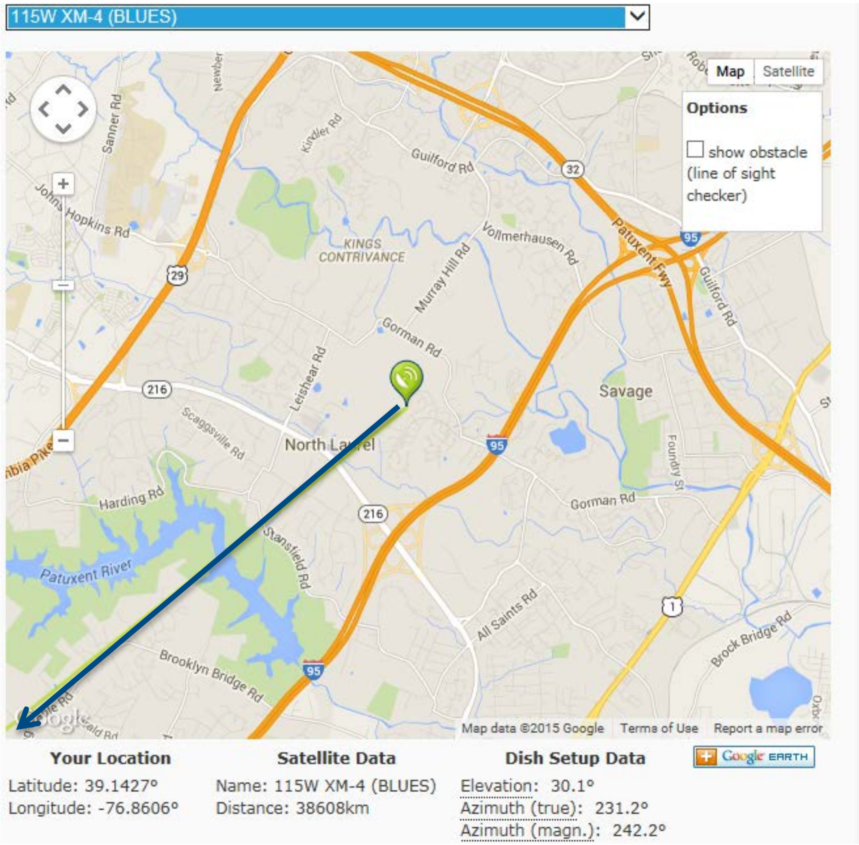
Summary of Module 9

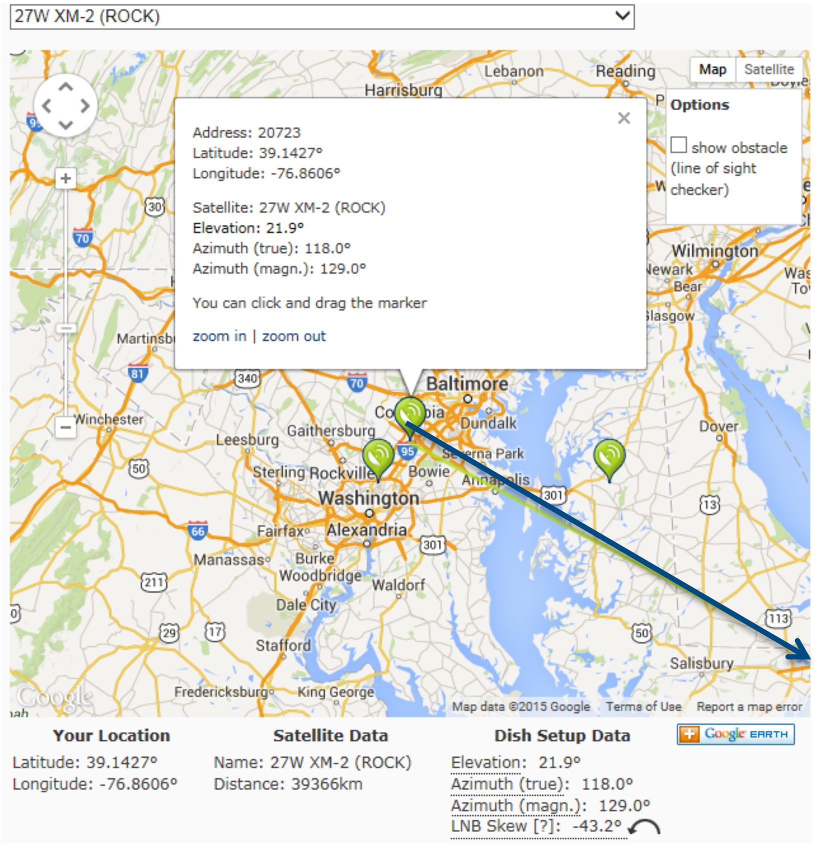
- Students will extend the algorithms used with sextants to the case of near-earth satellites, in particular geostationary satellites, thus introducing parallax (i.e, the ratio of the earth's radius R to the distance r from the center of the earth to a satellite or the moon). (9A)
- **Students will compute their location on earth using plotting techniques along with an "assumed position" and values for elevation measurements to each of the satellites that correspond to the "actual position." Students will re-compute their location on earth using the sextant algorithm from Module 8 with the same information. (9B)**
- Students will compute their location on earth using multivariable Newton's method using angle measurements to the two satellites. Then, they will combine angle and azimuth "measurements" for only a single satellite, thus developing a "mixed-mode" algorithm that would correspond to, for example the use of a gravity based inclinometer and a magnetic compass. (9C)

Getting started with the plotting technique

- You have already computed the look angles and ranges to the two XM satellites at 27W and 115W, from the actual position of Latitude: 39.1427°N and Longitude: 76.8606°W, which corresponds to zip code 20723. You have then used http://www.dishpointer.com to check your results.
- These angles are your "measured" values of *Ho*, analogous to the sextant measurements of a star

Here is what dishfinder yields for the "actual position" in zip code 20723 for the "measured angles" to be used in the navigation process

