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AUVfest 2008

The Robot Archaeologist

FOCUS

Marine Archaeology/Marine Navigation

GRADE LEVEL

9-12 (Earth Science/Mathematics)

FOCUS QUESTION

What information is needed to program an underwater robot to follow a desired course?

LEARNING OBJECTIVES

Students will be able to design an archaeological survey strategy for an autonomous underwater vehicle (AUV).

Students will be able to calculate expected position of the AUV based on speed and direction of travel.

Students will be able to calculate course correction required to compensate for the set and drift of currents.

MATERIALS

- ☐ Rulers or dividers for measuring distance
- ☐ Parallel rules or two drafting triangles for transferring course lines to a compass rose
- ☐ Copies of "Student Worksheet on Dead Reckoning and Navigation with Nautical Charts," one copy for each student or student group
- ☐ Internet access

AUDIO/VISUAL MATERIALS

None

TEACHING TIME

One or two 45-minute class periods, plus time for student research

SEATING ARRANGEMENT

Groups of 3-4 students

MAXIMUM NUMBER OF STUDENTS

30

KEY WORDS

18th century
Ship
Frigate
Ship of the line
Maritime history

BACKGROUND INFORMATION

On August 5, 1778, Captain John Symons gave the order to burn and sink his own ship, the British frigate HMS *Cerberus*, in Newport Harbor on the coast of Rhode Island. This was probably a difficult order for Captain Symons, but he was not alone: several other ships also were deliberately sunk when the British learned that a French fleet was headed for Newport under the command of Charles Henri Theodat, better known as Count D'Estaing. In February that same year, France had declared war on Britain as part of a treaty with America (this was the first document that officially recognizes America as an independent nation). D'Estaing left France on April 13, 1778 with a fleet of 12 ships of the line and five frigates to supplement the Continental Navy's efforts to attack the British fleet on the North

American coast. After arriving too late to confront British ships in Delaware and unable to cross a sandbar to meet them in New York, D'Estaing finally came to grips with British ships in Newport Harbor. The British sank their ships to prevent the revolutionaries from capturing the vessels for their own use, as well as to obstruct navigation within the harbor; a strategy which ultimately proved to be successful, since it helped prevent D'Estaing from entering the harbor and capturing Newport.

Almost 230 years later, the *Cerberus* is once again receiving attention from the American Navy, this time in partnership with NOAA's Ocean Exploration Program as part of the Autonomous Underwater Vehicle Festival 2008 (AUVfest 2008). Since 1997, the U. S. Navy's Office of Naval Research has sponsored Autonomous Underwater Vehicle Festivals (AUVfests) to demonstrate the capabilities of autonomous underwater vehicles (AUVs) for doing scientific and military work. In previous years, the emphasis has been on mine countermeasures and how AUVs can remove humans from the dangerous job of finding and destroying mines. AUVfest 2008 will expand this focus to include marine archeology using AUVs to map shipwrecks and discover long-buried artifacts.

These activities will take place at the Naval Undersea Warfare Center's Narragansett Bay Test Range off Newport, Rhode Island. In addition to being a site where Navy torpedos were tested for many years, Narragansett Bay is the site of many shipwrecks (if you want to get an idea about how many wrecks are in Narragansett Bay, visit http://www.wrecksite.eu/wreck.aspx?16438, click the "show wks" box near the bottom of the page, then click inside the red rectangle just below). In addition to finding and mapping buried mines, mine neutralization, and other mine countermeasure operations, AUVs will explore five marine archaeological sites including two Revolutionary War-era British frigates (the *Cerberus* is one) and two wrecks of 20th-century ships.

Archeology is the study of past civilizations and ways of life. Like other sciences, the goal of archeology is to understand these ways of life, not merely to describe their remains. "Marine Archeology" is archeology that takes place underwater. Archeological activities are fundamentally different from salvage or treasure hunting activities whose primary goal is collecting objects and artifacts. In some cases, archeology may include artifact retrieval; but when objects are recovered primarily for their commercial or souvenir value, important archeological evidence is almost always destroyed.

AUVfest 2008 is focussed on increasing marine archeologists' understanding of how AUV technology can be used to discover and study underwater cultural resources. Key questions related to this goal include:

- How can AUV and mine countermeasures technology be applied to archeological investigations of selected shipwrecks?
- How can mine countermeasures technology be used to identify materials and objects that are not normally MCM targets, such as glass, ceramics, and wood artifacts?
- How can AUV/MCM technology be extended for other purposes and benefits in addition to national defense?

Not surprisingly, AUVs are the technological centerpiece of AUVfest 2008. AUVs are underwater robots that operate without a pilot or cable to a ship or submersible. This independence allows AUVs to cover large areas of the ocean floor, as well as to monitor a specific underwater area over a long period of time. Typical AUVs can follow the contours of underwater mountain ranges, fly around sheer pinnacles, dive into narrow trenches, take photographs, and collect data and samples.

Until recently, once an AUV was launched it was completely isolated from its human operators until it returned from its mission. Because there was no effective means for communicating with a submerged AUV, everything depended upon instructions programmed into the AUV's onboard computer. Today, it is possible for AUV operators to send instructions and receive data with acoustic communication systems that use sound waves with frequencies ranging roughly between 50 hz and 50 khz. These systems allow greater interaction between AUVs and their operators, but basic functions are still controlled by the computer and software onboard the AUV.

Basic systems found on most AUVs include: propulsion, usually propellers or thrusters (water jets); power sources such as batteries or fuel cells; environmental sensors such as video and devices for measuring water chemistry; computers to control the robot's movement and data gathering functions; and a navigation system.

