ENGR90 Final Report: Adaptation of a Viking Boat

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Abstract

This project is focused on the simulation and adaptation of a Viking boat. Using the Danish Viking Museum's open-source plans from the Gislinge Boat Project, we constructed a two-thirds scale of the boat and adapted the construction to fit budget and time constraints, as well as our personal skill levels. The finished adaptation was tested in Ware Pool and was able to support up to five people. The boat had a high Reynold's number and low drag coefficient for two and five occupants, thus demonstrating the design of the boat results in good stability and speed. This project demonstrates how to adapt a boat from centuries ago using modern materials and methods, as well as giving more perspective on how well the boat functions.

Introduction

Ship hull design is a balance of many desired properties including speed, stability, and load capacity. Ship hulls are built for tasks ranging from competitive racing on inland rivers to mass transport of cargo across long stretches of ocean. The fluid dynamics of individual hulls, including properties such as drag, are reflective of their intended use.

Norse ships dated near the Viking Age are an interesting case study of hull dynamics. They present a balance of strength and speed that was unusually effective for the period. They also have a highly distinctive shape and style which, in future work, will make comparison to other types of ships more straightforward.

In this project, we chose to adapt the Gislinge boat from the Danish Viking Ship Museum. Plans for the Gislinge Boat reconstruction are available through the museum's Gislinge Boat Open Source Project [1].

The Gislinge Boat was built after the Viking Age. It is dated to around 1130 AD, the height of the medieval period. The Gislinge boat is believed to have been used for ordinary work like fishing and transportation, but its shape and intricacy bear many similarities to classic Viking Age war and merchant ships. The Gislinge boat has a full keel, shallow draught, and lapstrake planking. These features contribute to the Norse shipbuilding advantages for speed and maneuverability.

The goal of this project is to emulate the hull design of the Gislinge boat using adapted materials and methods. By measuring the drag force on the reconstructed boat and qualitatively assessing other factors of its handling in the water, including stability and maneuverability, we examine the relationship of ship hull design with performance and use.

Background

The Gislinge boat is the culmination of preceding centuries of Norse shipbuilding technology. Each aspect of the design is framed by its intended use for fishing, transportation, and other work in coastal waters under oars and sail. In this section, we define some historical context for Norse shipbuilding technology, as well as key terms and components for the construction of wooden ship hulls.

The Viking Age

The period from ca. 800 to 1066 AD is a medieval era of Norse expansion through Europe and North America known as the Viking Age [2]. The causes of the Viking Age are diverse and interconnected, and include such factors as economics, religion, and population size [3]. Although a single motivating factor is impossible to identify, the inarguable facilitator of the Viking Age was the advanced shipbuilding technology of Scandinavia in the period. Norse ships were fast and portable. They were equally capable of carrying raiders, merchants, and settlers across waters as vast and threatening as the Atlantic Ocean and as narrow and inland as the river Seine.

Norse ships of the Viking Age and high medieval period were the culmination of hundreds of years of incremental progress in wooden boat technology. The Gislinge boat, like others from the period, balances lightness and flexibility with stability and strength. Each component of the ship's design is crafted to maximize its performance as a working boat based in a fjord on the Danish coastline.

Portage

Norse maritime prowess depended heavily on the practice of portage, transporting ships overland from one body of water to another. Historical uses of portage include circumnavigating particularly treacherous stretches of water, such as those cluttered with ice floes or large rocks, and transporting a ship to an otherwise inaccessible body of water. Portage had valuable applications in Norse mercantile and military practice [4]. Portage of large ships required immense manpower and the construction of specialized sledges or wheeled tracks. Records exist of warships from Ancient Greece and Rome that were built on a deconstructible pattern to ease the porting process.

Figure 1. Portage of the reconstruction boat across the Science Center quad.

The irregular coastline found in many parts of Scandinavia is well suited to encourage the practice of portage. Traversing a narrow strip of land by dragging a ship along rollers was often safer and more efficient than sailing exclusively along the coast. It has been proposed that certain advantageous portage sites were considered an integral part of the Scandanavian concept of the sea, and maritime technologies including shipbuilding itself were developed with appreciation for this application [4].

The dominance of Norse sailors during the Viking Age is due in large part to the extensive range of their maritime reach. Norse ships are unusually shallow and light by the standards of the period. Shallowness grants ships the ability to navigate into less deep waters, such as those found in rivers, and the light and flexible build also facilitates portage over land. Viking ships were designed with a holistic understanding of their possible cases of use. Ease of inland navigation and portage has an identifiable influence on the overall hull design.

Keel

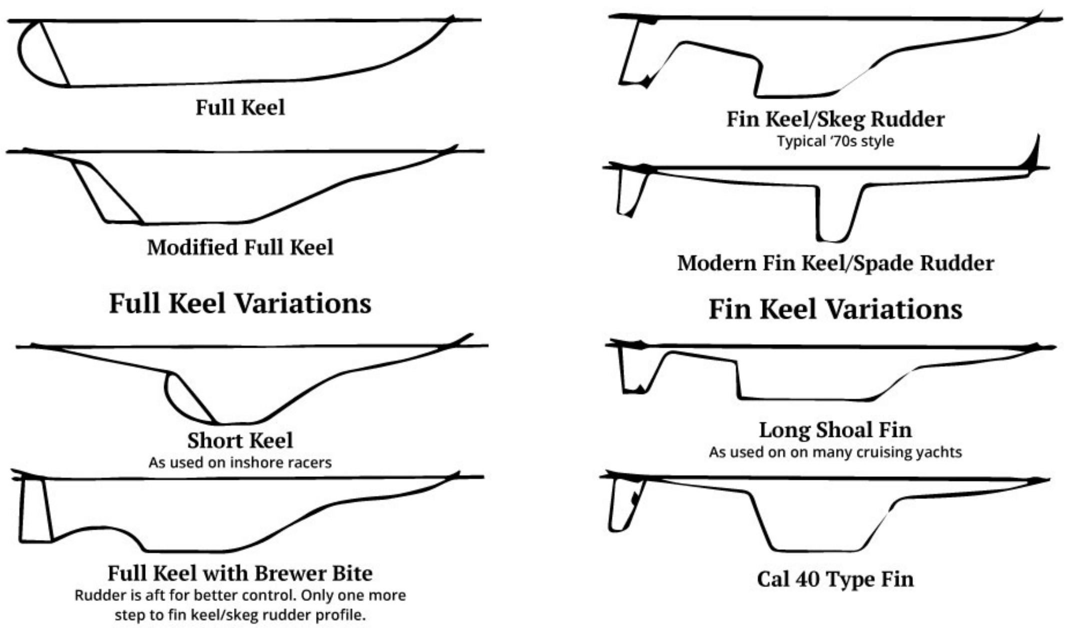

Figure 2.Visualization of common sailing ship keel types [5].

