Rudder Form in Inland and Oceangoing Dutch Merchantmen of the 17th Century

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The Dutch flourished in international and internal maritime trade during the 17th century. The typical oceangoing ship was the fluyt*, and the typical inland ship was the* wijdschip*. The rudders of historical and archaeological examples of these ships were analyzed and found to be strikingly different.* Wijdschips *had greater ratios of rudder area to both lateral waterplane area and approximate displacement than* fluyts*, but had lower draft:rudder breadth ratios. These design features may have been used to account for the shallower draft, larger breadth, and shallow water environment of* wijdschips *and a possibly greater reliance on sails to steer* fluyts.

Au 17e siècle, les Néerlandais ont prospéré grâce au commerce maritime international et intérieur. Le navire de haute mer typique était le fluyt*, tandis que le navire en eaux intérieures typique était le* wijdschip*. Une analyse des gouvernails tirés des exemples historiques et archéologiques de ces navires a révélé qu'ils étaient bien différents. Les rapports entre la surface du gouvernail et la surface du plan de flottaison latéral et le déplacement approximatif des* wijdschips *étaient supérieurs à ceux des* fluyts*, mais les rapports entre les largeurs du tirant d'eau et du gouvernail des* wijdschips *étaient inférieurs à ceux des* fluyts*. Ces caractéristiques de conception ont peut-être été utilisées pour tenir compte du tirant d'eau plus faible, de la largeur supérieure, de l'environnement marin peu profond des* wijdschips *et d'un recours accru aux voiles pour diriger les* fluyts.

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Introduction

Rudders are an important part of any ship's gear, allowing the ships to maneuver as needed. The development of the rudder through time has been studied in some depth, particularly the transition from the use of the quarter rudder to the use of the pintle-and-gudgeon (P&G) rudder.[1] However, research on the forms of rudders is limited. Modern and historical naval architects have touched on the subject,[2] especially with regard to their interactions with propellers, but comparisons of rudder form have rarely been studied archaeologically. Shipwrights have been characterized as conservative in their craft from ancient to modern times,[3] which suggests that alterations in rudder form were due to practical concerns rather than testing or whims.

This was especially true for Dutch shipwrights in the 17th century, who were building extremely standardized vessels for the sake of efficiency and cost limitations.[4] They were building ships for the most influential maritime merchant empire of the era, for whom success hinged on designing ships that were cheap and effective. However, the Dutch built different types of ships that sailed in varying environments and for different purposes, which had to be considered when designing steering gear.

Historical shipbuilders, including the Dutch, were in constant dialogue with the environment in which their ships sailed in order to maximize utility. Comparing the way ships were designed for different waterways provides insight into how they understood and accounted for the effects of different environments on functionality.

P&G rudders have a basic form, generally a modified rectangle, and can be easily described and compared mathematically. Though simple, their importance for a sailing ship is significant. The ability to effectively steer a vessel was paramount for the Dutch to reach their destination as quickly

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1 Lawrence V. Mott, *The Development of the Rudder: A Technological Tale*, Studies in Nautical Archaeology 3 (London: Chatham Publishing, 1997).

2 Anthony F. Molland and Stephen R. Turnock, *Marine Rudders and Control Surfaces: Principles, Data, Design and Applications* (Amsterdam; London: Elsevier/Butterworth-Heinemann, 2007). Cecil H. Peabody, *Naval Architecture* (New York: Wiley, 1917), https://catalog.hathitrust.org/Record/006586972. Volker Bertram, "Chapter 6 - Ship Maneuvering," in *Practical Ship Hydrodynamics (Second Edition)*, ed. Volker Bertram (Oxford: Butterworth-Heinemann, 2012), 241–98, https://doi.org/10.1016/B978-0-08-097150-6.10006-5.

3 Samuel Mark, "The Ship Depiction in the Tomb of Nebamun: The Earliest Egyptian Ship without a Hogging Truss," *Journal of Ancient Egyptian Interconnections* 16 (2017): 76.
James M. Haas, "The Introduction of Task Work into the Royal Dockyards, 1775," *Journal of British Studies* 8, no. 2 (1969): 48.

4 Niklas Eriksson, "Urbanism under Sail: An Archaeology of Fluit Ships in Early Modern Everyday Life" (PhD diss., Södertön University, 2014), 10, http://nbn-resolving.de/urn:nbn:se:sh:diva-24415.

and safely as possible, which allowed the ship owners to maximize trips (and profit). Therefore, the rudder was subject to modifications to mitigate a changing environment and associated effects. This may be used as a window into which environmental effects shipbuilders were concerned about and what they did to accommodate them.

The rudder forms on Dutch ships in the 17th century were variable and depended on the shape of the ship's hull, the sails, and the ship's environment. This research analyzes historical and archaeological examples of the most common oceangoing and inland merchantmen, *fluyts* and *wijdschips*, to assess the variations in rudder form and determine possible contributing factors that made each type appropriate for its environment.

Background

Dutch Maritime Trade in the 17th and 18th Centuries

The Netherlands revolted against Spanish Habsburg rule in the mid-16th century and were successful in establishing the Dutch Republic in the early 17th century, although official acknowledgement of the nation by Spain did not come until 1648.[5] However, it was acknowledged that the Dutch were becoming leading merchants in Europe even before the official recognition of the Dutch Republic. By 1550, the Dutch already had the largest merchant fleet in Europe, and it expanded greatly in the following century.[6] Initially, shipping focused on Northern Europe; however, by the end of the 16th century the Dutch were making their way into the Mediterranean and Asia.[7] The first expedition was sent around the Cape of Good Hope in 1595, and by 1602 the Dutch East India Company (VOC) was formed.[8] The VOC was extremely profitable and became the primary merchant organization in the Indian Ocean for a time, controlling more trade in the region than the rest of Europe combined.[9] This made the Dutch Republic wealthy and influential. In addition to the VOC, the Dutch operated a sister organization in the Caribbean - the Dutch West

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5 Graham Darby, *The Origins and Development of the Dutch Revolt* (London; New York: Routledge, 2001), 1.