Navigation has been one of the biggest challenges for AUV engineers. Today, everyone from backpackers to ocean freighters use global positioning systems (GPS) to find their location on Earth's surface. But GPS signals do not penetrate into the ocean (for more about GPS, visit http://oceanservice.noaa.gov/topics/navops/positioning/welcome.html). One way to overcome this problem is to estimate an AUV's position from its compass course, speed through the water, and depth. This method of navigation is called "dead reckoning," and was used for centuries before GPS was available. Dead reckoning positions are only estimates however, and are subject to a variety of errors that can become serious over long distances and extended time periods.

If an AUV is operating in a confined area, its position can be determined using acoustic transmitters that are set around the perimeter of the operating area. These transmitters may be moored to the seafloor, or installed in buoys. Some buoy systems also include GPS receivers, so the buoys' positions are constantly updated. Signals from at least three appropriately positioned transmitters can be used to accurately calculate the AUV's position. Although this approach can be very accurate, AUV operators must install the transmitters, and the AUV must remain within a rather small area.

A more sophisticated approach uses Inertial Navigation Systems (INS) that measure the AUV's acceleration in all directions. These systems provide highly-accurate position estimates, but require periodic position data from another source for greatest accuracy. On surface vessels and aircraft equipped with INS, additional position data are often obtained from GPS. On underwater vessels, the accuracy of INS position estimates is greatly improved by using a Doppler Velocity Logger (DVL) to measure velocity of the vessel's speed. On some AUVs, several of these systems are combined to improve the overall accuracy of onboard navigation. For more information about INS and DVL systems, visit http://www.oceanexplorer.noaa.gov/explorations/08auvfest.

In this activity, students will design an archaeological survey strategy for an AUV, and use dead reckoning techniques to calculate appropriate speed and course instructions that would allow the AUV to carry out this strategy, and to calculate course corrections

LEARNING PROCEDURE

[NOTE: Portions of this lesson are adapted from "Final Report, Ocracoke Remote Sensing Survey, Grant Number: NA16RP2698" by Runyan and Cantelas, et al., 2003; and from the National Ocean Service Discovery Classroom Lesson, "Plot Your Course" (http://oceanservice.noaa.gov/education/classroom/lessons/18_marinenav_plotcourse.pdf)]

1. To prepare for this lesson:
    - Review the background essays for AUVfest 2008 at http://www.oceanexplorer.noaa.gov/explorations/08auvfest/. If students will not have access to the internet for research, you will also need to download suitable materials, or

confirm that such materials are available in libraries to which students have access.

- Review "Student Worksheet on Dead Reckoning and Navigation with Nautical Charts," and work through the dead reckoning calculations.

2. Introduce AUVfest 2008, and discuss some of the reasons that scientists are interested in shipwrecks. Discuss the concept of AUVs and how these differ from remotely operated vehicles (ROVs). Briefly discuss the advantages and disadvantages of underwater robots compared to free divers or manned submersibles, particularly for activities that are inherently dangerous activities (such as locating underwater mines or working in the deep ocean) or repetitive and time consuming (such as surveying large areas of the ocean floor). You may want to show some examples of AUVs from http://www.oceanexplorer.noaa.gov/technology/subs/subs.html.

3. Provide each student group with a copy of the "Student Worksheet on Dead Reckoning and Navigation with Nautical Charts," and work through the example with the entire class to ensure that the basic concepts are understood. Be sure students distinguish between dead reckoning positions, which are estimates of the true geographic position, and fixes which are more accurate (but still subject to errors) position estimates. You may also want to remind students that velocity is a vector quantity that includes direction as well as speed.

4. Tell students that their assignment is to design an archaeological survey strategy for an AUV, and use dead reckoning techniques to calculate appropriate speed and course instructions that would allow the AUV to carry out this strategy.

5. Evaluate and discuss students' results. If time permits, you may want to have student groups try to plot the course instructions from another student group to see how well their plots match the original survey design. You may also want to discuss other navigation techniques that can be used to establish an AUV's geographic position.

THE BRIDGE CONNECTION

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Human Activities," then "Technology" for links to resources about submersibles, ROVs, and other technologies used in underwater exploration.

THE "ME" CONNECTION

Have students write a brief essay describing how AUVs might be of personal benefit during the next decade.

CONNECTIONS TO OTHER SUBJECTS

English/Language Arts, Social Studies, History, Mathematics

ASSESSMENT

Worksheet results and essays (if assigned) provide opportunities for assessment.

EXTENSIONS

1. Visit http://www.marinetech.org/rov_competition/rov_video_2007.php for a video from the the Marine Technology Society's student ROV competition, and links to other sites about underwater robots.

2. For ideas about building your own underwater robots, see Bohm, H. and V. Jensen. 1998. Build Your Own Programmable Lego Submersible: Project: Sea Angel AUV (Autonomous Underwater Vehicle). Westcoast Words. 39 pages; and Bohm, H. 1997. Build your own underwater robot and other wet projects. Westcoast Words. 148 pages.

3. For a marine archeology activity, see the "Lost at Sea: Sunken Slave Ship" activity

from Newton's Apple episode 1502. You can access this activity from http://www.ktca.org/newtons/15/sunken.html.

OTHER RELEVANT LESSONS FROM THE OCEAN EXPLORATION PROGRAM

My Wet Robot

http://www.oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf
(PDF, 300kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

Focus: Underwater Robotic Vehicles

In this activity, students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

Do You Have a Sinking Feeling?

http://oceanexplorer.noaa.gov/explorations/03portland/background/edu/media/portlandsinking.pdf
(9 pages, 764k) (from the 2003 Steamship Portland Expedition)

Focus: Marine archaeology (Earth Science/Mathematics)

In this activity, students plot the position of a vessel given two bearings on appropriate landmarks, draw inferences about a shipwreck given information on the location and characteristics of artifacts from the wreck, and explain how the debris field associated with a shipwreck gives clues about the circumstances of the sinking ship.

