# Physics of Viking Sailing Ships

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During the Viking Age, Scandinavian shipwrights designed sailing ships to convey people and cargo across the seas and rivers of the north. While they may not have known the physics acting on the structures they constructed, the ships they built are now known to be solutions to the complex physical problems of sailing. Their proportions, hull construction, flexibility, mast support, and sailing and steering mechanisms all incorporate principals of physics for which these ships deserve recognition as wonders of early engineering, as well as historical significance.

There were two main classes of ships during the Viking Age. The famous longships were designed to convey warriors and their weaponry with great speed through fairly calm waters, while the knarrs were built to carry heavy cargo across the open seas. Each ship type relied on different dimensions to achieve these goals.

Evolving from war canoes, the longships were designed to move warriors onto a beach for a quick landing in order to take enemy by surprise. In order to accomplish this, they were designed to have long hulls to allow them to travel at great speed through shallow water. Their design also made them very maneuverable, at the expense of their stability in heavy seas.

The most obvious characteristic of the longship is its length, which allows it to move at high speeds. A longer hull allows for more oars, which would produce more power to move the ship. These ships had a ratio of length to width of about 7:1, (Nurmann, Schulze, Versülsdonk, 1997) which means they provided a fairly small cross sectional area in proportion to their size, reducing the drag on the boat. A replica of the Gokstad ship was found to be able to attain speeds of ten to eleven knots as a result of its hull design. (Wooding, 1996)

By increasing the length of the ship, the depth of water drawn was also reduced. It is estimated that the Gokstad ship required only half a meter of water to be displaced when fully loaded. (Haywood, 2000) This allows the longboat to land on beaches and sail up shallow rivers, in order to make surprise attacks. (Wingate, Millard, 1993)

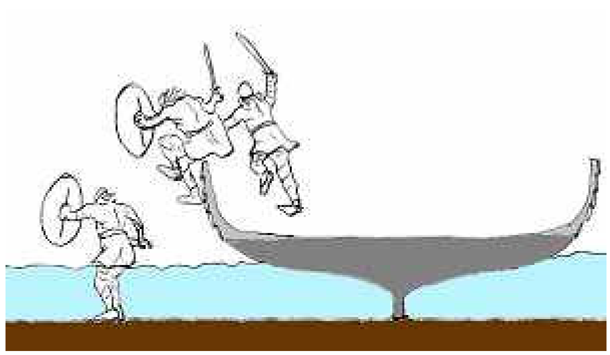

Figure 1: The longship had a shallow draft, allowing warriors to easily disembark for quick raids along coastal areas.

Maneuverability was aided by the curved stem and stern posts. (Nurmann, Schulze, Versülsdonk, 1997) These were beams that were attached onto the ends of the keel, which ran the length of the ship. As it would have been incredibly difficult to bend the ends of the oak keel out of the water, these posts were curved before being joined to the keel. This curvature reduces the resistance of the ship to turning. Opposing the ship's turning is a torque generated by the hydrodynamic resistance of the keel. Torque is the product of a force and the length of the lever arm, so the total torque is the sum of each drag force acting on the keel multiplied by the distance of the force from the central turning axis. The more of the ship that is in the water, the greater the resistance to turning, and the further this is from the turning axis, the greater the torque. By curving the ends of the ship, the ends of the boat, which are furthest from the central turning axis, are removed from the water. The keel's aspect ratio is thus increased, resistance decreased, and maneuverability improved.

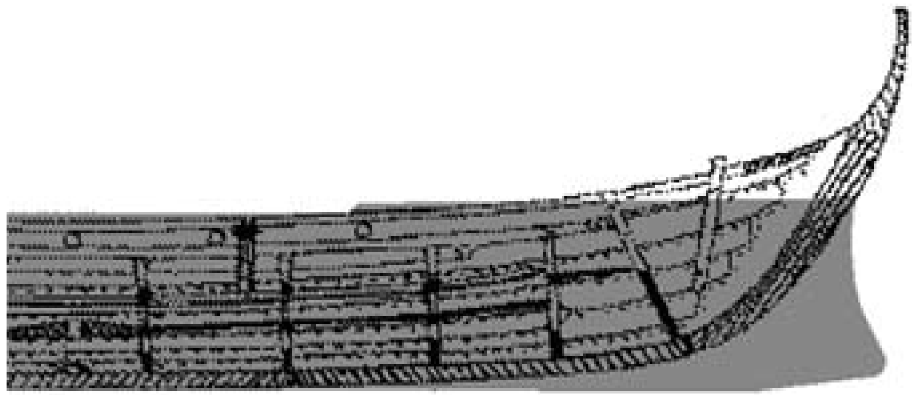

Figure 2: Comparison of hull shape for the USS Texas (gray) and an early longship. Note extra area in the battleship, which represents the additional water that must be pushed aside when turning, decreasing maneuverability. Scales adjusted to depict shape.