6 Milja van Tiehof and Jan Luiten van Zanden, "Productivity Changes in Shipping in the Dutch Republic: The Evidence from Freight Rates, 1550-1800," in *Shipping and Economic Growth, 1350-1850*, edited by Richard W. Unger, v. 7 (Leiden; Boston: Brill, 2011), 48.

7 van Tiehof and van Zanden, "Productivity Changes in Shipping in the Dutch Republic." 48.

8 Oscar Gelderblom, Abe de Jong, and Joost Jonker, "The Formative Years of the Modern Corporation: The Dutch East India Company VOC, 1602–1623," *The Journal of Economic History* 73, no. 4 (2013): 1053–54, https://doi.org/10.1017/S0022050713000879.

9 Jan Lucassen, "A Multinational and Its Labor Force: The Dutch East India Company, 1595-1795," *International Labor and Working-Class History* 66 (2004): 12.

India Company (GWC), which was influential but less successful and long-lived, in part because it had consistent financial struggles and some difficulty controlling the region.[10]

However, the emergence of trade in Asia and the Americas did not signal an end to Dutch trade in Northern Europe. In the 1630s, trade with the Baltic, Russia, and France accounted for more than half of the value of imports recorded, despite increasingly lucrative trade in the Indian Ocean.[11] In Northern Europe, the Dutch were primarily bulk cargo traders, carrying grain, lumber, and metals from the Baltic region to the rest of Europe, and bringing salt and colonial goods into the Baltic.[12] They were also the primary merchants in Russia during the 17th century, making up seventy-five percent of trade after 1650.[13] There, they traded initially in goods similar to those provided by Baltic countries, and later in hemp, leather, and ashes.

Various reasons have been given for the dominance of Dutch merchants in the 16th and 17th centuries. Some argue that the position of the Netherlands played a major role in the ability of the Dutch to operate efficient trading routes.[14] Because the Netherlands is centrally located along European trade routes, Dutch merchants could spend summers in the Baltic and winters in southwestern Europe, allowing for year-long trade. Alternatively, Sir Walter Raleigh, writing in 1605, attributed the dominance of the Dutch merchant empire mainly to the style of ships being built.[15] During the 16th century, the Dutch were constantly innovating, attempting to make their vessels more lucrative.[16] At the time, the goal of Dutch design was to build ships which carried as much cargo as possible but could be sailed by only a few men. Eventually, the Dutch were sailing ships in parts of Europe which had ton:man ratios of over twenty-four:one by 1700, growing from fourteen:one in 1636.[17]

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10 Alexander Bick, "Governing the Free Sea: The Dutch West India Company and Commercial Politics, 1618-1645" (Ph.D. diss., Princeton University, 2012), 9–10, https://www.proquest.com/docview/1238001630/abstract/8DE092A09B4240DEPQ/1.

11 van Tiehof and van Zanden, "Productivity Changes in Shipping in the Dutch Republic," 66.

12 M. Malowist, "The Economic and Social Development of the Baltic Countries from the Fifteenth to the Seventeenth Centuries," *The Economic History Review* 12, no. 2 (1959): 179, https://doi.org/10.2307/2599234.

13 Oscar Gelderblom, "Coping with the Perils of the Sea: The Last Voyage of Vrouw Maria in 1771," *International Journal of Maritime History* 15, no. 2 (2003): 96, https://doi.org/10.1177/084387140301500206.

14 van Tiehof and van Zanden, "Productivity Changes in Shipping in the Dutch Republic: The Evidence from Freight Rates, 1550-1800," 52.

15 C. A. Davids, *The Rise and Decline of Dutch Technological Leadership: Technology, Economy and Culture in the Netherlands, 1350-1800*, Knowledge Infrastructure and Knowledge Economy, vol. 1 (Leiden; Boston: Brill, 2008), 92.

16 van Tiehof and van Zanden, "Productivity Changes in Shipping in the Dutch Republic," 49.

17 Davids, *The Rise and Decline of Dutch Technological Leadership*, 93.

In addition to Dutch maritime dominance, the Netherlands was home to a significant inland trade network. Most intracountry trade took place on inland waterways, the most important of which was the Zuider Zee, an inland sea which covered a large portion of the northwestern Netherlands from about 1170 until 1932.[18] The Zuider Zee served to connect Dutch provinces through a system of ferries and merchantmen called the *beurtvaart* system.[19] The *beurtvaart* system operated on a regular, predetermined schedule to transport people and goods between cities.[20] Cities made arrangements between themselves to ensure a consistent shipping schedule.[21] It is estimated that up to 8,000 ships were operating on the Zuider Zee during the 17th century.[22] Many of these ships provided for both the movement of seasonal laborers and a method for farmers to get their products to city markets.[23] Others operated separately from the *beurtvaart* system and served other economic functions like fishing and peat transportation. The peat ships transported peat for use as fuel and have been credited with at least part of the booming economy of the 17th century by allowing a much easier and cheaper method of transportation compared to overland options.[24] The easy access to inexpensive peat allowed the Dutch to replace a dwindling wood supply and fill their energy needs that way, spurring business growth. Between internal and international trade, the Dutch were dominating the waterways during the 17th century.

18 Yftinus van Popta, "Lost Islands, Drowned Settlements and Forgotten Shipwrecks: Interaction between Aspects of the Maritime Cultural Landscape of the Former Zuiderzee (AD 1100–1400)," in *Baltic and beyond: Change and Continuity in Shipbuilding: Proceedings of the Fourteenth International Symposium on Boat and Ship Archaeology Gdańsk 2015*, edited by Jerzy Litwin and Eric Kentley (Gdańsk: National Maritime Museum, 2017), 107.

19 Erik van der Vleuten and Cornelis Disco, "Water Wizards: Reshaping Wet Nature and Society," *History and Technology* 20, no. 3 (2004): 294, https://doi.org/10.1080/07341510 42000287014. Herman J. De Jong, "Dutch Inland Transport in the Nineteenth Century: A Bibliographical Review," *The Journal of Transport History* 13, no. 1 (1992): 3, https://doi.org/10.1177/002252669201300102.