Where's My 'Bot?

http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf
(PDF, 492kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

Focus: Marine Navigation (Earth Science/Mathematics)

In this activity, students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

Designing Tools for Ocean Exploration

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l1.pdf
(13 pages, 496k) (from the Galapagos Rift 2002 Expedition)

Focus: Ocean Exploration

In this activity, students will understand the complexity of ocean exploration; learn about the technological applications and capabilities required for ocean exploration; discover the importance of teamwork in scientific research projects; and develop the abilities necessary for scientific inquiry.

Submersible Designer

http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9-12_l4.pdf
(4 pages, 452k) (from the Galapagos Rift 2002 Expedition)

Focus: Deep Sea Submersibles

In this activity, students will understand that the physical features of water can be restrictive to movement; understand the importance of design in underwater vehicles by designing their own submersible; and understand how submersibles such as ALVIN and ABE, use energy, buoyancy, and gravity to enable them to move through the water.

Where Am I?

http://oceanexplorer.noaa.gov/explorations/03portland/background/edu/media/portlandwhereami.pdf (4 pages, 344k) (from the 2003 Steamship Portland Expedition)

Focus: Marine navigation and position finding (Earth Science)

In this activity, students identify and explain at least seven different techniques used for marine navigation and position finding, explain the purpose of a marine sextant, and use an astrolabe to solve practical trigonometric problems.

OTHER LINKS AND RESOURCES

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration program

Green, J. 2004. Maritime Archaeology, Second Edition: A Technical Handbook. Academic Press.

Bass, G.F. (ed.). 1996. Ships and Shipwrecks of the Americas: A History Based on Underwater Archaeology. Thames & Hudson.

Bound, M. 1998. Excavating Ships of War. Anthony Nelson.

Villiers, A. 1973. Men, Ships and the Sea. National Geographic Society. Washington.

http://www.navyandmarine.org/ondeck/ – On Deck! from the Navy & Marine Living History Association, with articles and information for naval re-enactors and others having an interest in nautical history

http://www.wrecksite.eu/content/archive/vocabulary.aspx – Vocabulary of nautical terms

http://ina.tamu.edu/vm.htm – The Institute of Nautical Archaeology's Virtual Museum

http://projectsx.dartmouth.edu/history/bronze_age/ – Dartmouth University Web site, "Prehistoric Archaeology of the Aegean," with texts, links to other online resources, and numerous bibliographic references

http://ina.tamu.edu/Sercelimani.htm – The Byzantine Shipwreck at Serçe Limani

http://ina.tamu.edu/ub_main.htm – Web site with information about the excavation of a Bronze Age shipwreck at Uluburun, Turkey

http://sara.theellisschool.org/shipwreck – The Uluburun Shipwreck web site

http://score.rims.k12.ca.us/activity/bubbles/ – Marine archaeology activity guide based on investigations of the wreck of a Spanish galleon; from the Schools of California Online Resources for Education Web site

Macaulay, D. 1993. Ship. Houghton Mifflin Company. Boston.

http://www.marinetech.org/rov_competition/rov_video_2007.php – Video from the the Marine Technology Society's student ROV competition

Bohm, H. and V. Jensen. 1998. Build Your Own Programmable Lego Submersible: Project: Sea Angel AUV (Autonomous Underwater Vehicle). Westcoast Words. 39 pages.

Bohm, H. 1997. Build your own underwater robot and other wet projects. Westcoast Words. 148 pages.

NATIONAL SCIENCE EDUCATION STANDARDS

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Motion and forces

Content Standard D: Earth and Space Science

- Energy in the Earth system

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Science and technology in local, national, and global challenges

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Historical perspectives

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept c. The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.

Fundamental Concept d. Much of the world's population lives in coastal areas.

Essential Principle 7.

The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

SEND US YOUR FEEDBACK

We value your feedback on this lesson.
Please send your comments to:
oceanexeducation@noaa.gov

FOR MORE INFORMATION

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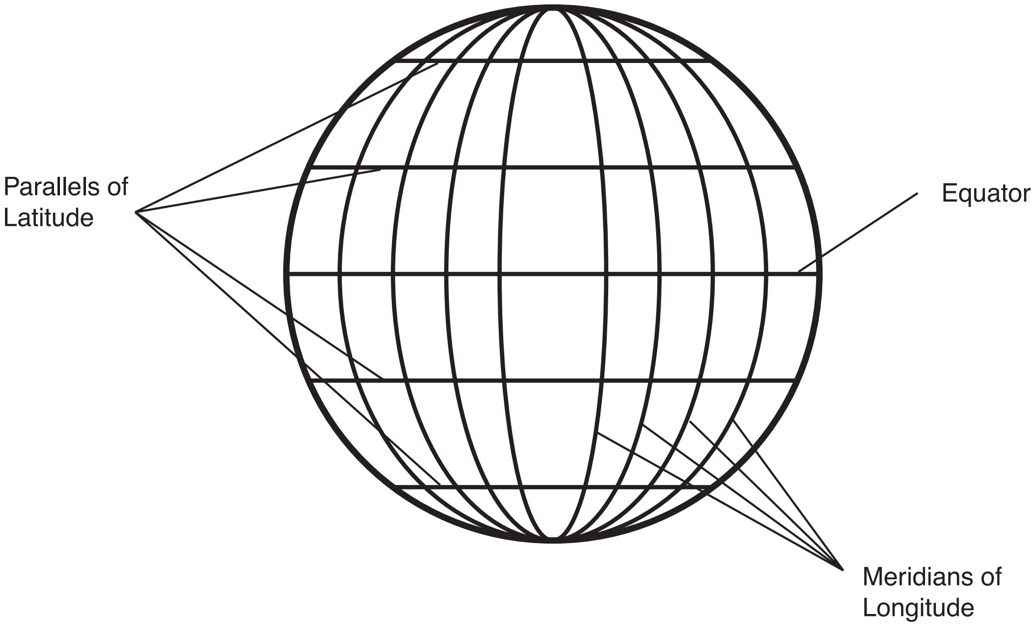
Student Worksheet on Dead Reckoning and Navigation with Nautical Charts