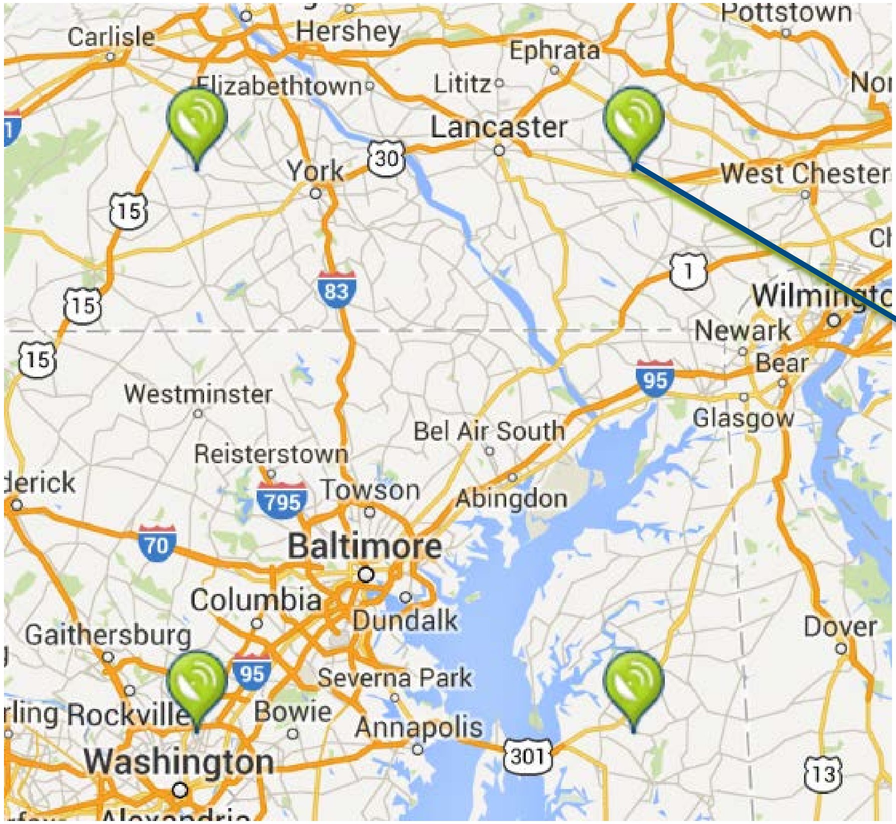




To use plotting techniques to find the correction location, start with an arbitrarily "guessed" *assumed position* AP

- Create an "assumed position" AP at, for example, 40° N and 76° W.
- Create a reference map using the online tool with convenient "fiducial" markers, one of which can be the AP.
- Ext, use the online tool to provide azimuth and elevation results for each of the two satellites based on the AP.
- Draw lines on the reference map from the AP in each of the two azimuth directions based on the AP.

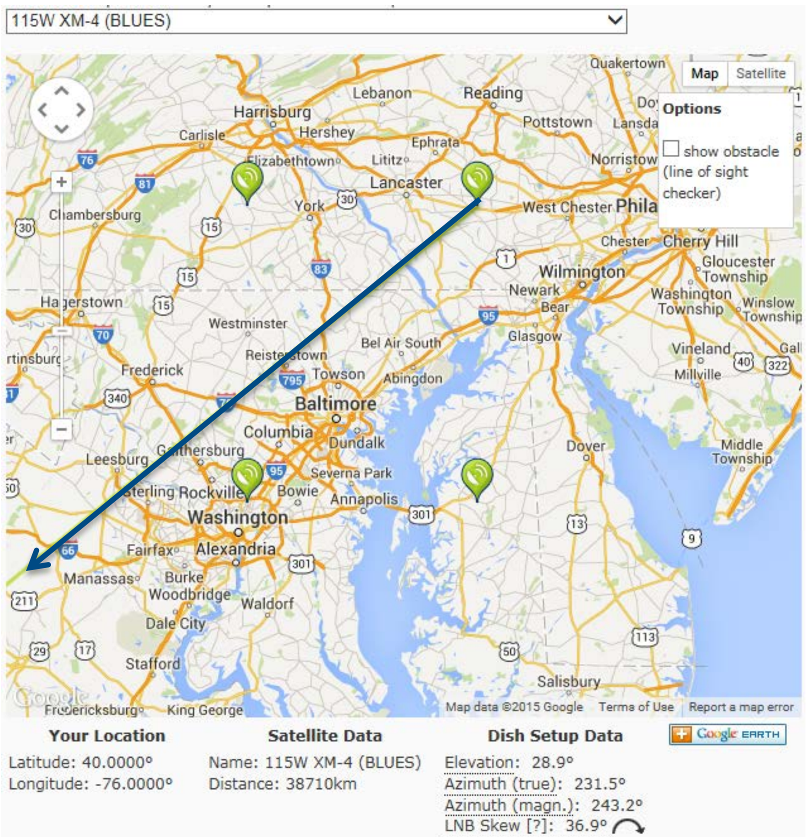
Specifically, here are results from Google Earth as implemented by “dishfinder”

