Lab 1 – Polynesian and Western Navigation

1. Introduction
People have been sailing the seas for thousands of years, during most of which time they relied on the sun and the stars to navigate the open ocean. It wasn't until the invention of the compass and the clock, along with other advances in the fields of geophysics and astronomy, that extremely accurate navigational techniques were utilized.

This lab will provide an overview of both Polynesian and modern wayfinding. You will use computer simulation, a star compass, a magnetic compass, and a global positioning system (GPS) unit to learn more about wayfinding techniques. During this lab you should accomplish the following objectives:
   1. Use maps to identify Latitude and Longitude, magnetic and true north;
   2. Find the coordinates of Oahu; and
   3. Learn orientation skills based on a star chart and a compass.

If you need further clarification after reading the sections below, please read Appendix 3 of the class textbook, *Oceanography: An Invitation to Marine Science* by Tom Garrison.

2. Polynesian Navigation
When European explorers first visited the Pacific Islands, they were quite impressed with the canoes used by the native peoples. When Captain Cook entered Kealakekua Bay in 1779, for example, the Resolution was met with 3,000 canoes filled with 15,000 passengers. It was clear that the canoe-making ability of the Polynesians was excellent.

For several hundred years, however, there was much debate concerning their navigational skills. Some researchers were convinced that long, open-ocean voyages were rare, and discoveries of new islands occurred mostly by accident (for example, a sailing canoe getting blown off course). It is now understood that, although some islands were discovered by mistake, active trading routes were well established on many islands in Polynesia, Melanesia, and Micronesia and the wayfinders, or navigators, had developed a sophisticated system to find their way during these long voyages. Much of the following information is taken directly from the Polynesian Voyaging Society (PVS) web site at http://www.pvs-hawaii.com/ (select the “Navigation” link).

Navigator Nainoa Thompson of the Polynesian Voyaging Society, who was taught by Mau Piailug, a master navigator from Satawal in Micronesia, explains how a star compass is used to tell direction without instruments:

The star compass is the basic mental construct for navigation. We have Hawaiian names for the houses of the stars – the places where they come out of the ocean and go back into the ocean. If you can identify the stars, and you memorized where they come up and go down, you can find your direction. The star compass is also used to read the flight path of birds and the direction of waves. It does everything. It is a mental construct to help you memorize what you need to know to navigate.
How do we tell direction? We use the best clues that we have. We use the sun when it is low in the horizon. Mau has names for how wide the sun’s path on the water is and for its different colors. When the sun is low, the path is tight, when the sun is high it gets wider and wider. When the sun gets too high you cannot tell where it has risen. You have to use other clues.

Sunrise is the most important part of the day. At sunrise you start to look at the shape of the ocean – the character of the sea. You memorize where the wind is coming from. The wind generates the swells. You determine the direction of the swells, and when the sun gets too high, you steer by them. And then at sunset we repeat the observations. The sun goes down – you look at the shape of the waves. Did the wind change? Did the swell pattern change? At night we use the stars. We use about 220 stars by name – having memorized where they come up, where they go down.

When it gets cloudy and you can’t use the sun or the stars all you can do is rely on the ocean waves. That’s why Mau said to me ‘If you can read the ocean, you will never be lost.’ One of the problems is that when the sky gets black at night under heavy clouds you cannot see the swells. You cannot even see the bow of the canoe. And that is where people like Mau are so skilled. He can be inside the hull of the canoe and just feel the different swell patterns moving under the canoe and he can tell the canoe’s direction lying down inside the hull of the canoe.

The Southern Cross is really important to us. It looks like a kite. These two stars in the Southern Cross always point south (Gacrux on top and Acrux on bottom). If you are traveling in a canoe and going south, these stars are going to appear to be traveling higher and higher in the sky each night. If you went down to the South Pole, these stars are going to be way overhead. If you are going north to Hawai`i, the Southern Cross travels across the sky in a lower and lower arc each night. When you are at the latitude of Hawai`i, the distance from the top star (Gacrux) to the bottom star (Acrux) is the same distance from that bottom star to the horizon. That only occurs in the latitude of Hawai`i.

