20

Water Vehicular Systems

Basic Concepts

- Define the four types of propulsion.
- Identify tools used to find direction, speed, time, and location in water transportation.
- Cite ways in which vessels are controlled.
- State the functions of hydrofoils and hovercraft.
- List several nautical terms and parts of ships.
- Name the support systems of water transportation.

Intermediate Concepts

- Chart a course on a nautical chart.

Advanced Concepts

- Calculate the hull speed of different sized vessels.
- Design hulls for different uses of vessels.

All water vehicles are designed for specific purposes. These vehicles may be used for recreation, to move cargo, or to transport people. Whatever the vehicle's purpose, all water vehicles are moved by propulsion systems, directed by guidance systems, steered by control systems, kept afloat by suspension systems, comprised of structural systems, and docked at support systems.

Propulsion Systems

Like all forms of transportation, water vessels require a propulsion system to move. The earliest forms of propulsion were the paddle and oar, followed by the sail. The most recent additions to water propulsion are the propeller and water jet. Each of these types of propulsion has some type of contact with either the water or wind that enables the vessel to be pushed or pulled across the water.

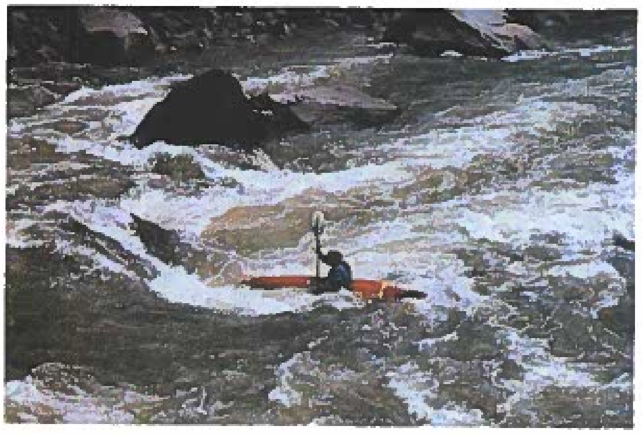
Paddle: An implement used to propel a boat using human power.

Sail: An extent of fabric by means of which wind is used to propel a ship through water.

Paddles and Oars

Paddles were the first type of propulsion used to move boats. Early rafts and canoes were put into motion by a flattened log under human power. For many years, human power was used to row canoes, boats, and even ships. Large ships built 2500 years ago were propelled by over 150 people rowing with large oars. The first boats to use engines were still also propelled by paddles. The steam engines in paddleboats were used to turn a wheel of paddles. The contact between the paddles and water is what propelled the boats. Today, paddles and oars are still used in small recreational watercraft. See **Figure 20-1.**

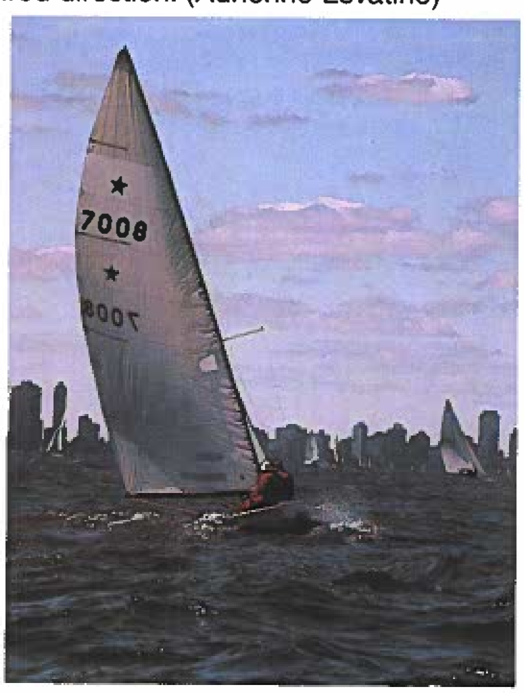
Figure 20-1. Oars and paddles are used today to propel and guide small recreational watercraft, such as rowboats, canoes, and this kayak.



Sails

A ***sail*** is a piece of fabric used to convert wind energy into a source of propulsion. Most sails are triangular and able to rotate into the wind. See **Figure 20-2.** Sails can be used to propel boats in any direction, except within 45° from the direction of the wind. This is because sails actually function as an airfoil (much like an airplane wing or race car spoiler). When the wind hits the sail, just enough air goes into the sail to give it the rounded shape. The rest of the air travels on either side. The air moving across the sail is deflected in one direction. This deflection generates motion roughly perpendicular to the bottom edge of the sail. Depending on the direction of the wind, it may tend to pull the sailboat sideways. To counteract this effect, sailboats have a keel, or centerboard, which is placed along the bottom of the boat.

Figure 20-2. A sailboat has triangular sails that can change positions to move the vessel in the desired direction. (Adrienne Levatino)



The mainsail and jib are the types of sails used to drive small sailboats. The ***mainsail*** is the larger of the two and is connected to the mast and a boom. It can be rotated by allowing slack on either side in the ropes, or ***sheets***, in nautical terms. The ***jib*** is a smaller sail and is connected to the mast and the bow. The ***bow*** is the very front of a vessel. The jib can be pulled tight on either side of the boat, depending on the angle of the wind. ***Spinnaker*** sails are used at the front of the boat when traveling downwind. These sails are typically large and colorful and resemble a section of a hot air balloon. See **Figure 20-3.**

Propellers

A ***propeller*** is a rotating blade that produces thrust. Thrust is the propeller's reaction to the water that pushes the boat forward. There are several types of propellers used in vessels. See **Figure 20-4.** An important part of a propeller is its pitch. The ***pitch*** is the angle of the blade. The greater the pitch is, the faster the propeller will travel. If the propeller pitch is too great or too little, however, the propeller is inefficient and travels slower. The propeller cannot turn by itself, so it requires a power source. Internal combustion engines, diesel engines, turboelectric generators, gas turbines, and even nuclear reactors are used to power propellers.

Outboard engines are most common on fishing boats and small motorboats. In this type of system, the power source and propeller are one piece. Outboard engines are attached to the ***stern*** (back) of the boat. See **Figure 20-5.** ***Inboard/outboard engines*** are used in mid-sized recreational boats. These systems have larger engines than outboard engines mounted inside the boat, with a propeller similar to an outboard engine's propeller. ***Inboard engines*** are used on most vessels over 36′ in length. These systems have a power source mounted inside the ship attached to a propeller shaft.

On large ships, engines are used to generate and store electricity. Military submarines, for example, use a system to generate power for electric motors. This inboard propulsion system, known as a ***nuclear turbine engine***, uses a nuclear reactor to heat water. The water becomes steam and turns a turbine engine, which creates electricity. The electricity is used to power the submarine and turn the propellers. Excess electricity is stored in batteries for later use. This allows the submarine to turn the turbine engine off, remain quiet, and still have electricity and propulsion.

Mainsail: The larger of the two sails on a sailboat. It is connected to the mast and a boom.

Sheet: A rope used on a sailboat.

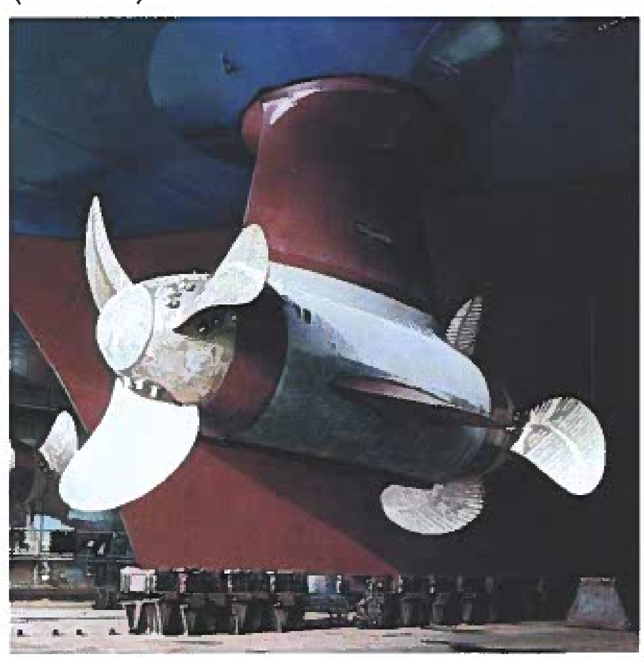
Jib: The smaller sail on a sailboat that is connected to the mast and the bow.