The keel is a structural element located on the underside of the boat. Keel designs vary according to application (Figure 2). The full keel used in traditional Norse shipbuilding spans the length of the ship from stem to stern and forms the basis of the entire ship's construction. The keel is the largest single part of the Gislinge boat hull and is the foundational element to the attachment and shaping of all other ship parts.

In addition to supporting the structure of the boat, the keel contributes to stability and steering in the water. Boats fitted for sailing in addition to rowing, like the Gislinge boat, require more lateral resistance to avoid drifting sideways due to wind. The keel allows the ship to 'bite' into the water and hold a steady course when the wind is not directly behind the sail, including through tacking maneuvers that cut against a headwind [6]. The full keel presents a significant surface area to counter unwanted sideways motion, called leeway.

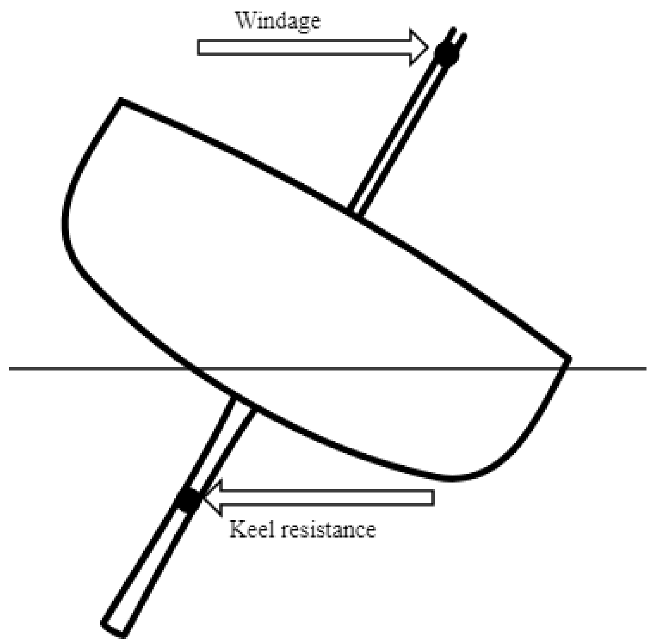

Figure 3. Keel resistance of a sailing ship [7].

Different shapes of keel contribute to the relative stability and maneuverability of a ship. Longer and deeper keels offer more steadiness but do not pivot as quickly from point to point. The fin keel is a common type on modern sailboats that uses a short but deep projecting element to reduce leeway without sacrificing steering speed. This keel type is not able to adapt to water as shallow as the full keel is, and the fin is additionally less suited to being ported or stored out of water. In regions of turbulent coastline such as those navigated by Norse ships, the ability to store the boat out of the water was an essential factor to its longevity [8]. For a working boat like the Gislinge, a stable full keel has practical advantages over a cumbersome and potentially fragile fin [9].

Lapstrake Planking

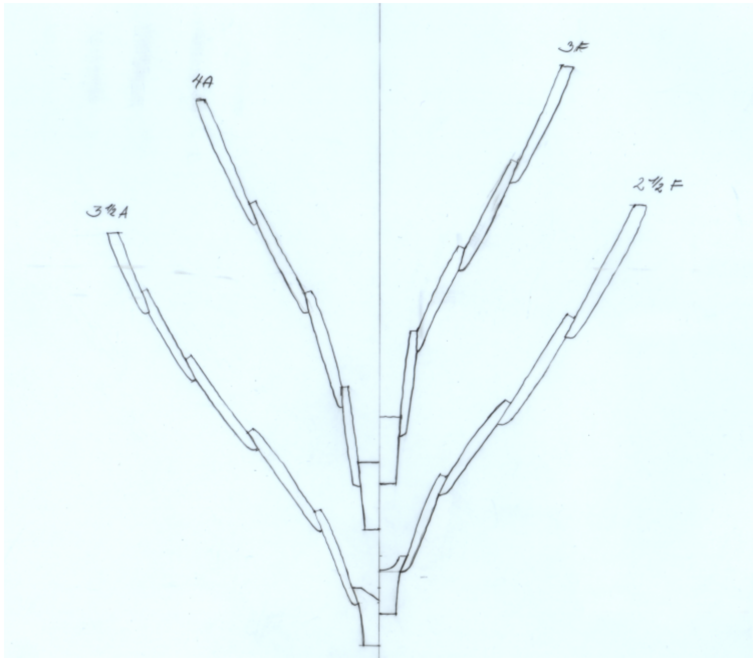

Figure 4. Lapstrake plank alignment on the Gislinge Boat.

Lapstrake is a technique for constructing the hull of a boat from planks, called strakes (Figure 4). In lapstrake construction, layers of planks with overlapping edges are used to construct the shape of the hull. Planks are laid beginning at the keel, and each plank overlaps slightly with the plank beneath it. Lapstrake hulls can be constructed from thin planks of wood and do not require heavy framing elements. The planks are secured before the supporting structure of lightweight ribs is installed.

Lapstrake construction allows the hull to be lighter than one made with cavel construction, which relies on firm, heavy scaffolding to set the planks. Because the support structure of the lapstrake hull is more sparse, the ship is also naturally more flexible than a cavel design. The ship's lightness allows it to traverse the water more quickly. Lapstrake ships are not solid or heavy enough to cut directly against waves and strong wind, and instead rely on the inherent elasticity of the hull to preserve the ship through choppy water. Because the lightweight hull is less able to withstand severely adverse weather than a sturdier clinker construction, lapstrake ships depend on their speed to outrun dangerous stormfronts [8].