20 De Jong, "Dutch Inland Transport in the Nineteenth Century," 3.

21 André van Holk, "The Zuiderzee (the Netherlands). Highway, Fishing Ground and Power Landscape," in *Ships and Maritime Landscapes: Proceedings of the Thirteenth International Symposium on Boat and Ship Archaeology, Amsterdam 2012*, edited by Jerzy Gawronsky, André van Holk, and Joost Schokkenbroek. (Amsterdam: Barkhuis, 2017), 74, https://www.academia.edu/34556245/The_Zuiderzee_the_Netherlands_Highway_fishing_ground_and_power_landscape.

22 J.W. De Zeeuw, "Peat and the Dutch Golden Age: The Original Meaning of Energy-Attainability," *A.A.G. Bijdragen* 21 (1978): 20–21.

23 Holk, "The Zuiderzee (the Netherlands). Highway, Fishing Ground and Power Landscape," 74.

24 De Zeeuw, "Peat and the Dutch Golden Age," 23.

The Inland Merchantmen - Wijdschips *and* Smalschips

As trade and industry on the Zuider Zee was variable, so were the ships that sailed upon it. In his shipbuilding treatise, Nicholas Witsen provided sketches for nine different types of inland vessels and named over thirty varieties, some of which were from specific Dutch provinces.[25] While most vessels described were for trade, some served other purposes, such as fishing, and some had unspecified functions. To limit the scope of this paper, the focus will remain on the main inland trading vessels, about which more information is available.

According to Witsen, these are the *smalschip* (narrow ship), which he named as the typical vessel for trading and towing, and the *wijdschip* (wide ship - also *wÿtschip*), also described as a peat ship, ferry, or envoy.[26] *Smalschips* and *wijdschips* were very similar and their classification depended on the breadth - any ship that was broader than sixteen Amsterdam feet and six inches (4.68m) could not fit through the Donkere Sluis and was considered a *wijdschip.*[27] As such, *wijdschips* were more limited in their trade routes, but could carry more cargo than *smalschips*. Both ships were sometimes also called *karveels*, after their carvel style planking, or *beurtscheppen* because they were used in the *beurtvaart* system.[28]

Oceangoing Merchantmen—Fluyts

As with inland merchantmen, there were a variety of Dutch oceangoing merchantmen. Witsen described five types of oceangoing merchantmen, not including those which were used in the East India trade.[29] This paper is focused on the most ubiquitous oceangoing Dutch merchantman, the *fluyt* (also *fluit*).[30] The *fluyt* was developed at the end of the 16th century and quickly became the standard cargo ship.[31] They were popular because their small sails and simple, standardized rigging were worked by a limited crew.[32] Rigging consisted of

25 Nicolaes Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier* (Amsterdam: Casparus Commelijn en Jan Appelaer, 1671), 169–86, http://archive.org/details/gri_33125008247716.

26 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier,* 169.

27 Frederick Martin Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World" (PhD diss., Texas A&M University, 1991), 217, https://oaktrust.library.tamu.edu/handle/1969.1/158191.

28 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 217.

29 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 158–69.

30 Niklas Eriksson, "Archaeology of Complete Ships – on the Potential of Well-Preserved Wrecks of 17th Century Merchant Fluyts in the Baltic Sea," in *Shipwrecks around the World: Revelations of the Past*, edited by Sila Tripati (New Delhi: Delta Book World, 2015), 176.

31 A. J. Hoving and Cor Emke, *The Ships of Abel Tasman* (Hilversum: Verloren, 2000), 34–35.

32 Richard W Unger, "The Fluit: Specialist Cargo Vessels 1500 to 1650," in *Cogs, Caravels,*

a main and foremast fitted with square sails and a mizzenmast fitted with a lateen sail.[33] Smaller *fluyts* could be handled by as few as seven men and a boy, while larger *fluyts* might have twenty-two or more sailors.[34] These ships were the primary reason why the Dutch were able to raise their ton-to-man ratio to the aforementioned twenty-four:one.

Like the rigging, the hulls of *fluyts* shared general characteristics. The hull had a high length to breadth ratio, usually falling between four:one and six:one.[35] Their holds were box-like both longitudinally and in cross-section, maximizing cargo space, while their decks were narrow, resulting in significant tumblehome.[36] Some speculate that this was an attempt to avoid taxes based on deck space, while others argue that it was mainly to keep the center of gravity low. Whatever the reason, it resulted in a characteristic pear-shaped aft profile which make *fluyts* easy to identify in maritime paintings.

Because of their popularity, *fluyts* were often modified to fill different roles.[37] In his contemporary account, Witsen described a standard *fluyt* followed by modifications made for *fluyts* sailing in the Indian Ocean (reinforced for rough voyages), *Oostervaerders* (Eastern ships; shallower drafts), and *Noortsvaerders* (Northern ships; deeper drafts and modified decks).[38] In addition, other specialized *fluyts* and variants were made for whaling, trade with the Iberian peninsula, or to reduce expenses.[39]

Pintle and Gudgeon (P&G) Rudders

The steering gear of a ship is one of the most important aspects of its outfitting because it allows the ship to move as intended. The earliest rudders were quarter rudders, which were mounted over either or both of the stern quarters of a ship.[40] The quarter rudder was improved and persisted as the dominant form in Europe through the Middle Ages and survives in the present

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and Galleons: The Sailing Ship, 1000-1650, edited by Robert Gardiner (Edison, NJ: Chartwell Books, 2000), 121.

33 Eriksson, "Archaeology of Complete Ships—on the Potential of Well-Preserved Wrecks of 17th Century Merchant Fluyts in the Baltic Sea," 176.

34 Unger, "The Fluit: Specialist Cargo Vessels 1500 to 1650," 122. Niklas Eriksson, "Lodging in a Fluitship: The Material Setting of Everyday Life on Board Anna Maria of 1694," *Journal of Maritime Archaeology* 10, no. 1 (2015): 57.

35 Hoving and Emke, *The Ships of Abel Tasman*, 35.

36 Eriksson, "Urbanism under Sail," 10.

37 Hoving and Emke, *The Ships of Abel Tasman*, 35.

38 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 158–60. Eriksson, "Urbanism under Sail," 11.