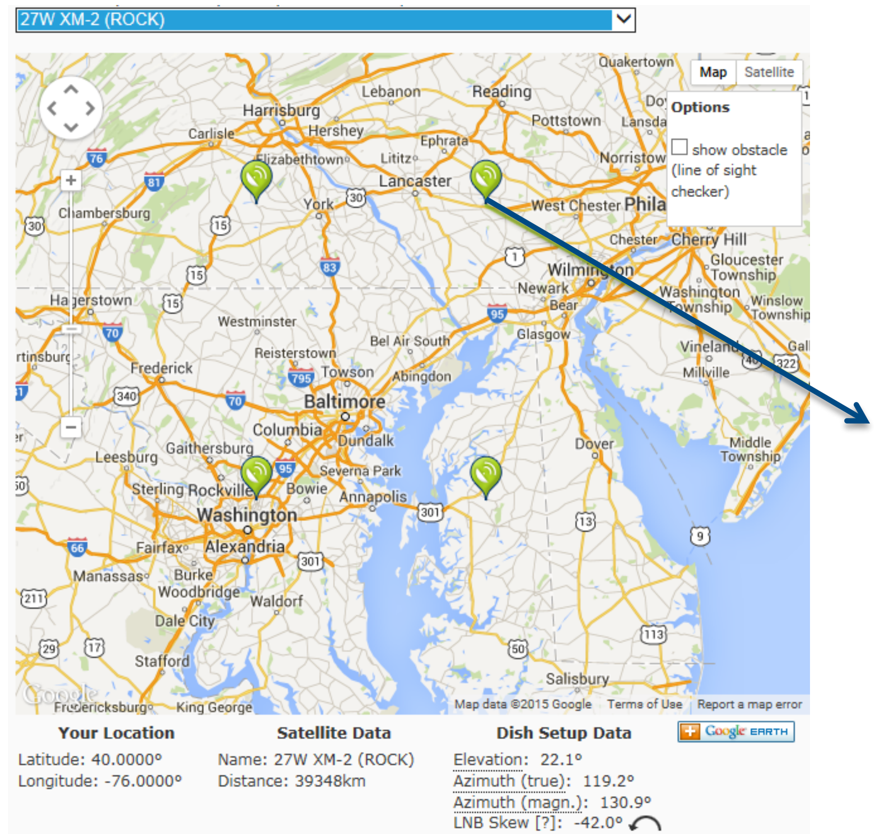


The markers here are at
(40,-77) (40,-76)
(39,-77) (39,-76)

The dark line points to the satellite at 27W from the AP location at (40, -76)

The azimuth lines from the AP, shown for each of the two XM satellites





Continuing…

- Subtract the "measured" elevation angles for each satellite from the "computed" angles to each satellite
- Multiply by 60 to change these angles to the distances *p* in nautical miles, as defined in the Nautical Almanac and used in Module 8.
- At the distance *p* along each line from the AP, draw two lines of position at right angles to each of the existing lines from the AP to the two satellites.
- Remember to use the sign convention for moving "forwards" or backwards when marking off the distances *p*. For this example, p_1 = -12 nautical miles (nm), and p_2 = 72 nm.
- Note that the carefully chosen fiducial marks permit this process to be accomplished using a ruler and linear interpolation
- Where these lines of positions intersect will be the approximate location at which the "measured" values were obtained (i.e., in zip code 20723, near JHU/APL).

Recap of the Nautical Almanac explanation

The position line of an observation is plotted on a chart using the intercept

$$p = H_O - H_C$$

and azimuth Z with origin at the calculated position ($Long$, Lat) at the time of observation, where H_C and Z are calculated using the method in section 6, page 279. Starting from this calculated position a line is drawn on the chart along the direction of the azimuth to the body. Convert p to nautical miles by multiplying by 60. The position line is drawn at right angles to the azimuth line, distance p from ($Long, Lat$) towards the body if p is positive and distance p away from the body if p is negative. Provided there are no gross errors the navigator should be somewhere on or near the position line at the time of observation. Two or more position lines are required to determine a fix.

from the Nautical Almanac

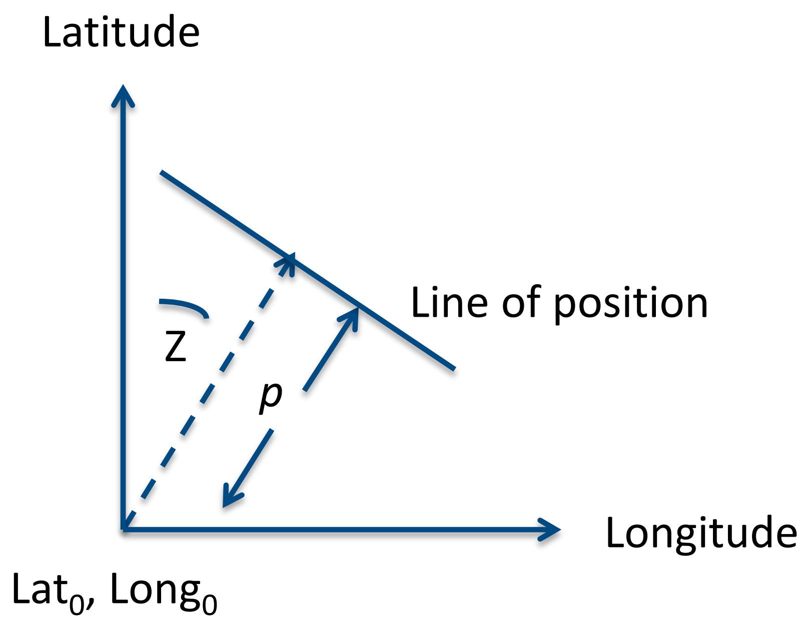
As shown previously in Module 8…

Z = computed azimuth
to a measured star
based on the initial
position guess Lat_0, $Long_0$

p is the distance
between Ho and Hc (based
on turning the angle into
a distance by scaling the arc-length
by the radius of the earth)

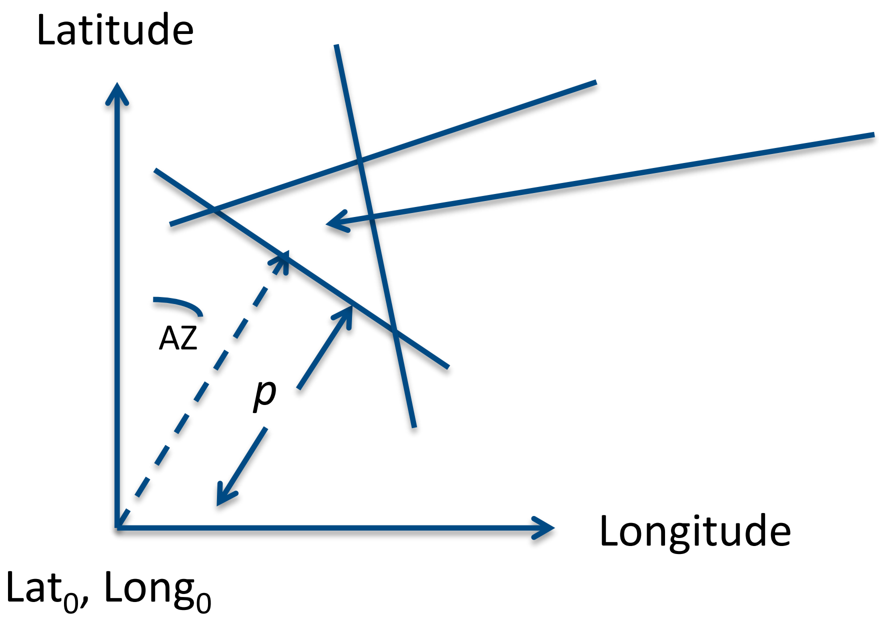
p and Z are used to compute a line of position
The intersection of multiple lines
Of position is used to compute Lat_1, $Long_1$