Bow: The very front of a vessel.

Spinnaker: A sail used at the front of a boat when traveling downwind.

Figure 20-3. The three basic types of sails are visible in this photograph. The sailboat in the foreground has both a mainsail and a jib. The blue-striped sail on the boat in the background is a balloon spinnaker.

Figure 20-4. The three-bladed propeller is most common for both large and small boats. This massive unit, called a *pod prop*, has propellers on both ends and can be swiveled in any direction. A matching unit is just visible on the other side of the ship's keel. The two units can be used to steer and maneuver a large ship in any direction, eliminating the need for a rudder. (Siemens)



Propeller: A rotating blade that produces thrust.

Pitch: The angle of a propeller's blade.

The advantage of nuclear power over diesel or gas is that one load of uranium fuel can last over a year, allowing the submarine to remain submerged without having to refuel.

Water Jets

Water jets are the newest form of marine propulsion. They use an inboard engine to turn an impeller. The impeller draws in water and expels it through a nozzle. The water forced out of the jet propels the craft. Water jets are extremely popular for personal watercraft, such as Jet Ski® watercraft, because they do not contain dangerous propellers. They are used in ferries and hydrofoils because of their higher top speed. Water jets, in the form of thrusters, are also used on large ships to help the ships move in and out of docks.

Figure 20-5. An outboard motor is a widely used propulsion method for recreational watercraft ranging from small fishing boats to speedboats. The power source is an internal combustion engine that turns a shaft directly connected to the propeller. When in use, the entire unit is rotated to steer the boat. The motor can be removed when the boat is not in use. (Bayliner Marine Corporation)

Figure 20-6. This compass is designed for use in automobiles. Instead of a simple magnetized needle that rotates on a pivot, it has a dome that rotates freely in a liquid. As the vehicle changes direction, the north-pointing magnet in the compass causes the dome to rotate. The direction the vehicle is traveling (southwest, in this case) is aligned with a red bar.

Guidance Systems

Boats and ships are able to be propelled in various directions and do not use fixed paths, like automobiles do. Shipping routes and sea-lanes help to keep ocean travel in set routes. These are not as easy to identify, however, as highways are. Boat and ship navigators must use navigational tools to find both their current location and their destination. The captain must then track the navigation variables: direction, speed, and time.

Direction-Finding Tools

Direction-finding devices have been used in ship navigation for hundreds of years. Several of these technologies are actually still used as references. ***Compasses*** are simple devices for determining which direction is north. The compass was an early navigational device developed in Europe and Asia in the 1100s. This technology was created soon after it became known that lodestone, a type of magnetite that has polarity, would point north when allowed to rotate freely. The first compasses were simply pieces of lodestone floating in water. Today, simple compasses use a free-floating, magnetized needle that spins on an axis. See **Figure 20-6.** The needle will always point north (unless it is placed near a magnetic field). Compasses are used to determine both heading and bearing. The direction the boat is pointed at a given time is the

heading. The ***bearing*** is the desired direction of travel. See **Figure 20-7.** Many ships and boats also use radio direction-finding equipment. Electronic equipment aboard the vehicle receives transmissions sent by radio transmitters (beacons). The navigator adjusts the antenna until its signal is locked onto the direction of the incoming signals. The heading of the vessel can then be adjusted according to the position of the beacon. The locations of beacons are identified on nautical charts.

Outboard engine: The most common motor used on fishing boats and small motorboats. Its power source and propeller are one piece.

Stern: The back of a boat.

Inboard/outboard engine: An engine used in mid-sized recreational boats. These systems have larger engines than outboard motors mounted inside the boat.

Speed Tools

Speed indicators aboard marine transportation vehicles are called ***logs***. Historically, wooden logs were used as the first speed indicators in sailing. Logs were tied to a rope and dropped overboard. The rope had a series of knots tied in it every 47′ 3″. Once the log was in the water, a sailor would count the number of rope knots that passed the back of the ship in 28 seconds. If the log carried eight knots past the back of the boat, the boat was traveling at 8 knots (nautical miles per hour). A ***nautical mile*** is roughly equal to 1 minute, or 1/60 of a degree, of latitude around the earth. It is equal to about 1.15 statute miles. The measurement of nautical miles was first used in sailing. Today, mechanical devices have taken the place of the logs thrown overboard. The speed logs currently in use are made up of two electronic transducers and a digital monitor. The transducers are placed in the ***hull***, or the body of the boat or ship, one in front and the other in the rear. The rear transducer sends a signal to the front. The speed of the vessel determines the amount of time it takes to receive the signal. This is then displayed on the digital display.

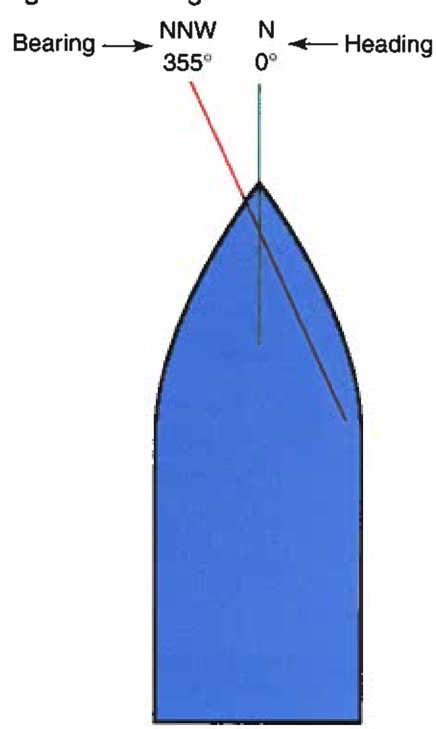
Time Tools

Speed logs often have a setting that will display the current time or even act as a stopwatch. A timepiece of some sort is an essential tool for navigation of a vessel. It can be helpful in determining location. If the ship has been traveling at the same speed and in the same direction, it is easy for the captain to determine how far it is from shore. It is also helpful, especially for a novice sailor, to know what time it is. With a timepiece, he can get back into the harbor before nighttime, so he can use visual navigation aids.

Location Tools

Nautical charts are maps that show coastal waters, rivers, and other marine areas. These charts are specially designed to show information for navigating waterways. They are marked with special symbols that represent things such as depths of water, channel markers, buoys, underwater phone and electric lines, and wrecks. Coastal features that can aid

Figure 20-7. Heading and bearing may be different. Turning the ship until it is pointed in the desired direction (bearing) is known as "changing the heading."



STEM Connection

Science: Relative Velocity

Imagine you are riding in a car traveling 65 miles per hour (mph). Sitting in the back seat, you toss a ball up in the air and then catch it. The ball is in the air for a total of 1 second.

From your point of view (referred to as *frame of reference*) in the car, the ball moves straight up and down. If your friend was standing along the side of the road watching this through the car window, however, she would see the ball travel over 95′ in the air. This is the distance that you, the ball, and the car travel in 1 second at 65 mph. Thus, you are actually throwing the ball nearly 100′ when you toss it in the car!