(adapted, in part, from the National Ocean Service Discovery Classroom Lesson, "Plot Your Course"; http://oceanservice.noaa.gov/education/classroom/lessons/18_marinenav_plotcourse.pdf)

Latitude and Longitude

All nautical charts are based on a system of geographic coordinates that can be used to describe a specific location on a body of water. One of the best-known and most widely used set of geographic coordinates is the latitude - longitude system. This system is based on two sets of imaginary circles on the Earth's surface. One set includes circles that pass through the north and south poles. These circles are known as "meridians of longitude." The other set includes circles that would lie on plane surfaces cutting through the Earth perpendicular to the polar axis (and therefore perpendicular to meridians of longitude). This second set of circles is known as "parallels of latitude" (see Figure 1).

Figure 1. Parallels of Latitude and Meridians of Longitude



Geographic coordinates using the latitude - longitude system are measured in terms of degrees. The reference point for all measurements of longitude is the meridian passing through Greenwich, England; this meridian is called the "prime meridian," and is represented by 0 degrees. The meridian of longitude that passes through any position on Earth is described in terms of how many degrees that meridian is to the east or west of the prime meridian. The maximum in either direction is 180 degrees. Parallels of latitude are measured in terms of how many degrees a given parallel is north or south from the equator (which is assigned a latitude of 0 degrees). Fractions of degrees are expressed in minutes (there are 60 minutes in one degree) and seconds (there are 60 seconds in one minute). Minutes and seconds are sometimes divided decimally for very precise descriptions of geographic location. Each degree of latitude corresponds to sixty nautical miles, so one minute of latitude corresponds to one nautical mile (a nautical mile is equal to about 6,076 ft, or about 1.15 statute miles).

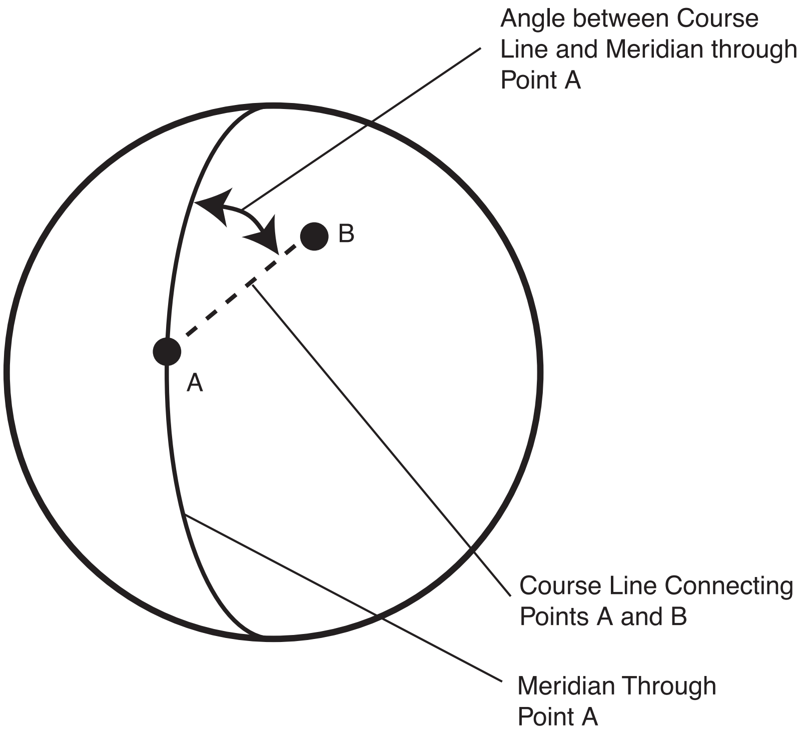
Useful Features of the Mercator Projection

A fundamental problem faced by all mapmakers is how to depict the three-dimensional curved surface of Earth on the two-dimensional flat surface of a paper chart. To deal with this problem, mapmakers use mathematical constructions known as "projection systems" to approximate Earth's curved surface in two dimensions. One of the most familiar projection systems is the Mercator projection, which is often explained as projection of Earth's surface features onto a cylinder wrapped so that the long axis of the cylinder is parallel to Earth's polar axis and the inner surface of the cylinder touches Earth's equator. A conspicuous feature of the Mercator projection is that meridians of longitude appear as straight vertical lines, and do not converge at the poles. The main advantage of charts that use the Mercator projection is that the geographic position of an object on the chart can be easily measured using the latitude and longitude scales along the four outer borders of the chart. A straight line drawn between two points on a Mercator chart corresponds to the compass direction between these points, and to the course that should be steered to navigate from one point to the other. In addition, the distance between the two points can be easily determined by transferring the length of a line between these points to the latitude scale on the left or right sides of the chart (most often using a pair of dividers), since one minute of latitude corresponds to one nautical mile as described above.

