

# The Robot Archaeologist

(Adapted from the AUVfest 2008 Expedition)



Image captions/credits on Page 2.

## lesson plan

### Focus

Marine Archaeology/Marine Navigation

### Grade Level

9-12 (Earth Science/Mathematics)

### Focus Question

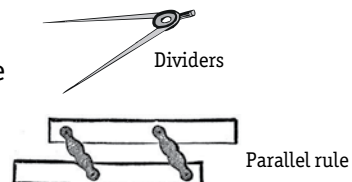
What information is needed to program an underwater robot to follow a desired course?

### 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 and Autonomous Underwater Vehicles Overview*, one copy for each student or student group



### Audio-Visual Materials

- None

### Teaching Time

One or two 45-minute class periods

### Seating Arrangement

Classroom style, or groups of 2-4 students

### Maximum Number of Students

30

## Key Words

Paleoamerican  
Underwater archaeology  
Autonomous Underwater Vehicle (AUV)  
Navigation  
Dead reckoning  
Drift  
Set  
Sonar  
Magnetometer

## Background Information

*NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.*

Recent archaeological and molecular genetic evidence (Goebel, *et al.*, 2008) indicates that the first humans to inhabit North America migrated from Siberia around 15,000 years ago, near the end of the Pleistocene Epoch. These migrants are believed to have crossed a land bridge to the Pacific coast of North America, and continued southward, possibly using boats. Some of their descendants spread across what is today the United States, while others continued southward into South America. An important characteristic of these first Americans is that they used thrusting spears tipped with specialized stone points, and were very successful hunters. At this time, North America was inhabited by many large mammals that are now extinct, including mammoths, bison, short-faced bears, giant sloths, and sabre-toothed cats.

Some of the oldest archaeological sites discovered in North America are in the eastern United States, and there are numerous quarry-campsites in the southeastern states. Quarries are locations where raw rock material was mined and processed to make tools. If a reliable source of water is nearby (or was nearby during late Pleistocene times), residential sites are often found near the quarry. When the first humans arrived in Florida, sea level was much lower and there was more than twice as much dry land as exists today. The climate was considerably drier, and water was scarce. Not surprisingly, early American settlements that have been discovered in the state are almost always associated with a reliable water supply such as rivers and springs. These areas would also have been attractive to animals, increasing the likelihood that human hunters would be able to find food.

Limestone bedrock that underlies the Florida peninsula strongly influences the state's landscape. Limestone dissolves in acidic solutions, and over time has been sculpted by rainwater which is weakly acidic. This sculpting

### Images from Page 1 top to bottom:

The eastern Gulf of Mexico showing the three sub-areas examined in 2008, the Florida Middle Grounds, and the Suwanee River paleo channel.  
[http://oceanexplorer.noaa.gov/explorations/09newworld/background/plan/media/fmg\\_surveyareas.html](http://oceanexplorer.noaa.gov/explorations/09newworld/background/plan/media/fmg_surveyareas.html)

During the Late Pleistocene Florida's shoreline extended much farther offshore than the present coast. The Florida Middle Grounds were part of the exposed coastal margin.  
<http://oceanexplorer.noaa.gov/explorations/09newworld/background/climatechange/media/pleistocene.html>

Map of the Bering land bridge during the late Wisconsin glaciation, when global sea level dropped to about 120 meters or more below its present position.  
[http://oceanexplorer.noaa.gov/explorations/09newworld/background/occupation/media/beringia\\_late\\_wisconsin.html](http://oceanexplorer.noaa.gov/explorations/09newworld/background/occupation/media/beringia_late_wisconsin.html)

This image portrays a more accurate reconstruction of Ice Age human behavior with a focus on small familial groups and the processing and use of plants as opposed to athletically fit young men attacking large, dangerous animals.  
<http://oceanexplorer.noaa.gov/explorations/09newworld/background/beliefs/media/correctpaleobehavior.html>

All images courtesy NOAA.

includes the formation of underground caves. When the roof of a cave becomes unstable, it collapses to form a hole in the ground called a sinkhole. Florida has hundreds of sinkholes, some of which became natural reservoirs for fresh water. Not surprisingly, some of the most artifact-rich paleoamerican sites are located near sinkholes. Coastal areas inhabited by early Americans are difficult to explore because the coastlines of 15,000 years ago are now under more than 300 feet of water! As the last ice age drew to a close, melting ice sheets caused a rapid rise in sea level just as the first Americans were entering the New World. Drowned settlements may contain well-preserved artifacts that can provide important new information about how the first Americans lived and when they arrived at various locations in North and South America. The eastern Gulf of Mexico in the vicinity of the Ocala Uplift Zone (Florida) is particularly promising as a potential location for drowned coastal settlements because:

- There are numerous onshore archaeological sites along the same zone that are more than 13,000 years old;
- Clusters of similar sites have been identified along drowned shorelines in the northern Gulf of Mexico;
- Rivers that discharge into this part of the Gulf do not carry large quantities of sediment, so sites should not be deeply buried;
- The coastal shelf is gently sloped which would reduce the impact of waves and storms; and
- Rapid sea level rise would have reduced the impact of waves as coastal settlements were inundated.

