



# Proposal for a Modified Steering System for Bluenose II

Prepared for the Minister of Transportation and Infrastructure Renewal of the Province of Nova Scotia

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## 2 Introduction

The following proposal is a follow-up to the engineering review conducted by our office for the Minister of Transportation and Infrastructure Renewal for the Province of Nova Scotia. The Province of Nova Scotia is the owner of the sailing vessel “Bluenose II”.

The purpose of this proposal is to examine the possible alternative steering arrangements for Bluenose II – arrangements that meet the objectives outlined in the engineering review prepared by our office and dated January 15<sup>th</sup>, 2016.

## 3 Design Objectives

When considering a new steering arrangement for Bluenose II the following design objectives were established in the engineering review of the existing steering system:

- Significantly reduce the weight of the rudder to reduce friction and allow a return to manual steering.
- Reduce the weight of the overall steering system to minimize the strains being placed on the ship’s structure
- Modify the shape and size of the rudder to reduce steering loads
- Create a streamlined lightweight rudder to improve performance and to provide enough buoyancy to offset any effort required to “lift” the blade due to the weight of the rudder blade and the angled rudder stock.
- Increase the overall tolerances being used to reduce the possibility of unnecessary friction due miss-alignment, and generally ensure the least amount of friction to turning the rudder.



## 4 Regulatory Context

### 4.1 Applicable rules

The vessel was built using rules from the American Bureau of Shipping (ABS). The specific rules used during construction were:

- The “Rules for the Construction and Classification of Wood Ships”, dated 1943
- The “Rules for Building and Classing Steel Vessels Under 90 Meters (295 ft.) in Length”
- The 1994 “Guide for Building and Classing Offshore Racing Yachts” (Now retired)

In our recent discussions with ABS it has been determined, based in part on the historical tie that this vessel has, that a new wood rudder could be designed to the 1943 ABS “Rules for the Construction and Classification of Wood Ships”. In the case of a steel rudder the “Steel Vessels Under 90 Meters” would be used. Finally, in the case of a composite rudder (carbon and or fiberglass) ABS would require the use of the 2014 “Guide for Building and Classing Yachts” instead of the 1994 “Guide for Building and Classing Offshore Racing Yachts” since this rule is no longer in effect.

In all cases the rudders would need to meet all the requirements of the relevant ABS sections. The ABS rules specify the parameters, methodology and calculations that need to be used and adhered to in order to establish the minimum engineering requirements.

One should note that regulatory approval for a “standard” rudder – one that falls cleanly inside the definitions of the relevant rules – is relatively straightforward and should not be expected to hit regulatory snags. The risk goes up substantially when considering a hybrid design that combines different materials or unusual geometry.

In addition to these ABS requirements the vessel had originally needed to comply with the regulations set forth by Transport Canada, specifically items 9 and 10 of Schedule VII, Division 1 found in the “Marine Machinery Regulations”.

Item 9 relates to the ability to turn the rudder from 35 degrees to port to 35 degrees to starboard while running at its maximum operating speed (in this case 8.7 knots as determined by sea trials), and the ability to turn the rudder from 35 degrees to one side to 30 degrees to the other in less than 28 seconds. This requirement does have some impact on the design of the rudder: designing a rudder with too much area would mean turning the wheel will take more effort, thus more time.

The vessel has obtained dispensation for the requirement found in item 10 namely the requirement for the steering to be power-operated for rudder stocks in excess of 120 mm in diameter at the tiller. (The current rudder stock is 190.5 mm in diameter). This dispensation was issued by the “Transport Canada Marine Technical Review Board”.



## 4.2 A discussion of Design Speed

When calculating the forces that are generated by a rudder there are typically three parameters that enter into the calculation: the area of the rudder, the position of the center of effort (this relates directly to the shape of the blade), and the speed of the vessel.

Speed is a critical design factor as the forces generated by the rudder tend to increase with the square of the speed. This is reflected in the formulae used by most modern classification societies.

It is critically important, however, to understand the difference between the design speed specified by the classification society – in this case ABS – and the actual maximum speed of the vessel. These are sometimes two very different speeds.

It is also important to understand how and when these rules were developed, and how that may have impacted the way the rules were written. (See discussion of the wood rule below).

The following brief discussion examines each of the three rules being considered and how they approach design speed:

### 4.2.1 Design Speed - ABS Wood Rule (1943)

In the 1943 version of the wood rule the definition of design speed is very simple: “Maximum sea speed of vessel in knots. V [speed] for sailing vessels is to be taken at ten knots”. This *design* speed does not imply that the classed vessels would never exceed 10 knots. The likely reason for this limited design speed is that most wood boats of the period would have had manual steering gear. It would have been impossible for a helmsperson to fully rotate the rudder at speeds above 10 knots – the implication being the rudder would never be allowed to be fully loaded in such a manner.

In the case of a wood rudder with a manual steering gear the design speed for Bluenose (2014) would be 10 knots. Based on this design speed, the vessel’s length, the proposed new rudder area and shape the wood rudder stock would be 13 ½ inches in diameter. Note that a hydraulic steering system can impose steering forces far greater than that of a helmsperson and Langan Design would advise against using any form of hydraulic steering with a wood rudder.

### 4.2.2 Design Speed – ABS Steel Vessels Under 90 M Rule

The definition of design speed in the ABS Steel Vessels rule is as follows: “design speed in knots with the vessel running ahead at the maximum continuous rated RPM and at the summer load waterline”. Given that the sea trials for Bluenose established a maximum speed of 8.6 knots, rounding this up to 9.0 knots would be a conservative design speed. ABS specifies a formula that has the effect of increasing the minimum design speed if the design speed is less than 10 knots – in this case this works out to be 9.7 knots.

The Steel Rule also examines the case in which the rudder gets loaded when going astern. Although astern speed is typically slower than forward speed the torque on the rudder stock can be substantial, and sometimes greater than in the forward condition.

In the case of a newly designed rudder for Bluenose II (2014) a solid stainless upper stock would need to be approximately 4 inches in diameter although in the case of a hydraulically operated rudder one



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should consider increasing this diameter. This solid stock can be replaced by an equivalent hollow stock provided it provides the same ability to resist torque and bending.

### 4.2.3 Design Speed – 2014 Yacht Rule

The 2014 yacht rule shares many definitions with the ABS Steel Vessels Under 90M Rule: the definition of design speed is identical, and many of the formulae used in calculating forces and torques are also similar. The Yacht rule has an additional section for sailing yachts that contains a different formula for the required rudder stock diameter. If the new rudder was to be designed to this rule the calculation would be performed both as a motor yacht AND as a sailing yacht – the greater of the required diameters would then be chosen as the minimum required diameter.

## 5 General Parameters

### 5.1 Rudder Blade Area

Prior to designing a new rudder blade, it is important to set the overall parameters of the design: all the structural calculations derive from these overall parameters.

The starting point of this process is to look at the previous iterations of Bluenose. The following table shows the areas for the three iterations of the vessel up to today: The original Bluenose, Bluenose II and the newly rebuilt Bluenose II.

Version	Rudder Area	Rudder Length	Source
	<i>m<sup>2</sup></i>	<i>m</i>	
<b>Bluenose (1921)</b>	<b>5.364 (approx.)</b>	4.777	Roué (*)
<b>Bluenose II (1963)</b>	<b>4.044</b>	4.974	Measurements
<b>Bluenose II (2014)</b>	<b>5.542</b>	4.625	CAD drawings

*(\*) The drawing used to estimate the area was of moderate quality so determining the measured area is an approximation.*

The most relevant data point one can glean from the table above is that the area of the rudder for Bluenose II (1964) was significantly smaller than the area of the current metal rudder. The captain at the time has reported that the vessel did not have any steering issues. This is critical in establishing the area for a re-designed rudder. Although it may appear at first that a bigger rudder is better, excessive area has dramatic consequences: the loads used in the design grow significantly (with the net result of building a heavier than necessary rudder) and the ability of the helmsman to turn the wheel when sailing or motoring is decreased. The effect of area is further compounded by the fact that a larger area implies in most cases a longer distance between the center of pressure of the rudder and the axis of rotation – further increasing the torque, and therefore the effort required to turn the rudder.



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A secondary source of data to inform the decision on rudder area comes from the historical record. The rudder areas for a number of comparable vessels were extracted from Chapelle's book "The American Fishing Schooners" and can be found in the comparison chart in Appendix A.

Given that the Bluenose II (1964) rudder was not significantly under-sized, it appears there is considerable flexibility in sizing a new rudder – specifically in making it smaller than the current metal rudder. For this preliminary study we are suggesting that the new blade area be chosen in between the two bands shown on the chart in appendix A: somewhere in **between 4.25 and 4.9 square meters** or 50 and 52.75 square feet respectively.

### 5.2 Rudder Blade Shape

At this early proposal stage the shape of the rudder is not playing a critical part other than helping to determine some preliminary scantlings.

Looking back through the historical record there seems to be as many rudder shapes as there are designers. One trend that emerges is the tendency for the rudder blade to be significantly wider at the top for powered vessels – one argument put forward is that this places more rudder area in the wash of the propeller. This effect may be lessened in the case of Bluenose as there are two propellers on either side of the stern post instead of one on centerline.

A thinner blade at the bottom produces less torque for the bottom half of the rudder – in the case of a tapered wood rudder this can become relevant.