The lateral stability of the of early longships was sacrificed in order to attain the aforementioned sailing characteristics. One full scale replica was shown to be vulnerable to large waves from the side, due to its low freeboard. (Sawyer, 1997) Later ships were made more seaworthy by making them broader, deeper, and with higher stems. (Haywood, 2000) While this would have caused a reduction in top speed and an increase in the depth of water displaced, it allowed them to be able to cross stormy seas, as one longship replica did in 1893. (Nurmann, Schulze, Versülsdonk, 1997)

The Viking traders and colonists relied on a completely different sort of vessel from the warriors' longship. The Knarr was "wider, deeper, and slower than a longship, and could carry 30-40 people. In the middle of the boat was a large, open area into which goods could be packed." (Wingate, Millard, 1993) It was designed to carry cargo through sometimes stormy seas, without the aid of oars. Having only a 4:1 length-to-width ratio meant a lower top speed and an increased draft. (Nurmann, Schulze, Versülsdonk, 1997) As a result of its bulky profile, maneuverability was less than that that of the longboat, and the crew had to use oars in order to maneuver the ship into and out of harbor. (Haywood, 2000) However, it was much more stable than the longship, with the tons of cargo in the hold acting as ballast, and higher freeboards and closed ends. One replica sailed around the world, proving its stability." (Wooding, 1996)

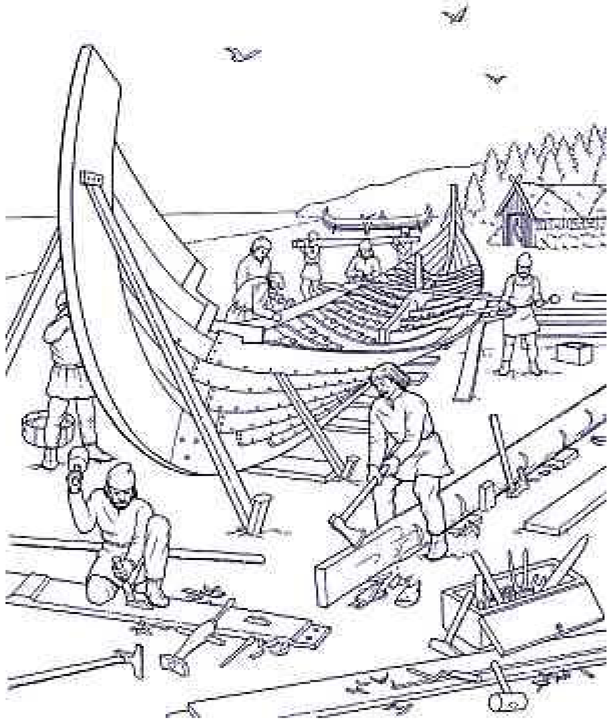

Figure 3: Ship under construction.

Both types of Viking ship were built in the same manner, known as clinker-building. Construction of a Viking ship began with the keel, which was a single beam hewn from the trunk of an oak tree. The stem and stern posts were also made of oak, for maximum strength. (Nurmann, Schulze, Versülsdonk, 1997) These beams formed the backbone of the ship, to which long planks were Figure 3: Ship under construction. attached, each row covering a portion of that below it, and attached to it by rivets. Afterwards, the internal frame members were attached for added strength. This method of construction meant that hull acted as a single body, with the water exerting a force on the planks, and the planks exerting forces directly onto the keel and end-posts. The force of the oars was also conserved, as it traveled along the length of the planking to the keel, rather than through a series of internal structures.

The internal frames supported the decking, and provided minimal structural support. This is why the keel had to be so strong, it ran the length of the ship, and was responsible for supporting the entire hull. Later ships relied on a complex frame to give the ship strength, with the outer shell merely keeping water out. (Wooding, 1996)

Because the forces acting on the hull were diverted along its length to the keel, the planks could be thinner than those used in conventional ships. Wood has a high compressive strength, and any force along the outside of a ship would result in a compressive force being delivered down the length of the board to the keel. The keel would then experience tension or compression, depending on the direction of the force. When in calm seas, the forces acting on the ship would be balanced, though in heavy seas, the ship would have to rely on its flexibility. The planks were split radially from logs, which minimized shrinkage and afforded them greater strength and flexibility than sawed boards. (Haywood, 2000) It was found that, even in the largest ships, the planks used below the waterline were only 26 mm thick. (Nurmann, Schulze, Versülsdonk, 1997) Thinner planks reduced the weight of the ship, allowing it to move faster and draw less water.

