Sailing

Introduction

Sailing is the propulsion of a vehicle and the control of its movement with large (usually fabric) foils called sails. By changing the rigging, rudder, and sometimes the keel or centreboard, a sailor manages the force of the wind on the sails in order to move the vessel relative to its surrounding medium (typically water, but also land and ice) and change its direction and speed. Mastery of the skill requires experience in varying wind and sea conditions, as well as knowledge concerning sailboats themselves and an understanding of one's surroundings.

While there are still some places in the world where sail-powered passenger, fishing and trading vessels are used, these craft have become rarer as internal combustion engines have become economically viable in even the poorest and most remote areas. In most countries sailing is enjoyed as a recreational activity or as a sport. Recreational sailing or yachting can be divided into racing and cruising. Cruising can include extended offshore and ocean-crossing trips, coastal sailing within sight of land, and daysailing.

Credits

This material is adapted from the following Wikipedia pages:

- Sailing
- Glossary of nautical terms

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History

Throughout history sailing has been instrumental in the development of civilization, affording humanity greater mobility than travel over land, whether for trade, transport or warfare, and the capacity for fishing. The earliest representation of a ship under sail appears on a painted disc found in Kuwait dating between 5000 and 5500 BCE. Polynesian oceanfarers traveled vast distances of open ocean in outrigger canoes using navigation methods such as stick charts. Advances in sailing technology from the Middle Ages onward enabled Arab, Chinese, Indian and European explorers to make longer voyages into regions with extreme weather and climatic conditions. There were improvements in sails, masts and rigging; improvements in marine navigation including the cross tree and charts, of both the sea and constellations, allowed more certainty in sea travel. From the 15th century onwards, European ships went further north, stayed longer on the Grand Banks and in the Gulf of St. Lawrence, and eventually began to explore the Pacific Northwest and the Western Arctic. Sailing has contributed to many great explorations in the world.

America's Cup defender *Reliance*

Introduction

The air interacting with the sails of a sailing vessel creates various forces, including reaction forces. If the sails are properly oriented with respect to the wind, then the net force on the sails will move the vessel forward. However, boats propelled by sails cannot sail directly into the wind. They must tack (turn the boat through the eye of the wind) back and forth in order to progress directly upwind (see Close Hauled or “Beating”).

Sails as airfoils

Sails are airfoils that work by using an airflow set up by the wind and the motion of the boat. Sails work in two "modes" to use the wind to generate force (see Forces on sails):

- **PUSH**: when the boat is going in the same direction as the wind, the wind force simply pushes on the sail. The force on the sail is mostly aerodynamic drag, and sails acting in this way are aerodynamically stalled.
- **PULL**: when the boat is traveling across the wind, the air coming in from the side is redirected toward the rear; according to Newton's Third law, the air is accelerated towards the rear of the boat and the sails experience a force in the opposite direction. This force manifests itself as pressure differences between the two sides of the sail — there is a region of low pressure on the front side of the sail and a region of high pressure on the back. Another way to say this is that sails generate lift using the air that flows around them in the same way as an aircraft wing. The wind flowing over the surface of the sail creates a force approximately perpendicular to the sail; the component of that force parallel to the boat's keel pulls the boat forward, the component perpendicular to the keel makes the boat heel and causes leeway.

Apparent wind

The wind that a boat experiences is the combination of the true wind (i.e. the wind relative to a stationary object) and the wind that occurs due to the forward motion of the boat. This combination is the apparent wind, which is the relative velocity of the wind relative to the boat.

When sailing upwind the apparent wind is greater than the true wind and the direction of the apparent wind will be forward of the true wind. Some high-performance boats are capable of traveling faster than the true windspeed on some points of sail, see for example the Hydroptère, which set a world speed record in 2009 by sailing 1.71 times the speed of the wind. "WSSR Newsletter No 177. Hydroptere World Records. 23/09/09". Sailspeedrecords.com. 2009-09-04. Retrieved 2010-06-30. "l'Hydroptère". Hydroptere.com. Retrieved 2010-06-30. Iceboats can typically sail at 5 times the speed of the wind. See "How fast do these things really go?" in the "FAQ published by the Four Lakes Ice Yacht Club"

The energy that drives a sailboat is harnessed by manipulating the relative movement of wind and water speed: if there is no difference in movement, such as on a calm day or when the wind and water current are moving in the same direction at the same speed, there is no energy to be extracted and the sailboat will not be able to do anything but drift. Where there is a difference in motion, then there is energy to be extracted at the interface. The sailboat does this by placing the sail(s) in the air and the hull(s) in the water.