The following drawing shows the various shapes of rudders for Bluenose and Bluenose II along with one of the current "working" shapes being used in this proposal. This shape is likely to change as the design firms up. The shape was chosen to provide ample area close the props while keeping the centroid of the blade closer to the rudder stock.

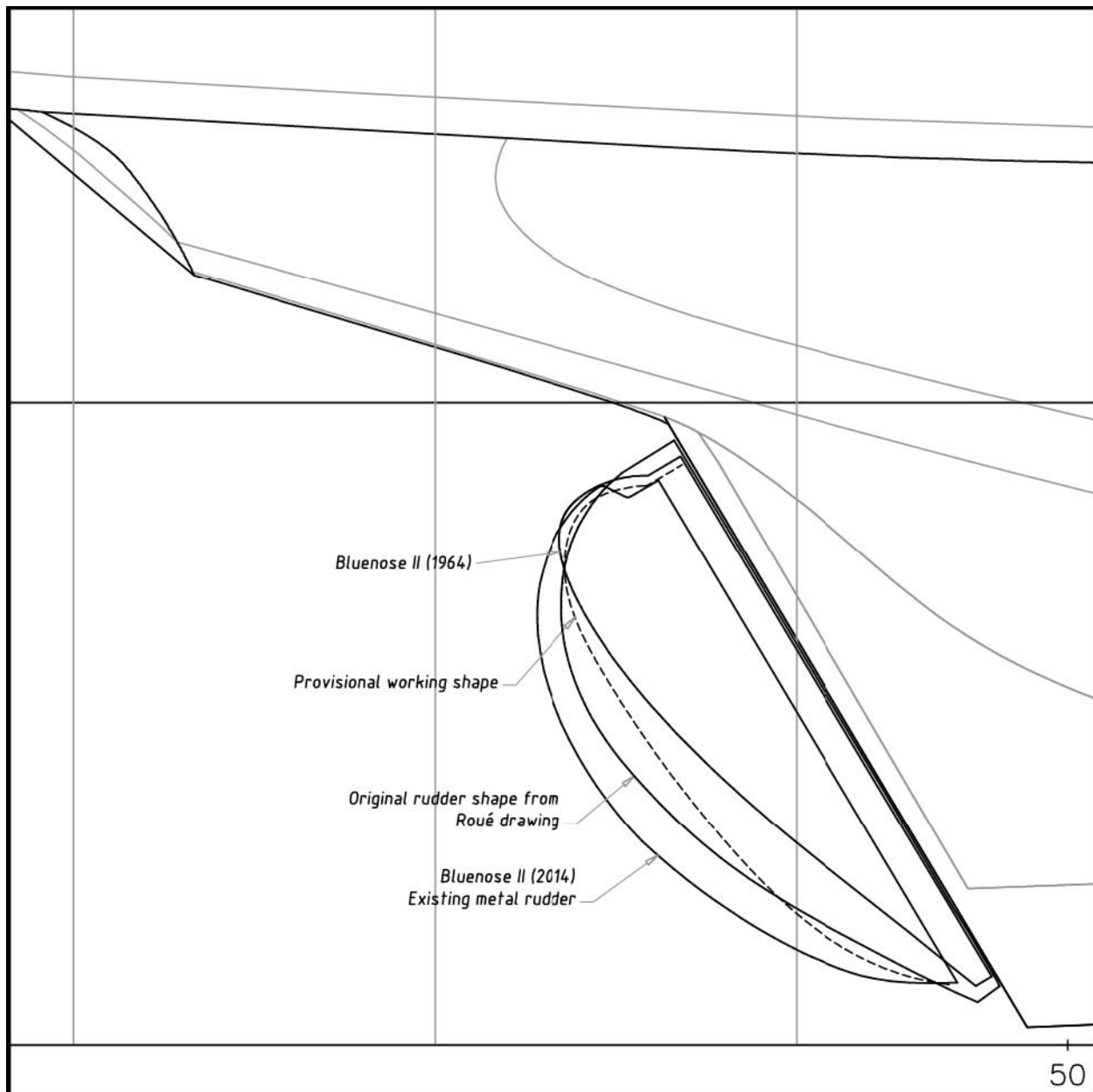


Figure 1: Bluenose Rudder Shapes

### 5.3 Modification to the Stern Post

The existing rudder has a large gap between the leading edge of the rudder and the trailing edge of the stern post. This gap is on the order of 11". In all the configurations in this report it is assumed that this gap will be suitably filled. This will be achieved by changing the shape of the rudder blade and adding wood strips to the trailing edge of the stern post. Note that the authors are aware that the stern post has significant penetrations from the 4 gudgeons. Prior to determining a final arrangement, a review of this structure will need to be carried out. One possible solution to filling the gap between the new





rudder and existing stern post could be with the incorporation of metal plate that could also function as re-enforcement to the stern post.

## 6 Steering System Discussion

As part of the design of a new rudder there has been some discussion about the appropriateness of the current manual steerer. In this context this proposal quickly reviews the different options available and makes the case that this is still the appropriate solution for this vessel.

### 6.1 Oscillating Worm Gear Steerer

As part of the engineering review it was established that there was no available information that would support the notion that the new worm gear steerer designed for the rebuilt Bluenose II was ineffective.

The large diameter of the screw thread does increase friction significantly relative to the original steerer; in the event this unit will be re-used proper consideration should be given to reducing the friction by switching to a smaller screw size.

Since this type of steering system was used extensively for vessels of this type its appropriateness is established. This type of steering system provides significant mechanical advantage (on the order of x36 times) and the lack of “feedback” ensure one can hold the wheel even if the rudder is under significant temporary load.

### 6.2 Hydraulic Steering System

Bluenose II currently has a power driven hydraulic steering system. Although this system has proved functional it presents significant drawbacks that were enumerated in the engineering review. It was designed to overcome the significant loads necessary to rotate the current metal rudder.

In the authors’ opinion this system is overly complex, heavy and is not needed for a well-designed, light-weight rudder.

### 6.3 Manual Hydraulic System

An alternative to a powered hydraulic Steering system is a manually driven hydraulic steering system. This configuration incorporates one or more helm pumps and steering cylinders. In this case, the wheel would be directly attached to a helm pump with either a fixed displacement output or with adjustable variable output.



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Many components of the current power driven hydraulic steering system are manufactured by Kobelt Marine. Kobelt also produces manual hydraulic steering systems.

After discussing the different possible options with them it appears that the torque loads for both the existing rudder as well as new smaller area rudder are beyond the operating limits of a manual hydraulic system.

### 6.4 Quadrant and Wire Steering System

Most large yachts that are manually steered tend to go with a version of the quadrant + chain system. Typically, the wheel is connected to a gear box connected to a chain. This chain is in turn connected to a set of wires that terminate on a quadrant tied to the rudder stock. Turning the wheel displaces the chain, which moves the wires, which rotates the rudder. This system is particularly suited for racing and cruising yachts as the rudder can provide “feedback” to the helmsperson. If the helmsperson lets go of the wheel the rudder will tend to “unload” itself – the wheel will turn so that the rudder is no longer loaded.

Usually this type of steering system is installed in boats that have a balanced or semi-balanced rudder. The rudder is designed so that some of the force required to turn the rudder is provided by the rudder itself – its axis of rotation is placed aft of the leading edge of the rudder blade.

In the case of Bluenose, the rudder is not balanced – almost all of the area of the rudder sits aft of the axis of rotation. Should Bluenose II be equipped with a quadrant + chain the helmsperson will always feel some load on the wheel – the wheel will always be loaded. Should a gust or a big wave overcome the vessel the helmsperson would likely not have the required strength to hold the wheel. One option to mitigate this effect is to use a gear box with several speeds: the load is reduced for the helmsperson, however the number of turns required to swing the rudder is increased in proportion.

In addition to the permanent load on the wheel the size of the rudder on Bluenose would imply a large quadrant. These are typically installed inside the hull, along the rudder post, between the lower and upper bearings. In the case of Bluenose this space is very limited and would require significant reconfiguration, if at all possible.

In the absence of a working solution (worm gear) this direction would warrant further investigation, but in this instance we feel that this option does not make sense for this vessel.

### 6.5 Gearbox and Torque System

There are alternative methods of transmitting the rotation of the wheel to the rudder – one of these replaces the chain and wire described above by a set of torque tubes. This solution has been used on various sailing vessels with this style rudder. One such vessel is Spirit of Bermuda which was designed by the Langan Design. This system, however, requires considerable space for the gear box and torque tubes below decks and would be at or above the upper limit of the commercially available units.



## 6.6 Final Steering Configuration Recommendation

The details and dimensions of the steering system will vary according the method used to build the rudder, however it is **our recommendation to stick with a worm gear type steerer**. Some of the rudders described in this proposal can make use of the existing manual steerer, and some others may require either a complete re-design or a modification to the existing unit.



## 7 Possible Construction Details

The following section describes in some detail some potential ways of building a new rudder system for Bluenose II. The construction methods described are:

- An all wood rudder
- A hollow steel rudder
- A steel stock with a wood blade
- A carbon hollow stock and a composite rudder blade

### 7.1 Original Bluenose II Wood Rudder

A reasonable starting point would be to take the old Bluenose II rudder and examine whether this solution is workable. The rudder was in service from 1964 to 2005, and although it may have gone through some changes over the years the last iteration still exists. Given that Bluenose II (1964) was built as a copy of the original Bluenose (1921) one can assume that the concept and scantlings were close to those of the original vessel, although the shape may have been different. The following photograph shows the 1964 rudder in its current condition.