The lapstrake design favored by Norse shipwrights contributed significantly to the famous speed and lightness of Viking Age ships. By splitting the planks into shape instead of sawing them, much of the natural strength of the wood was preserved. In this way, they created ships that were strong, flexible, and fast.

Software Simulation

This project originally consisted of two portions: simulation of the boat with software and the construction of the boat. In January, we started working on the proposed simulation of the boat using Ansys Fluent. We were able to successfully replicate a tutorial that used this software to find out the drag on an arbitrary object. Additionally, we found a free 3D model of the Gislinge boat online and was able to convert it to a compatible file for Ansys DesignModeler (Figure 5). Unfortunately, we were unable to complete the simulation using this model because some of the components from the model could not be made into a mesh on Ansys. Instead of focusing on this additional component to the project, we decided to focus our attention on the construction and testing of our adaptation of the Viking boat.

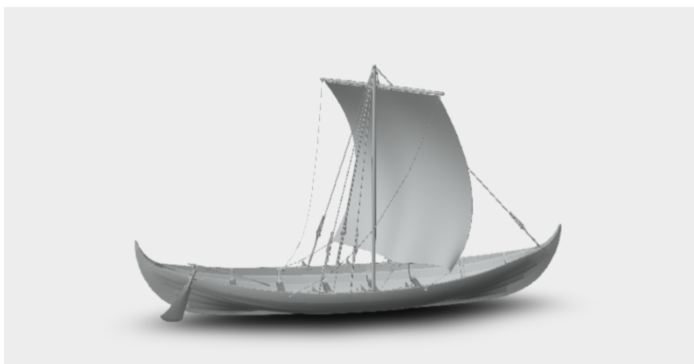

Figure 5. Free 3D model of Gislinge Boat [10].

Design and Construction of the Boat

The original plans for the Gislinge boat provided by the Danish Viking Museum had a total length of 25 feet. We decided to scale down the boat by one-third in order to have a more manageable size, which would require fewer materials and less labor. We built the boat incrementally, starting with the keel and subsequently working on the ribs, stems, and planks. The wood used for the keel and stems was salvaged wood from the BEP construction site.

The plans for the boat include additional components used for steering and maneuvering the boat. We decided to forgo constructing the mast, oars, and rudder, since our focus was to construct the boat such that the drag on it could be tested.

Keel

Since the keel required large pieces of lumber, we decided to use salvaged lumber from the BEP construction site. Since this lumber was roughly cut and did not have the thickness that was desired, we first planed the wood using the planer in the Makerspace and then resawn the wood using the bandsaw to obtain the thickness needed for the keel. In the original plans for the Gislinge boat, the keel, which spans most of the length of the boat, consists of one continuous piece of wood carved in a ‘Y’ shape that varies in shape along the length. In order to simplify the construction process, we decided to shape the keel in a ‘T’ shape that varies in thickness along the length. The bottom portion of the ‘T’ shape consists of two pieces of wood that angle up slightly at the ends, as shown in Figure 6. The two pieces were joined together using a half-lap joint, which was made using the table saw.

The top portion of the keel consists of three pieces of wood that vary in width and taper towards the end of the keel. We originally followed the provided plans and ended the two top pieces of the keel in a point (shown in Figure 7); however, we redid these pieces to only slightly taper in order to accommodate our modifications to how the stems are connected to the keel. Instead of using a simple Miter joint to connect the two parts of the boat, we decided to brace the stems against the keel from both sides. The redone pieces were made on the milling machine to save time. The pieces of the keel were secured together using hex-head bolt screws, thus allowing the pieces to be taken apart easily (Figure 8).

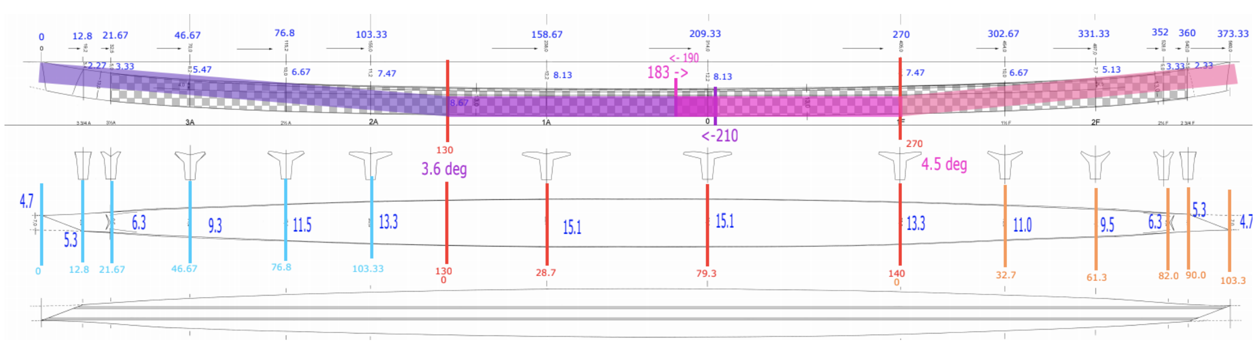

Figure 6. Annotated plans of the keel from the Danish Viking Museum (colored markings indicate the measurements according to the two-thirds scale).

Figure 7. Layout of keel pieces using original top keel pieces.

Figure 8. Constructed keel with new top keel pieces bolted together.

Ribs

The Gislinge boat has six ribs that are placed on top of the keel. The original plans show the ribs formed to fit inside the planks, since the Gislinge boat is normally constructed with planks nailed in place before the ribs are added.This technique would require precisely fitting the ribs to the shape of the planks. Instead, we decided to attach the ribs to the boat first, then form the planks around them. The provided measurements give the distance from the top center part of the keel to the outer edge of each rib at different points. This creates ribs with a varying 'Y'-like shape. The plans show that the ribs were made with a varying number of pieces (Figure 10 shows the rib being made up of three attached parts). To simplify the plans, we decided to make each of the six ribs consist of two half pieces.