The Northeastern Gulf of Mexico 2008 Expedition focused on ancient river channels in the vicinity of the Florida Middle Grounds, which are now several hundred feet below the Gulf's surface. Major accomplishments included:

- Locating and high resolution mapping of a large, essentially intact, and infilled ancient river channel several kilometers long, east of the Florida Middle Grounds;
- Identifying additional stream and river channels, some with clearly visible deposits along the banks;
- Locating and identifying more than 100 sinkhole features filled with material in stratified layers that may contain human artifacts as well as plant and animal material from early American times; and
- Mapping nearly 10 square kilometers of intact, shallow-water, near-shore sand ripples/ridges adjacent to an area that would have been Florida's shoreline when sea level was at its lowest point during the last glacial period.

The latter achievement is particularly important because it shows that the oldest shoreline is extraordinarily well preserved. Most interesting, though, are the infilled sinkholes with multiple layers of distinct strata. These sinkholes are a potential treasure trove of new information about the late Pleistocene landscape and environment, as well as about the humans who lived there.

Key questions for the Exploring the Submerged New World 2009 expedition included:

- Is there evidence of human activity at sites identified in 2008 that is visible to diver and/or video examination?
- Does the previously identified ancient river channel form a “T” intersection with another river channel (three modern terrestrial sites where rivers form a “T” junction have extensive paleoamerican settlements with hundreds of thousands of artifacts)?
- Is the previously identified ancient river channel the former course of the modern Suwannee River?
- Are several “channel-like” features identified in 2008 tributaries of the ancient river channel (areas where major and minor tributaries converge also have a high potential as locations for paleoamerican settlement sites)?

The Northeastern Gulf of Mexico 2008 expedition used a Remotely Operated Vehicle (ROV) to obtain video images of underwater sites that were surveyed for archaeological potential. As technologies improve, robots are becoming an important tool for underwater archaeologists. In this activity, students will design an archaeological survey strategy for an Autonomous Underwater Vehicle (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 required to compensate for the set and drift of currents.

### 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](http://oceanservice.noaa.gov/education/classroom/lessons/18_marinenav_plotcourse.pdf))]

1. To prepare for this lesson:

- (a) Review introductory essays for the Exploring the Submerged New World 2009 Expedition at <http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html>; and
- (b) Review *Autonomous Underwater Vehicles Overview* and *Student Worksheet on Dead Reckoning and Navigation with Nautical Charts*, and work through the dead reckoning calculations.

2. Briefly review the background and mission of the Exploring the Submerged New World 2009 expedition, highlighting the reasons for exploring ancient shorelines that are now under several hundred feet of water. 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 copies of *Autonomous Underwater Vehicles Overview* and *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/archeology.html](http://www.vims.edu/bridge/archeology.html)

[www.vims.edu/bridge/](http://www.vims.edu/bridge/) – In the “Site Navigation” menu on the left, scroll over “Ocean Science Topics,” then “Human Activities,” then “Technology” for links to resources about submersibles, ROVs, and other technologies used in underwater exploration. From the “Human Activities” menu bar you can also link to “Heritage,” then “Archaeology” for resources about underwater archaeology.

### The “Me” Connection

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

### Connections to Other Subjects

English/Language Arts, Social Studies, History, Mathematics

### Evaluation

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

## Extensions

1. Visit <http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html> for more about the Submerged New World 2009 Expedition.
2. Visit <http://www.pbs.org/wgbh/nova/first/> for information and resources about the discovery and controversy surrounding a well-preserved, 9,000-year-old human skeleton called Kennewick Man.
3. Visit [http://www.marinetech.org/rov\\_competition/rov\\_video\\_2007.php](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.
4. 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.
5. For a marine archaeology activity, see the "Lost at Sea: Sunken Slave Ship" activity from Newton's Apple, Episode 1502. <http://www.newtonsapple.tv/TeacherGuide.php?id=1675>.

## Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

*(The following Lesson Plans are targeted toward grades 9-12)*

### My Wet Robot

(9 pages, 300kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

<http://www.oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf>

Focus: Underwater Robotic Vehicles (Physical Science)

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?

(9 pages, 764k) (from the 2003 Steamship Portland Expedition)

<http://oceanexplorer.noaa.gov/explorations/03portland/background/edu/media/portlandsinking.pdf>

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?**

(17 pages, 492kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

<http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf>

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**

(13 pages, 496k) (from the Galapagos Rift 2002 Expedition)

[http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal\\_gr9\\_12\\_l1.pdf](http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9_12_l1.pdf)

Focus: Ocean Exploration

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

**Where Am I?**

(4 pages, 344k) (from the 2003 Steamship Portland Expedition)

<http://oceanexplorer.noaa.gov/explorations/03portland/background/edu/media/portlandwhereami.pdf>

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 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> – NOAA's Ocean Explorer Web site

<http://oceanexplorer.noaa.gov/explorations/09newworld/welcome.html> – Web site for the Submerged New World 2009 Expedition

<http://celebrating200years.noaa.gov/edufun/book/welcome.html#book> – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

<http://centerfirstamericans.org/index.php> – Web site for the Center for the Study of the First Americans

<http://www.jqjacobs.net/anthro/paleoamericans.html> – Online article on issues and evidence relating to peopling of the New World

<http://www.pbs.org/wgbh/nova/first/> – Web site to accompany the NOVA presentation, "Mystery of the First Americans" (originally broadcast on February 15, 2000) documenting the discovery and controversy surrounding a well-preserved, 9,000-year-old human skeleton called Kennewick Man; includes "Does Race Exist?," "Meet Kennewick Man," "Claims for the Remains," "The Dating Game" (about carbon-14 analysis), and links to resources

<http://www.cr.nps.gov/archeology/eam/index.htm> – National Park Service Archaeology and Ethnography Program's Web site, The Earliest Americans

Goebel, T., M. R. Waters, and D. H. O'Rourke. 2008. The Late Pleistocene Dispersal of Modern Humans in the Americas. *Science* 319:1497-1502. [www.anthro.utah.edu/PDFs/Goebel\\_et\\_al\\_2008.pdf](http://www.anthro.utah.edu/PDFs/Goebel_et_al_2008.pdf)

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

[http://www.marinetech.org/rov\\_competition/rov\\_video\\_2007.php](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
- Understandings about scientific inquiry

#### Content Standard B: Physical Science

- Motions 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 1.

##### The Earth has one big ocean with many features.

*Fundamental Concept d.* Sea level is the average height of the ocean relative to the land, taking into account the differences caused by tides. Sea level changes as plate tectonics cause the volume of ocean basins and the height of the land to change. It changes as ice caps on land melt or grow. It also changes as sea water expands and contracts when ocean water warms and cools.

#### Essential Principle 2.

##### The ocean and life in the ocean shape the features of the Earth.

*Fundamental Concept a.* Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.

*Fundamental Concept b.* Sea level changes over time have expanded and contracted continental shelves, created and destroyed inland seas, and shaped the surface of land.

**Essential Principle 6.**

**The ocean and humans are inextricably interconnected.**

*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.

*Fundamental Concept f.* Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

**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](mailto:oceanexeducation@noaa.gov)

**For More Information**

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## The Robot Archaeologist Student Worksheet

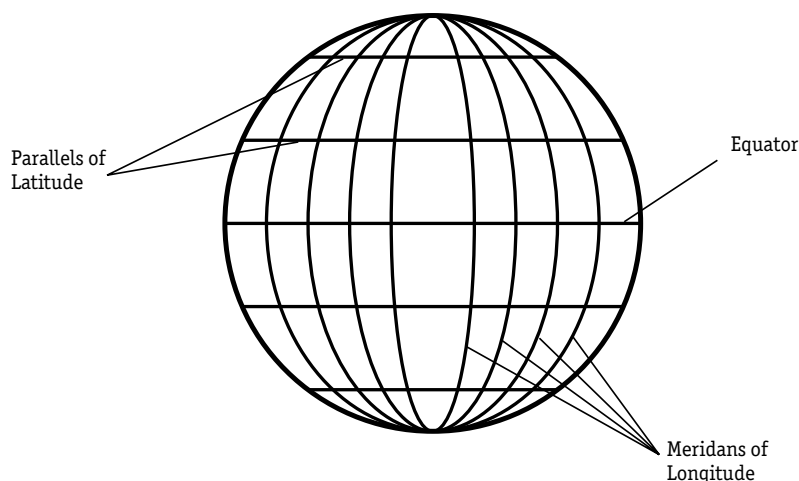
# Dead Reckoning and Navigation with Nautical Charts

### 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).

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).