*Figure 2: Old Bluenose II Rudder, Current Condition*



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The rudder stock was cut at some point however the dimensions of the rudder and stock were taken and made available to the authors of this proposal. The following page shows the dimensions and shape of this rudder. In this picture the old rudder stock can be seen lying just above the rudder.

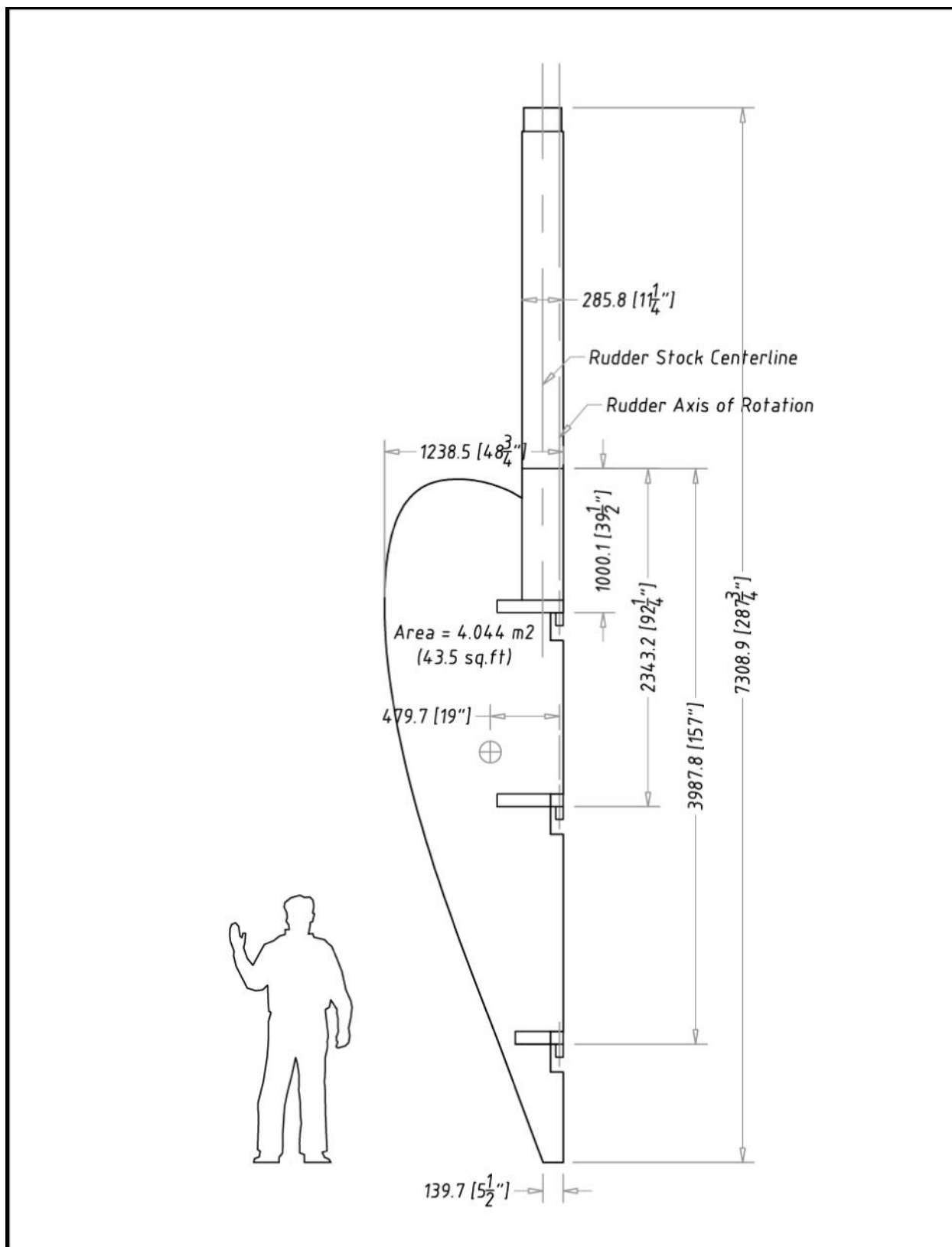


Figure 3: Size and Shape of the original Bluenose II rudder



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This rudder has a stock diameter of 11-1/4" which tapers down in width to about 8" at the tip. The rudder was designed to sit inside the streamlined flow coming off the stern of the vessel: the stern post measured 12" in width.

A reading of the ABS 1943 Wood Rules show that the rule requires a wood rudder stock to be at least 13-1/2" in diameter for vessels of a rule length "L" of 110 feet. The rule length L for Bluenose II is 109'2-1/2" which would place her in this requirement.

The immediate conclusion is that **re-using the original rudder design would not be an option** under the ABS rules in force for this project.

It is worth noting that although the 11-1/4" diameter stock would not meet the regulatory requirements of the 1943 ABS wood rule this rudder was in use for about 40 years. A similarly sized rudder stock can also be observed on the fishing schooner "Theresa E. Connor" currently on display at the "Fisheries Museum of the Atlantic".

### 7.2 Updated Wood Rudder as per ABS 1943 Rules

The next logical configuration to examine is a new wood rudder designed and built to the ABS 1943 wood rule. As was stated in the previous section the minimum required diameter for the wood rudder stock is 13-1/2" (342.9 mm).

As per the original configuration the rudder would be hung with 3 pintles. The scantlings of these new pintles would need to comply with the ABS rule requirements – they would likely be bigger than the old pintles. The existing 10" steel tube inside the hull, and its flanges connected to the deck and hull would need to be removed from the vessel and replaced with a wood tube of approximately 20" inside diameter.

Although there is nothing with this arrangement that looks to be unrealistic there are several key considerations:

- The old rudder was 11-1/4" diameter and sat behind a 12" stern post. In this case the 13-1/2" wood rudder would protrude on either side of the stern post leading to some disturbed flow. The ABS rule does allow the stock to taper in diameter which means this protrusion would not be a problem for the entire length of the rudder. Indeed, for that section of the rudder that does protrude one could consider building up the stern post locally to produce a more streamlined flow on to the rudder blade.
- The work involved in removing the steel tube and replacing it with a wooden staved tube would be significant and may involve redesign of the aft counter structure to locally strengthen the hull in way of the large 20" diameter hole required. This amounts to relatively significant surgery to the aft end of the vessel and would imply being hauled for some length of time.



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- The new worm gear steerer was designed to sit atop a 7-1/2" steel stock and would therefore not be suitable for use in this configuration. A newly designed steerer would need to be designed and submitted to ABS for review.
- The friction component inherent in a pintle and gudgeon arrangement is very small as the amount of contact with the vessel is small and the torque required to overcome the friction is greatly reduced. This is a significant advantage when considering a manually steered vessel.
- A benefit of this configuration is that the rudder can potentially be installed and removed while the vessel is in the water. It was confirmed by first-hand accounts that this was indeed the case for the original Bluenose II. Note that the Lunenburg slipway has a removable section of its wooden deck to allow the rudder to be dropped far enough to get out of the trunk.