A sailing vessel is not maneuverable due to sails alone-the forces caused by the wind on the sails would cause the vessel to rotate and travel sideways instead of moving forward. In the same manner that an aircraft requires stabilizers, such as a tailplane with elevators as well as wings, a boat requires a keel and rudder. The forces on the sails as well as those from below the water line on the keel, centreboard, and other underwater foils including the hull itself (especially for catamarans or in a traditional proa) combine and partially cancel each other to produce the motive force for the vessel. Thus, the physical portion of the boat that is below water can be regarded as functioning as a "second sail." The flow of water over the underwater hull portions creates hydrodynamic forces, which combine with the aerodynamic forces from the sails to allow motion in almost any direction except straight into the wind. How sail boats sail against the wind? Faster than the wind? http://PhysicsForArchitects.com/Sailing_against_the_wind.php When sailing close to the wind the force generated by the sail acts at 90° to the sail. This force can be considered as split into a small force acting in the direction of travel, as well as a large sideways force that heels (tips) the boat. To enable maximum forward speed, the force needs to be cancelled out, perhaps using human ballast, leaving only a smaller forward resultant force. Depending on the efficiency of the rig and hull, the angle of travel relative to the true wind can be as little as 35° or may need to be 80° or greater. This angle is half of the tacking angle and defines one side of a 'no-go zone' into the wind, in which a vessel cannot sail directly.

Tacking is essential when sailing upwind. The sails, when correctly adjusted, will generate aerodynamic lift. When sailing downwind, the sails no longer generate aerodynamic lift and airflow is stalled, with the wind push on the sails giving drag only. As the boat is going downwind, the apparent wind is less than the true wind and this, allied to the fact that the sails are not producing aerodynamic lift, serves to limit the downwind speed.

Points of sail

The point of sail describes a sailing boat's course in relation to the wind direction.

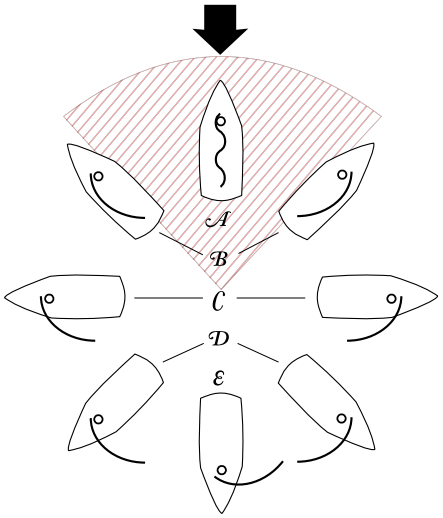
No sailboat can sail directly into the wind (known as being "in irons"), and for a given boat there is a minimum angle that it can sail relative to the wind; attempting to sail closer than that leads to the sails luffing and the boat will slow down and stop. This "no-go zone" (shown shaded in accompanying figure) is about 45° either side of the true wind for a modern sloop.

There are 5 main points of sail. In order from the edge of the no-go zone (or “irons”) to directly downwind they are:

1. close haul (the minimum angle to the wind that the boat and its rig can manage - typically about 45°)
2. close reach (between close hauled and a beam reach)
3. beam reach (approximately 90° to the wind)
4. broad reach (between a beam reach and running)
5. running (close to directly downwind)

The sail trim on a boat is relative to the point of sail one is on: on a beam reach sails are mostly let out, on a run sails are all the way out, and close hauled sails are pulled in very tightly. Two main skills of sailing are trimming the sails correctly for the direction and strength of the wind, and maintaining a course relative to the wind that suits the sails once trimmed.

The points of sail.