39 Eriksson, "Urbanism under Sail," 11.

40 Mott, *The Development of the Rudder*, 3.

in some vernacular boat building traditions.[41] Various stern-hung rudders were invented globally, including the stern-hung rudders mounted on central stanchions in ancient Egypt that emerged by the Middle Kingdom,[42] and rudders mounted on the stern of Chinese vessels.[43] Quarter rudders remained the primary form in Europe until the P&G rudder was invented in the early 12th century.[44] The introduction of the P&G rudder in Northern Europe, and subsequently the Mediterranean, allowed ships to be steered by a single, fully supported rudder. This was an advantage over the quarter rudders they replaced, which were unsupported over a large portion of the blade and could break more easily.[45] The effects of the P&G rudder on sailing properties were mixed. On one hand, it improved the ship's sailing when the sea was following.[46] On the other hand, the rounded hulls of Dutch ships typical of the time created turbulence around the rudder that degraded its performance compared to quarter rudders.[47] However, the benefits must have outweighed the drawbacks because by the 17th century, the Dutch were using exclusively P&G rudders on their merchantmen.

The P&G rudder works as a lifting foil to turn the ship in the desired direction.[48] At rest, the rudder sits in line with the keel. When the tiller of the rudder is turned, either directly or with a whipstaff or wheel, the blade angles to one side, which forces water to travel a longer distance around the outside of the angle than the around the inside. This creates a pressure difference with a low-pressure area along the outside and a high-pressure area along the inside of the rudder angle. The pressure difference in turn creates lift toward the outside of the angle. The rudder and stern follow the transverse force toward the outside of the angle while the bow moves in the opposite direction, turning the ship.[49]

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41 Nick Burningham, "Indonesian Quarter-Rudder Mountings," *International Journal of Nautical Archaeology* 29, no. 1 (2000): 100, https://doi.org/10.1111/j.1095-9270.2000.tb01385.x.

42 Michael Allen Stephens, *A Categorisation and Examination of Egyptian Ships and Boats from the Rise of the Old to the End of the Middle Kingdoms*, BAR International Series 2358 (Oxford: Archaeopress, 2012), 69.

43 Mott, *The Development of the Rudder*, 7.

44 Mott, *The Development of the Rudder*, 106.

45 Mott, *The Development of the Rudder*, 111.

46 Mott, *The Development of the Rudder*, 113.

47 Mott, *The Development of the Rudder*, 132.

48 Molland and Turnock, *Marine Rudders and Control Surfaces*, 36.

49 Bertram, "Chapter 6 - Ship Maneuvering," 271.

Methodology

Historical drawings were retrieved primarily from Nicolaes Witsen's *Aeloude en hedendaegsche scheeps-bouw en bestier*, a treatise on 17th century Dutch shipbuilding freely available and archived online by the Getty Research Institute.[50] Archaeological drawings were retrieved from published reports on relevant ship types. Significant excavations and reports on *fluyts* have been directed by Niklas Eriksson, while the only well-published excavation of a *wijdschip* was directed by Fred Hocker.[51]

Ships were selected for analysis based on their ability to provide all the information required to perform the calculations described below. It had to be possible to measure the length, breadth, and draft of the ship as well as the breadth and draft of the rudder. Archaeological ships that did not have sufficient rudder preservation were omitted as were any drawings or paintings of ships for which the angle did not permit measurement and/or the ship was obscured below the waterline.

Analysis was performed following Peabody's method, which compares rudder size based on the ratio between the submerged area of the rudder and the underwater lateral plane of the ship.[52] The same method is still used today, and the process is described by Molland and Turnock: the rudder area (A) is divided by the length of the vessel at the waterline (L) and the draft of the vessel (T) (Equation 1).[53] By dividing the rudder area by the lateral hull area, it compares the proportion of the rudder and ship size and avoids biasing results based on overall ship size. For all ships, length and draft includes the endposts and keel because they increase the water-facing length and depth of the hull, which affects the amount of ship the rudder must act upon.

$$\frac{A}{LT} \qquad \text{Equation 1}$$

After initial calculations, it was revealed that the *wijdschips* had extremely high A:LT ratios, so a second equation was also introduced based on studies

50 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*.

51 Niklas Eriksson, "The Lion Wreck: A Survey of a 17th-century Dutch Merchant Ship—an Interim Report," *International Journal of Nautical Archaeology* 41, no. 1 (2012): 17–25, https://doi.org/10.1111/j.1095-9270.2011.00319.x. Niklas Eriksson and Johan Rönnby, "'The Ghost Ship'. An Intact Fluyt from c.1650 in the Middle of the Baltic Sea," *International Journal of Nautical Archaeology* 41, no. 2 (2012): 350–61, https://doi.org/10.1111/j.1095-9270.2012.00342.x. Eriksson, "Urbanism under Sail." Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World."

52 Peabody, *Naval Architecture*, 553.

53 Molland and Turnock, *Marine Rudders and Control Surfaces*, 189.

of Lake Champlain steamboats which had encountered similarly high ratios. They added a division by breadth to accommodate the difference, since the recommended ratio for steamboats was less than half the calculated ratio (Equation 2).[54] For the purposes of this study, both equations were used to calculate rudder size.

$$\frac{A}{LBT} \qquad \text{Equation 2}$$

To calculate the submerged area of the rudder, the breadth at the waterline and the keel were averaged to produce the mean breadth of the submerged area. The result was multiplied by the height of the submerged area of the rudder. The height of the rudder was considered equal to the draft of the ship in all cases, because the rudder blade begins above the waterline and terminates at the depth of the keel. The waterline given by the author of each respective drawing was used as the basis for length at waterline measurements. In cases where the waterline was not drawn, it was estimated based on the position of the lowest wale and by comparison to drawings of similar ships. The shape of the rudders was also evaluated to determine differences in form. The height of the rudder to the waterline (R(h)) was divided by the average of the breadth (R(b)) of the rudder.

The data needed to perform this analysis was the overall hull length, height, and breadth of the ship at the waterline and a measurable rudder profile including the width and height of the rudder at the waterline. Without all appropriate data, it would not be possible to perform the calculations in a way that allowed the ships to be compared to each other. Each measurement was taken off the scale drawings of the ships unless formal numbers were presented in the text, in which case that data was used instead. Once each measurement was collected, they could be used in the equations described above.