The following techniques are used by Hawai`ian and Polynesian navigators taught by Mau and Nainoa. The art, as is practiced today in Hawai`i, uses a Hawai`ian star compass developed by Nainoa, incorporating principles from Mau’s Micronesian star compass and traditional Hawai`ian names for directions and winds.

(1) The Sun
The sun is the main guide for the navigator without instruments. Twice a day, at sunrise and sunset, it gives a directional point to the traveler, as it rises in the east and sets in the west. The exact direction changes during the year. To hold a course, the navigator aligns the rising or setting sun to marks on the railings on each side of the canoe, each paired
with a single point at the stern of the canoe, giving bearings in two directions, 32 bearings in all to match the 32 directional houses of the Hawaiian star compass.

(2) The Stars
Like the sun, most stars rise in particular directions on the eastern horizon, travel across the sky, and set in particular directions on the western horizon. The directional point at which a star sets is at the same angular distance (declination) and in the same direction (i.e., north or south) from west as the house in which it rose is from east. For example, at the equator, Hokulei (Capella) rises at 46° N of east in Manu Ko’olau (NE) and sets at 46° N of west in Manu Ho’olua.

As the wind drift may be carrying the canoe to the right or left of its apparent heading, the navigator corrects his steering for this sideway drift, called leeway; as the night passes and stars rise and set, moving about 1° across the celestial sphere every four minutes, the navigator uses as many stars as possible to use as clues to hold his direction.

If the star is above the horizon, the navigator imagines a line from it down to its rising or setting point. The angles at which the stars rise and set will change with latitude. Only at the equator do stars appear to rise perpendicular to the horizon. In Hawai’i, at 20° N, stars rise and set at a 20° angle, leaning south from straight up; in Tahiti, at 17° S, stars rise and set at a 17° angle, leaning north from straight up. In other words, the angle at which stars rise and set from a line perpendicular to the horizon is equal to the latitude of the observer. The pathways of the stars lean south in the northern hemisphere and north in the southern hemisphere.

During a voyage, stars may be available for navigation only about 20% of the time; daylight and cloud cover at night hide them from the navigator during the other 80% of the time.

(3) Ocean Swells
During midday and on cloudy nights when celestial bodies are not available at the horizon as directional cues, the navigator uses the wind and swell to hold a course. However, the direction of the wind and swells cannot be determined independently; their directions can only be determined by reference to celestial bodies such as the rising or setting sun.

Swells are waves that have traveled beyond the wind systems that have generated them, or waves that persist after the generating storm has died away. Swells are more regular and stable in their direction than waves (“Waves,” as opposed to “swells,” are generated by local, contemporary winds). Sometimes swells can be felt better than they can be seen, having flattened out after traveling long distances. In the Pacific, the northeast trade winds create a northeast swell; the southeast trade winds generate a southeast swell, and so on. Storms in the South Pacific during the Hawaiian summer generate a south swell; storms in the North Pacific during the Hawaiian winter generate a north or northwest swell.
Figure 1. Using markers on the sailing canoe to determine your heading

(4) Winds
The direction of the wind can be used to hold a course – the person steering holds the wind at a constant bearing to the canoe. However, the wind may change directions during the day (it’s less stable than swells), so the direction must be checked frequently against rising or setting celestial bodies and the ocean swells.

(5) Landmarks
On coastal voyages, a navigator can steer by landmarks. Lining up two landmarks (e.g. a hill and a mountain) allows him to hold a straight line. Two pairs of landmarks allow him to find a spot, such as a deep-sea fishing ground, where the two lines intersect. One can also navigate by knowing the shapes of reefs or underwater topography that can be seen from the surface. While leaving an island for the open ocean, the navigator looks back on the island, lining up two landmarks to hold his desired direction.
(6) Signs of Landfall
Once the canoe is in the vicinity of its destination according to the navigator’s dead reckoning and latitude measurements, the navigator starts looking for land.

Navigating without instruments is not a precise science. Poor weather and mental lapses on a long voyage adversely affect its accuracy. But the navigator does not need to sail to a destination with pinpoint accuracy to be successful. Instead, the navigator in the Pacific tries to hit a “screen” of islands, that is, a group of islands that stretches out in either side of his destination. The longer or wider the screen, the less likely the navigator will miss it. Islands in the Pacific are seldom isolated; they are usually found in clusters. The Tuamoto Archipelago stretches 550 miles north to south and 500 miles east to west; the Society Islands stretch 160 miles north to south and 310 miles east to west; the Hawai`ian islands extend more than 1000 miles across the ocean east to west; the major islands form a north-south screen of about 240 miles.