In science, this concept is called relative velocity. Relative velocity states that the speed of an object is relative to the frame of reference from which it is viewed. This is an important concept for boats traveling on rivers. In a river, water flows downstream. A boat's propulsion system determines the boat's speed, relative to the water. For example, imagine you are rowing a rowboat in a river. The water in the river is flowing at a rate of 3 mph. You may be able to row a rowboat at a constant speed of 5 mph, relative to the water. If your friend was watching you from the riverbank, your rowboat would be moving 8 mph if you were heading downstream (the boat's 5 mph, plus the river's 3 mph). If you were heading upstream, your boat would be traveling 2 mph, relative to your friend (the boat's 5 mph, minus the river's 3 mph). The concept of relative velocity serves as the foundation for Albert Einstein's theory of relativity and perhaps physics' most well-known equation, $E = mc^2$.

in navigation also appear on nautical charts. These include lighthouses, church steeples, and water towers. Nautical charts also show latitude and longitude lines, and some show the grid pattern used with the Loran-C navigation system. Ships use charts on the open sea and in waterways to plot their own positions and, possibly, those of other craft in the area. See **Figure 20-8.**

Electronic navigation tools

There are a number of electronic devices used to aid marine navigation. ***Radio detecting and ranging (radar)*** systems contain a transmitter, a receiver, and a display. The transmitter sends radio waves in a circle around the vessel. The receiver picks up the waves that have bounced off of an object and are returning back. The results are sent to the display, and the operator is able to view a 360° view of the objects around the vessel. Radar is especially helpful in bad weather conditions and in avoiding other vessels. ***Loran-C*** is a long-range navigation system. The location is displayed as a series of numbers that can be plotted on a nautical chart with Loran-C lines. Loran-C determines location by figuring the difference in time it takes two base stations to send timed signals to the receiver. The global positioning system (GPS) has quickly become a useful tool in marine navigation. It is extremely accurate and can be used in all weather conditions. This system consists of 24 satellites that circle the earth in a

Inboard engine: An engine used on most vessels over 36′ in length. Its power source is mounted inside the ship attached to a propeller shaft.

Nuclear turbine engine: An inboard propulsion system that uses a nuclear reactor to heat water.

Water jet: The newest form of marine propulsion. It uses an inboard engine to turn an impeller.

specific configuration. Both GPS and Loran-C receivers allow the navigator to input way points (destinations). Once the way points are input, the navigation receivers provide the bearing the vessel must follow to reach the destination.

Visual navigation aids

Navigational tools are helpful while in route from one place to another. When entering and exiting a harbor, port, or waterway, however, it is easier to use visual aids. A system of different colored buoys, known as the U.S. Aids to Navigation System (US ATONS), has been designed to ensure the meanings of the buoys are consistent. ***Buoys*** are painted markers anchored in a body of water to guide water vehicles. See **Figure 20-9.** Their colors have significant meanings to boat pilots. Red buoys mark the right side of a channel as the boat is coming into port. Green buoys mark the left side. Buoys painted in red and white bands mark safe water. Orange diamonds painted on buoys mark dangerous water and should be avoided. Some buoys have messages marked on them so their meanings are clear. Many buoys have lights so they can be seen easily at night. Navigators can tell what each lighted buoy means by the color of its light and the length of its flashes.

Control Systems

The control systems of water vessels perform two functions. The first is to the steer the boat or ship from side to side. The second function is to raise or lower the vessel.

Steering Systems

Steering vessels from side to side can be done by turning the propulsion units. For example, in water jet–propelled vehicles, the operators change the position of the jet nozzles to change the direction of thrust. The sterns of jet-propelled marine vehicles will move in the opposite direction of the thrust. See **Figure 20-10.** Boats with outboard engines are steered this way. When the engine is rotated, the stern of the boat is pushed in the opposite direction. The sailor is usually able to turn the engine or water jet about 45° in either direction.

Compass: A simple device for determining which direction is north.

Heading: The direction a boat is pointed.

Bearing: The desired direction of travel.

Log: A speed indicator aboard a marine transportation vehicle.

Nautical mile: Roughly 1 minute, or 1/60 of a degree, of latitude around the earth. It is equal to about 1.15 statute miles.

Hull: The body of a boat or ship.

Nautical chart: A map that shows coastal waters, rivers, and other marine areas. It is designed to show information for navigating waterways.

Figure 20-8. A ship's navigators plot courses and positions on a nautical chart. (U.S. Navy)

Figure 20-9. A red buoy such as this one marks the right side of a channel leading into a port. The opposite side of the channel is marked with green buoys.

Figure 20-10. This Jet Ski® watercraft is steered by changing the position of the jet propulsion nozzles.

In all other craft, including large ocean-going vessels, steering is done by the use of a rudder. ***Rudders*** are hinged vertical surfaces on water vehicles. They are usually located near the output of the propulsion source. Ships with more than one propeller typically have an equal number of rudders. The rudders act to change the direction of water pressure against the vessel. Because of the change in pressure, the vessel's heading is changed. Rudders control the stern of most marine vehicles. This is similar to the way rear-steered land vehicles are controlled. Rudders can either be balanced or unbalanced. An unbalanced rudder is the simpler of the two and is usually found on small sailboats. See **Figure 20-11.** In small sailboats, rudders can be turned by hand. In large ships, however, the rudders may weigh thousands of pounds. In mid- to large-sized ships, gears, hydraulics, or pneumatics turn the rudders.

Air-cushioned marine vehicles have the rudders behind the propulsion fans that move air. The rudders or vanes use the airflow to change the vehicle's direction of travel. See **Figure 20-12.**

Radio detecting and ranging (radar): An electronic navigation tool that contains a transmitter, a receiver, and a display.

Loran-C: A long-range navigation system.

Buoy: A painted marker anchored in a body of water to guide water vehicles.

Diving and Rising Systems

Submarines and submersibles operate at many depths under the surface of the water. They have very specialized control systems that allow them to dive and rise. Basically, they can increase or decrease their buoyancy or weight to control their depth.

Submersibles often carry weights that pull them down to the desired depth. They have specialized compartments that fill with water to equalize the pressure as they are descending. Once the submersible is ready to ascend, it releases the weights and allows the water to drain on the way to the surface.

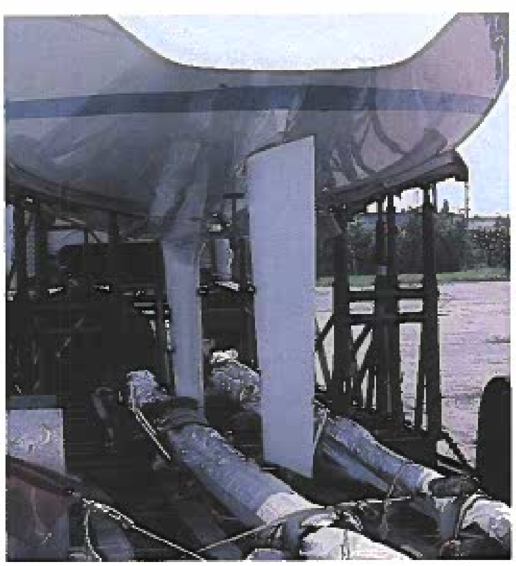


Figure 20-11. Balanced or unbalanced rudders are used on different types of boats. This is an unbalanced rudder on a medium-sized sailboat. It consists of the rudder, which is usually shaped like the letter *D*; a tiller, which is the steering rod the sailor uses to turn the rudder; and the stock, which is a vertical shaft connecting the rudder with the tiller. Balanced rudders have the same configuration, except there is an additional small rudder on the opposite side of the stock. The additional rudder helps push the main rudder into position.

Submarines dive and rise a little differently from submersibles. They are constructed with inner and outer hulls. See **Figure 20-13.** To dive, the submarine allows the space between the two hulls, or the ballast area, to be filled with water. This creates negative buoyancy, and the submarine dives. Once a submarine is underwater, it uses propellers, wings, and rudders to maneuver. In order to surface, the submarine uses compressed air to pump the water out from the ballast area. The submarine again becomes buoyant, rises to the surface, and floats.