The process is iterated until the
incremental change in estimated
position falls below the desired margin of error.



**Admiral Marc St. Hilaire of the French Navy, late 1800's.

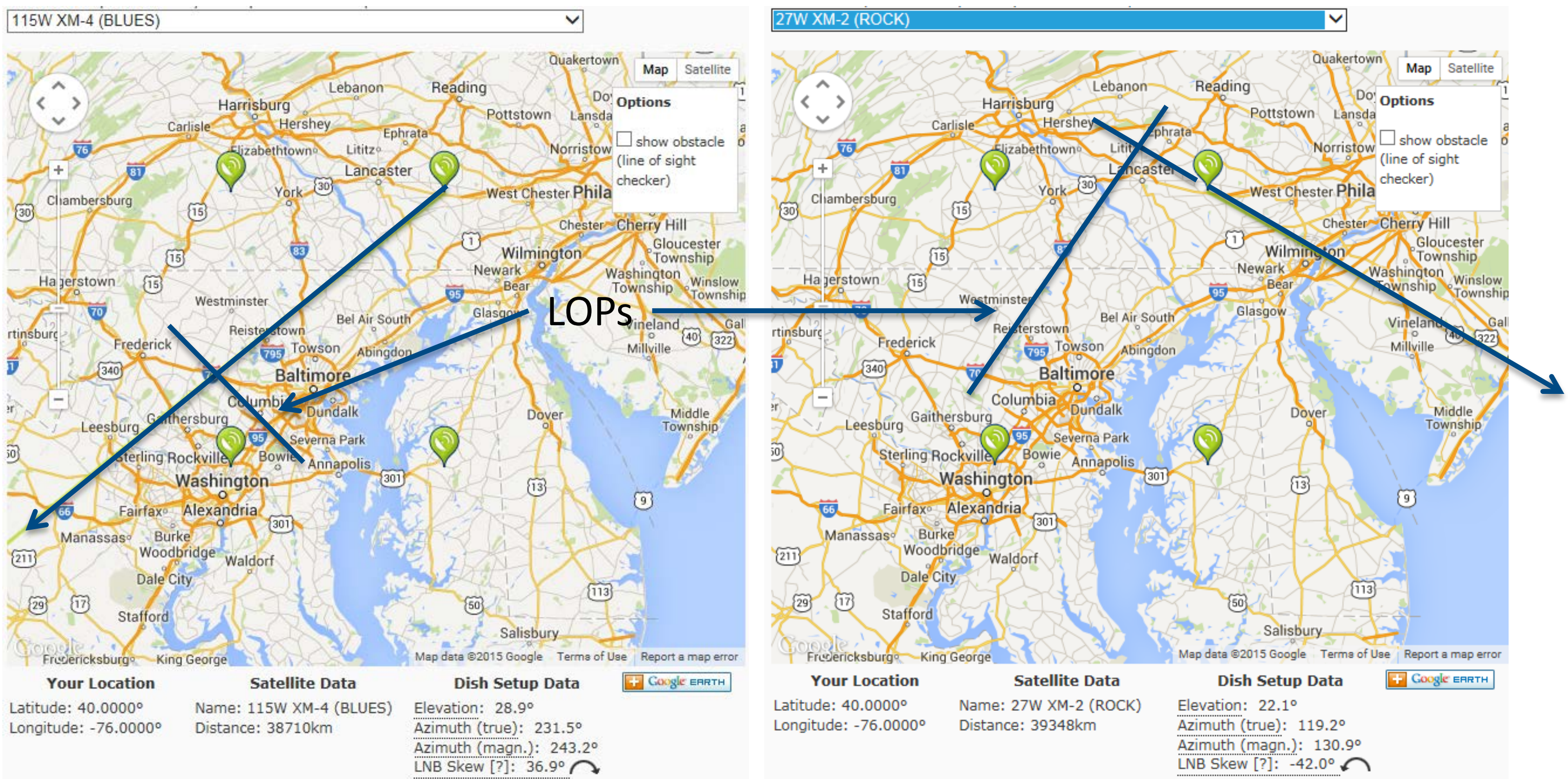
Multiple lines of position



Lat_1, $Long_1$ based on least Squares intercept of the Multiple lines of position

Note that a chart table is ideal for solving this problem graphically! Parallel rulers (shown in one of the next slides) referenced to a "compass rose" on a chart make this Straightforward and easy.