The Compass Rose

The compass rose is a tool provided on all nautical charts to simplify the process of measuring directions. The most commonly used reference point for direction on nautical charts is Earth's geographic north pole ("true north"). The direction from one point on Earth's surface to another point on Earth's surface is usually described as the angle between a line connecting the two points and the meridian that passes through the first point. It may be easier to visualize this angle as the compass course that one would follow to move from one point to the next if the compass pointed toward true north (see Figure 2).

Figure 2. Direction Between Two Points on Earth's Surface



This angle is measured in degrees moving clockwise from the meridian. A compass rose on most charts consists of two or three concentric circles, several inches in diameter. Each circle is subdivided into smaller segments. The outer circle is divided into 360 segments (degrees) with zero at true north, usually indicated by a star. The next inner circle describes magnetic direction, also in degrees, with an arrow at the zero point which corresponds to the direction of magnetic north. The innermost circle (if there is one) is also oriented to magnetic north, but is divided into "points." This is a traditional way to express nautical directions based on subdividing the intervals between the four "cardinal" directions (north, east, south, and west). There are 32 points on the traditional mariner's compass (in this system, the points between north and east are named north, north by east, north-northeast, northeast by north, northeast, northeast by east, east-northeast, and east by north), and each point may be further divided into half- and quarter-points. This system is rarely used, except that north, northeast, east, southeast, etc. are sometimes used to give rough descriptions of direction, particularly wind direction.

To use a compass rose to determine direction (or "bearing") between two points, draw a line from the origin point to the destination point, then transfer the angle of this line to the nearest compass rose on the chart using parallel rulers or a pair of drafting triangles. Parallel rulers are two rulers connected by linkages that keep their edges parallel. To measure direction, line up the edge of one ruler with origin and destination points (or the bearing line), then "walk" the rulers (see Figure 3) to the nearest compass rose by alternately holding one ruler and moving the other until the edge of one ruler intersects the center point of the compass rose. Read the true direction on the scale of the outermost circle of the compass rose. To use a pair of drafting triangles, place the hypotenuses of the triangles together, then line up one of the other sides with the origin and destination points (or the bearing line). Holding one triangle in place, slide the other along the hypotenuse to the nearest compass rose, and read the direction as described above.

Example of Dead Reckoning

Dead reckoning is the process of determining the geographic position of a vessel using the vessel's speed and course through the water. Because this position can be affected by many factors, it is only an estimate of a vessel's actual position, and is corrected from time to time by obtaining additional information that establishes a more accurate geographic position called a "fix" (such as information from a global positioning system or GPS). Often, a dead reckoning position is calculated using a nautical chart. Figure 4 shows an example of dead reckoning:

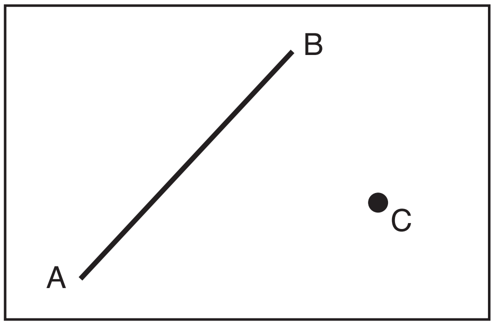
1. At 0800 vessel obtains a GPS fix that establishes its geographic position as 12 degrees, 3.5 minutes north latitude, 68 degrees, 11.6 minutes west longitude (usually written as 12°03.5'N, 68°11.6'W). Plot this position on the chart using the latitude (left and right sides) and longitude (top and bottom sides) scales. Indicate the position by a small circle with the time of the fix written nearby.

2. The vessel steers a course of 130° true (written 130T) with a speed of six knots (6 kn) for 15 minutes. Draw a line from the starting point in the direction of 130T using parallel rules and the compass rose as described in Figure 3. Label the line with the course steered (beginning with a "C") written on top of the line and the speed in knots (beginning with an "S") written beneath the line.

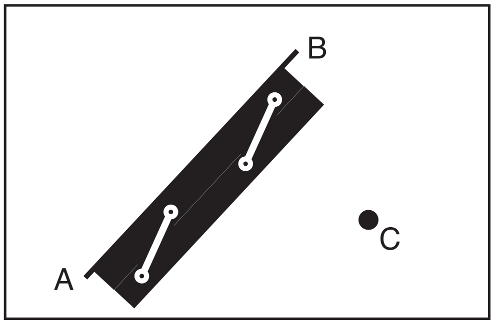
3. Since one knot is equal to one nautical mile per hour, a speed of 6 kn is equal to 6 nautical miles per hour, so in 15 minutes the vessel travelled

   (15 min ÷ 60 min/hr) • (6 nm/hr) = 1.5 nm

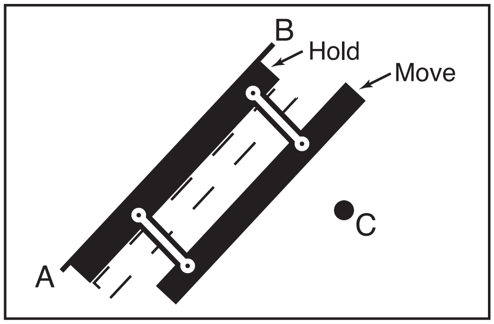
Figure 3: How to Transfer the Angle of a Line to Another Point Using Parallel Rules



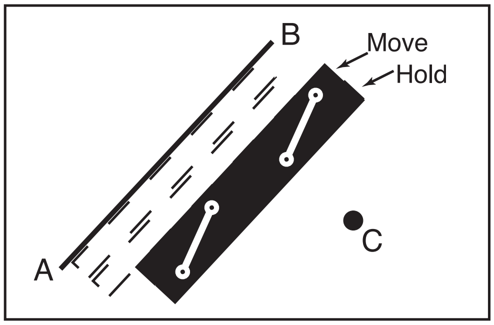
1. The Problem: How to transfer the angle of Line AB to Point C.