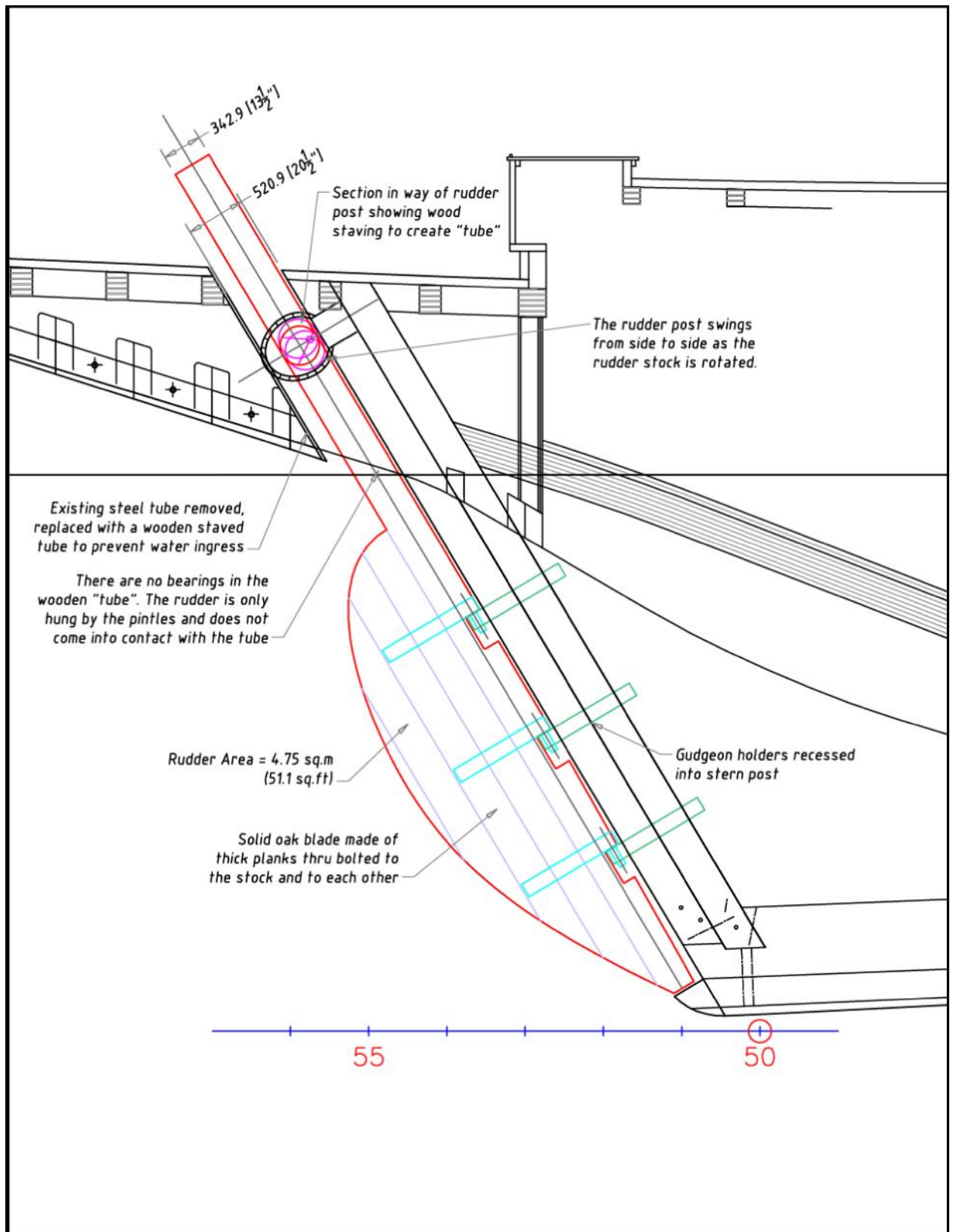


Figure 4: Wood Rudder to the 1943 Wood Rules



### 7.3 New Hollow Steel Rudder

There are two issues with the current steel rudder: the stock used is solid steel, and the blade has no buoyancy. The option considered below is to replace the current solid stock with a hollow tube, and to replace the flat plate blade with a hollow steel fabrication. This enables considerable weight savings compared to the current design – savings which are enhanced by the significant buoyancy force generated by the blade volume.

New hollow steel rudder configuration notes:

- The existing metal rudder bearing tube is kept in place. This reduces to a minimum the modifications inside the boat which will consist mostly in removing the existing hydraulic components.
- One could consider switching to a larger diameter lower stock. This should enable further savings in weight, and allow for better flow off the stern post and on to the blade. There are several possible methods of connecting the upper and lower stocks which can be investigated at the detailed design phase.
- The bearings considered are split UHMW sleeve bearings, or straps, that bolt on from either side of the stock. In this configuration the rudder is removed by removing the bearing straps and lifting the rudder off of the shoe fitting at the bottom end of the rudder.
- Because of the split stock configuration, the rudder can be removed or installed without requiring a large trough below the vessel when she is hauled out. The top and bottom stocks are disconnected, the bearing straps removed and the rudder lifted off for servicing.
- The split/strap UHMW bearings can be inspected and replaced without removing the rudder.
- We are proposing the use of a heel fitting at the bottom of the rudder stock. This fitting helps contain the lower end of the rudder while allowing it to pivot within the heel shoe. The mid strap bearings help keep the rudder in column and reduces the bending moment impact on the stock.
- Since we are keeping the same diameter upper stock (albeit hollow) one could re-use the existing worm drive steerer. A new steering head would be required and can be manufactured using the previously approved ABS drawings.
- The buoyancy impact on the blade is significant in reducing the overall weight felt by the vessel. A rough estimate of the weight for the hollow stock and blade is 1,360 kg (3,000 lbs.). The buoyancy reduces this weight by approximately 800 kg (1,763 lbs.) – the “wet” weight of the rudder is 560 kg (1,235 lbs.). Note: this weight is preliminary and is likely to change somewhat upon final design.



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- Further reductions in “wet” weight may be achieved by increasing the buoyancy of the blade – perhaps by increasing the trailing edge thickness. This would have the double effect of reducing friction and decreasing the force required to turn the blade.
- As currently designed a new hollow metal rudder would see a reduction in the bearing friction forces of approximately 75% and a total reduction in effort required to turn the blade at 35 degrees of approximately 79%, in a static condition.
- There is a misalignment between the position of the downward force from gravity acting through the center of gravity of the rudder and the upward force created by the buoyancy in the blade. The longitudinal distance between these two forces introduces a torque on the rudder which will tend to increase the load on the bearings more than if these forces were in the same longitudinal position. The torque numbers used in the graph below should therefore be thought of as minimum.