Figure 20-12. Large vanes or rudders positioned behind the propulsion fans steer airboats used in swampy areas. (U.S. Navy)

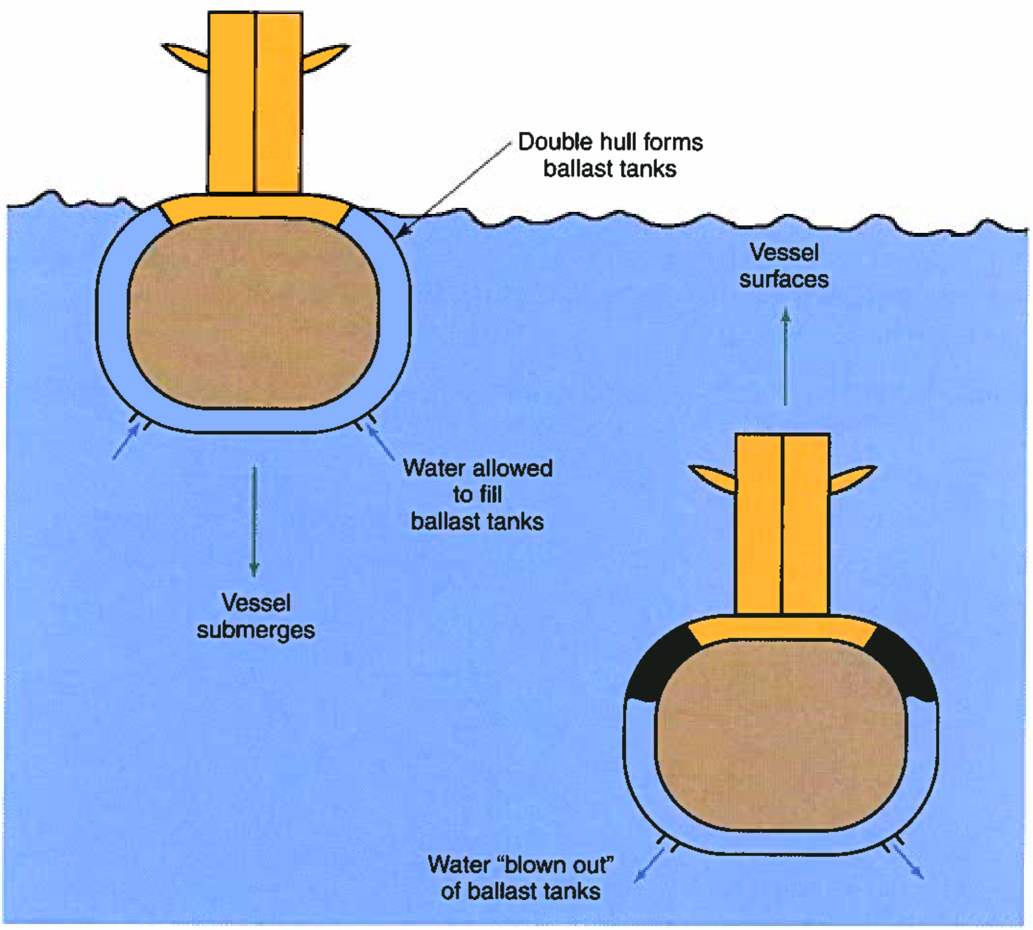
Suspension Systems

Hulls serve as the suspension systems of marine vehicles. They must keep the vessel afloat and stabilize the vessel in various water and weather conditions. Hulls stay afloat by moving, or displacing, the same

Rudder: A hinged vertical surface on a water vehicle. It acts to change the direction of water pressure against the vessel. Rudders control the stern of most marine vehicles.

GREEN TECH
Submarines that are not in use may pose a threat to the environment. If nuclear submarines are allowed to degrade and sink, the nuclear fuel may contaminate the water. Measures have been taken to attempt to prevent this from happening.

Figure 20-13. The submarine dive process involves flooding the space between the submarine's hulls (ballast tanks) to create negative buoyancy. To rise to the surface, compressed air is used to "blow the tanks," forcing out the water and creating positive buoyancy.



amount of water as the ship weighs. They must be designed to displace the additional weight of the people or cargo when the vessels are loaded. If the additional weight is not factored into the design, the ship will capsize as the weight of the ship becomes greater than the weight of the displaced water.

Full displacement hull: A hull that sits low in the water and has the greatest draft. It is very economical and efficient.

Draft: The distance from the waterline to the bottom of the boat.

Waterline: The location at which the water stops along the side of the hull.

Hull speed: The top speed at which hulls become inefficient and dangerous. It is figured by measuring the length of the boat at the waterline, finding the square root of the length, and multiplying by 1.34.

There are three types of hulls used on all types of watercraft, from speedboats to ocean liners. The intended use of the vessel determines whether the hull is a full displacement, semiplaning, or planing hull. At rest and at very low speeds, all hulls act as ***full displacement hulls.*** Displacement hulls sit low in the water. They have the greatest draft. ***Draft*** is the distance from the waterline to the bottom of the boat. The ***waterline*** is the location at which the water stops along the side of the hull. See **Figure 20-14.** The advantage of displacement hulls is that they are very economical and efficient. A cruising vessel, or yacht, with a displacement hull may be able to obtain around 7 nautical miles to the gallon of fuel. Displacement hulls also handle better and require less power than the other two types of hulls. Because full displacement hulls have so much draft, however, they make a great amount of contact with the water, which causes friction. Due to this friction and the way in which the waves are formed under the bow of the ship, these are the slowest hulls. In fact, these hulls have a top speed at which they become inefficient and dangerous, known as ***hull speed***. Hull speed can be figured by measuring the length of the boat at the waterline, finding the square root of the length, and multiplying by 1.34. For example, a boat with a 26′ waterline would be able to travel at just under 7 nautical miles per hour (knots). You would take the square root of 26, which is 5.10, and then multiply that by 1.34 to get the answer of 6.83.

The ***planing hull*** is the exact opposite of the displacement hull. See **Figure 20-15.** When the vessel is being driven, the planing hull actually rides on top of the water. There is no maximum hull speed with planing hulls. A lot of power is required, however, to keep planing hulls on top of the water. Fuel efficiency may be as low as 1 mile per gallon. Planing hulls are also much harder to handle and much rougher in heavy waves.

Figure 20-14. A ship's draft is directly related to the speed and amount of force needed to move it through the water. A greater draft results in greater displacement and more friction.

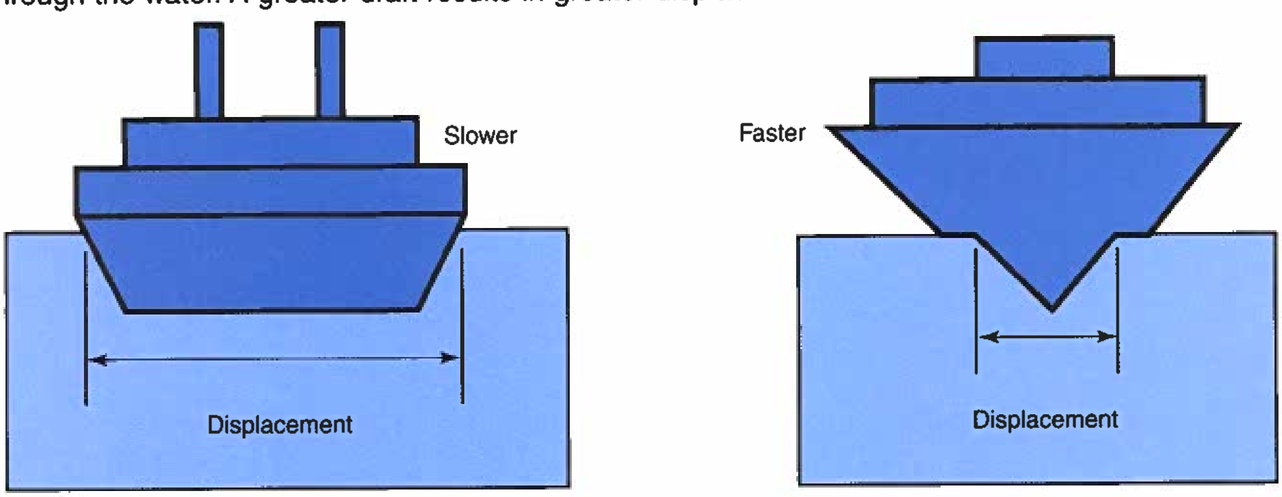


Figure 20-15. A boat with a planing hull lifts almost completely out of the water when it is "on plane." This makes the planing hull faster than the full displacement hull and the semiplaning hull. Vessels with planing hulls can travel two to three times faster than those with displacement hulls.