Ship Analysis

The following ships were selected for analysis based on their adequate preservation or drawing layout in treatises.

54 Dan Bishop and Kotaro Yamafune, "Analyzing Nineteenth-Century Steamboat Rudders of Lake Champlain: Using Photogrammetric Modeling to Aid the Archaeological Process," paper presented at the 49th Annual Conference on Historical and Underwater Archaeology (Washington D.C., January 8, 2016).

Wijdschips and their Rudders

Oostflevoland B-71

The *Oostflevoland B-71* ship (also called the *Lelystad beurtschip*) was discovered by construction workers in 1980 while they built a drainage canal, and excavated in the following years.[55] Hocker estimated that the ship was in service for up to forty years when it sank in the 1620s, based on the numerous repairs that were made to the hull.[56] He also identified it as a *beurtschip* due to its varied cargo and shape, which suggested that it functioned as a ferry. The ship has a wide, flat bottom, particularly in the midsection.[57] The hull is full throughout, with some tapering at the bow and stern. Based on draft marks found on the stem and sternpost, the draft was raised from 1.42 meters (five Amsterdam feet) to 1.60 meters (six feet) during the ship's life.[58]

The rudder of the vessel was found nearly intact but leaning against the port quarter of the hull.[59] It is quite broad below the waterline, and tapers toward the stock before entering through a "pink" style stern (Fig. 1).[60] The rudder is large compared to the underwater lateral plane of the ship, yielding an A:LT ratio of 0.0982. When taking the breadth of the vessel into consideration the A:LBT ratio drops to 0.0196. The increase in draft does not impact either of these calculations, as the added depth is added to both the hull and the rudder. The submerged depth of the rudder is small compared to the breadth, with an

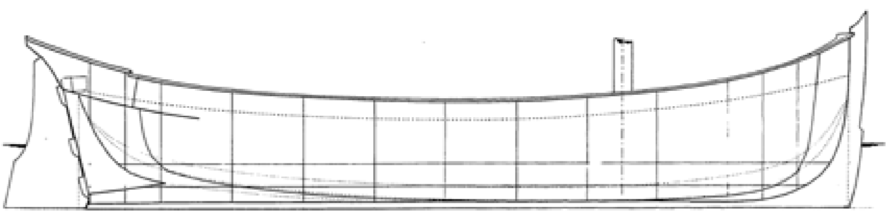

Figure 1. Sheer plan of the Oostflevoland B-71 ship (from Hocker 1991, 186, used with permission from Fred Hocker)

55 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 181.

56 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 184.

57 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 185–87.

58 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 185.

59 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 183.

60 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 185.

R(h):R(b) ratio of 0.8685 when using the original draft and 0.9785 after the draft was increased.

Comments from Nicolaes Witsen

Witsen provided a contemporary drawing of a *wijdschip* in his 1671 treatise (Fig. 2).[61] Despite being drawn nearly a century after the estimated construction date of the *Oosflevoland B-71* vessel, Witsen's ship closely resembles it. The ship is broad with a shallow draft and limited tapering at the bow and the stern. Hatches are found in identical locations and a cover over the central hatch is shown for added storage. The rudder is also broad, although it tapers less at the stock. When compared to the underwater lateral plane of the ship, it yields a similarly high A:LT ratio of 0.0903. When the breadth of the vessel is taken into account, the A:LBT ratio drops to 0.0194. The submerged height of the rudder is even smaller compared to the breadth at Witsen's waterline than the *Oostflevoland B-71*, yielding a R(h):R(b) ratio of 0.553. Witsen's waterline is lower on the hull than the draft marks on the *Oostflevoland B-71 beurtschip*, which is a contributing factor to this difference.

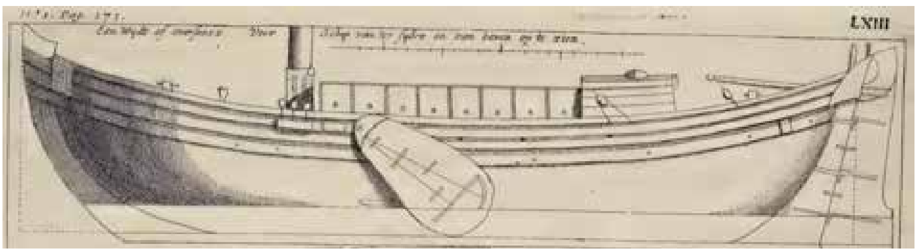

Figure 2. Sheer view drawing of a *wijdschip* drawn by Nicolaes Witsen in 1671 (from Witsen and Hooghe 1671, 171, used with permission from Getty Research Institute, Los Angeles (94-B21672))

In addition to his drawing of the *wijdschip*, Witsen directly commented on the rudders of inland merchantmen. Beginning his description with the *smalschip*, he noted that the ship, like most other inland vessels, had a remarkably broad and heavy rudder.[62] In a later discussion of a *weyschuit*, Witsen reiterated his point that small and shallow-hulled vessels ought to be built with broad rudders for enhanced steering.[63] Witsen then described his reasoning behind choosing a broader rudder for the inland ships, stating that they have such shallow drafts and rounded hulls that not much water can catch

61 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 171.
62 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 169.
63 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 172.

on the rudder, but that it was known to ship-builders that ships were much better steered when more water flowed against the rudder.[64] Since the hulls needed to have shallow drafts to sail the shallow Zuider Zee and rounder hulls carried more cargo, the solution was to create rudders much broader than usual so the extra breadth would provide the necessary surface area against which the water could flow.

Fluyts *and their Rudders*

The "Ghost Ship"

Deep Sea Productions and MMT discovered the so-called "Ghost Ship" off the coast of the Swedish island of Gotska Sandön in 2003 while attempting to locate a Swedish reconnaissance plane.[65] Sitting upright at a depth of 130m, the fluyt is inaccessible to divers but has been surveyed using ROVs with cameras and echosounders to create scaled drawings and a 3D model of the ship. The wreck has been dated to the 1670s based on sculptural styles and dendrochronology performed on a decorative *hoekman*, or corner man, removed from the site.[66] It is characteristically *fluyt*-like, with significant tumblehome, a full, boxy hull, and a small stern panel.[67]

Figure 3. Sheer plan of the Ghost Wreck (from Eriksson 2014, 65, used with permission from Niklas Eriksson)

64 Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 169.