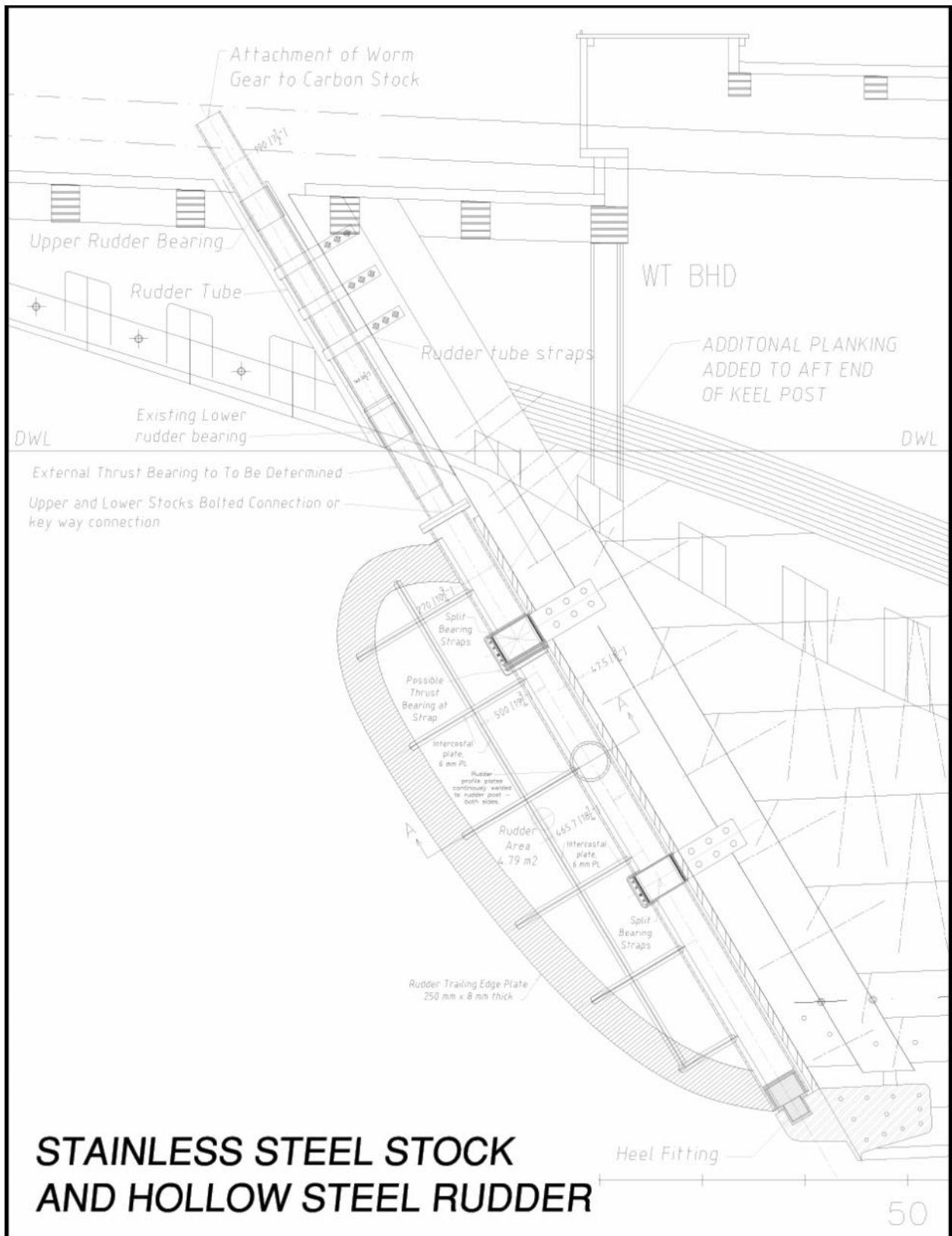


Figure 5: All Metal Rudder - Arrangement



## STAINLESS STEEL STOCK / HOLLOW STEEL BLADE

Stock: 316L Stainless Steel

Upper Stock OD 190 mm/ID 166 mm/Wall 12 mm

Lower Stock OD 270 mm/ID 246mm/Wall 12 mm

Blade: Mild Steel: Blade Plating to be 6 mm

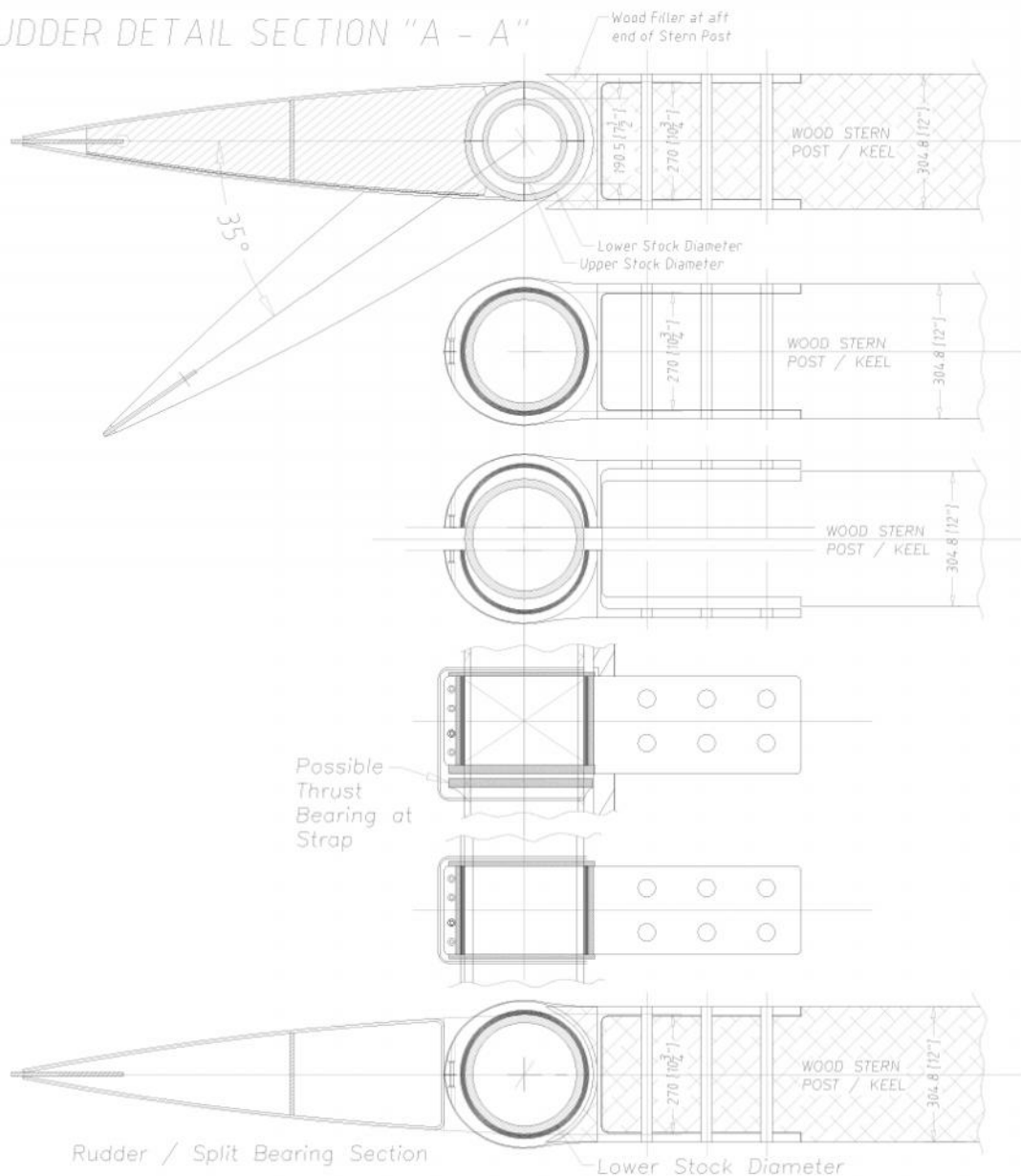
Approx Weight: Stock Upper Section = 385 lbs

Stock Lower Section = 818 lbs

Blade and Internals = 1797 lbs

Total Rudder & Stock = 3000 lbs

### RUDDER DETAIL SECTION "A - A"





*Figure 6: All Metal Rudder - Details*

## 7.4 New Hollow Steel Rudder Stock and Wood Blade

One of the options examined by our office was to use steel for the rudder stock and wood for the rudder blade. The idea behind this approach was to create a lighter rudder with a neutrally buoyant blade that would only require a small amount of force to turn.

- There is a substantial amount of historic precedent for this approach dating back to the early 1900s however the technologies used at the time would be cost-prohibitive today: most of the metal rudder stocks were forged and not welded and the typical details used would be expensive to reproduce today.
- Using a more modern approach would imply using a fabricated stainless steel rudder stock built from round pipe. A vertical tapping plate would be located aft of the stock and would be welded to side plates that in turn would be welded to the stock itself. This would allow for a series of vertical white oak planks to be fit up and through bolted using both staggered and continuous bolts and tapped into the vertical steel plate. In addition to the fore and aft bolting, a series of metal brackets running from the rudder side plates to the rudder tip would be recessed into the wood planking and bolted through port and starboard. Preliminary details of such an approach can be seen on the two pages that follow.
- A preliminary weight estimate of this rudder produces an all up weight of 1370 kg (3021 lbs.) which includes upper and lower hollow steel stocks, steel framing, oak wood rudder planking, brackets and bolts. This first pass preliminary design yields a rudder that is only 9.35 kg (21 lbs.) lighter than a metal framed and plated blade and hollow metal stock solution.
- A rudder fabricated of steel and wood will likely present significant maintenance issues. This structure will have longevity concerns compared with modern all steel or composite rudder fabrications.
- The biggest draw-back of such a solution has to do with the regulatory void this solution would fall into: it does not fall cleanly in either the 1943 “Wood” rule or the modern steel rules. The path to getting regulatory approval would likely be complicated, and perhaps difficult.