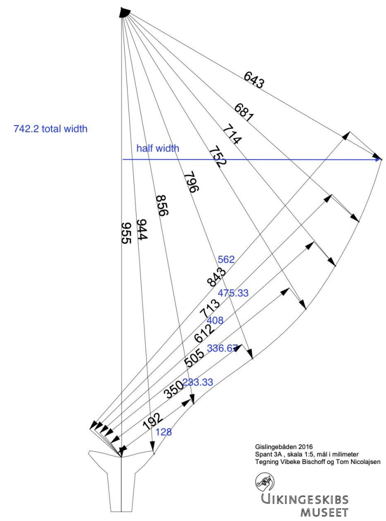

Figure 9. Lines drawing of rib 3A used for template with colored markings indicating measurements for two-thirds scaling.

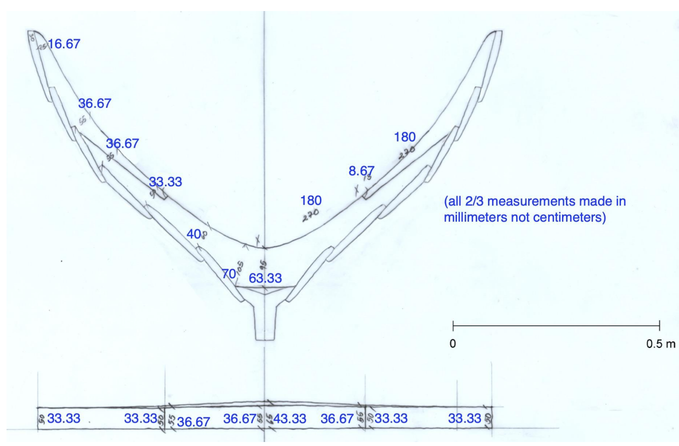

Figure 10. Cross sections drawing of rib 3A with colored markings indicating measurements for two-thirds scaling.

Since the ribs were a complex shape that would have been difficult to create by hand, we decided at J's suggestion to trace the outside edge of the rib in Autodesk Fusion 360. We then uploaded the dxf file to the milling machine to cut the shape precisely (Figure 11). Since only the outer edge of each rib was traced, the inner edges were drawn free-hand in Autodesk to roughly mimic the shape shown in the plans. The first two sets of milled ribs were drawn to end exactly at the center of the keel. The following sets of ribs were extended so that there would be overlap between the two rib pieces, thus allowing a half-lap joint to better secure the rib pieces. For rib 3A, the cut for the half-lap joint was done on the incorrect side, which was fixed by not overlapping the two pieces and inserting a piece of wood to fit between the gap (Figure 12).

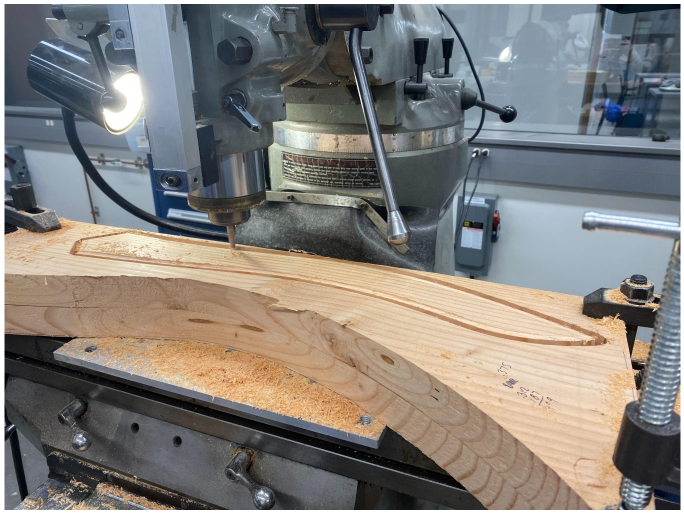

Figure 11. Rib being milled on milling machine.

Figure 12. Fix for accidental cut for rib 3A.

The ribs were attached to the keel using two metal brackets for each set of ribs. The metal brackets were constructed from scrap metal and cut on the bandsaw, then bent into an approximately right angle. Ribs with half-lap joints were secured with five hex-head screws through the brackets, while ribs with no overlap only had four screws. Each bracket was secured to the keel with two hex-head screws (Figure 13).

Figure 13. All six ribs connected to the keel.

Stems

In the original plans, the two stems have steps on the inner edge, where the planks connected, and a circular outer edge. The inner portion of the stems is carved out, as shown in the drawing on the left of Figure 14. Due to the size of the stems, we decided to construct each stem out of two pieces that would then be bolted together. We used salvaged wood from the BEP, which was smoothed using the planer and the jointer in the makerspace. When tracing the measurements out on the pieces of wood, we realized that the measurements for the side width (shown on the drawing on the right in Figure 14) referenced a point that was not shown in the diagram. To obtain the correct measurements, we imported the plans for the stem into Autodesk Fusion 360 and calculated the measurements according to the correct scaling.

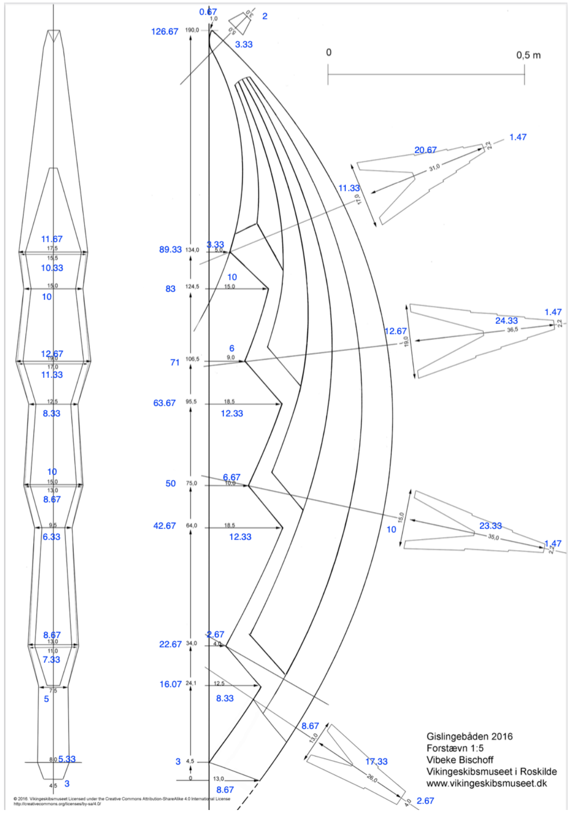

Figure 14. Plans for fore stem with annotations for two-thirds scaling.