Figure 1. Parallels of Latitude and Meridians of Longitude



### 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 Robot Archaeologist Student Worksheet – 2

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.

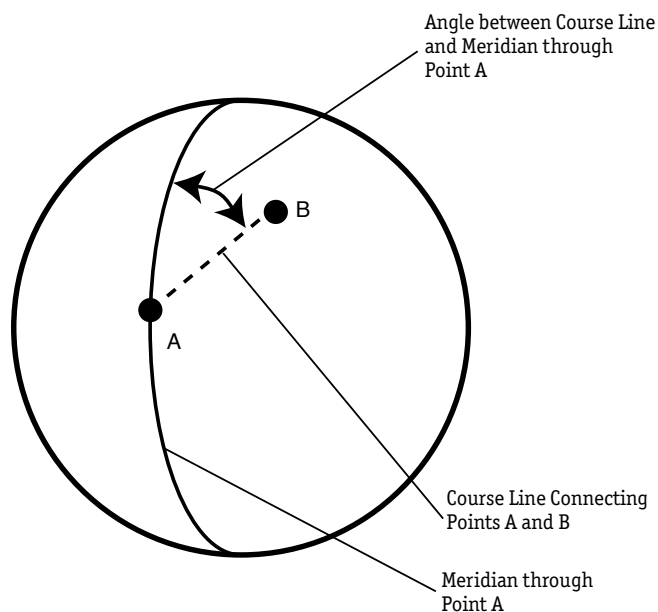
### The Compass Rose

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).

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.

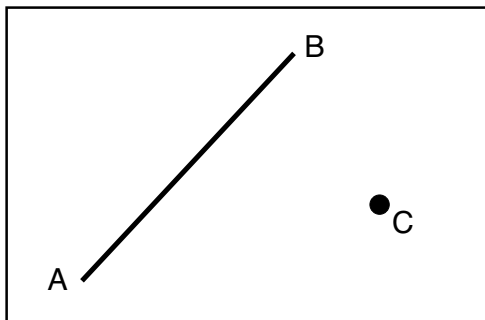
To use a compass rose to determine direction (or "bearing") between two points, draw a line from the origin point to the destination point, then transfer the angle of this line to the nearest compass rose on the chart using parallel rules or a pair of drafting triangles. Parallel rules are two rulers connected by linkages that keep their edges parallel. To measure direction, line up the edge of one rule with origin and destination points (or the bearing line), then "walk" the rules (see Figure 3) to the nearest compass rose by alternately holding one rule and moving the other until the edge of one rule 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

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

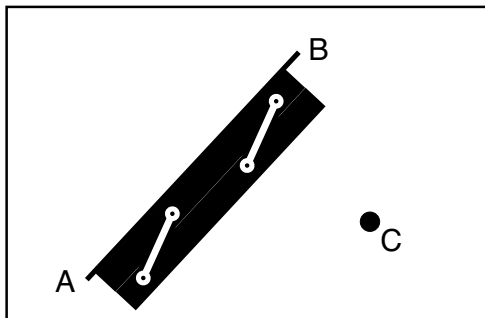


### The Robot Archaeologist Student Worksheet – 3

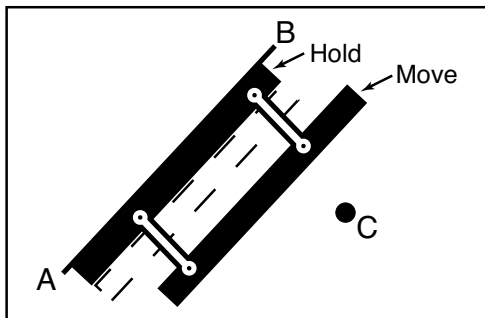
Figure 3: How to Transfer the Angle of a Line to Another Point Using Parallel Rules



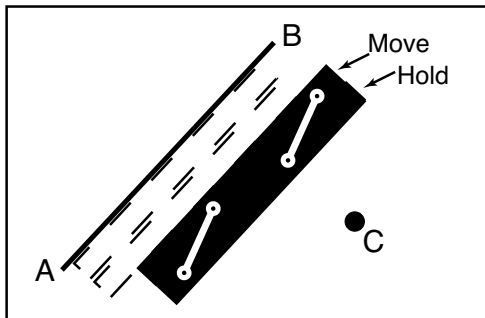
1. The Problem: How to transfer the angle of Line AB to Point C.