A. In Irons (into the wind); **B**. Close Hauled; **C**. Beam Reach; **D**. Broad Reach; **E**. Running (not shown: Close Reach, between Close Haul and Beam Reach)

Close Hauled or “Beating”

A boat can be ‘worked to windward’, to arrive at an upwind destination, by sailing close-hauled with the wind coming from one side, then tacking (turning the boat through the eye of the wind) and sailing with the wind coming from the other side. By this method of zig-zagging into the wind, known as beating, it is possible to reach any upwind destination. How sail boats sail against the wind? Faster than the wind? http://PhysicsForArchitects.com/Sailing_against_the_wind.php A yacht beating to a mark directly upwind one mile away will cover a distance through the water of at least 1.4 miles, if it can tack through an angle of 90 degrees including leeway. An old adage describes beating as sailing for twice the distance at half the speed and three times the discomfort. Each leg at 45 degrees to the true wind is 0.71 miles, but in reality is longer as total tacking angles greater than 90° are the norm and leeway can be significant.

Reaching

When the boat is traveling approximately perpendicular to the wind, this is called reaching.
A *beam reach* is with the wind at right angles to the boat, a *close reach* is anywhere between beating and a beam reach, and a *broad reach* is between a beam reach and running.

For most modern sailboats, that is boats with fore-and-aft sails, reaching is the fastest way to travel. The direction of the wind is ideal when reaching because it can maximize the lift generated on the sails in the forward direction of the boat, giving the best boat speed. Also when reaching, the boat can be steered exactly in the direction that is most desirable, and the sails can be trimmed for that direction.

warning:
Reaching may, however, put the boat on a course parallel with the crests of the waves. When the waves are steep, it may be necessary to sail closer to the wind to avoid waves directly on the beam, which create the danger of capsizing.

Running

Sailing the boat within roughly 30 degrees either side of dead downwind is called a run.

This can be the most comfortable point of sail, but requires constant attention. When the wind is coming directly behind the boat, the sailor must sail *wing on wing*, one sail on port the other on starboard. Loss of attention by the helmsperson can lead to an accidental jibe, causing injury to the boat or crew. All on deck must be aware of, and if possible avoid, the potential arc of the boom, mainsheet and other gear in case an accidental jibe occurs during a run. A preventer can be rigged to reduce danger and damage from accidental jibes.

Another technique used while running is *sailing by the lee*. Here the main sail is placed on the windward side of the boat, leading to a heightened risk of gybing. With the main placed perpendicular to the boat to windward, and then pulled in slightly, the leech is allowed to act as the leading edge of an airfoil. (Usually, the luff is the leading edge, such as when close-hauled.) This position, though unstable to accidental gybes, allows the sail to generate some force from lift, just as when sailing on a broad-reach. In fact, because there is no mast to generate turbulence around the sail's leading edge (as happens on the broad reach) the lift generated is somewhat stronger than might be expected for such an oblique profile.

Another technique often used by cruisers is to set two head sails, one to port and one to starboard. Depending on the sails, this can often give as much sail area as a spinnaker, but is easier to control. It is also easier to handle than going wing and wing, as the main sail is not set and does not disturb the air flow to the head sails. The main boom then can be rigged as a whisker pole too, to stabilize one of the head sails.

Running is generally the most unstable point of sail, but the easiest for a novice to grasp conceptually, making it a common downfall for beginners. In stronger winds, rolling increases as there is less rolling resistance provided by the sails, as they are eased out. Also, having the sails and boom(s) perpendicular to the boat throws weight and some wind force to that side, making the boat harder to balance. In smaller boats, death rolls can build up and lead to capsize.

warning:
Also on a run an inexperienced or inattentive sailor can easily misjudge the real wind strength since the boat speed subtracts directly from the true wind speed and makes the apparent wind less. In addition sea conditions can also falsely seem milder than they are as the waves ahead are being viewed from behind making white caps less apparent. When changing course from this point of sail to a reach or a beat, a sailboat that seemed under control can instantly become over-canvassed and in danger. Any boat over-canvassed on a run can round up, heel excessively and stop suddenly in the water. This is called broaching and it can lead to capsize, possible crew injury and loss of crew into the water.

Options for maneuvering are also reduced. On other points of sail, it is easy to stop or slow the boat by heading into the wind; there may be no such easy way out when running, especially in close quarters or when a spinnaker (including an Asymmetrical spinnaker), whisker pole or preventer are set.

Trim

An important aspect of sailing is keeping the boat in “trim”.