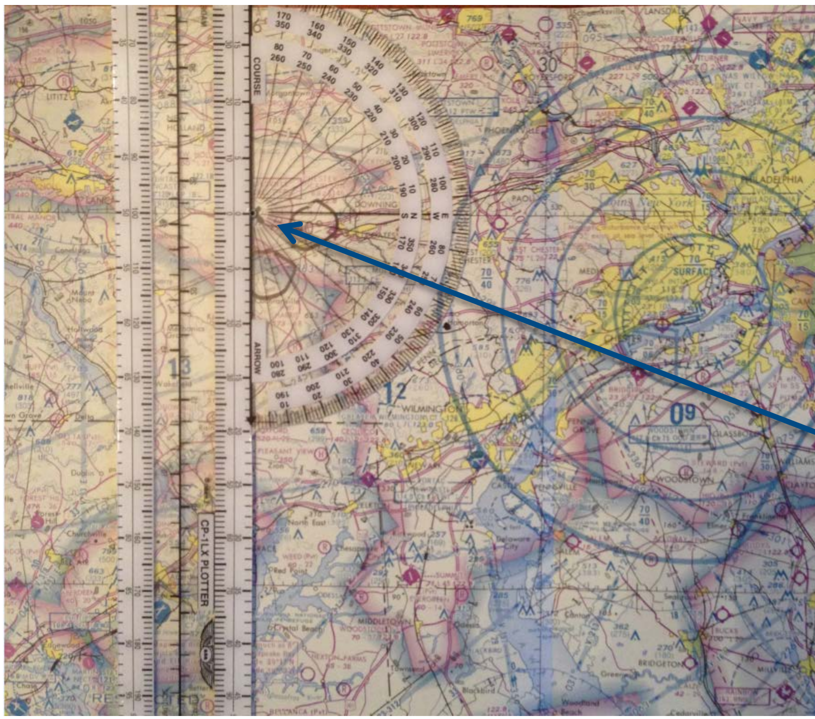
The lines of position (LOPs) from the AP for the case at hand, shown for each of the two XM satellites



But, this can be done more elegantly using appropriate charts and tools

- The next several slides show how the process is done using an aviation chart known as a Sectional Chart.
- A plotting tool that combines a protractor and a ruler is used in combination with the latitude and longitude lines on the chart.
- The ruler is designed for the chart, and is scaled in nautical miles, as is the chart.
- There is a separate slide for each step of the process

Plotter tool centered at the AP of 40° N, -76°W

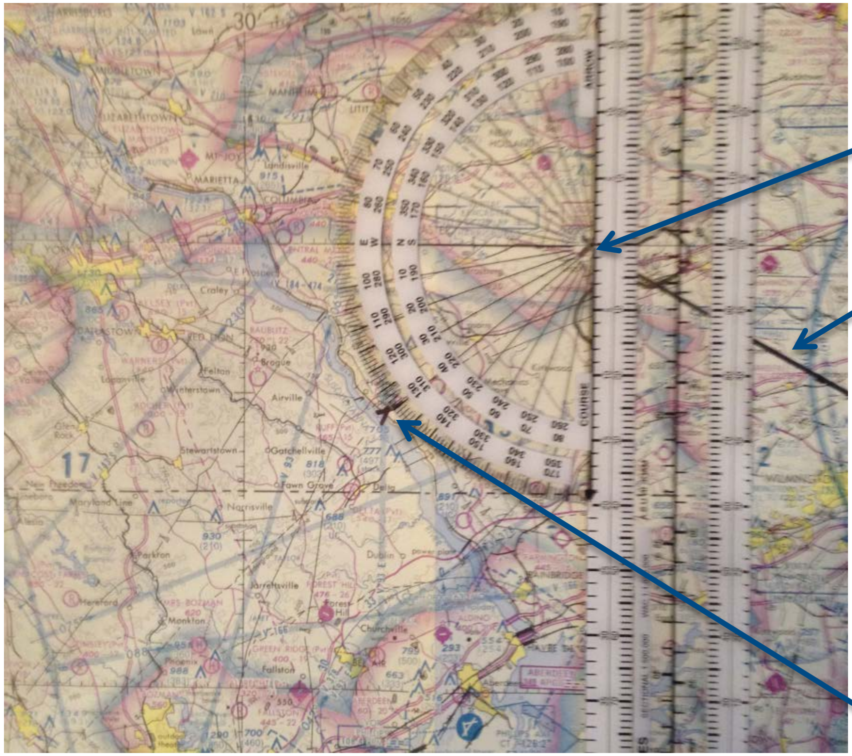


The map is a “sectional” chart of the flight airspace managed by the “Washington” regional air traffic control center.

The circles show the Lat/Long ID markings on the chart

The assumed position *AP*

Laying out the angle to XM “Blues” at 115° W

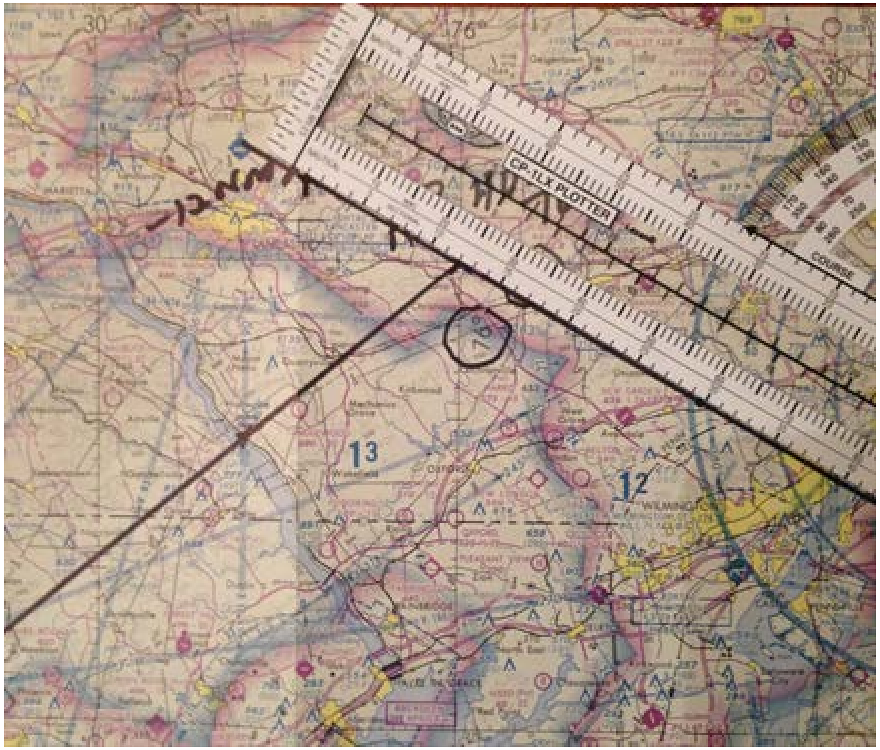


The assumed position

The azimuth line to XM “Rock” at 27° W is already drawn.