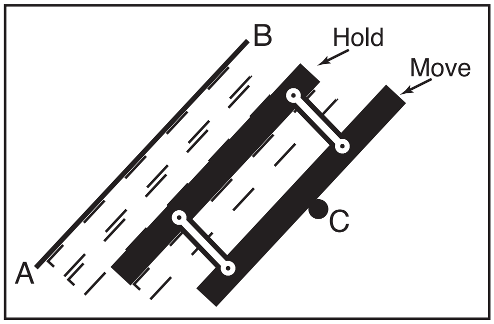
2. Align one edge of the parallel rules with Line AB.



3. Hold the rule next to Line AB, and "walk" the other rule toward Point C.

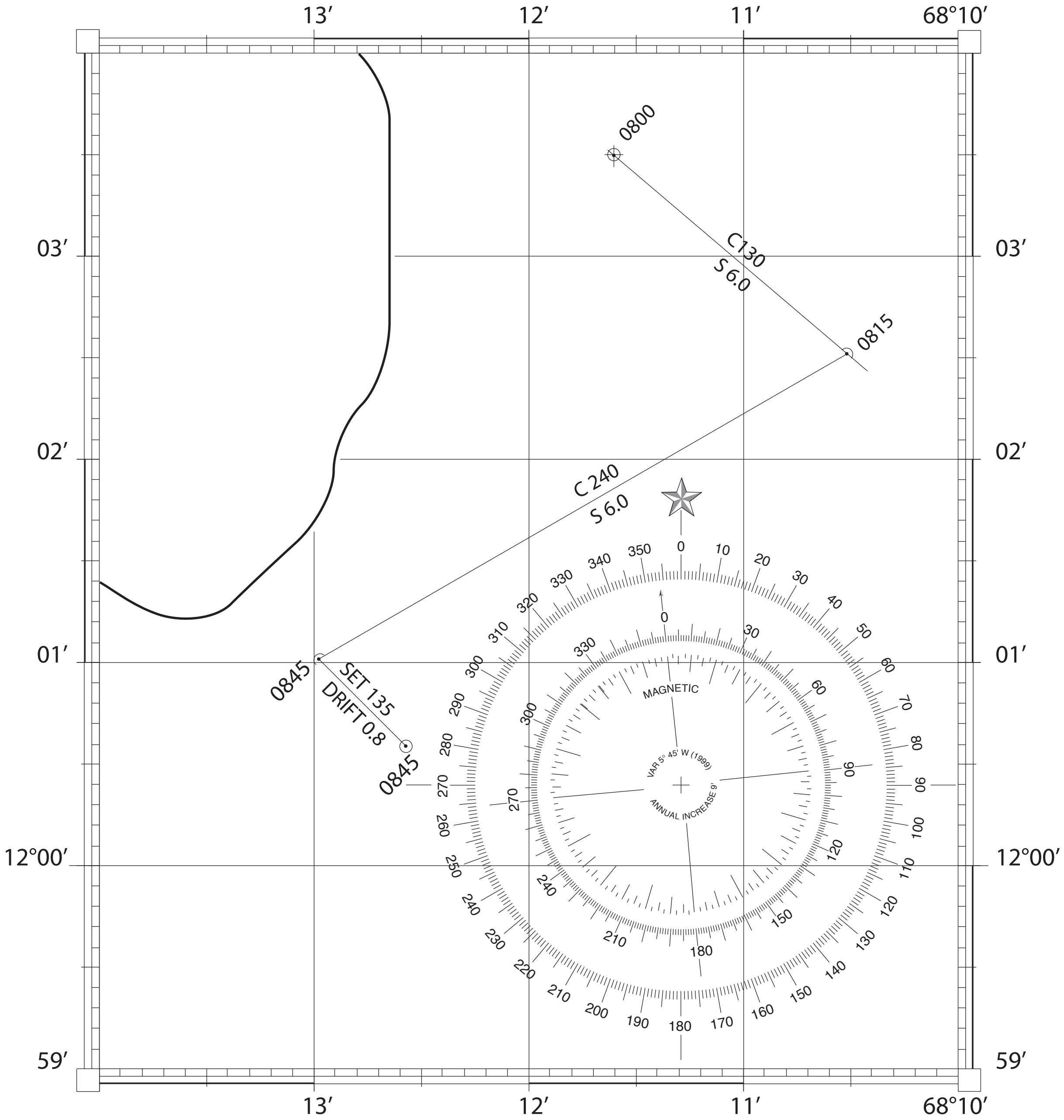


4. Hold the rule that was "walked," and move the other rule in the direction of Point C.



5. Continue "walking" the rules until Point C is reached. You can now draw a line through Point C that is parallel to Line AB.

Figure 4. Example of Dead Reckoning



Since one minute of latitude is equal to one nautical mile, you can use the latitude scale on the left or right side of the chart to find the length of a line equivalent to 1.5 nm. Use a ruler or pair of dividers to transfer this length to the course line drawn in Step 2. The end of this line represents a dead reckoning position at 0815. Notice that dead reckoning positions are marked with a semicircle and the time.

4. At 0815, the vessel changes course to 240T, and continues for 30 minutes at the same speed (6 kn). To plot this information, draw a line from the 0815 position in the direction of 240T, and measure a length equal to the distance travelled in 30 minutes
(30 min ÷ 60 min/hr) • (6 nm/hr) = 3 nm which is equivalent to three minutes of latitude.