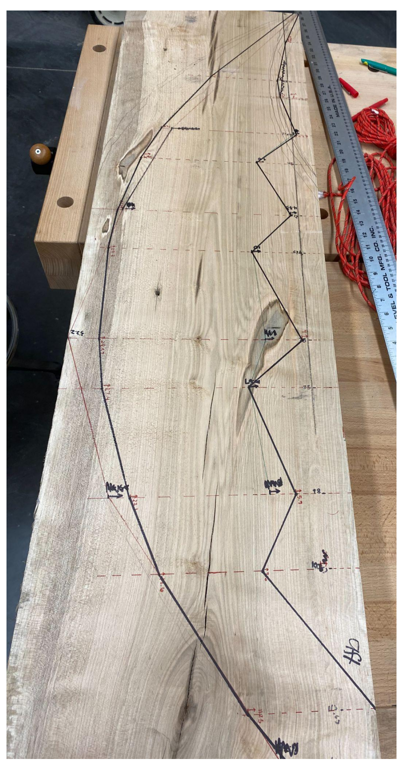

Figure 15. Measurements for the stem on wood.

The sides of the stems were cut using the bandsaw. The outer edge of the stem has a thickness of 2 centimeters, and the inner edges (towards the steps) have varying thickness along the length. Originally, the desired thickness was roughly obtained by taking off pieces with axes. We then transitioned to using a circular chainsaw attachment to shape the wood more efficiently. The shape of the stems was then refined using a circular sander. At the bottommost step of each keel, a notch equal to half the width of the keel was made on the inner edge. This allowed the two stem pieces to fit over the end of the keel. The two pieces for each stem were connected using Phillips-head screws and secured with threaded anchors. Shims were placed in the space between the stems and keel to ensure a tighter fit and align the stems correctly (Figure 16). The stems were secured to the keel using three flathead screws kept in place with threaded anchors.

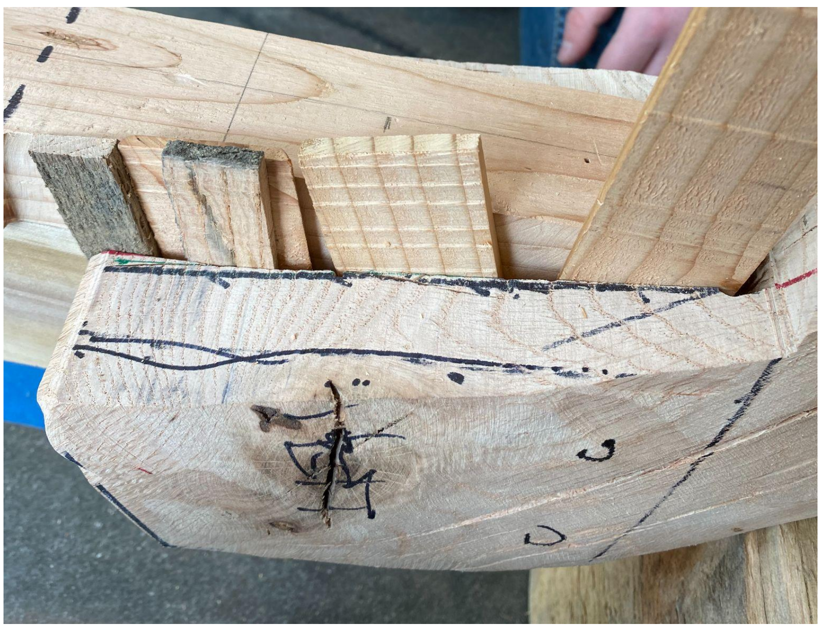

Figure 16. Shims inserted between the end of the keel and the side of the stem.

Planks

The planking on our adaptation approximately follows the lapstrake design provided by the plans for the Gislinge boat. The plans include drawings of the shape of the planks, but do not give dimensions for these pieces (Figure 18).

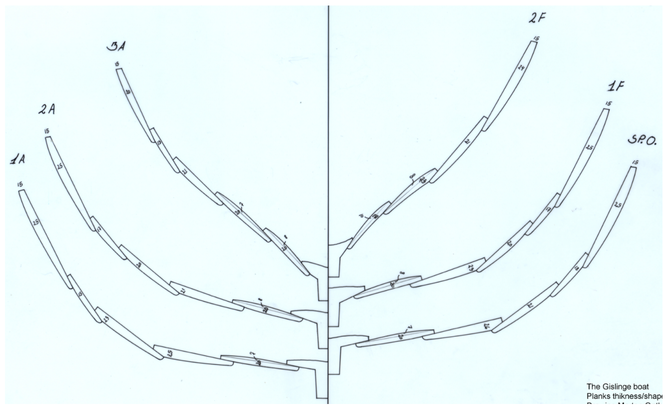

Figure 17. Plans for the placing of planks on the boat.