65 Eriksson and Rönnby, "The Ghost Ship," 350.

66 L. Koehler, M. Domínguez-Delmás, L. Megens, B. du Mortier, M. de Keijzer, H. van Keulen, M. Manders, and B. van Tilburg "Tracing the Ghost Ship: Can the Hoekman Reveal Her Construction Date and Origin?" poster presented at the 13th International Symposium on Boat and Ship Archaeology, (Amsterdam, the Netherlands, October 8, 2012), https://www.academia.edu/2760382/Tracing_the_Ghost_Ship_can_the_hoekman_reveal_her_construction_date_and_origin.

67 Eriksson and Rönnby, "The Ghost Ship," 352.

The rudder of the Ghost Ship is unshipped from its pintles but intact and stands just to the port side of the sternpost.[68] Decorating the tiller are three flowers, a motif common in Dutch artistic tradition at the time. It has one visible step which broadens the rudder just below the waterline (Fig. 3). The submerged rudder area yields an A:LT ratio of 0.0264 when compared to the submerged lateral area of the ship, a A:LBT ratio which decreases to 0.00824 when divided by the breadth of the ship. In contrast to the *wijdschips* discussed above, the submerged depth of the rudder at the estimated waterline is more than four times the average breadth with a ratio of 4.593.

The "Lion Wreck"

The Lion Wreck, named for the carving of a lion found on the tiller, was discovered in 2009 during a search for a sunken steamer.[69] Like the Ghost Ship, the Lion Wreck was found in deep water off the coast of Sweden and remains well preserved due to the cold and brackish qualities of the Baltic Sea. Eriksson identified it as a small *fluyt* based on its characteristic pear-shaped stern with a bulky, rounded hull.[70] Based on damage at the bow, it sank as the result of a collision.[71] The presence of an intrusive spar indicates that it may have collided with another ship.

The rudder of the ship is still intact at the stern of the ship.[72] It has one visible step which broadens the rudder just below the waterline, and what is possibly a second step just above where the hull sinks into the mud (Fig. 4). It

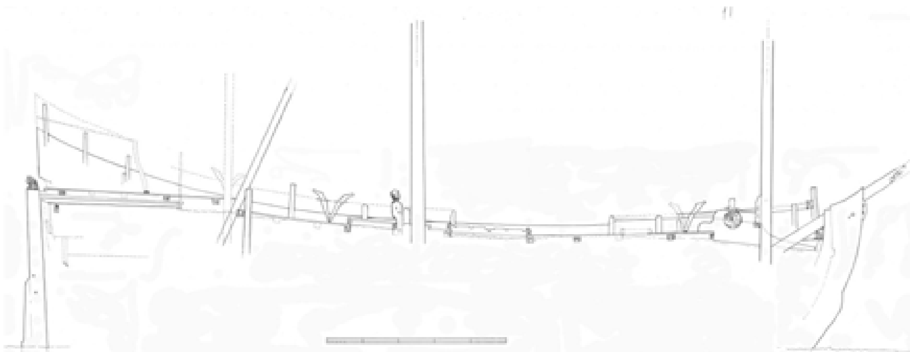

Figure 4. Sheer plan of the Lion Wreck (from Eriksson 2012, 20, used with permission from Niklas Eriksson)

68 Eriksson and Rönnby, "The Ghost Ship," 356.
69 Eriksson, "Urbanism under Sail," 92.
70 Eriksson, "The Lion Wreck," 19.
71 Eriksson, "Urbanism under Sail," 92–93.
72 Eriksson, "The Lion Wreck," 19.

is unclear how much of the hull is below the mud. The submerged rudder area yields a ratio of 0.0218 when compared to the submerged lateral waterplane of the ship, which decreases to 0.004079 when breadth is taken into account. The rudder height to breadth ratio is 4.1886, although this is almost certainly an underestimate as the ship seems to have settled into the sediment.

Comments from Nicolaes Witsen

Witsen provided a profile drawing of a *Noortsvaerter*, a type of *fluyt* specifically designed to trade lumber in the Nordic region (Fig. 5).[73] His drawing shows the boxiness of the *fluyt*, both in the half-breadth and half body plan, which also shows the tumblehome and narrow upper works. He described the form and function of other types of *fluyts* but does not provide the information necessary to analyze their rudders. He included a drawing of *fluyts* in the water, but the angle and water obscure important aspects of their form. The rudder on the *Noortsvaerter* is double stepped, having a broader bottom, slightly narrowed middle, and more pronounced narrowing toward the head. The A:LT ratio is 0.03448, which decreases to an A:LBT ratio of 0.0119 when divided by breadth. The rudder has a lower R(h):R(b) ratio than other *fluyts* analyzed, coming in at 2.222. Like in his drawing of the *beurtschip*, Witsen presented a relatively low waterline, which contributes to this low R(h):R(b) ratio. Unlike his discussion of inland ships, Witsen did not comment on the rudders used on oceangoing ships. They may have been considered standard at the time, and he felt no need to do so.

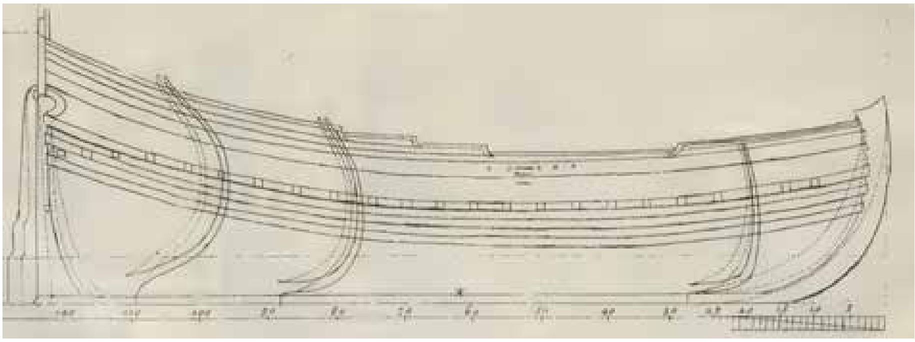

Figure 5. Sheer plan of Witsen's *Noortsvaerder* (from Witsen and Hooghe 1671, 161, used with permission from Getty Research Institute, Los Angeles (94-B21672))

[73] Witsen, *Aeloude en hedendaegsche scheeps-bouw en bestier*, 160.