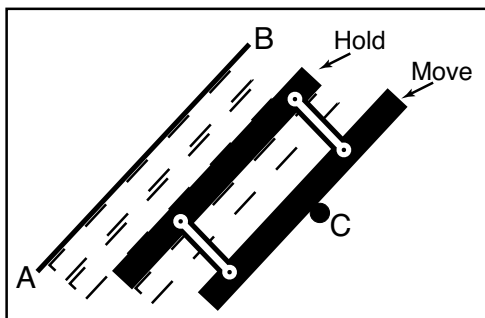
2. Align one edge of the parallel rules with Line AB.



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.

## The Robot Archaeologist Student Worksheet – 4

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.

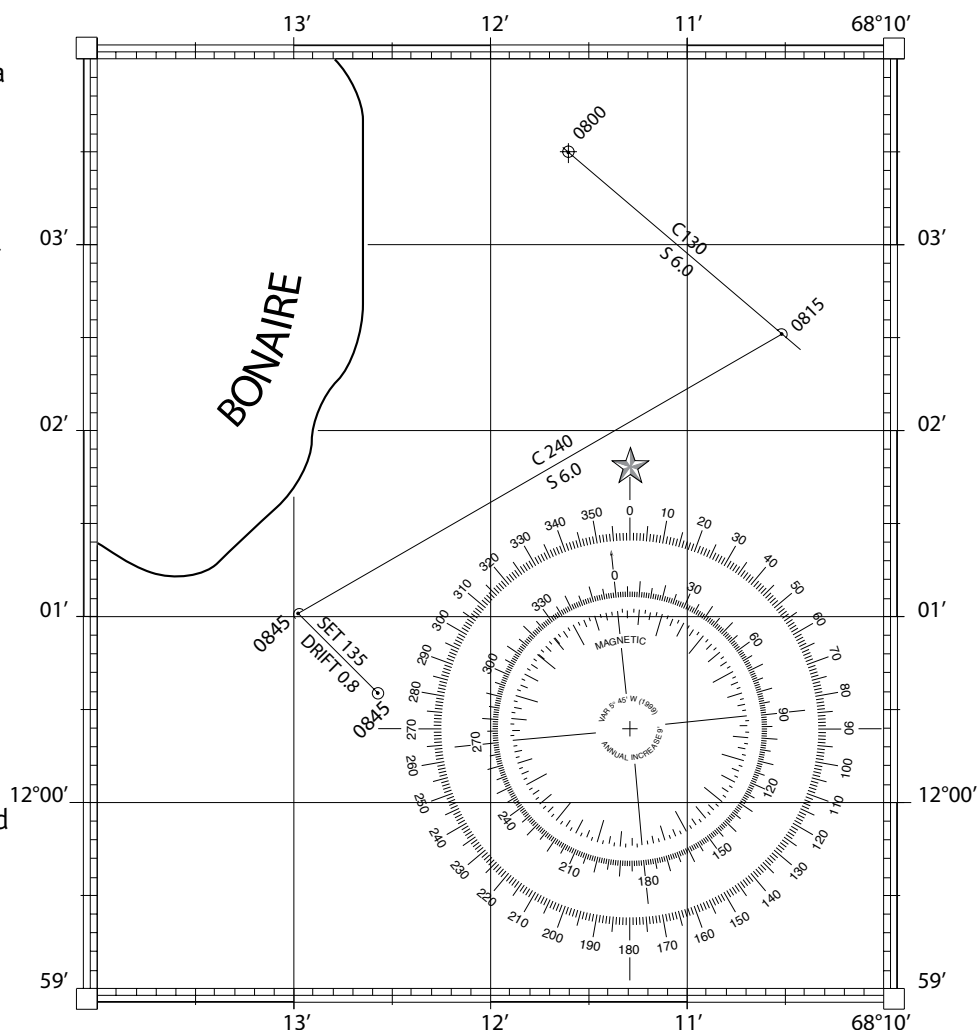
### Example of Dead Reckoning

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 based on the following:

1. At 0800 the 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  $12^{\circ}03.5'N$ ,  $68^{\circ}11.6'W$ ). This position is plotted on the chart using the latitude (left and right sides) and longitude (top and bottom sides) scales. The position is indicated by a small circle with the time of the fix written nearby.

Figure 4. Example of Dead Reckoning

2. The vessel steers a course of  $130^{\circ}$  true (written 130T) with a speed of six knots (6 kn) for 15 minutes. A line is drawn from the starting point in the direction of 130T using parallel rules and the compass rose as described in Figure 3. The line is labelled 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. Since all courses and directions are plotted as true directions, it isn't necessary to include a "T" after the number of degrees.