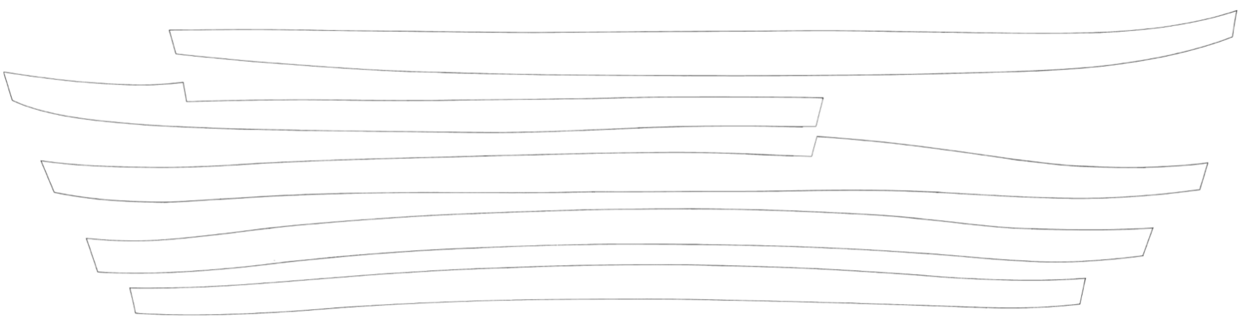

Figure 18. Plans for the shape of the plank pieces.

<u>Sawhorse</u>

In order to place the planks onto the boat, we decided to flip the boat upside down, since lapstrake construction requires the bottom planks to be secured first. Since the boat is not able to rest on the ground upside down due to the height of the stems, a sawhorse was constructed to support the boat (Figure 19). The legs of the sawhorse were made from repurposed 2-inch by 4-inch pieces of wood such that the height of the sawhorse would exceed the height of the stems. Excess wood from the construction of the ribs was used for the top of the sawhorse. The parts were secured using 2-inch screws. Before the sawhorse could be used, the metal brackets securing the ribs to the keel had to be shortened using the metal grinder and sander. This prevented the boat from resting on the uneven metal brackets. After the height of the metal brackets was adjusted, the boat was flipped upside down and placed on top of the sawhorse (Figure 20).

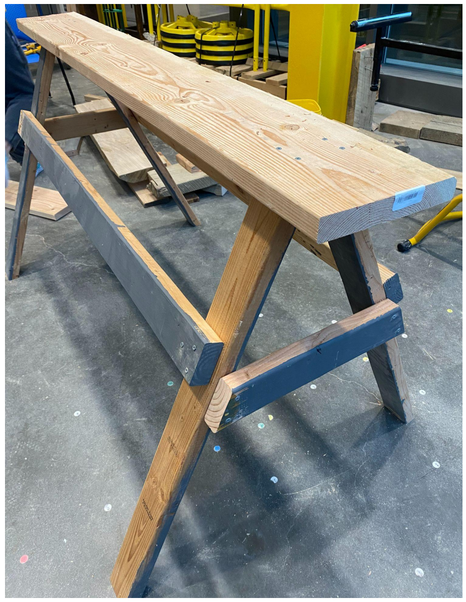

Figure 19. Sawhorse constructed for supporting the boat.

Figure 20. Boat flipped upside down on the sawhorse.

Construction and Placements of Planks

For the planks, we decided to use ¼-inch thick plywood from 4-feet by 8-feet sheets. This made the planks pliable and lightweight. Since the shape of the planks would be difficult to replicate exactly, we decided to roughly cut strips of plywood on the circular saw, which ranged in width from 14 to 25 centimeters, and trim them to fit with a jigsaw. On each side of the boat, five layers of planks were bolted alongside the ribs. Since the length of the plywood is significantly shorter than the overall length of the boat, two or three strips of plywood were used for each layer.

We decided not to steam the wood, which would have allowed the plywood to more easily be twisted. Instead, we used clamps to force the plywood to approximate the desired profile given by the ribs.

Figure 21. Most of the planks attached to the boat with clamps holding the last layer of planks in place.

In the process of installing the planks to our reconstruction, we gained an understanding of the plank shapes modeled in the Gislinge plans. The planks have a broad inverted "U" shape, with a high center, flared ends, and mostly uniform width. The earliest layers of planks on our reconstruction were only trimmed on one side (top of Figure 22). This resulted in a flared section of width near the center of the boat that made it difficult to fit the planks against the shape defined by the ribs. We trimmed later planks on both sides (bottom of Figure 22). Overlapping fully trimmed planks allowed us to achieve a tighter profile for the boat.

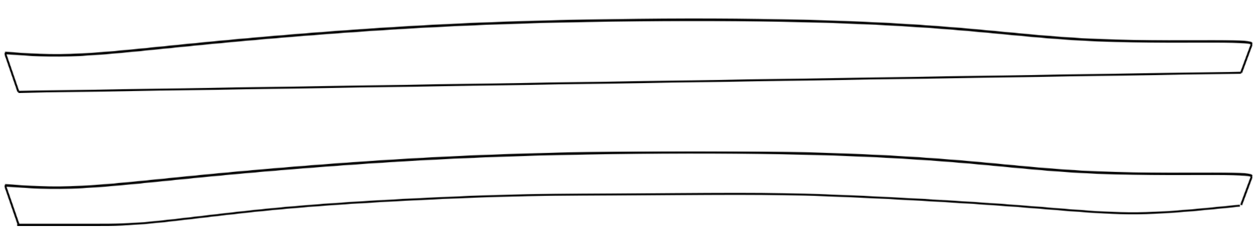

Figure 22. Plank profile with trimming on one side (top) and on both sides (bottom).

We began the planking of our reconstruction on the port side of the ship and improved our plank trimming technique before beginning work on the starboard side. For this reason, the starboard side planks lie visibly closer to the ribs. Viewed from above, the starboard side of the boat is narrower than the port (Figure 23).

Waterproofing

Since the boat would be tested in a body of water, we decided to waterproof the wood to prevent any warping or other negative consequences from placing the boat in the pool. The seams between planks were caulked with clear waterproof construction adhesive. Areas of the boat that the planks did not cover were sealed using patches of plywood kept in place with the construction adhesive and screws. Both the interior and exterior of the boat were sealed using epoxy resin (Figure 24).

Figure 23. Epoxy resin applied to the majority of the exterior of the boat.

Figure 24. Finished boat with epoxy resin applied to the interior and exterior of the boat.