Åke Classon Rålamb

Witsen was not the only treatise-writer who addressed the topic of *fluyts* in the 17th century. Rålamb, who published his treatise "Skeps Byggerij" in 1691, also included a drawing of a *fluyt* which has been republished in other forms.[74] He drew two different types of *fluyts*, however only one displays the full depth and rudder. The *fluyts* are drawn to be approximately the same size, and he seems to have implied that the rudder would not change. Rålamb's drawings have been helpful in determining the interior layout of the *fluyt*.[75]

Rålamb's *fluyt* has rudder dimensions similar to the *fluyts* already mentioned. At 0.02707, the A:LT ratio is higher than the two archaeological examples but lower than Witsen's *Noortsvaerder*. This A:LBT ratio lowers to 0.007519 when accounting for breadth, making it most similar to the Ghost Ship. The Rh:Rb ratio, 3.647, is lower than the two archaeological examples but higher than that of Witsen's drawing. The rudder has a single step, again broadening approximately at the waterline.

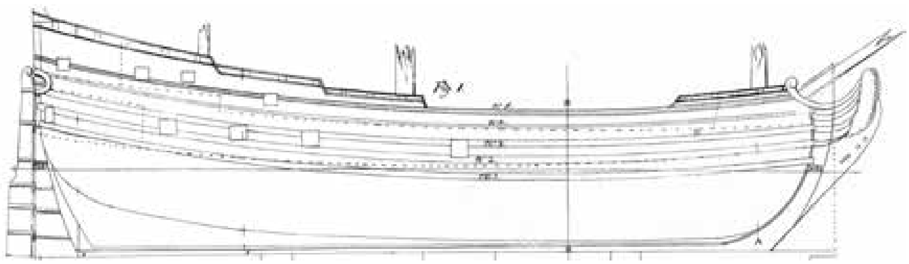

Figure 6. Sheer plan of Rålamb's *fluyt* (from Eriksson 2014, 61, edited after Rålamb 1943:25, plate G, used with permission from Niklas Eriksson)

Discussion

Ratio Comparisons: Contemporary and Modern

The average A:LT ratio of studied *wijdschips* was over 3 times larger than that of all *fluyts* (Table 1). The average for *fluyts*, 0.02667, is slightly higher than would be expected for a modern twenty-first century merchant vessel, which has a ratio of 0.016-0.022 depending on whether it is a single- or twin-screw ship.[76] It falls squarely in the range of modern warships (0.024-0.028) and is lower than that of tugs and trawlers (0.030-0.040). Ships just

74 Eriksson, "Urbanism under Sail," 61.
75 Eriksson, "Urbanism under Sail," 83.
76 Molland and Turnock, *Marine Rudders and Control Surfaces*, 189.

after the turn of the 20th century had a similar range of ratios.[77] The average for *wijdschips* was well beyond the highest ranges given by either Peabody or Molland and Turnock. It was beyond even the ratio found for Lake Champlain steamboats (0.055), on which the A:LBT ratio was based.[78]

Similarly, the average A:LBT ratio of studied *wijdschips* was over twice that of the *fluyts* (Table 1). For *wijdschips*, the ratio was almost ten times as large as the average adjusted ratios of the Lake Champlain steamboats (0.0022) originally used to develop the method, which demonstrates just how comparatively large the *wijdschips*' rudders were during the 17th century.[79] The method has not been used to analyze modern sea-going merchant ships, but the average adjusted ratio for the *fluyts* was also much higher than the steamboats. With such high ratios, it is unsurprising to find that the *wijdschips* also had on average much broader rudder shapes than the *fluyts* (Table 1).

Table 1. Average ratios for *fluyts* and *wijdschips*.

	Fluyts	Wijdschips
A/LT	0.02667	0.09425
A/LBT	0.0079	0.0195
R(h)/R(b)	3.66	0.8

It is important to note the limitations of these averages, namely that they come from extremely small sample sizes (n=4 for *fluyts* and n=2 *wijdschips)*. Unfortunately, the number of ships that meet the qualifying criteria is currently limited. Results presented in this paper appear to be supported by contemporary nautical art. *Fluyts* were sometimes depicted in the background of scenes and *wijdschips* often appeared in harbor scenes. For example, an engraving from 1640 shows a *wijdschip* or *smalschip* acting as a ferry and the proportionally broad rudder is clearly on display, although the waterline is obscured so it could not be analyzed.[80] *Fluyts*, while common ships, are rarely found in the foreground in Dutch nautical paintings. However, one such example is *The Whaler, "Prince William," on the River Maas, near Rotterdam*, by Lieve

77 Peabody, *Naval Architecture*, 553.

78 Bishop and Yamafune, "Analyzing Nineteenth-Century Steamboat Rudders of Lake Champlain."

79 Bishop and Yamafune, "Analyzing Nineteenth-Century Steamboat Rudders of Lake Champlain."

80 Irene de Groot and Robert Vorstman, *Sailing Ships: Prints by the Dutch Masters from the Sixteenth to the Nineteenth Century*, A Studio Book ([s.l.] : New York: Uitgeverij G. Schwartz ; Viking Press, 1980), fig. 53.

Pietersz Verschuier.[81] It is clear in the painting that the *fluyt*'s rudder is similar to those drawn in the treatises and site plans studied here. A drawing by Willem van de Velde the Younger shows a similar *fluyt* in better detail, with its narrow rudder and stepped design obvious just above the waterline.[82] While nautical art cannot be analyzed because of angled perspectives and obscured sightlines, a basic qualitative assessment of some of the rudders provides at least some support for the conclusions drawn.