Planing hull: A hull that rides on top of the water. It has no maximum hull speed, but fuel efficiency is low, and it is hard to handle and rough in heavy waves.

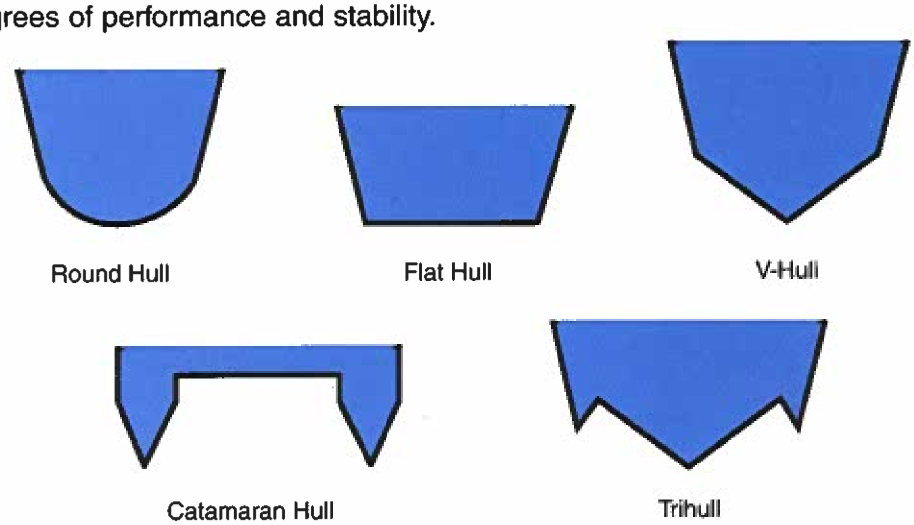
Semiplaning hull: A hull in which the stern of the boat remains in the water, like a displacement hull, and the bow is raised on top of the water, like a planing hull.

Semiplaning hulls may be the best of both worlds. Vessels designed with semiplaning hulls can attain higher speeds than those with full displacement hulls. They can also get better gas mileage than vessels with planing hulls. This is possible because the stern of the boat remains in the water, like a displacement hull, and the bow is raised on top of the water, like a planing hull.

Hulls can take on different shapes. See **Figure 20-16.** The following are the five basic hull shapes:

- **Round hull.** These are displacement hulls and are easily moved through water. They are the least stable of the group, as they tend to roll in the water. For this reason, most round hull boats use a keel or centerboard to add stability.
- **Flat hull.** These are generally planing hulls and provide more stability because of the surface area that comes in contact with the water. Their stability can be compared to a book resting on a table. They do not roll easily.

Figure 20-16. The five basic hull shapes. The shapes allow for various degrees of performance and stability.



Catamaran: A stable type of boat that has two hulls in the water.

Bilge keel: An extension protruding downward from the centerline of a boat. If the boat starts to lean, it acts as a hydrofoil and pushes against the water in the opposite direction.

- **V hull.** This design is similar to the round hull, except its undersides are flatter. Because of this, it is generally more stable than the round hull design. The pointed bow of boats leads to a partial V shape in many hulls.
- ***Catamaran.*** Boats with this type of hull are some of the most stable. They essentially have two hulls in the water. The hulls are placed far apart so the boat is difficult to roll.
- **Trihull.** Boats with this type of hull are some of the most stable. They have three hulls in the water. The hulls are side by side to increase stability.

Antirolling Devices

Stability is an important aspect of suspension systems. Vehicles must be able to remain upright while in operation. Unstable vehicles compromise the safety of passengers and cargo. Ships are subjected to large waves on the ocean. These waves can cause the ship to roll, leading to an uncomfortable ride. They may even cause the ship to capsize.

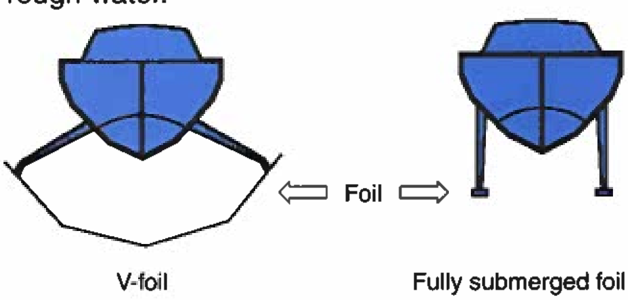
Bilge keels are extensions protruding downward from the centerline of a boat. See **Figure 20-17.** If the boat starts to lean, the keel acts as a hydrofoil and pushes against the water in the opposite direction. Antirolling, or passive, stabilizer tanks are U-shaped tanks, partially filled with water, located inside the hull of a ship. As the ship rolls to one side, the water in the tank will flow to the low side, causing the ship to roll back in the opposite direction. Activated ***fin stabilizers*** are fins located on the sides of a ship, below the waterline. Fin stabilizers basically act the same as bilge keels. When the ship rolls to one side, the increased surface area offers resistance to keep the ship upright.

Figure 20-17. Bilge keels are used on sailboats to keep them from tipping over. These keels increase the amount of surface area below the water surface.

Hydrofoils

The suspension systems of hydrofoils are completely different from those of other marine vehicles. Although hydrofoils are currently not in heavy use, their design is an important part of nautical suspension. Hydrofoils use airfoil-shaped devices to hold them up in the water. The main hulls of these vehicles rise out of the water when the vehicle is in operation. See **Figure 20-18.** Hydrofoil action is similar to an airfoil's action. The basic difference in a hydrofoil is that the fluid environment is water, not air. The foil creates a pressure difference between the top and bottom of the wing. When the boat is in motion, the foil deflects the oncoming water. As the water is deflected, the wing is forced upward in the water.

Figure 20-18. Hydrofoils are produced in two designs. The v-foil is very stable, but it is not suitable for rough water conditions. The fully submerged foil provides a smoother ride in rough water.



The wings are attached to the vehicle with long struts, so they push the main hull of the vehicle out of the water. The struts are lowered once the boat reaches a given speed. The foils, or wings, then lift the boat out of the water. They are always totally submerged. The foils are controlled, using a computer, to pivot the wings up and down on their struts. This increases or decreases the angle of attack and directly affects lift. The use of sensors and computer technology automates the process of control.

Fin stabilizer: A fin located on the side of a ship, below the waterline. When the ship rolls to one side, the increased surface area offers resistance to keep the ship upright.

Air Cushions

Air-cushion vehicles, sometimes known as ***hovercraft*** or ground-effect machines, are designed to ride on a cushion of air the vehicle generates. This type of suspension system allows travel over land or water. Flexible skirts at the bottom of the vehicle let the vehicle pass over obstacles without jarring itself.

These vehicles generate the cushion of air with powerful fans. The fans draw air from the top or sides of the vehicle and force it out the bottom. Two types of hovercraft configurations are the plenum chamber and the annular jet. The plenum chamber is the simpler of the two. See **Figure 20-19.** Air is essentially pumped straight through the craft to produce lift. The annular jet configuration directs the air so the air comes from the sides of the vehicle's bottom. The air is directed inward. The cushion of air the annular jet creates is stronger than that which the plenum chamber creates. It is also created with less energy.

Hovercraft: An air-cushion vehicle designed to ride on a cushion of air the vehicle generates. This type of suspension system allows travel over land or water.

Port: The left side of a ship.

Starboard: The right side of a ship.