Testing

We tested our finished adaptation of the Gislinge in the Ware Pool in order to assess the drag on the boat.

Transportation

In order to commence testing, the boat was transported from the high bay in the BEP to Ware Pool. We placed a cart underneath the middle of the boat and were able to transport it downhill towards Ware Pool.

Methods of Testing

We used three lanes of the pool to ensure sufficient space for the boat to sit in the pool. We originally planned to use a winch to drag the boat across the length of the pool. Since the drag was low and the boat moved easily across the water, we were unable to achieve any tension in the winch cable to pull the boat. Instead, occupants sat in the boat while a person at the edge of the pool applied a force to the bow or stern. We video recorded a tape measure while walking beside the moving bow to estimate the velocity of the boat through the water. These measurements were used to calculate the Reynolds number and drag coefficient of the boat for loading conditions. With the two-thirds scale, we estimated that the boat would support less than three people. We were able to successfully test the boat with two and five occupants (Figures 25 and 26).

Figure 25. Testing boat in Ware Pool with two occupants.

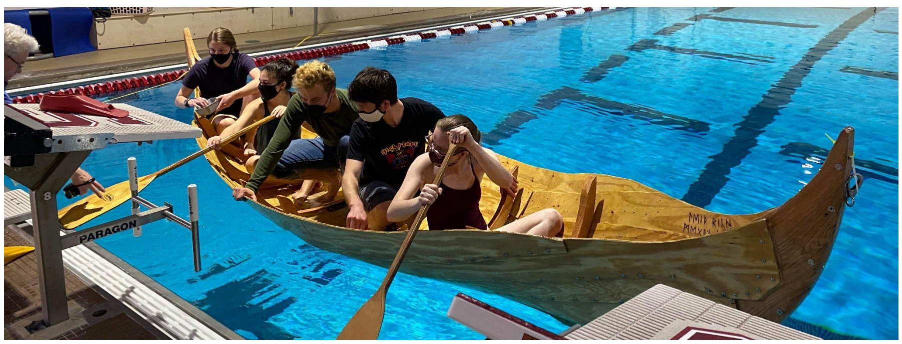

Figure 26. Testing boat in Ware Pool with five occupants.

Results

Prior to testing the boat in Ware Pool, we weighed the boat without any occupants, which came to a total of 190 pounds. The force applied to the boat was roughly estimated and used along with the total length of 18 feet (5.5 meters) to obtain approximate calculations for the Reynolds number and drag coefficient for two and five occupants (Table 1) with assistance from Professor Everbach.

The estimated Reynolds number and drag coefficient were calculated using equations 1 and 2, below.

$$Re = \frac{vl}{\nu} \qquad (1)$$

$$C_d = \frac{2*F_d}{\rho*v^2*A} \qquad (2)$$

Our calculations use the known properties of water given below.

$$\nu_{water} = 1 * 10^{-6}\, m^2/s$$

$\rho_{water} = 998\ kg/m^3$

	2 occupants	5 occupants
Estimated applied force	89 N (20 lb)	134 N (30 lb)
Velocity	1 m/s	3 m/s
Reynolds number	16 million	5.3 million
Drag coefficient	0.02	0.26

Table 1. Calculated Reynolds number and drag coefficient for two and five occupants

Discussion

The two-thirds reconstruction Gislinge boat floats and can hold five people without sinking. The original design includes three pairs of oars and a rudder, suggesting it was crewed by at least four people. The ability of our scaled reconstruction to support more than four occupants without sinking suggests that the original Gislinge's buoyancy and stability, as well as its waterproofing, were replicated successfully.

Though the qualitative results and approximated calculations for the Reynold's number and drag coefficient give a rough estimate of how well the boat functions, there were several assumptions made that would impact the validity of the results. Both the applied force, F_d, and velocity, v, used in our calculations were based on best-estimates in the limited scope of our testing. Precise instrumentation was not used to obtain either value. We generalize our calculated Reynolds number to be high and drag coefficient to be low, indicating that the hull experiences small resistance in both load conditions. More precise analysis and comparison is recommended as the subject for future research.

Conclusion

We were able to achieve our goal of constructing a scaled version of a Viking boat out of wood. In the process, we acquired a profound appreciation of Viking shipbuilding. Using modern tools and techniques, we successfully approximated a scale model of a simple working boat.

The narrow stems, broad and shallow hull, and full keel grant our reconstruction ship the same powerful dynamics as Norse ships in the Viking Age and later. Like the Gislinge model, our reconstruction ship is lightweight but sturdy. It can be lifted by as few as two people and easily ported overland with a simple wheeled cart. It can support five occupants in the water without sinking, and it is possible to stand upright in the boat without tipping.

The Norse craftsmen who built the original Gislinge boat surpassed all facets of our reconstruction on a larger scale ship using simple hand tools. Our boat leaked slowly as we rowed it around the placid surface of Ware pool; its Norse counterpart was put to work in fishing and transportation on the rough ocean of the Danish coast. With more time and experience, it will be possible to not only replicate but improve on the original Norse design. A deep understanding of historical maritime technology can offer valuable insights for contemporary ship hull design. The balance of lightness and strength present in Viking Age shipbuilding is particularly suited to informing the design of efficient wind powered ships. By looking to the knowledge and craftsmanship of masters from ages past, we can find inspiration for the ships of the future.

Future Work and Considerations

Propulsion

In the current construction of the boat, the methods of propulsion and steering were excluded. In order to better test how the Gislinge boat moved across the water, the mast, oars, and rudder would be included. With the original scaling of the boat, there would be three sets of oars. Figure 27 displays drawings of the finished Gislinge boat with the mast and rudder.