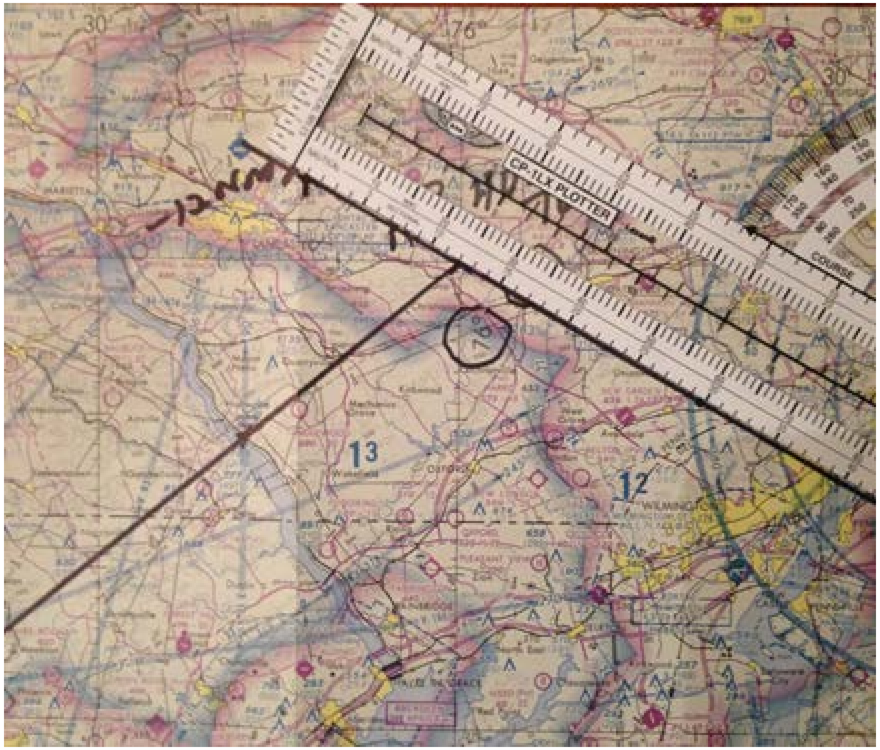
The azimuth to the satellite Blues” at 115°W is 231.5 degrees.

Laying out p_1 = -12 nm



Both azimuth lines have been drawn. Since p_1 is negative, the first azimuth line needs to be extended *12 nm* in the reverse direction from the AP.

Laying out $p_2 = +72$ nm

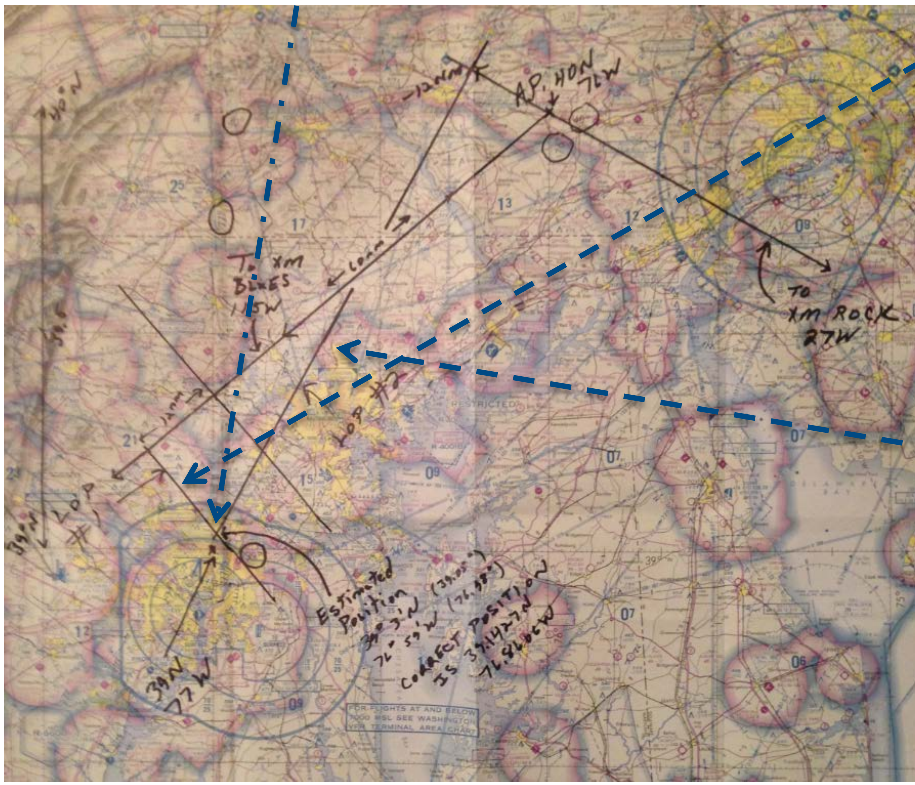


Both azimuth lines have been drawn. Since p_2 is positive, the second azimuth line, to the sat at 115° W, needs to be marked *72 nm* in the forward direction from the AP.

The lines of position

The updated position estimate

LOP 1



Both LOPs have been drawn, each at right angles to its respective azimuth line. The new estimate of position Is located at the intersection of these LOPs.

LOP 2.