Structural Systems

In all vessels, the very front is known as the bow. The rear is known as the stern. The areas in-between are divided into three zones: forward, amidships, and aft. The left of the ship is the ***port*** side. The right is the ***starboard*** side. See **Figure 20-20.** The measurements of the hull are known as the length overall (LOA) and beam. ***Length overall (LOA)*** is measured from the tip of the bow to the stern. Beam is the width of the ship at its widest point. Internal components used to strengthen the hull are known as ***bulkheads***. The top edge of the hull is named the ***gunwale***, or gunnel.

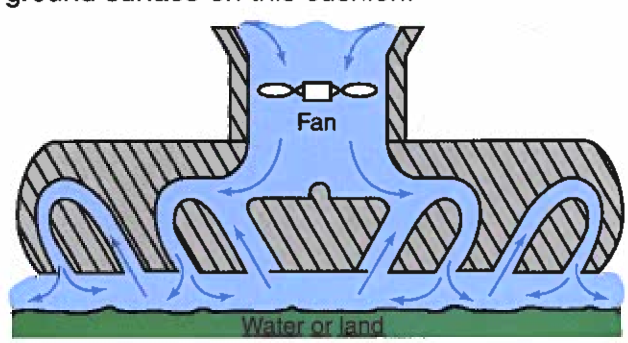
Length overall (LOA): The measurement from the tip of the bow to the stern.

Bulkhead: An internal component used to strengthen the hull.

The hull and other structural members of marine vessels are made from a number of materials. Traditionally, wood was used. Wood has natural buoyancy, is easy to work, and is readily available. Typical wooden boat construction requires a set of ribs built up around a keel. The keel is a frame member that runs the length of the boat on its centerline. Attached to this skeleton is wooden planking. The planking is cut and formed so it follows the contours of the skeleton.

Modern boat technology makes wide use of fiberglass-reinforced plastic, aluminum, and other lightweight alloys. Small, fiberglass boats usually do not need to be built around a central structure. Manufacturing processes

Figure 20-19. In the plenum chamber design used for air-cushion vehicles, a fan pumps air down through the vehicle to provide an air cushion. The vehicle rides above the water or ground surface on this cushion.



Gunwale: The top edge of the hull. Also called the gunnel.

Classification society: A society that sets and enforces the construction standards for shipbuilding.

Figure 20-20. A boat has its own special set of terms. A—The front of the boat is the bow. The rear is the stern. The left side (when facing the bow) is the port side, and the right side is the starboard side. B—When you are standing on the deck in the middle of the boat, you are amidships. If you walk toward the bow, you are going forward, and if you turn and walk toward the stern, you are heading aft.

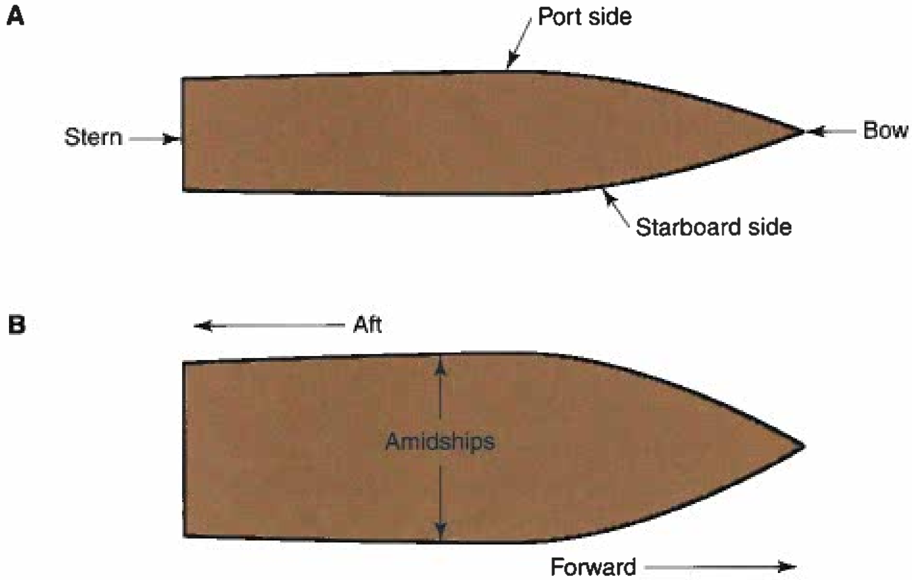
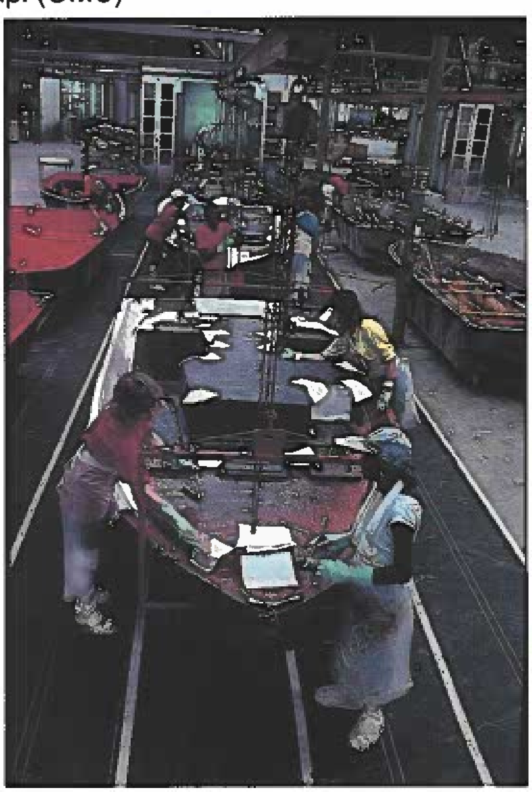


Figure 20-21. In this boat manufacturing plant, fiberglass hulls are shown in various stages of layup. (OMC)



allow a relatively strong shell to be made in a mold. See **Figure 20-21.** Attached to this shell are the propulsion and control systems. Other features that add to the comfort and pleasure are also built onto these structures. See **Figure 20-22.**

Ship Structural Systems

Oceangoing ships are made of metal and metal alloys. The main structural hull and supporting bulkheads are steel. Other structures on the vessels, such as the crew's living areas, passenger areas, and control room areas, may be constructed of lighter materials, such as aluminum alloys.

Shipbuilders must follow a rigid set of rules and regulations for construction of their vessels. Almost every shipbuilding country has its own ***classification society***. These societies set and enforce the construction standards. A prominent classification society is Lloyd's Register of Shipping in the United Kingdom. The American Bureau of Shipping is another large classification society. These organizations send representatives who watch the

Figure 20-22. Fiberglass hulls combine strength with light weight, making them ideal for racing.

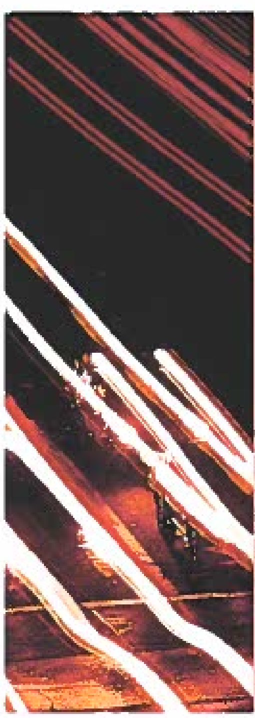
GREEN TECH

The manufacture of fiberglass may be harmful to the environment. Not only is there the possibility of emissions, but the water and soil can be affected. Emissions can be estimated, and waste that may impact water and soil can be managed and disposed of properly.

construction of ships to ensure that quality materials, equipment, and construction techniques are used. They then determine the classification of each vessel. This rigid system ensures high standards for the shipbuilding industry.