## The Robot Archaeologist Student Worksheet – 5

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

$$(15 \text{ min} \div 60 \text{ min/hr}) \cdot (6 \text{ nm/hr}) = 1.5 \text{ nm}$$

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. Using a ruler or pair of dividers, this length is transferred 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, a line is drawn from the 0815 position in the direction of 240T, and a length equal to the distance travelled in 30 minutes is measured on the latitude scale:

$$(30 \text{ min} \div 60 \text{ min/hr}) \cdot (6 \text{ nm/hr}) = 3 \text{ nm which is equivalent to three minutes of latitude.}$$

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. This position is plotted and labelled 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, a line is drawn between the two positions, and the true compass direction is found by transferring the direction of the line to the compass rose. In the example, the direction is 135°T. Next, a ruler or pair of dividers is used 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.

Dividing this distance by the time between fixes (in hours) gives the drift of the current in knots:

$$(0.6 \text{ nm}) \div (45 \text{ min} \div 60 \text{ min/hr}) = (0.6 \text{ nm}) \div (0.75 \text{ hr}) = 0.8 \text{ nm/hr} = 0.8 \text{ kn}$$

The line is labelled 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.

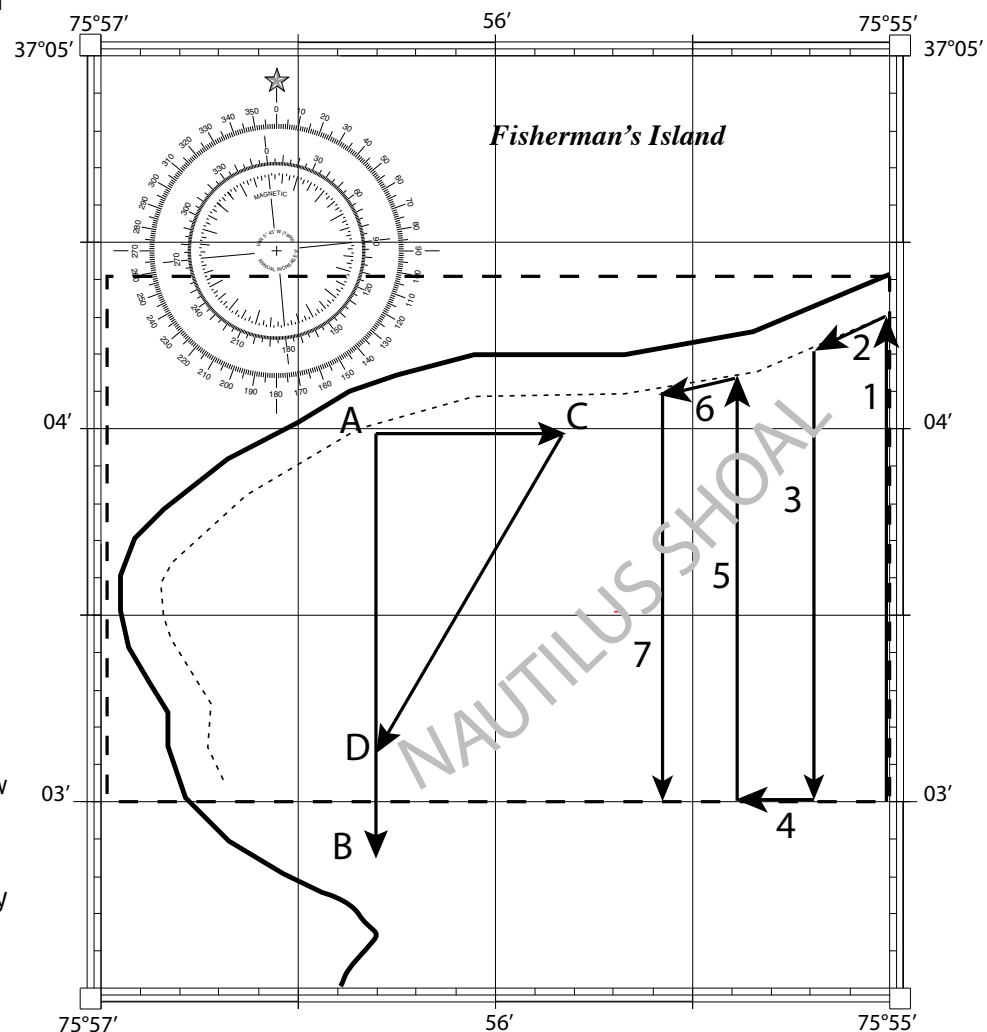
## The Robot Archaeologist Student Worksheet – 6

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 sea floor 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 archaeology, a magnetometer is used to measure Earth's magnetic field near the sea floor. 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 available 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.