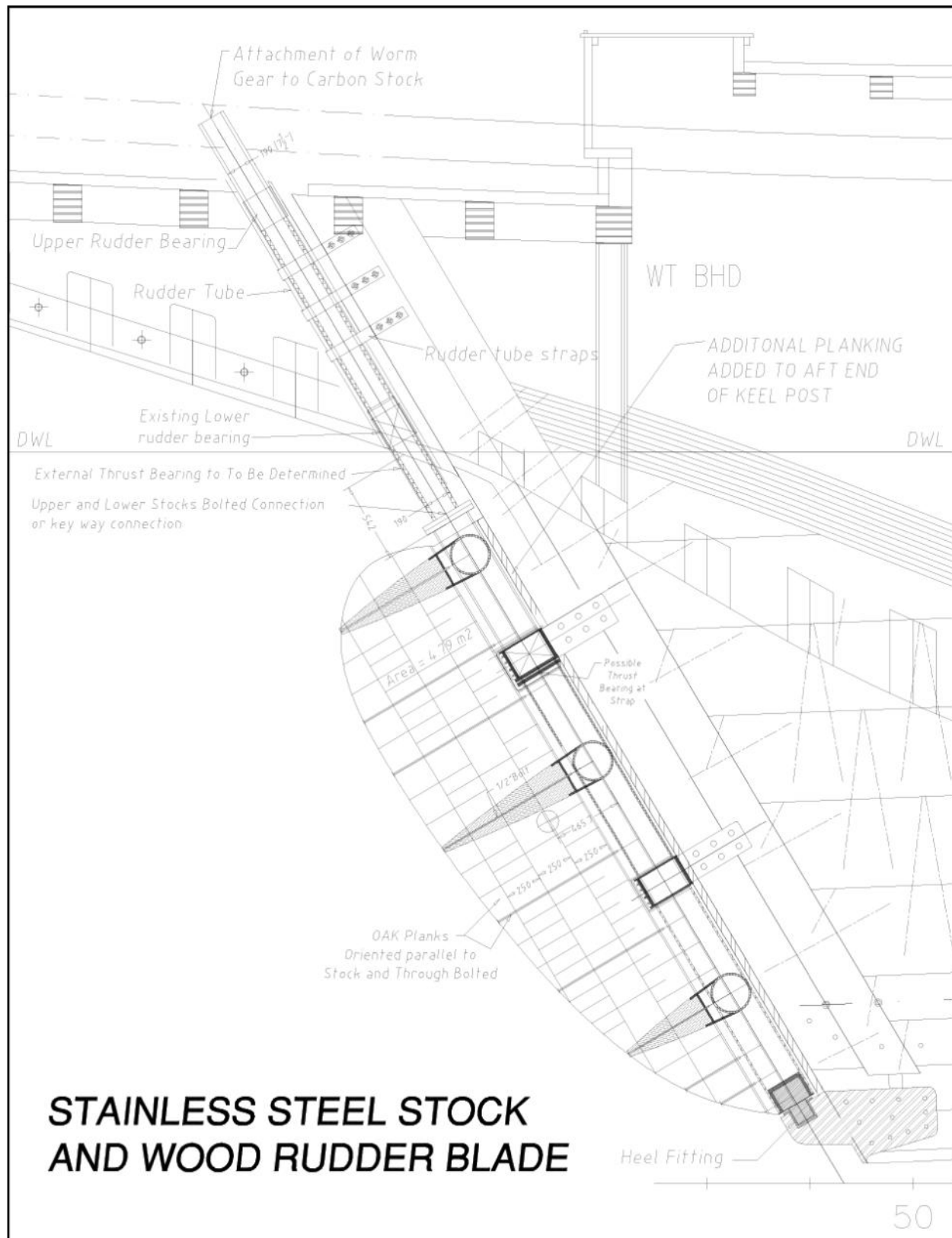


Figure 7: Steel and Wood Rudder Arrangement

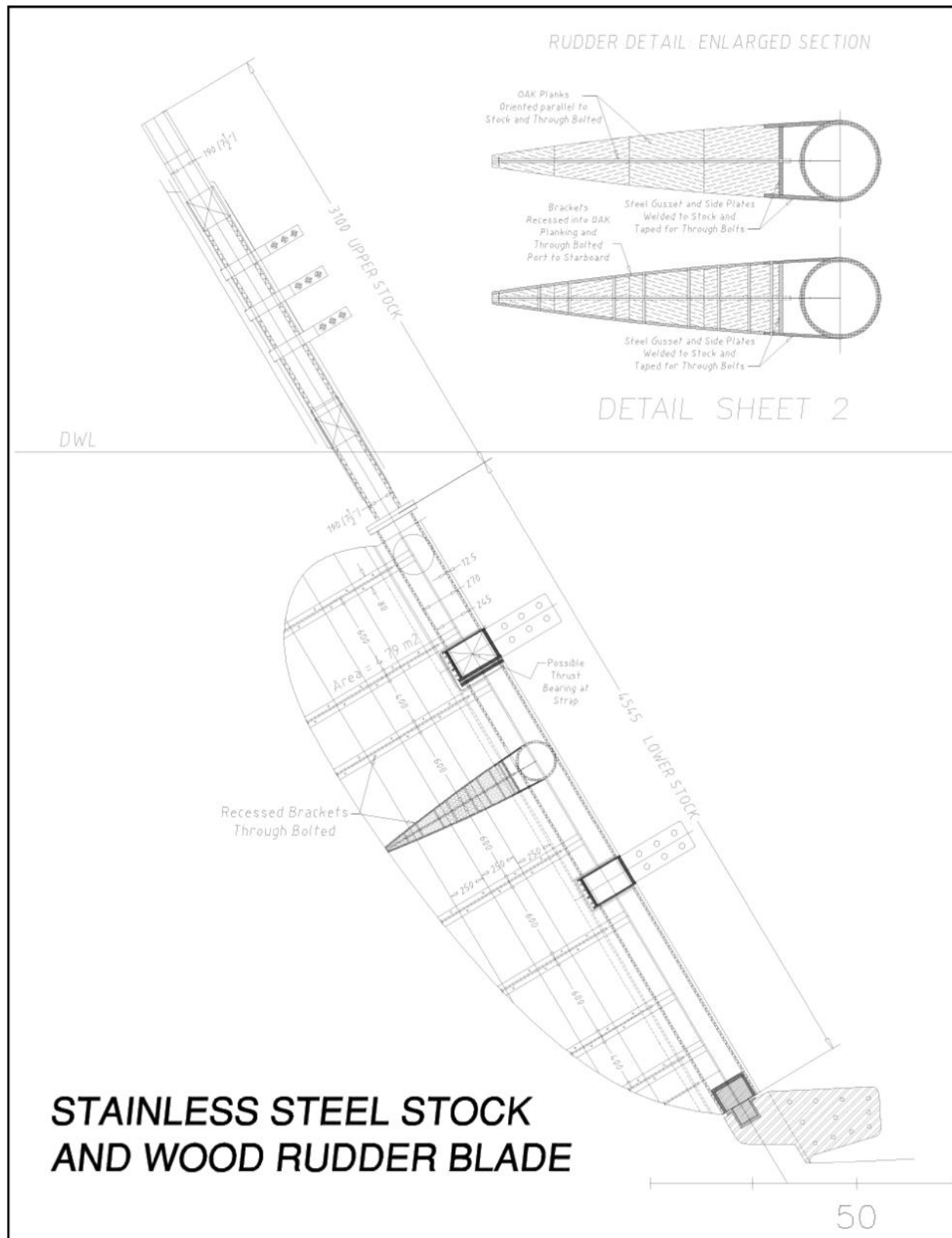


Figure 8: Steel and Wood Rudder Details





## 7.5 Carbon Hollow Stock and Composite Blade

In this configuration the rudder stock would leverage the high strength and stiffness of carbon fibers for the rudder stock. The rudder blade would typically be built around a shaped foam core with either carbon or fiberglass skins. In this proposal the term “composite” construction refers to building the rudder using modern fiberglass construction methods, including the use of carbon, e-glass fibers and a suitable resin matrix.

- In this configuration the stock would be a single continuous hollow carbon stock running from the steering gear at the top to the bottom of the rudder.
- The rudder stock increases in diameter below the stern tube to allow for a reduction in thickness of the stock laminate. The stock diameter, and therefore the blade thickness can be tailored to the size of the stern post.
- This configuration makes use of a heel fitting to capture the bottom end of the rudder. This heel fitting can be raised so that it sits above the bottom of the keel: in the event of a grounding this protects the rudder from being ripped off.
- A pair of split UHMW strap bearings along the length of the blade allow for a reduction in the thickness of the stock laminate. They would also act as thrust bearing for the case when the rudder is pushed up by dynamic forces or by buoyancy
- The blade may be fabricated using plain fiberglass to save cost since weight is not an issue. Some carbon may be added to increase strength in critical areas.
- Some weights may be required to reduce the blade’s buoyancy and to allow for a neutral immersed weight (to eliminate the tendency of the rudder to turn up its own). A very preliminary all up weight of this rudder is 400 kg (885 lb.), excluding any corrective weights. The buoyancy generated by the rudder volume is expected to be approximately 850 kg – this would suggest the addition of approximately 400 kg of weight.
- Even with the addition of compensating weights this solution is the lightest solution by far, on the order of half of a modern metal rudder with a hollow stock and blade and close to 1/8<sup>th</sup> the weight of the current rudder.
- The feel of the rudder is likely to be comparable to the original all wood solution due to its light weight although the use of the rudder tube bearings and larger diameter strap bearings will imply some additional friction when the rudder is loaded. This friction should be carefully addressed at the detailed design stage.



- As per the all metal solution no modifications are needed to the current stern tube with the possible exception of the stern tube bearings: the supplier may suggest a different bearing material. The carbon stock would have a GRP overwrap in way of the bearings and a possible stainless steel tube used to reduce friction as much as possible.
- It is possible that most of the existing manual steerer may be re-used providing a suitable coupling can be developed between the rudder stock and the steerer. It is likely that a new steering head will need to be manufactured.
- If the carbon stock is made in one part, there will need to be at least 3 meters of depth below the keel to remove the rudder from the boat. This is similar to what would be needed for a wooden rudder. This could be achieved either on the Lunenburg slipway or while in the vessel is in a travel-lift (The authors acknowledge there are no suitably sized travel-lifts in Nova Scotia – the closest unit appears to be at Front Street Shipyard, in Belfast, Maine).
- A two-part carbon stock would ease installation and service of the rudder stock and blade although this will likely increase the cost and complexity of the configuration. This should be explored during the detailed design stage.
- A composite rudder is likely to be the lowest maintenance solution: a properly built composite part can be expected to be in service for decades with little to no servicing other than paint and anti-fouling. The lower weight will reduce the wear on the bearings.
- A preliminary estimate of time needed to build this rudder is approximately 3 to 4 months.
- The use of bearing straps as opposed the traditional pintle and gudgeon arrangement allows for a simpler construction methodology for the rudder. This bearing concept has been used successfully on *Spirit of Bermuda* which was designed by Langan Design. Care should be taken to minimize friction at the detailed design stage.
- The carbon stock can be fabricated as a single straight tube which is the most affordable construction method.
- Should there be a desire to make use of a pintle/gudgeon type arrangement the carbon stock could be fabricated with an offset shape but the cost of the rudder would increase significantly: The stock would likely require custom tooling and be designed in two parts to allow the removable of the rudder.
- Although it may be possible to reduce the two intermediate strap bearings to one unit only this would increase the loads on the center bearing significantly. Details should be worked out at the final design stage.
- Preliminary studies suggest that going with no intermediate bearings would significantly increase the bending moments at the rudder tube lower bearing – increasing them to the point



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where the laminate would be excessively thick, heavy and difficult to build. The point loading on the shoe bearing at the tip of the keel may also be a concern.

- Composite rudders are a known quantity with ABS and we do not foresee any difficulty in getting such a rudder approved.