When sailing to Tahiti from Hawai`i, the navigator can target a 400-mile wide screen of islands between Manihi in the ester Tuamotos, and Maupiti in the Easter Society Islands. If the navigator can hit any one of the islands in this target screen, he can reorient the canoe after he identifies the island and determines its position in relationship to his destination. If he does not recognize the island and the island is inhabited, he can ask the islanders where he is and if possible, get directions to his destination.

While there are open-ocean gaps between islands in a screen, a navigator looks for signs to let him know the proximity and direction of land even when he cannot see it. Signs of land include drifting land vegetation, clouds piled up over islands, the loom above an island created by sunlight or moonlight reflecting up from the white sand and smooth water of a lagoon, distinctive patterns of swells created by swells refracting around and/or reflecting off islands, and seabirds.

3. Modern Navigation
Instead of splitting the sky into star houses, modern navigators split the globe into a system of quadrants formed by imaginary lines called latitude and longitude. Latitude lines run parallel to the equator and indicate North or South positions. Longitude lines run from pole to pole and indicate positions on meridians East and West of the Greenwich meridian (designated as the zero meridian).

By convention, degrees (symbol “°”) and minutes (symbol “‘”) are the units used to describe position. This is based on 360° in a circle and 60’ in a degree. When writing coordinates, the latitude always goes first. For example, the coordinate "22° 18.5’ N 155° 34.6’ W" is read as "22 degrees, 18.5 minutes North and 155 degrees, 34.6 minutes West."

The distance between each line of latitude is the same, and one degree of latitude is equal to 60 nautical miles (1 nautical mile = 1.15 mile). In contrast, lines of longitude are not spaced evenly. At the poles, all lines of longitude converge. At the equator, lines
of longitude have their greatest spacing, which is equal to the distance between lines of
latitude. For the purposes of this lab activity, we will assume that one degree of longitude
is equal to 60 nautical miles because Hawai‘i is reasonably close to the equator. To find
out location relative to the latitude/longitude coordinate system, modern navigators use
equipment such as charts (nautical maps), a magnetic compass, and the Global
Positioning System (GPS). The basis for the magnetic compass is discussed below,
followed by a brief discussion of GPS.

The earth's magnetic field is probably caused by motions in the liquid outer core. This
magnetic field has moved around over the history of the earth, but also the poles have
been flipping sides! They also drift to a small extent. Figure 2 illustrates the movement
of the North magnetic pole over the past 100 years. Right now, it seems to be 8 degrees
south of the geographic North Pole. This means that depending on where you are in the
world, you have to be careful to correct the reading on your compass accordingly.

The difference between the magnetic and the geographic North Pole is referred to as the
magnetic declination or magnetic variation. (The word declination is also used in a
different context to refer to a star or celestial object’s position.) The magnetic declination
of a map changes from year to year, so if you use an old map, you will end up travelling
off course. For this laboratory, we read on our map that if we are on the Hawai‘ian
Islands, magnetic North lies 10 degrees east of geographic North, as we look towards it.
That means that we must add 10 degrees to our compass reading to see our direction in
relation to geographic North. This direction in relation to geographic North is known as
the bearing. For example, if our compass says that we are looking in a direction of 275°,
our bearing is 285°.

GPS uses satellites that are orbiting the earth to transmit signals to a receiver on earth.
Multiple satellites transmit signals to a single receiver. By analyzing the distances
between you and each of the satellites, your GPS unit determines your location. This
method is referred to as trilateration: a sphere is “drawn” around each satellite, with a
radius equal to its distance from your GPS unit. If three such satellites are used, and there
is no error whatsoever, they should only intersect at one or two points, and the point on
Earth’s surface is your position. Since in reality there is some error, more than three
satellites make the determination of your position more accurate!
Figure 2: The position of the magnetic North over time. As you can see, the magnetic North in the year 2000 was on 250° in this strange projection. That is the same as 110° West in the system we are familiar with. Figure courtesy of USGS (originally at http://geomag.usgs.gov/models.html).