In the design and construction of ships, naval architects must be aware of the major hazards the ships face. When an iceberg or some other underwater obstacle tears open a hull, stranding occurs. The use of a double hull design usually controls damage from this type of problem. A second hull is built inside the main hull. The space between hulls can also be used as a stabilizer (antirolling) tank or as added flotation. Collision

Career Connection



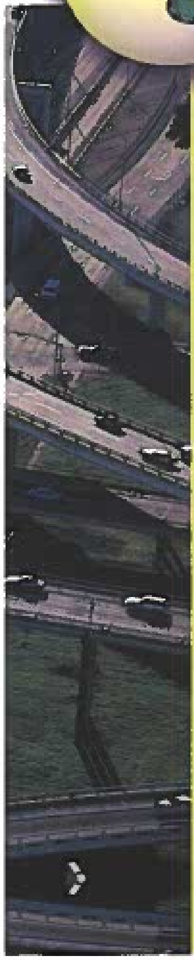
Marine Industry Metal Fabricators

Manufacturing

Metal fabricators ensure that engineering details are completed and materials are on hand to fabricate a wide variety of aluminum products for the recreational and commercial marine industry. They fabricate everything from custom rails for boats to standard production equipment found on some of the most popular commercial and recreational boats on the water today. Creating marine hardware can be both challenging and fun.

Like any job, this career has both positive and negative points. One of the most desirable aspects of this job is the personal satisfaction you can feel from seeing your products in use for both work and pleasure. Some disadvantages of this job, however, are the varying demands of the production schedule and the variations in weather conditions while working in an open-air shop.

A high school diploma is essential for a marine industry metal fabricator. Beyond that, vocational training or attending a technical college would be helpful. Experience in any aspect of metal fabrication, such as machining or welding, would be useful. A business degree or business experience would also be beneficial, but neither is required. The entry-level position in this field is an assistant. After gaining some experience, you can become a welder or fabricator, and eventually you may become a production manager.



Technology Link

Manufacturing: Shipbuilding

When you think of the manufacturing processes used to build vehicles, the first thing to come to mind may be the mass production lines used to build automobiles. Not all vehicles, however, are mass-produced. Ships, for example, are not mass-produced in an assembly line. The manufacturing process of shipbuilding is a very customized and time-consuming process. Ships are simply too large and customized to be manufactured using mass production techniques.

The facilities used to manufacture ships are known as shipyards. Shipyards contain several large buildings, including design offices, machining buildings, structural assembly buildings, and a shipway, or dry dock. Once the ship is designed to meet the customer's requirements, the designs are sent to the machining buildings. Most of the cutting and bending of steel required to manufacture the ship is completed using computer-controlled equipment. The fabricated pieces are moved to a structural assembly building, where sections of the ship are assembled. Relative to the size of the entire ship, ships are built in small blocks. The blocks can be manufactured and assembled inside climate-controlled buildings. Once the blocks are completed, they are moved to a dry-dock area. The dry dock is an open-air structure adjacent to the ocean. Water can either be pumped into or out of the dry dock. Final assembly of the ship begins without water in the dock. The ship is assembled from the ground up and welded together. Once the hull of the ship is completed, water is pumped into the dry dock, and the ship begins to float. When the manufacturing is completed, the ship is moved out of the dry dock and tested in open water.

A majority of the ships built for the transportation industry are built in China and Japan. Both the United States and England, however, have several leading global shipbuilding companies. All shipyards across the globe are modernizing, in an effort to manufacture ships more efficiently and to stay ahead of the competition.

accidents may result in part of both layers of the hull being damaged at sea. In such cases, part of the ship becomes flooded. Bulkheads are used to divide the hull into different watertight sections. These are designed in such a way that only the damaged section floods. See **Figure 20-23.**

Figure 20-23. Watertight bulkheads are keeping this ship afloat, even though its bow was punctured in a collision, allowing water to flood some compartments. In such situations, the vessel is usually able to stay afloat and get to a port, where the hull can be repaired. All ships are fitted with collision bulkheads at the front. Areas where propulsion systems are located are also enclosed with bulkheads so this equipment is protected in the event of an accident. (U.S. Coast Guard)

Submarine Structural Systems

As you know, submarines are vehicles designed and built for underwater use. See **Figure 20-24.** During the study of fluid power, you learned that water exerts pressure. This pressure is directly related to the depth of water. The deeper a submarine travels, the more pressure it must be able to withstand. For this reason, submarines use a strengthened steel pressure hull.

Figure 20-24. A submarine hull is designed and built to withstand tremendous pressure from the surrounding water when it submerges. (U.S. Navy)

Usually, submarine hulls are doubled, similar to those of oceangoing ships. The void between hulls is used for fuel storage and as a water ballast. Because many submarines are designed and built for the military, the double hull technique has an added advantage. Antisubmarine weapons tend to damage the outer hull, while the inner hull remains intact.

Projecting from the top of the submarine, usually in the center of the vessel, is the ***conning tower***. This is where the ship's periscopes, radio antennas, and radio detecting and ranging (radar) equipment are located. Snorkel tubes are also part of the sail structure. They let the vehicle take in fresh air without actually surfacing.

Conning tower: Part of a submarine that projects from the top, usually in the center of the vessel. It is where the ship's periscopes, radio antennas, and radio detecting and ranging (radar) equipment are located.

Support Systems

Water transportation is made possible through its support facilities. Support facilities aid in keeping vessels maintained and operational. Vessels need places to be repaired, refueled, loaded, and unloaded. Harbors, docks, ports, locks, and terminals are all support systems. Without them, ships could not operate effectively.

Harbor: A point along the coast where the water is deep enough for the vessel to come very close to shore.

Harbors

A ***harbor*** is a point along the coast where the water is deep enough for the vessel to come very close to shore. See **Figure 20-25.** The main purpose of a harbor is to get the vessels in close to land. A ***harbormaster*** controls the flow of traffic in and out of the port. If the channel heading into a port is particularly dangerous, the harbormaster may be required to board a ship and assist in the navigation of the ship until it reaches safe waters. A small chase boat then picks up the harbormaster and returns to the port.

Figure 20-25. A modern deepwater harbor, which permits large vessels to tie up directly to a dock for loading or unloading. If a ship's draft is too great to tie up at the dock, it must anchor in deeper water. Smaller vessels called *lighters* are used to shuttle cargo between the dock and the anchored ship.

Ports

A port is a place where vessels load and unload cargo or passengers. There are many ports located along seacoasts, lakefronts, and rivers. Ports also have means for fueling and repair.

Harbormaster: An officer who controls the flow of traffic in and out of a port.

Lock: A chamber-like facility constructed in a canal between two different water levels. It is made up of gates, pumps, and filling and draining valves.

Terminal: A physical facility or building used to load and unload passengers and cargo.

Docks

Located at the port are docks. A dock is an area totally closed in by piers. Ships are usually not docked long at a port. They must get loaded or unloaded and continue on their journeys to other ports.

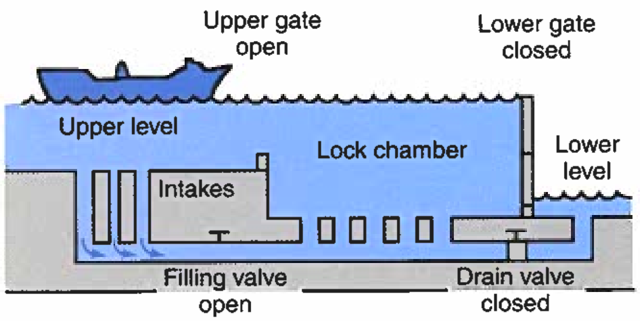
Locks

Locks are used in the inland waterways. A ***lock*** is a chamberlike facility constructed in a canal between two different water levels. It is made up of gates, pumps, and filling and draining valves. See **Figure 20-26.** As the vessel enters the upper level, the lock chamber is already filled to the same level by the filling valve. When the gates close behind the vessel, the drain valve opens to lower the water level. The water is now level with the lower level. The gate will open, and the vessel will be on its way out.