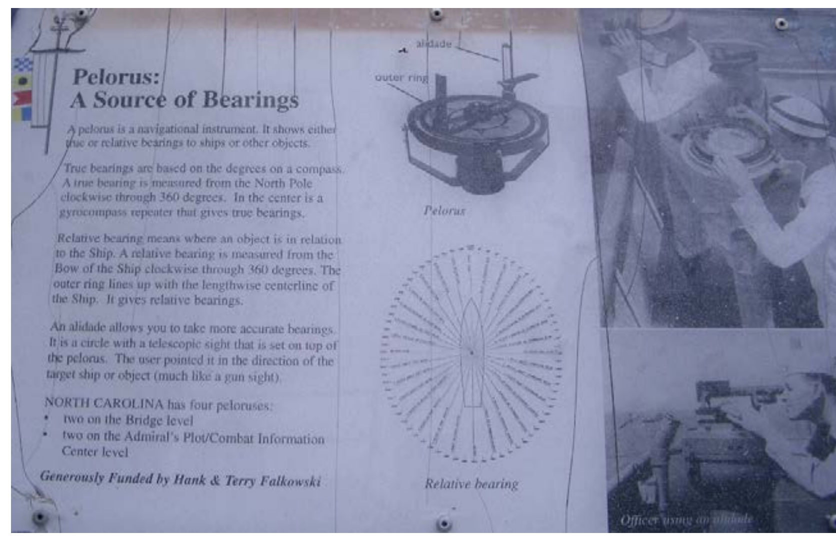
Does anyone actually do this?

The decommissioned WW II battleship USS North Carolina, at dock in Wilmington, NC.

The *pelorus* is an instrument for measuring angles to be laid out on charts as part of the plotting procedures used for navigation

The pelorus is a "sideways" sextant. Even on modern ships, there is typically a pelorus mounted on each of the "flying bridges".

(see http://en.wikipedia.org/wiki/Flying_bridge)



Plotting table on the North Carolina

This is an operational chart used on the North Carolina in WWII.

Plotting instruments

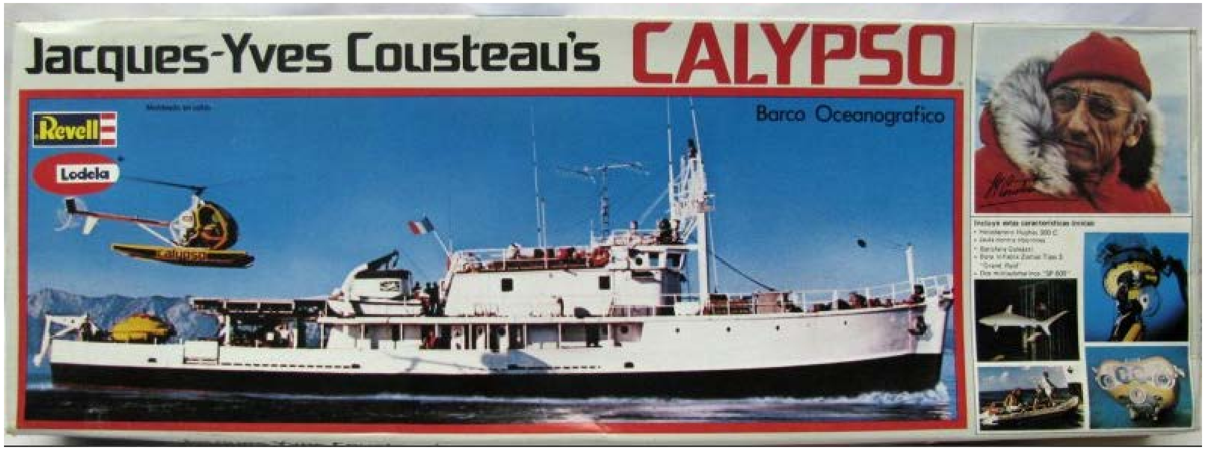
Although the exercise here used a ruler/protractor scaled for use with aviation charts, parallel rulers, a drafting compass, and a compass with “spreaders” for transferring distances from a chart’s scale to an azimuth line are still used, as shown in the Buckley video.

The navigator’s case

The navigator’s case shown here was used in the Pacific during WWII aboard the YDG-7 by Lt. JG F. Jablonski, the 28 year old XO of the ship. Jack Kennedy, a LT JG operating in the Pacific the year before, and a year younger, would likely have had an identical case.

The YDG ships were converted minesweepers, built of wood, used as a degaussing ships to demagnetize the hulls of large ships such as the North Carolina and the Arizona. This was thought to minimize their risk of triggering magnetic mines.

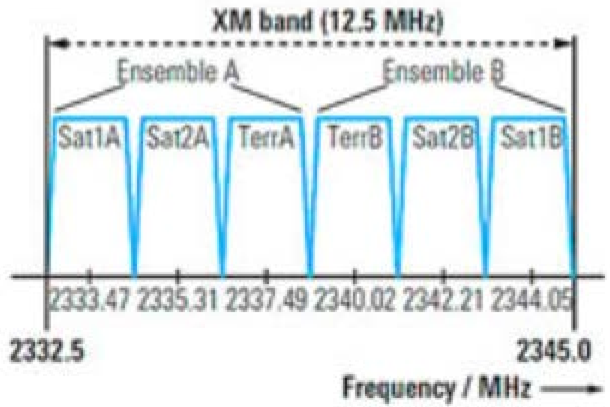
Jacques Cousteau’s Calypso began life as a US Navy YDG



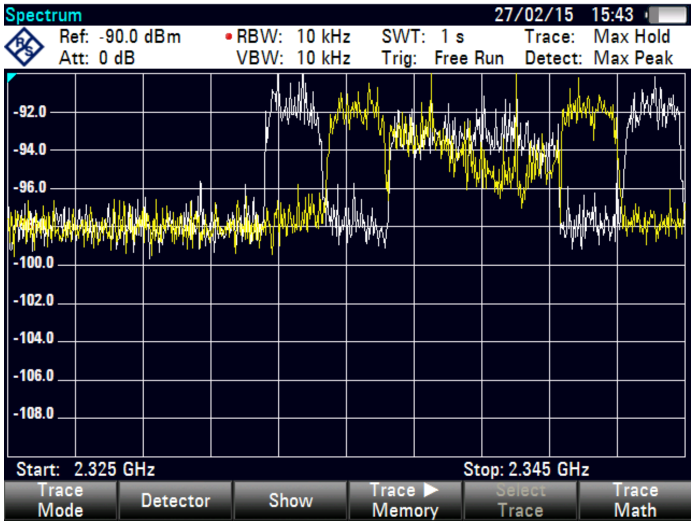
A portable 3 foot diameter parabolic dish antenna

The antenna is easily adjusted to point at geostationary satellites.