Reasoning for Rudder Form

A next appropriate step is to understand what factors affect the choices Dutch shipwrights made when designing rudders for inland and seagoing ships. Witsen's comments in his discussion of inland vessels shed some light on reasons why the rudders of *fluyts* and *wijdschips* were so different. As mentioned above, he specifically addressed the need for broader rudders in inland vessels to accommodate for the shallower draft. According to Peabody, the preferred rudder is deep and narrow, as such rudders have a large surface area and turning moment without adding a significant twisting moment on the rudder head.[83] Thus, the structure of the *fluyt'*s rudder would be considered superior to that of the *wijdschips*. However, ships traveling on inland waterways must be able to navigate and dock in the shallower environments of rivers and lakes. The depth of the southern section of the Zuider Zee was between 2.4 and 4.6 meters (8.5-16.25 Amsterdam feet), limiting the possible draft of a ship intended to sail upon it.[84] Some areas could be even shallower, especially where rivers deposited silt. The lower draft limited the possible depth of the rudder, so to make up the surface area it had to be broader.

Witsen also commented on the roundedness of the hulls of inland ships and how it contributes to the need for broader rudders. Indeed, broader hulls with high block coefficients have higher wake fractions, which make for a lower wake speed into the rudder, reducing its effectiveness.[85] Increased breadth (compared to length) is taken into account in modern equations estimating the ideal A:LT ratio, and results in a higher ratio than is needed for narrower ships.[86] The *wijdschips* studied had length to breadth ratios around 3, while the

81 George S. Keyes, *Mirror of Empire: Dutch Marine Art of Seventeenth Century* ([Minneapolis] : Cambridge ; New York: Minneapolis Institute of Arts ; Cambridge University Press, 1990), 182–83.

82 Hoving and Emke, *The Ships of Abel Tasman*, 41.

83 Peabody, *Naval Architecture*, 553.

84 J. W. Thierry, "The Enclosure and Partial Reclamation of the Zuider Zee," *The Geographical Journal* 77, no. 3 (1931): 228.

85 Molland and Turnock, *Marine Rudders and Control Surfaces*, 54.

86 Bertram, "Chapter 6 - Ship Maneuvering," 295.

fluyts varied between just under 4 and just over 5.[87] Just as the decreased draft of the *wijdschips* requires the use of broader rudders than the comparatively narrower *fluyts*, the increased breadth requires an increase in size to make up the difference in rudder efficacy.

Furthermore, simulations have shown that maneuvering capabilities like turning speed and course stability decrease in shallow water.[88] Bertram explains this phenomenon by showing that the effects of shallow water and irregular currents are greater on the hull of the ship than the rudder, resulting in less comparative turning effect from the same surface area.[89] The *wijdschips* sailing on the Zuider Zee therefore required larger rudders not only because of their shallow draft and large breadth, but also because they spent their whole careers sailing in relatively shallow water which decreased the effectiveness of their rudders.

Additionally, the maneuvering of sailing ships often relied heavily on the positioning of the sails themselves.[90] A ship which was able to take full advantage of the power of its sails to set a course needed comparatively less turning moment from the rudder than one which could not rely so heavily on its sails. Oceangoing sailing ships relied on square sails to catch the reliable trade winds that blow for months at a time.[91] Alternatively, coastal and inland ships relied on winds that are much more variable. Therefore, an oceangoing ship sailing longer distances on higher and more reliable winds relied less heavily on its rudder to provide a turning moment and used a comparatively smaller rudder than a ship sailing on calmer and more variable inland waterways. Dutch oceangoing vessels, even those with simplified rigging like the fluyt, carried multiple square sails per mast (on the main and foremast), an innovation used to increase the total sail area relative to the ship's size.[92] The increased sail area could be used to harness those winds and used them to direct the ship's motion without relying on the rudder.

Depictions of *wijdschips* show that they typically carried a single spritsail, a rig which was helpful for sailing upwind and in the variable wind conditions more common in inland waterways.[93] However, this rigging style was much

87 L:B = 3.3 (Oostflevoland B-71), 2.8 (Witsen's *wijdschip*), 4.4 (Rålamb's fluyt), 3.9 (Ghost Ship), 4.5 (Witsen's *Noortsvaerder*), 5.2 (Lion Wreck)

88 Yasuo Yoshimura, "Mathematical Model for the Manoeuvring Ship Motion in Shallow Water," trans. Yasuo Yoshimura, *Journal of the Japan Society of Naval Architects and Ocean Engineers* (1986): 46.

89 Bertram, "Chapter 6 - Ship Maneuvering," 256.

90 Peabody, *Naval Architecture*, 548.

91 Peabody, *Naval Architecture*, 570.

92 Hocker, "The Development of a Bottom-Based Shipbuilding Tradition in Northwestern Europe and the New World," 163.

93 Julian Whitewright, "Sailing and Sailing Rigs in the Ancient Mediterranean: Implications of

less effective for steering. Therefore, *wijdschips* required a rudder with more turning moment to steer as effectively as a fluyt more able to rely on setting sails to steer. To achieve this, the rudder needed to be comparatively broader.

Conclusion

A preliminary analysis of available rudders from Dutch oceangoing *fluyts* and inland *wijdschips* reveals that *wijdschips* had larger rudders than *fluyts* when comparing rudder size to both the lateral waterplane and the approximate displacement of the ship. They also had much broader rudders in comparison to the draft of the ship than *fluyts*, which helped account for the gap in comparative rudder area. The need for increased rudder breadth on *wijdschips* could be due to the lower draft which reduced the rudder area. The additional increase in rudder area compared to the ship is likely the result of a mix of factors, including the increased breadth of the ship and shallow water of the Zuider Zee, both of which decreased the effectiveness of rudder, and the probable decreased use of sails for steering which put more emphasis on the rudder. Which factor was most influential is unknown, and further study could help illuminate the influence of each. The builders of Dutch inland watercraft believed that the shape of the ship, with its lower draft and decreased length to breadth ratio, was the key reason why they needed to increase the breadth of the rudder. However, the design was almost certainly also influenced by the other physical factors mentioned, which have only been studied more recently. Regardless, the variation in rudder form was intentional and served to optimize the ships for their environments.

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