Clinker building also allowed the ships to be more flexible. Each plank was attached firmly to the keel, but only loosely to those above and below it. The spaces between the planks were filled with a variety of materials in order to keep the ship watertight. (Haywood, 2000) Having the planks loosely attached to each other meant the ship was very flexible, and could bend rather than break. This flexibility was conserved by indirectly connecting the deck to the hull by a frame via a series of L shaped blocks and cross timbers. (Nurmann, Schulze, Versülsdonk, 1997)

Flexibility gave the Viking ship some amazing characteristics at sea. It was reported that the gunwale of one replica was able to give with the movement of the sea, twisting as much as 15 cm out of line, while remaining watertight. (Wooding, 1996) By being able to bend with a force, the ship can be made lighter, again adding to the top potential speed of the ship:

"When a ship's hull is under one set of pressures from the motion of the waves, the sail may be at the same time being pushed in the other direction by a strong wind. The ability of the sides of the sides of the ship to twist and "give" by a matter of inches is an immeasurable asset. The danger of the boat breaking under the strain thus becomes reduced and the boat can be made of much lighter materials than if the vessel were to rely upon sheer solidity of construction." (Wooding, 1996)
In order to sail, the force of the sail must travel to the keel to push the boat. At the critical juncture where the mast meets the keel, the Vikings added a block known as the "keel pig" to support the base of the mast, and resist the torque and compressive forces exerted by it. To maximize its strength, this block was an L shaped block of oak cut from the section of trunk where a large branch grew. (Nurmann, Schulze, Versülsdonk, 1997) The mast and keel pig were mounted on top of a keelson, which was designed to spread the force of mast and sail over a larger area. (Haywood, 2000) The size and shape of these varied between ships and time periods. The length of the keelson was dependent on the size of the ship, with the largest keelsons covering about 4 meters, while smaller ships might have keelsons only 2 meters long. (Sawyer 1997) The keelson and keel pig were especially important in the longships, which had masts that could be taken down as needed. In the Oseberg ship, the keelson and keel pig seem to be too small, and the keel pig shows evidence of repair. The mast was also supported by ropes known as shrouds. (Sawyer, 1997) These ran from the top of the mast to anchor points along the gunwales, and kept the mast upright.

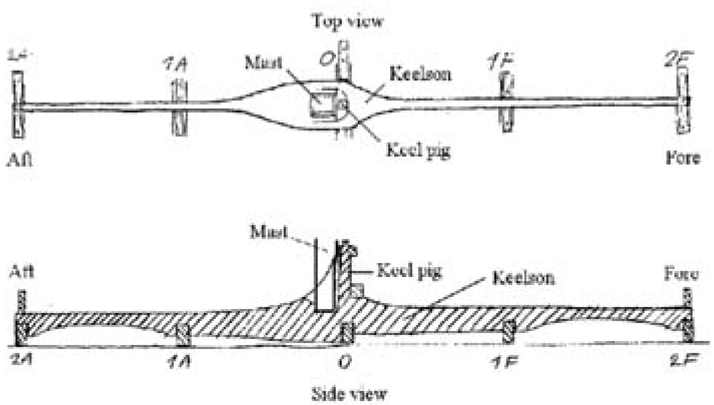


Figure 4: Diagram showing supporting structures for mast in a longship.

Two tools were used to guide the boat while under sail. In order to sail close to the wind, the Vikings employed a simple bar-like tool known as the beitass, which allows the edge of the rectangular sail to be held out. By experiment, these devices have been shown to allow the Viking ships to sail effectively against the wind. (Wooding, 1996) This represents a small advancement from the plain rectangular sails of the dark ages to the carefully controlled sails in use today.

The rudders of these large ships are also interesting, having evolved from oars to a fairly advanced steering mechanism. These were attached at the right side of the ship, (which became known as the steering board, or starboard side), but had a profile like that of an airplane wing, which helped to correct the bias of having the rudder off-center. During tests of replicas, it was found that the rudder could be operated by a single person, even in heavy seas. (Nurmann, Schulze, Versülsdonk, 1997)

While the Vikings were no physicists, it turns out that their solutions to the problems of sailing are actually remarkably inventive mechanisms, which can be explained with the knowledge of physics we have today. From the compression-resistant keel to the removable mast of the longship, these ships are ingenious wonders of the sailing world.

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**Images**

Figure 1
From http://www.hurstwic.org/history/articles/manufacturing/text/norse_ships.htm

Figure 2
Modified from http://vestrusvikingships.org/ and http://users3.ev1.net/~cfmoore/images/deckplans/1944plans/full-size/1944large.html

Figure 3:
From http://www.hurstwic.org/history/articles/manufacturing/text/norse_ships.htm

Figure 4
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