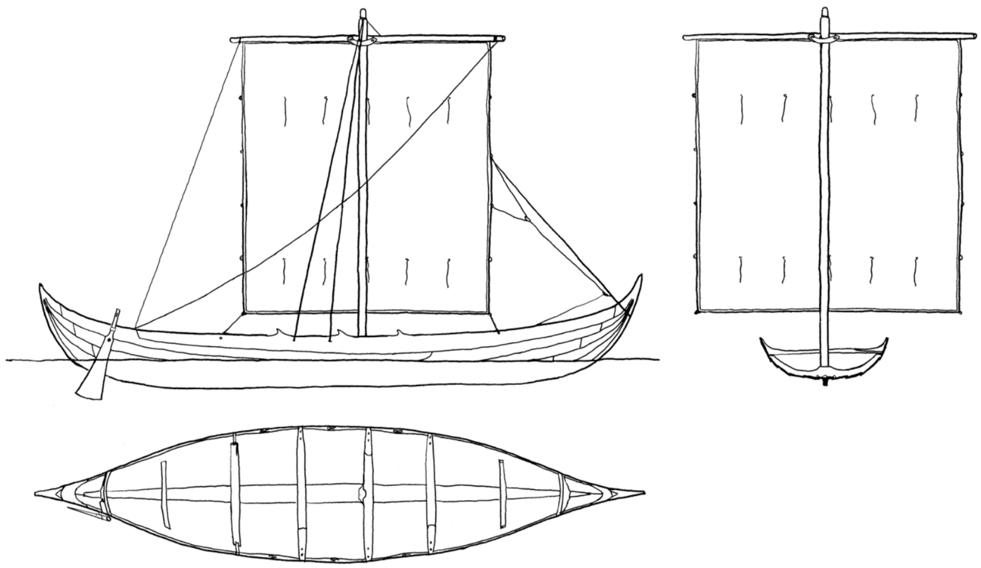

Figure 27. Sail and rig for Gislinge boat plans

Scaling

Our reconstruction ship was created at two-thirds scale for feasibility and convenience. At this scale, the boat was watertight and capable of supporting five occupants. The drag coefficient we obtained for our reconstruction is scalable, so it should correspond to the fluid dynamic properties of the Gislinge boat at full size. However, the total resistance includes non-viscous resistance, such as wave drag, which is not proportional to the Reynolds number. For this reason, the resistance cannot be scaled with perfect accuracy [11].

It is also possible that the reduced scale of the boat impacted its shape and line in the water. Twisting the planks into the correct position was more difficult over the shortened length of the boat. This contributed to the improper fit of planks onto the ribs. Additionally, the two-thirds boat is shallower than the full scale model. When it is heavily loaded, as it was with five occupants, the waterline fell much closer to the gunwale of our reconstructed hull than it is expected to on the original. In order to get an accurate measurement of drag in different loading conditions, a full size reconstruction that reacts predictably to different occupancies would be preferable.

Wood Type

In our adaptation of a Viking boat, we used a mix between salvaged wood from the BEP and wood provided to us from a hardware store. We chose which pieces of salvaged wood to use depending on the dimensions and condition of the pieces, but did not consider the type of wood that it was. This led to multiple pieces of the boat being made out of different types of wood. The two pieces of wood that made up the bottom of the keel were different types of wood. After we redid the tapered ends on the top of the keel, the two top end pieces were made of leftover wood from the machine shop, while the middle top piece was made of salvaged wood from the BEP. Additionally, three of the stem halves were constructed out of the same type of wood, while the fourth half was made out of a light wood, which was presumed to be poplar. Though the stability and balance of the boat was not significantly impacted when testing in water, recreating these components of the boat with the type of wood in mind could lead to better weight distribution.

Keel Shape

Through the construction process of the boat, we have learned how to improve our design if we were to recreate the adaptation. Though it would not be feasible with our skill levels to make the keel in the exact shape as the one illustrated in the plans, having a keel with more of a ‘Y’ shape instead of a ‘T’ shape and having varying dimensions would improve the design. The current ‘T’ shape with a relatively flat center made it difficult to twist the planks and attach to.

Rib Alignment

Another consideration that would be taken into account is aligning the ribs more exactly. Since each of the six sets of ribs were constructed in two separate pieces, some of the rib halves sat higher on the keel than their counterparts. This misalignment led the boat profile outlined by the ribs to be slightly different on the starboard side compared to the port side. In future iterations of this reconstruction, ribs could be constructed out of one piece or the placement of the rib halves could be more carefully chosen in order to prevent issues with alignment.

Planking

If the boat was reconstructed, we would alter the shape of the planks that were attached to the sides of the boat. The bottom-most planks, which were attached first, had a more rectangular shape than the planks outlined in the plans for the Gislinge boat. The divergence from the plans made it more difficult to attach the subsequent planks to the previous planks while maintaining the desired profile outlined by the ribs. The wide inverted “U” shape from the plans would prevent the ends of the planks from flaring out, making it easier for the planks placed on afterwards to more closely approximate the shape of the ribs.

In this adaptation of the Gislinge boat, the planks were bent in shape using clamps and having a person apply a force against the wood. This method was effective enough to allow screws to secure the plywood into place, but required an enormous amount of effort. A more practical approach to bending the plywood would be to steam or soak the plywood to make it more pliable and easier to attach.

In the original boat plans, the ‘step’ shape of the stems includes a recessed notch where each plank is affixed. This design allows the edges of the planks to lie flush to the surface of the stem. On our boat, we chose not to carve any recesses in the stem so that we would have more flexibility when positioning planks. The planks are instead bolted directly to the outer surface of the stem in the position most convenient for our design. Attaching the planks without recessed notches made siding the boat much simpler. However, it exposed the ends of the planks on the bow and stern. This reduced the streamline of the boat and offered more entry points for serious leaking. In future iterations of the design, our enhanced understanding of the plank shape and attachment would allow us to correctly inset the plank attachments on the stems of the boat.

Fluid Dynamic Analysis

The restricted timeline of this project required that most focus be given to the physical construction of the boat. Thorough analysis and consideration were given to adapting the original design and the techniques used to construct the boat. In future work, a more comprehensive review of the boat’s fluid dynamic properties may prove an interesting and fruitful point of study. A procedure may be designed to allow more accurate calculation of the Reynolds number and drag coefficient through precise measurement of applied force and velocity. Comparison of the drag coefficient with the theoretical Froude number, which relates flow velocity to hull length and gravity, may yield useful data for comparison to other hull types.

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