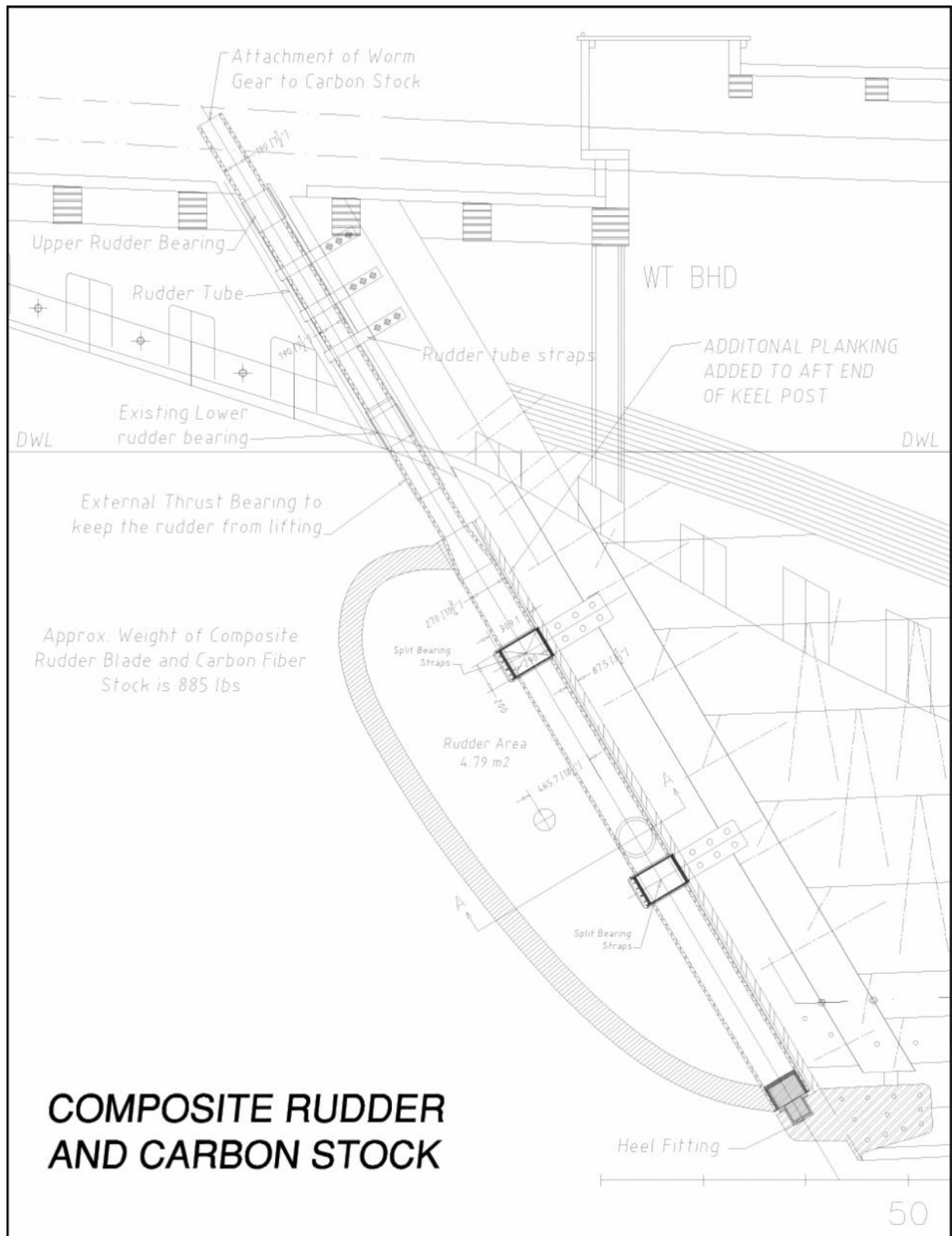


Figure 9: All Composite Rudder - Arrangement

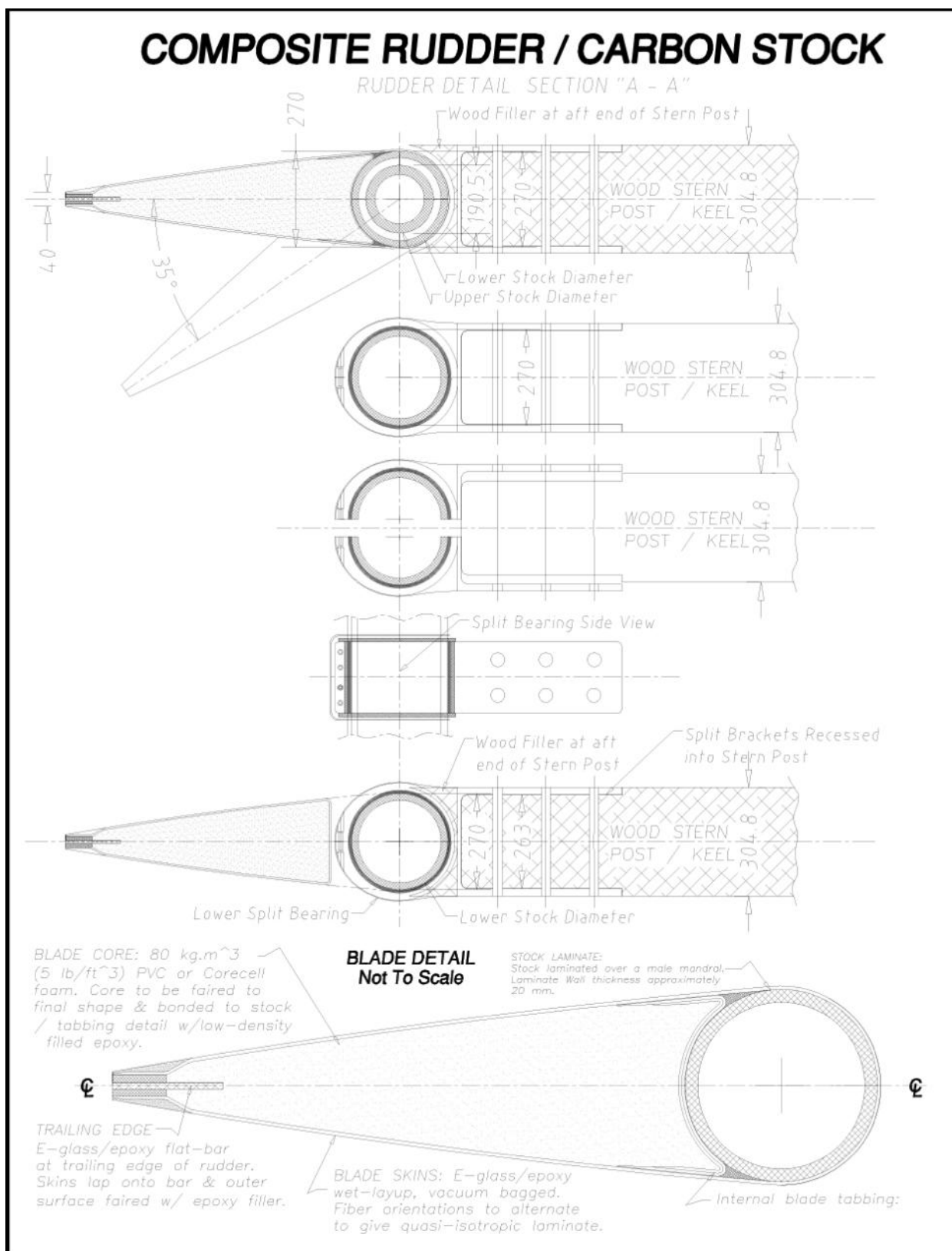


Figure 10: All Composite Rudder - Details



## 8 Ranking Methodology

Given the number of possible alternative construction methodologies for a new rudder, and the different pros and cons of each solution, the authors thought it might be useful to develop a ranking system in order to rate each solution relative to a limited set of criteria. Acknowledging the fact that each criterion may be more or less relevant to the overall project each one is given a particular weight.

The following criteria were chosen:

- Weight of the rudder (20%): As was discussed at length in the engineering review the weight of the rudder has a direct impact on the ability to be manually steered: more weight means more friction. It was also established that more weight on the structure of the vessel would likely accelerate the aging of the vessel's structure.
- Modifications to the Existing Vessel (20%): This criterion attempts to quantify the amount of modifications that will need to be done to the ship's structure. Although there is nothing inherently wrong with modifying the vessel the increase in cost may be significant, the regulatory burden will increase, and the potential for infringing on a relatively short sailing season should also be taken into account. In the case of an all wood rudder the modifications are significant. For all other cases examined they are limited to the existing steering mechanism and changing the hardware on the sternpost (gudgeons)
- Service Life (15%): Given Bluenose's active sailing season and the costs involved with the design and construction of a new rudder blade the ability of the new rudder to last seems relevant. It would be expected that the service life of a wood rudder will be shorter than the alternative.
- Ease of Repair (15%): This may be the subject of some debate but attention was given to the presence of talented wooden boat builders in Nova Scotia. Repairing a composite rudder is also quite simple as the tooling and materials involved are easy to bring on site. In the case of a metal rudder the tools required may be larger depending on the extent of the damage and the weight of the rudder blade will make handling more challenging.
- Cost of replacing the rudder only (10%): The authors are estimating that the cheapest rudder to replace will likely be the wood rudder. The material is readily available and the workforce exists in Nova Scotia to take on such a project.
- Regulatory Risk (10%): For a metal or a composite rudder the regulatory risk is low. These are modern construction methods and ABS is well suited to review such arrangements. The risk increases slightly, in the authors' opinion, with an all wood rudder as the modifications to the vessel are significant, and the possible lack of experience in wood boats at ABS could mean a more challenging process. The metal and wood solution presents the highest risk as it does not fall cleanly in any regulatory category.