1. Course made good

   The turning or steering of the boat vessel using the wheel or tiller to the desired course or buoy. See different points of sail. This may be a definite bearing (e.g. steer 270 degrees), or along a transit, or at a desired angle to the apparent wind direction.
2. Trim

   This is the fore and aft balance of the boat. The aim is to adjust the moveable ballast (the crew) forwards or backwards to achieve an ‘even keel’. On an upwind course in a small boat, the crew typically sit forward to reduce drag. When ‘running’, it is more efficient for the crew to sit to the rear of the boat. The position of the crew matters less as the size (and weight) of the boat increases.
3. Balance

   This is the port and starboard balance. The aim, once again, is to adjust weight 'windward' or ‘leeward’ to prevent excessive heeling. The boat moves at a faster velocity if it is flat to the water.
4. Sail trim

   Trimming sails is a large topic. Simply put, however, a sail should be pulled in until it fills with wind, but no further than the point where the front edge of the sail (the luff) is exactly in line with the wind. Let it out until it starts to flap, and then pull it in until it stops.
5. Centreboard (Daggerboard)

   If a moveable centreboard is fitted, then it should be lowered when sailing "close to the wind" but can be raised up on downwind courses to reduce drag. The centreboard prevents lateral motion and allows the boat to sail upwind. A boat

with no centreboard will instead have a permanent keel, some other form of underwater foil, or even the hull itself which serves the same purpose. On a close haul the daggerboard should be fully down, and while running, over half way up.

Together, these points are known as ‘The Five Essentials’ and constitute the central aspects of sailing.

Sail trimming

The most basic control of the sail consists of setting its angle relative to the wind. The control line that accomplishes this is called a “sheet”. If the sheet is too loose the sail will flap in the wind, an occurrence that is called “luffing”. Optimum sail angle can be approximated by pulling the sheet in just so far as to make the luffing stop, or by using of tell-tales - small ribbons or yarn attached each side of the sail that both stream horizontally to indicate a properly trimmed sail. Finer controls adjust the overall shape of the sail.

Two or more sails are frequently combined to maximize the smooth flow of air. The sails are adjusted to create a smooth laminar flow over the sail surfaces. This is called the “slot effect”. The combined sails fit into an imaginary aerofoil outline, so that the most forward sails are more in line with the wind, whereas the more aft sails are more in line with the course followed. The combined efficiency of this sail plan is greater than the sum of each sail used in isolation.

More detailed aspects include specific control of the sail's shape, e.g.:

- reefing, or reducing the sail area in stronger wind
- altering sail shape to make it flatter in high winds
- raking the mast when going upwind (to tilt the sail towards the rear, this being more stable)
- providing sail twist to account for wind speed differential and to spill excess wind in gusty conditions
- gibbing or lowering a sail.

Abaft

Toward the stern, relative to some object (“abaft the fore hatch”).

Backstays

Long lines or cables, reaching from the stern of the vessel to the mast heads, used to support the mast.

Centreboard

A board or plate lowered through the hull of a dinghy on the centreline to resist leeway.

Going about or tacking

Changing from one tack to another by going through the wind (see also *gybe*).

Gybe

To change from one tack to the other away from the wind, with the stern of the vessel turning through the wind. (See also *going about* and *wearing ship*.)

Heeling

Heeling is the lean caused by the wind's force on the sails of a sailing vessel.

Jibe

See *gybe*.

Keel

The central structural basis of the hull.

Leech

The aft or trailing edge of a fore-and-aft sail; the leeward edge of a spinnaker; a vertical edge of a square sail. The leech is susceptible to twist, which is controlled by the boom vang, mainsheet and, if rigged with one, the gaff vang.

Luff

The forward edge of a sail.

Luffing

1. When a sailing vessel is steered far enough to windward that the sail is no longer completely filled with wind (the luff of a fore-and-aft sail begins to flap first).
2. Loosening a sheet so far past optimal trim that the sail is no longer completely filled with wind.
3. The flapping of the sail(s) which results from having no wind in the sail at all.

Rigging

The system of masts and lines on ships and other sailing vessels.

Sheet

A rope used to control the setting of a sail in relation to the direction of the wind.

Tacking

1. Zig-zagging so as to sail directly towards the wind (and for some rigs also away from it).
2. *Going about* (*q.v.*).

Weatherly

A ship that is easily sailed and maneuvered; makes little leeway when sailing to windward.

Windward

In the direction that the wind is coming from.