Spectrum analyzer plots of the signals from the two XM satellites

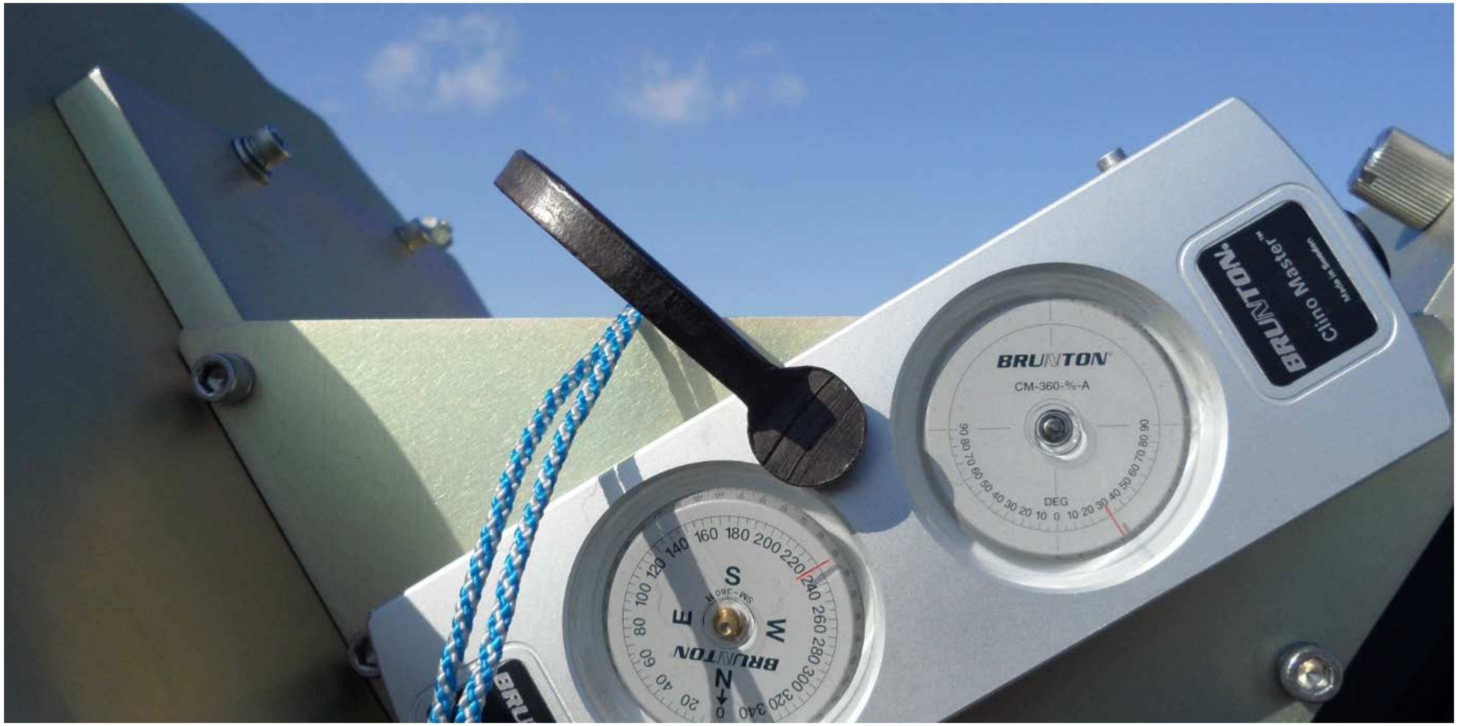


The frequency band plan for the XM satellites and terrestrial repeaters.



Data measured recently using the portable dish antenna.

A combined compass/inclinometer attached to the back of the portable dish antenna to facilitate aiming the dish at a satellite of interest



Recap of the Numerical Method based on Least Squares

11. *Position from intercept and azimuth by calculation.* The position of the fix may be calculated from two or more sextant observations as follows.

If p_1, Z_1, are the intercept and azimuth of the first observation, p_2, Z_2, of the second observation and so on, form the summations

$$A = \cos^2 Z_1 + \cos^2 Z_2 + \cdots$$
$$B = \cos Z_1 \sin Z_1 + \cos Z_2 \sin Z_2 + \cdots$$
$$C = \sin^2 Z_1 + \sin^2 Z_2 + \cdots$$
$$D = p_1 \cos Z_1 + p_2 \cos Z_2 + \cdots$$
$$E = p_1 \sin Z_1 + p_2 \sin Z_2 + \cdots$$

The least squares equations

where the number of terms in each summation is equal to the number of observations.

With $G = A\,C - B^2$, an improved estimate of the position at the time of fix (L_I, B_I) is given by

$$L_I = L_F + (A\,E - B\,D)/(G \cos B_F), \qquad B_I = B_F + (C\,D - B\,E)/G$$

Calculate the distance d between the initial estimated position (L_F, B_F) at the time of fix and the improved estimated position (L_I, B_I) in nautical miles from

$$d = 60\sqrt{((L_I - L_F)^2 \cos^2 B_F + (B_I - B_F)^2)}$$

If d exceeds about 20 nautical miles set $L_F = L_I$, $B_F = B_I$ and repeat the calculation until d, the distance between the position at the previous estimate and the improved estimate, is less than about 20 nautical miles.

Assignment 9.2

1. Reproduce the navigation exercise shown herein, using the reference map approach shown in slide 6. This will allow you to use a ruler, protractor, and hand calculator to perform the necessary interpolations, to draw the LOPs on a printout of the map, and to estimate the improved position fix.
2. Compare your results with the known location from which the “measured” angles were derived.
3. Explain why this method works, despite its use of azimuth angles that are computed relative to an assumed position that is known to be incorrect.
4. Use the algorithm from the Nautical Almanac (slide 28) to compute the updated position, and compare this value with that obtained from the plotting exercise.

End of Mod 9B