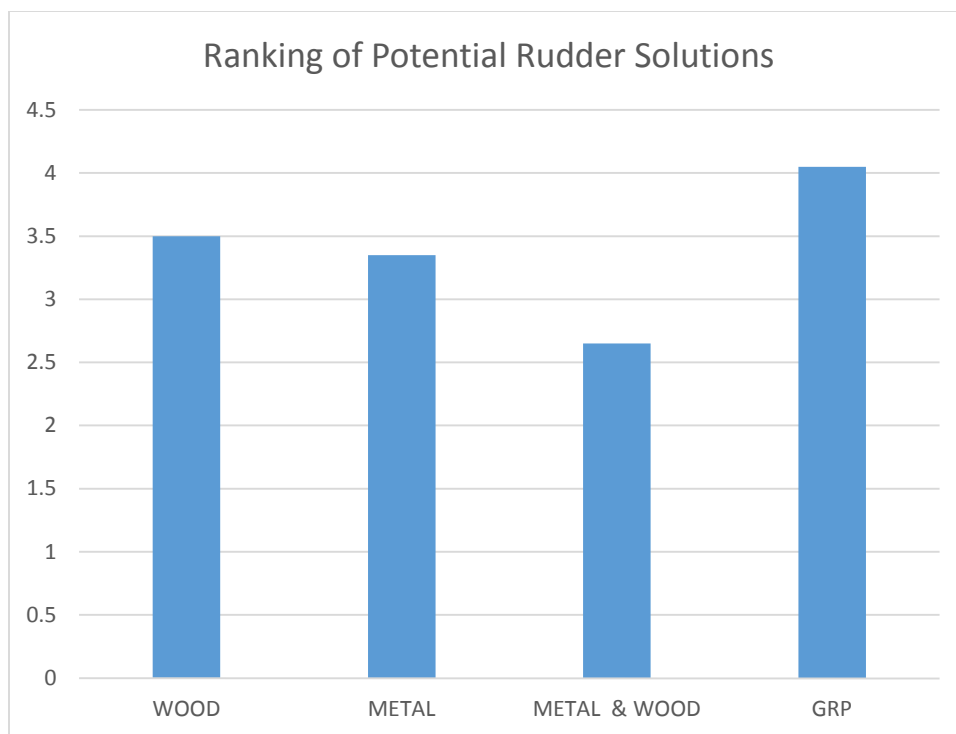


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- **Historical Accuracy (10%):** This criterion is likely to be the most controversial given the historic nature of the project. It should be noted that the existing vessel has not strictly adhered to the construction methods of the 1920s. Several modern construction techniques have been used to strengthen the overall structure in an attempt to delay the onset of global structural deformations typical of older sailing vessels. In this context historical accuracy may not be that useful. The author's feel that manual steering is more relevant to historical accuracy than the material used for the construction of the rudder.

The table below summarizes the ranking methodology the authors are suggesting. A ranking of 5 means that solution is the best performer for that criterion. The authors have attempted to rate each solution as objectively as possible but acknowledge that others may give different weights to each solution. In this table a higher score is better – the conclusion is that using this methodology the GRP rudder is the best solution, followed by the wood rudder.

		WOOD	METAL	METAL & WOOD	GRP
<b>Weight of the Rudder</b>	<b>20.0%</b>	<b>5</b>	<b>2</b>	<b>2</b>	<b>5</b>
<b>Modification to the Vessel</b>	<b>20.0%</b>	<b>1</b>	<b>4</b>	<b>4</b>	<b>4</b>
<b>Service Life</b>	<b>15.0%</b>	<b>2</b>	<b>4</b>	<b>2</b>	<b>5</b>
<b>Ease of Repair</b>	<b>15.0%</b>	<b>4</b>	<b>3</b>	<b>3</b>	<b>4</b>
<b>Cost of rudder replacement</b>	<b>10.0%</b>	<b>5</b>	<b>4</b>	<b>3</b>	<b>2</b>
<b>Regulatory Risk</b>	<b>10.0%</b>	<b>4</b>	<b>5</b>	<b>1</b>	<b>5</b>
<b>Historical Accuracy</b>	<b>10.0%</b>	<b>5</b>	<b>2</b>	<b>3</b>	<b>2</b>
<b>Weighted Sums</b>		<b>3.5</b>	<b>3.35</b>	<b>2.65</b>	<b>4.05</b>







## 9 Recommendation and Next Steps

Bluenose II (2014) is not a replica of the original Bluenose (1921) or of Bluenose II (1964). It is a modern reconstruction of a historic vessel.

The improvements made during the re-construction were made to *replicate the experience* for its passengers while addressing some of the shortcomings of the original construction methodology.

**Based on our exploration of the different possible options, and weighing each against a set of relevant criteria, it is our recommendation that the existing metal rudder be replaced with a composite rudder (hollow carbon stock with composite blade). This solution would allow for a return to a manually steered configuration and significantly decrease the long term impact of the very heavy metal blade in service today.**

This recommendation does NOT take price into consideration. It is not meant to imply that building a composite rudder will be cheaper than modifying the vessel to accept a traditional wood rudder. It does, however, assume that there is some amount of risk involved in modifying the structure of a vessel that depends on a relatively short sailing season to complete its mission.

It would also be our recommendation that a preliminary design be prepared for both a composite rudder AND a wood rudder. These drawings can be used to obtain preliminary pricing from shipyards and suppliers and to begin discussions with ABS to ensure that the regulatory risk is managed. Most of this work has already been completed in the context of this proposal and could be produced in relatively short order.

**Should the wood solution end up being significantly more affordable, and the impact on the sailing season manageable, the authors of this proposal can find no reason why a return to a wood rudder should not be considered.**

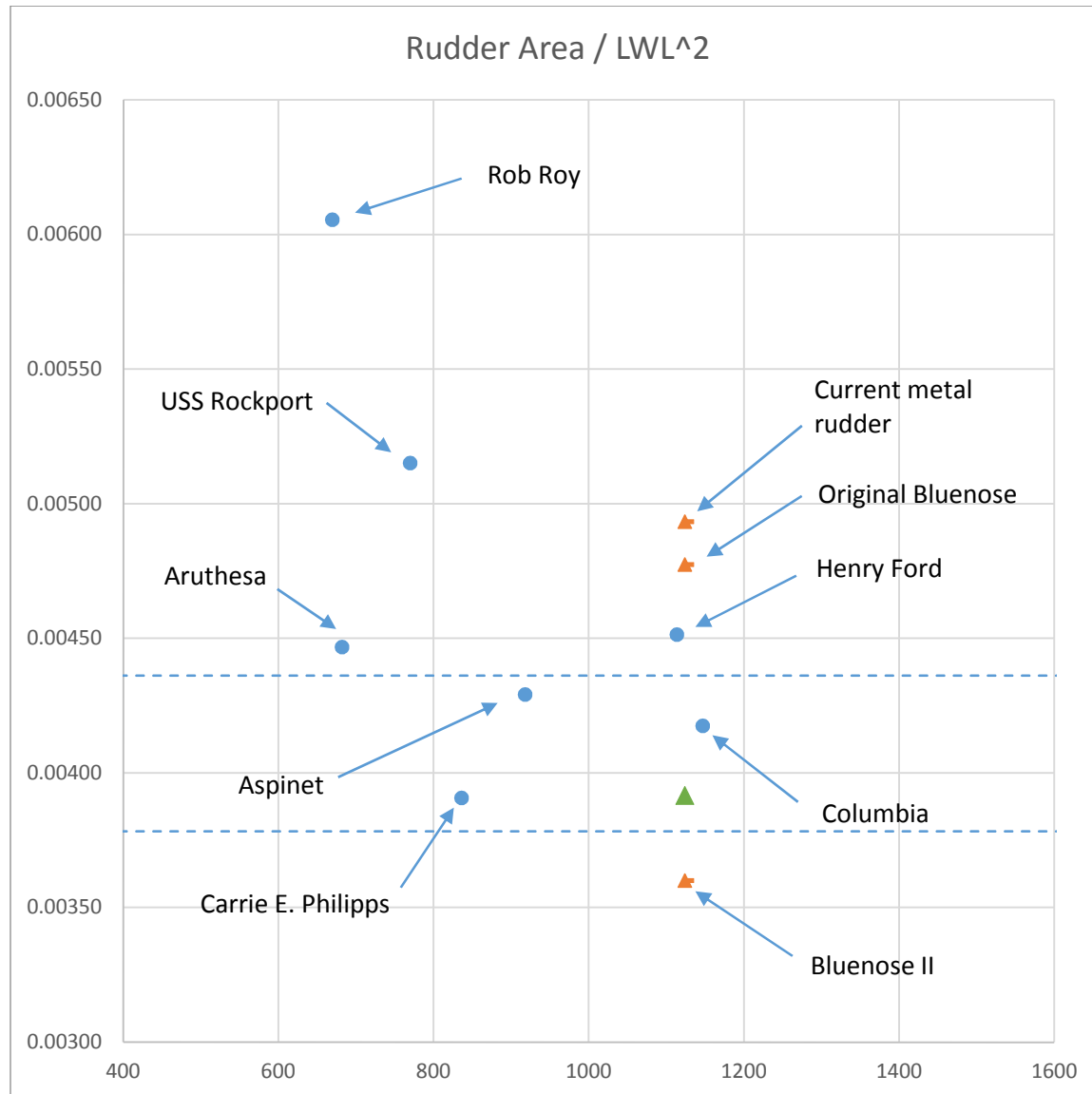
The following next steps are suggested as a way to move forward from this proposal:

- Make the decision to move forward with either one of these two solutions and retain a design firm to see the project thru from preliminary design to sea trials.
- Prepare preliminary drawings for both a composite rudder and a wood rudder and send to shipyards and suppliers for preliminary quotes and schedules. In parallel send these proposals to ABS for a preliminary review.
- Once the costs have been tabulated and the impact on schedule has been determined make the final decision to move ahead with construction for one of these two options.



## Appendix A: Rudder Area Comparison

The follow graph shows the relative rudder sizes of comparable vessels.



In the chart above the rudder areas are plotted as ratios of the rudder area divided by the design waterline length squared on the vertical axis, and the square of the waterline length on the horizontal axis. This enables a relative comparison of vessels of different design lengths. Points higher on the vertical axis have more rudder area. The green square represents the current preliminary design solution.