   Again, the dead reckoning position at 0845 is marked on the chart with a semicircle.

5. At 0845, the vessel obtains a GPS fix that establishes its true geographic position as 12°00.65'N, 68°12.6'W. Plot this position and label the location with a small circle and the time.

6. The true position is a little different than the dead reckoning position. In many cases this is due to currents, and the dead reckoning plot can be used to estimate the speed and direction of a current that could have caused the dead reckoning position to be off. The speed of a current is called "drift" and the direction of a current is called "set."

   To find the set and drift of a current that would account for the difference between the dead reckoning position and the true position, draw a line between the two positions, and find the true compass direction by transferring the angle to the compass rose. In the example, the angle is 135°T. Now use a ruler or pair of dividers to transfer the length of the line to the latitude scale. In the example, the length of the line is equal to 0.6 minutes of latitude, which is equal to a distance of 0.6 nautical miles.
   Divide this distance by the time between fixes (in hours) to find the drift of the current in knots:

   (0.6 nm) ÷ (45 min ÷ 60 min/hr) = (0.6 nm) ÷ (0.75 hr) = 0.8 nm/hr = 0.8 kn

   Label the line between the two positions with the set on top of the line and the drift below the line.

Navigating an Underwater Robot

A key step in any archeological investigation is to locate the target site (a shipwreck, for example). Searching for these targets can involve a variety of techniques. The two most common search techniques used in marine archaeology are sonar and magnetometer, because they cover ground very quickly and are not affected by water clarity which is often bad in places where ships wreck.

Sonar (which is short for SOund NAvigation and Ranging) systems transmit a pulse of sound into the water by a sort of underwater speaker known as a "transducer." The transducer may be mounted on the hull of a ship, or may be towed in a container called a "towfish." If the seafloor or other object is in the path of the sound pulse, the sound bounces off the object and returns an "echo" to the sonar transducer. The system measures the strength of the signal and the time elapsed between the emission of the sound pulse and the reception of the echo. This information is used to calculate the distance of the object, and an experienced operator can use the strength of the echo to make inferences about some of the object's characteristics.

A magnetometer is an instrument that measures the strength and/or direction of magnetic fields. Magnetometers used in ocean exploration are usually towed behind a research vessel, or in some cases may be carried aboard aircraft or satellites. In marine archeology, a magnetometer is used to measure Earth's magnetic field near the seafloor. This magnetic field will be changed by large masses of iron or some ceramic materials (such as bricks, or pottery storage containers that were used for many centuries on cargo ships), so changes (called "anomalies") in Earth's magnetic field can indicate the presence of buildings, shipwrecks or cargo from wrecked vessels.

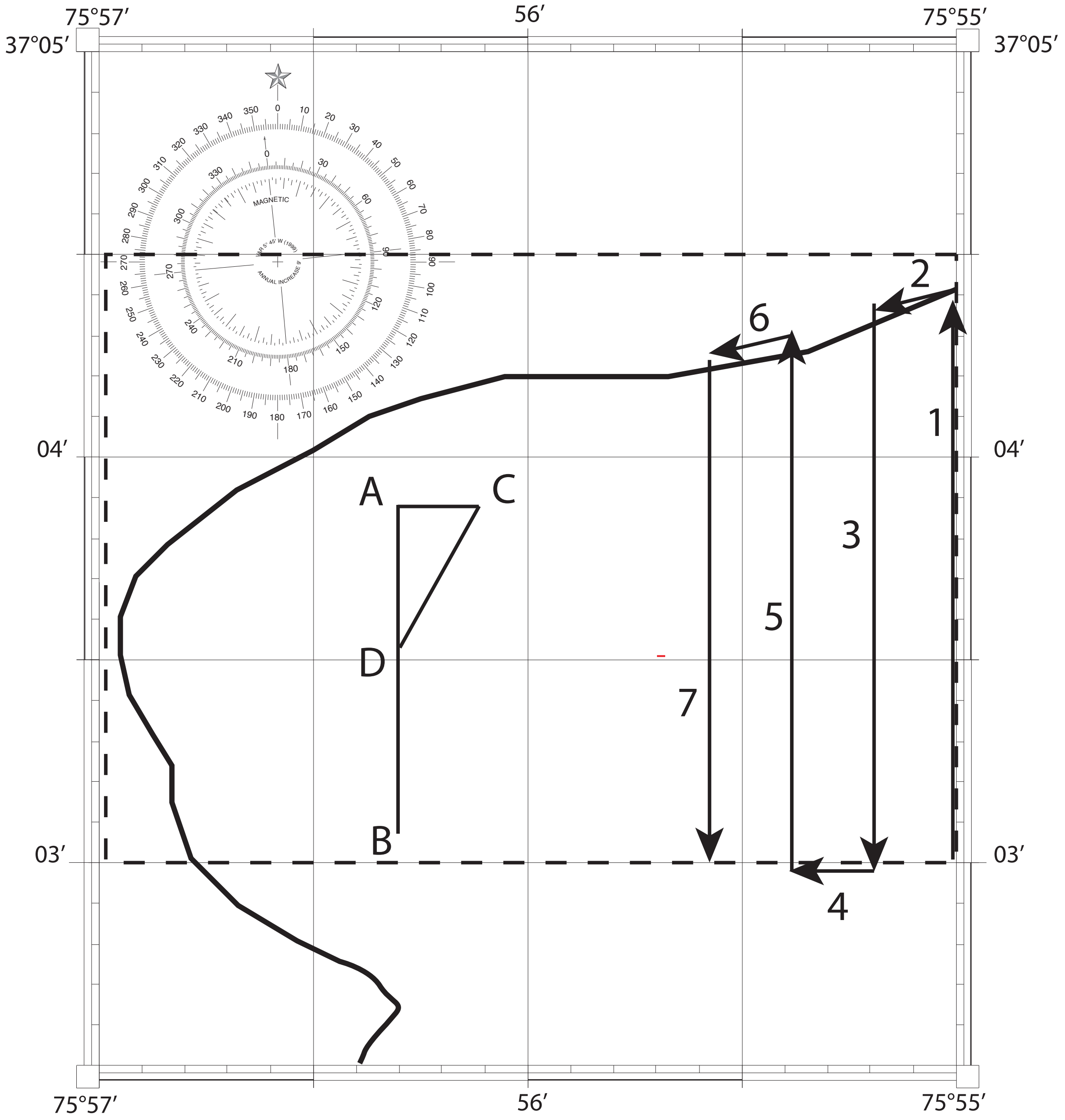
Autonomous Underwater Vehicles (AUVs) used for marine archaeology often carry sonar as well as a magnetometer. Before a search can begin, an archaeologist must decide on a path that the AUV should follow to adequately cover the area to be searched. This usually depends upon the time availabe for the search, and the area covered by the sonar and magnetometer in a single pass. Once a path has been decided, the computer that controls the AUV must be programmed to follow the desired path. This will usually be a sort of zig-zag across the survey area.