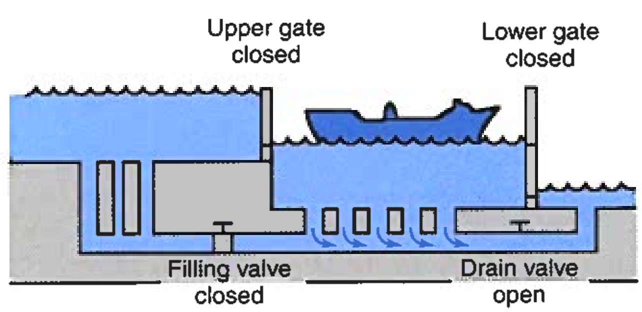
Terminals

Terminals are physical facilities, or buildings. They are needed to load and unload passengers and cargo. In passenger terminals, there are restaurants, waiting areas, and shops of various kinds. In cargo terminals, cargo is stored and later loaded onto another vessel or reshipped by rail, air, or highway transport.

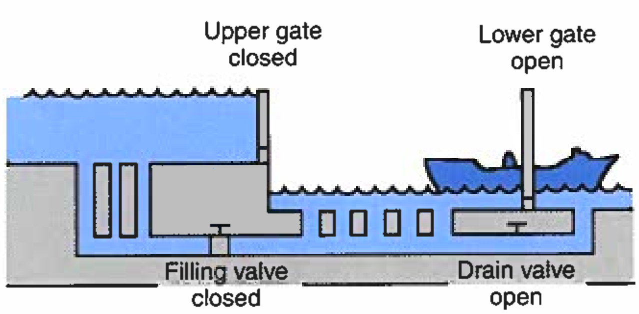
Figure 20-26. Operation of a lock used to transfer vessels between higher and lower levels on a waterway, such as a canal. Locks work similar to the way elevators work. Whereas elevators move people from one floor to another, a lock moves a vessel from one water level to another.



1. The lock chamber is filled to the same level as the upper level. The upper gate opens, and the vessel enters the lock chamber.



2. The upper gate is closed. The water in the lock chamber is allowed to drain.



3. When the water drains to the same level as the lower level, the lower gate opens, and the vessel moves out of the lock.

Summary

Water vehicles, like all vehicles, must have systems of propulsion, guidance, control, suspension, structure, and support. Propulsion systems include paddles, sails, propellers, and water jets. Small vessels, especially recreational types, typically use sails, small engines, and water jets. Large ships use diesel power to turn propellers. Vessels use guidance systems to navigate the waterways and oceans. Being able to navigate a ship or boat requires an understanding of nautical charts and buoy markings. The control systems of vessels rely on rudders to steer ships and boats. The hull of a vessel acts as the suspension system and, when properly designed, allows the boat or ship to float. Vessels also include a structural system comprised of bulkheads and other members that keep the vessel strong. Lastly, support facilities, such as harbors, ports, and docks, aid vessels.

Key Words

All the following words have been used in this chapter. Do you know their meanings?

bearing
bilge keel
bow
bulkhead
buoy
catamaran
classification society
compass
conning tower
draft
fin stabilizer
full displacement hull
gunwale
harbor
harbormaster
heading
hovercraft
hull
hull speed
inboard engine
inboard/outboard engine
jib
length overall (LOA)
lock
log
Loran-C
mainsail
nautical chart
nautical mile
nuclear turbine engine
outboard engine
paddle
pitch
planing hull
port
propeller
radio detecting and ranging (radar)
rudder
sail
semiplaning hull
sheet
spinnaker
starboard
stern
terminal
water jet
waterline

Test Your Knowledge

Write your answers on a separate sheet of paper. Do not write in this book.

1. List the four methods of propulsion used in water transportation.
2. The _____ is the small sail connected to the mast on a sailboat.
   A. spinnaker
   B. jib
   C. mainsail
   D. trifold
3. *True or False?* Inboard engines are the most popular type of engine for small fishing boats.
4. What type of propulsion do most military submarines use?
5. Why do submarines use the type of propulsion mentioned in Question 4?
6. Discuss the difference between heading and bearing.
7. Give examples of five elements that would be included on a nautical chart.
8. The _____ uses a constellation of 24 satellites to determine a vessel's location.
   A. Loran-C system
   B. global positioning system (GPS)
   C. radio detecting and ranging (radar) system
   D. nautical charting system
9. *True or False?* Rudders are used to control ships.
10. *True or False?* Outboard engines are able to rotate 360°.
11. Describe how a submarine dives.
12. *True or False?* Full displacement hulls ride on the top of the water.
13. *True or False?* A nautical mile is longer than a statute mile.
14. Determine the hull speed of a 15′ boat.
15. Recall and describe two hull shapes.
16. Sketch the type of hull used in barges. Explain why this type is used for this boat design.
17. A _____ rises out of the water with the use of foils when it reaches top speed.
    A. hydrofoil
    B. submarine
    C. hovercraft
    D. containership

Matching questions: For Questions 18 through 21, match the words on the left with the correct term on the right.

18. Front.
19. Back.
20. Left.
21. Right.

A. Port.
B. Stern.
C. Bow.
D. Starboard.

22. The beam of a ship is its _____.
    A. length
    B. height
    C. depth
    D. width
23. *True or False?* Bulkheads are used to divide the hull into separate sections.
24. Name two examples of classification societies.
25. If a ship is returning to port, what color buoy will be on port side?
26. Write a brief description of how a lock functions.

STEM Activities

1. Using the library or school resource center, research the history of boat propulsion. Select one system and explain how it operates. Prepare a report to the class on your findings.
2. Build a working model of a boat that can be propelled either by the release of stored energy (potential energy) or energy in motion (kinetic energy).
3. Using a container, such as a fish tank, tubing, and a small water pump system, build a working model of a lock system for raising a model boat from one water level to another.

Career Skills

Entrepreneurial Skills

People who desire to work for themselves can start and run their own businesses. These people are entrepreneurs. Entrepreneurship allows people to run a money-making venture for several hours a week. Some ventures become so successful that full-time careers are possible.

Entrepreneurship is a good way to have a successful career that you can control. However, success is not guaranteed. People who want to become entrepreneurs need to be prepared for the risks and responsibilities of running their own businesses.

Certain characteristics are vital for a person to succeed as an entrepreneur. Entrepreneurs must be self-starters who can recognize when they need to initiate action. They should be hard workers who are willing to put extreme effort into the business. They must be innovative, having interesting new ideas about doing or providing something that is not available anywhere else. Usually, a business succeeds by fulfilling a consumer need. A perceptive entrepreneur will be able to recognize a need that could become a money-making opportunity.

An entrepreneur needs to be committed to the business. This involves using his or her personal money, time, or other resources to make the business succeed. Entrepreneurs must be energetic and in good health to handle long workdays. An entrepreneur must also be willing to take risks. It is a huge risk to give up a steady paycheck for a business that may not succeed.

Entrepreneurs need to be capable of running all aspects of a business. They must be good managers. They must have some business acumen so they understand what is happening in the business. They may hire others to handle certain jobs, but they must be able to evaluate their employees' performance. They must be good at decision making, since the final decision on all matters lies with them. Problem-solving skills are also essential and include developing creative solutions that work.

In addition, entrepreneurs need basic skills. Communication skills are important for dealing with employees as well as clients. These skills are also important for communicating with other businesses, such as suppliers. In business, it is essential that written communications are clear because miscommunication can cost money.

Interpersonal skills go hand-in-hand with communication skills. You must be courteous in your communications with customers if you want repeat business. You should also be aware of how to best relate to employees. You will want to have cordial relationships with them, yet still remind them at all times that you are the boss.

It is important to have good math skills. Entrepreneurs use them to keep track of their business's profits, losses, assets, and liabilities. Without math skills, you could be cheated by a supplier or underpay your taxes. More importantly, you could lose everything by making a bad deal.

Entrepreneurs also need computer skills. Most procedures today, from inventory to billing, require computers. You must have good knowledge of computers and their uses, or the wisdom to seek an expert's advice.