**Figure 5. Survey Plan for an Underwater Robot**





## The Robot Archaeologist Student Worksheet – 7

Suppose you wanted to survey Nautilus Shoal in the Chesapeake Bay, covering the area of the Shoal included inside the dashed rectangle in Figure 5 beginning at the location  $37^{\circ}03.0'N$ ,  $75^{\circ}55.0'W$ . A shoal is a shallow area within a body of water surrounded by deeper water; in this case we will assume that the edge of Nautilus Shoal is the 2 m depth contour indicated by the dotted line 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).

The following steps explain how you would create an instruction set for an AUV to do this survey. Figure 5 shows all of these steps. Your instruction set would begin with the starting location, which in this case is  $37^{\circ}03.0'N$ ,  $75^{\circ}55.0'W$ . The first leg of your survey (labeled "1" in Figure 5) will have a course of  $0^{\circ}$  (due north). Looking at the latitude scale on the right side of the chart, you find that the edge of the shoal is 1.3 nautical miles from the starting position (remember that one minute of latitude equals one nautical mile). So, the first leg of your survey should be 1.3 nm long. At 4.0 knots, your AUV will cover 1.3 nautical miles (nm) in

$$1.3 \text{ nm} \div 4.0 \text{ nm/hr} = 0.325 \text{ hr}$$

So your survey plan now has these steps:

1. Begin at  $37^{\circ}03.0'N$ ,  $75^{\circ}55.0'W$
2. Run on Course =  $0^{\circ}$  for 0.325 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, which should be on the 2m depth contour. This short line is Leg 2. Measure the length of Leg 2 (slightly more than 0.2 nm, but we'll use 0.2 nm for our calculations), and find the course by "walking" the direction of Leg 2 to the compass rose with a parallel rule (the course for Leg 2 is  $246^{\circ}$ ). Your AUV will cover 0.2 nm in

$$0.2 \text{ nm} \div 4.0 \text{ nm/hr} = 0.05 \text{ hr}$$

Find the length of Leg 3 using the latitude scale (about 1.2 nm). At 4.0 kn, your AUV will cover this distance in

$$1.2 \text{ nm} \div 4.0 \text{ nm/hr} = 0.30 \text{ hr}$$

The course for Leg 3 will be  $180^{\circ}$  (due south). So now you can add two more steps to your survey plan:

3. Run on Course =  $256^{\circ}$  for 0.05 hr (Leg 2)
4. Run on Course =  $180^{\circ}$  for 0.30 hr (Leg 3)

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

## The Robot Archaeologist Student Worksheet – 8

5. Run on Course =  $270^\circ$  for 0.05 hr (Leg 4)
6. Run on Course =  $0^\circ$  for 0.275 hr (Leg 5)
7. Run on Course =  $257^\circ$  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.

### Correcting for Currents

Suppose for Leg 7 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 (labeled "AB" in Figure 5). Because the scale of Figure 5 is very large, we will calculate the effect of the current over 15 minutes instead of over an entire hour. In 15 minutes, the current will move the AUV 0.5 nm toward the east. Draw a line indicating the set (east) with a length equal to the drift in 15 minutes ( $2 \text{ nm} \times 0.25 \text{ hr} = 0.5 \text{ nm}$ ). This line is labeled "AC" in Figure 5.

Now, space your dividers so they represent the distance your AUV will cover in 15 minutes ( $4 \text{ nm/hr} \times 0.25 \text{ hr} = 1.0 \text{ nm}$ ). Place one point of the dividers on point C, and the other point on line AB (this point is labeled "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  $210^\circ$ . Navigators call line CD "course steered," while line AB is called "course made good."

To find out how long it will take for the AUV to cover leg 7, you need to know the speed that the AUV would actually achieve on the course made good. This speed is called "speed made good." To find speed made good, measure the length of line segment AD using the latitude scale (about 0.85 nm). This is the distance that the AUV will actually cover in 15 minutes. Now you can calculate the speed made good by dividing this distance by the time (in hours) required to cover this distance:

$$0.85 \text{ nm} \div 0.25 \text{ hr} = 3.4 \text{ nm/hr} = 3.4 \text{ kn}$$

To add Leg 7 to the survey with correction for current set and drift, draw Leg 7 and measure its length (about 1.05 nm). Calculate the run time by dividing the length of Leg 7 by the speed made good:

$$1.05 \text{ nm} \div 3.4 \text{ nm/hr} = 0.306 \text{ hr}$$

So, step 8 of your survey plan would read:

8. Run on Course =  $210^\circ$  for 0.35 hr (Leg 7)

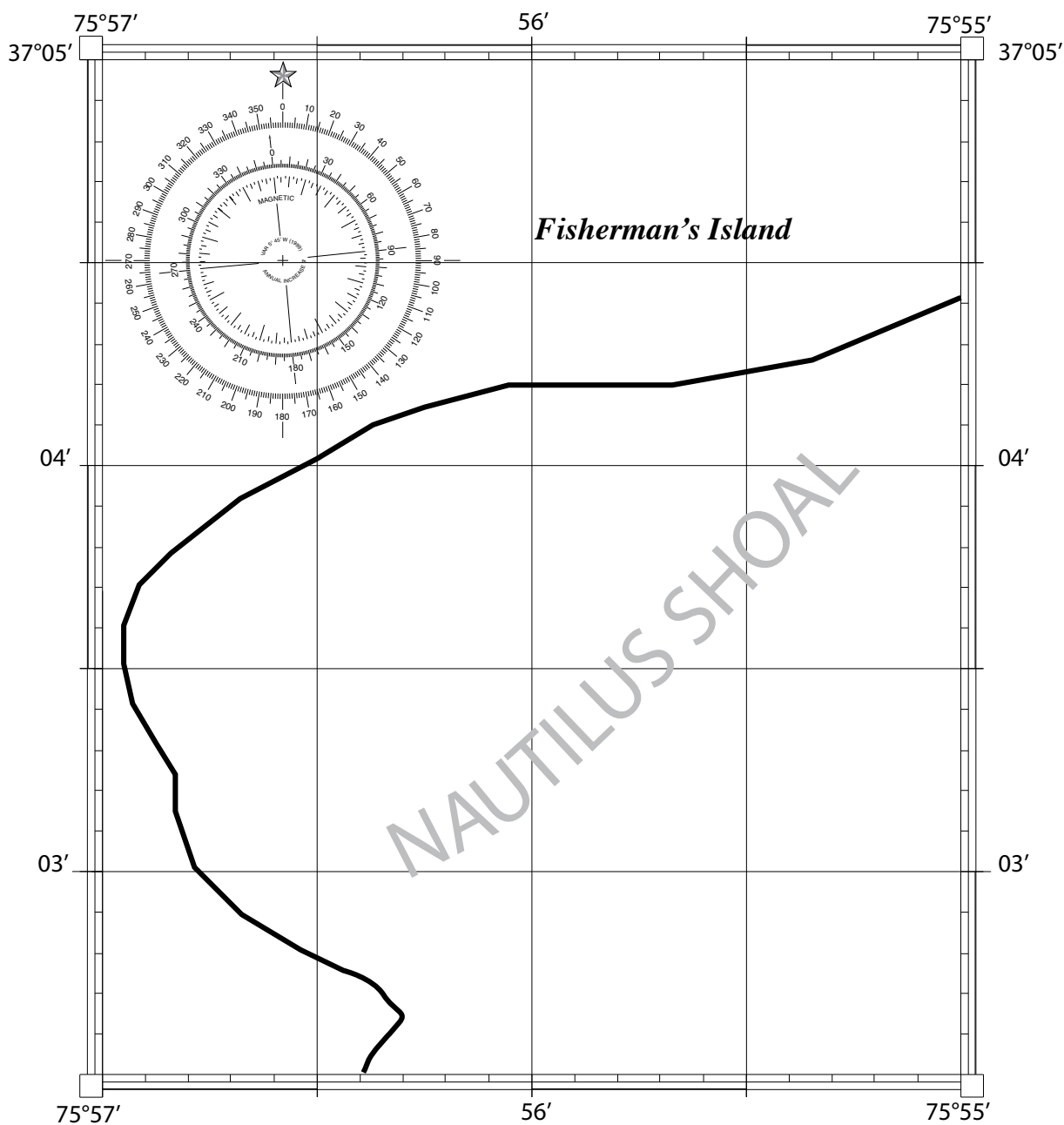
## The Robot Archaeologist Student Worksheet – 9

### 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  $37^{\circ}03.0'N$ ,  $75^{\circ}56.8'W$ , and running your survey lines in an east-west direction. Draw your complete survey plan on Figure 6.

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



## The Robot Archaeologist Student Handout

# Autonomous Underwater Vehicles Overview

Autonomous Underwater Vehicles (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); a power source such as batteries or fuel cells; environmental sensors such as video and devices for measuring water chemistry; a computer 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/08aувfest>.