Suppose you wanted to survey Nautilus Shoal near Fishermans Island in the Chesapeake Bay, covering the area shown by the dashed rectangle in Figure 5. Your AUV has a survey speed of 4 knots (4 nautical miles per hour). You need to provide a set of instructions that tells the AUV where to start the survey, and then how long to run on a series of courses that will cover the area. You have decided to space your survey lines 0.2 nautical miles apart (this is fairly wide spacing, and would only be appropriate if you were looking for very large objects).

Your instruction set would begin with the starting location, which in this case is 37°03.0'N, 75°55.0'W. The first leg of your survey (labelled "1" in Figure 6) will have a course of 0° (due north). Looking at the latitude scale on the right side of the chart, you find that this leg has a length of 1.4 nautical miles (remember that one minute of latitude equals one nautical mile). At 4.0 knots, your AUV will cover 1.4 nautical miles (nm) in

$1.4 \text{ nm} \div 4.0 \text{ nm/hr} = 0.35 \text{ hr}$

Figure 5. Survey Plan for an Underwater Robot



So your survey plan now has these steps:

1. Begin at 37°03.0'N, 75°55.0'W
2. Run on Course = 0° for 0.35 hr (Leg 1)

To make the next leg of your survey ("3"), your AUV needs to move 0.2 nm to the west. Measure 0.2 nm on the latitude scale, and draw a line parallel to Leg 1 that is 0.2 nm to the west. Now draw a line from the end of Leg 1 to the start of Leg 3. This short line is Leg 2. Measure the length of Leg 2 (slightly more than 0.2 nm), and find the course by "walking" Leg 2 to the compass rose with a parallel ruler (the course for Leg 2 is 256°). Your AUV will cover 0.2 nm in

0.2 nm ÷ 4.0 nm/hr = 0.05 hr

Find the length of Leg 3 using the latitude scale (it is slightly less than 1.4 nm). The course for Leg 3 will be 180° (due south). So now you can add two more steps to your survey plan:

3. Run on Course = 256° for 0.05 hr (Leg 2)
4. Run on Course = 180° for 0.35 hr (Leg 3)

Continuing the same process, you would add Legs 4, 5, and 6 to your survey plan:

5. Run on Course = 270° for 0.05 hr (Leg 4)
6. Run on Course = 0° for 0.325 hr (Leg 5; note this is shorter than Legs 1 and 3, so less time is needed)
7. Run on Course = 259° for 0.05 hr (Leg 6)

To complete your survey plan, you would continue the same process until all the area on Nautilus Shoal inside the dashed rectangle was covered.

Suppose there is a current setting due east with a drift of 2.0 kn. You will need to adjust your course and run time to compensate for the offset caused by the current. To calculate these adjustments, draw a line that represents the course you want (labelled "AB" in Figure 5). Because the scale of Figure 5 is very large, we will divide AUV speed and current drift by 10. Next, draw a line in the direction of the set with a length equal to the drift (2 nm ÷ 10 = 0.2 nm), This line is labelled "BC" in Figure 5.

Now, space your dividers so they represent the speed of your AUV (4 nm/hr ÷ 10 = 0.4 nm). Place one point of the dividers on point "C", and the other point on line "AB" (this point is labelled "D" in Figure 5). Line CD is the course that must be steered to compensate for the set of the current, and is equal to 209°. Measure the length of line segment "AD" using the latitude scale (about 0.35 nm). Now convert back by multiplying this answer by 10. This is the "speed over ground" that combines the speed of the AUV with the effect of the current, and it is equal to 3.5 kn

Now draw Leg 7, and measure its length (about 1.25 nm). Calculate the run time by dividing the length of Leg 7 by the speed over ground:

1.25 nm ÷ 3.5 nm/hr = 0.35 hr

So, step 8 of your survey plan would read:

8. Run on Course = 209° for 0.35 hr (Leg 7)

Now It's Your Turn!

Make a survey plan for Nautilus Shoal using the same AUV and same survey line spacing, but starting on the lower left portion of the shoal near 37°03.0′N. 75°56.8′W, and running your survey lines in an east-west direction. Draw your complete survey plan on the blank survey plan below.

For the last four legs of your survey plan, calculate the course and run time adjustments needed to compensate for a current setting due south at 1.5 kn.

Figure 6. Blank Survey Plan for Nautilus Shoal