THE DEVELOPMENT OF THE RUDDER, A.D. 100-1600:

A TECHNOLOGICAL TALE

A Thesis

by

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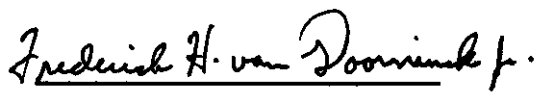

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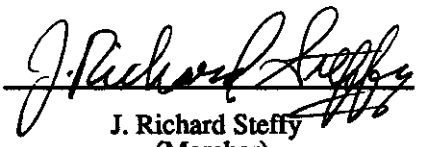

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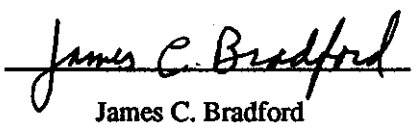

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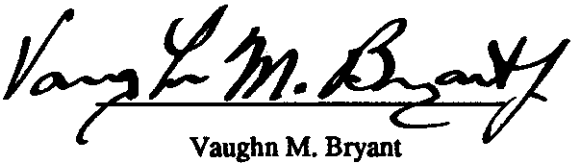

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ABSTRACT

The Development of the Rudder, 100-1600 AD: A Technological Tale
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The one instrument which all ships have in common is a rudder. Until the 13th century A.D., the primary instrument used to control ships was the quarter-rudder system. Unlike the present-day rudder which is mounted on the stern, quarter-rudders were mounted on the sides of ships towards the stern.

The Mediterranean quarter-rudder was an inherently simple device and had only three basic requirements for mounting. This simplicity allowed shipwrights to adapt the quarter-rudder for use on a wide variety of vessels. Not only did the quarter-rudder concept permit the use of this type of rudder on different kinds of ships, but the basic system was also sufficiently flexible to evolve, thus insuring its continued use through the Middle Ages. As the methods for mounting the quarter-rudder changed, so did the design of the rudders themselves. The traditional Greco-Roman rudder gave way to the more efficient medieval rudder, which enhanced the overall performance of the quarter-rudder system.

A unique quarter-rudder system indigenous to northern Europe had also evolved, but unlike its southern counterpart, this system was rather inflexible. Northern shipwrights found that their system could not be adapted to the new ship designs which were continually increasing in size. This inability of northern shipwrights to adapt their system to larger ships created a technological crisis which forced them to look for a new device. The result was a rudder mounted on the stern by a hinge device called the pintle-and-gudgeon. Because this new device had several deficiencies, it did not immediately replace the Mediterranean quarter-rudder. Only after a significant change in hull design, and the appearance of the full-rigged ship, did the pintle-and-gudgeon rudder finally supplant the quarter-rudder.

The history of the quarter-rudder shows that technologies which are flexible are the ones which tend to survive the longest, while that of the pintle-and-gudgeon system is a classic example of a technology having to await the development of others before it can realize its full potential. The continued use of the quarter-rudder, despite some inherent drawbacks, demonstrates that there is a human tendency to try to modify existing technologies to their extremes, instead of immediately searching for more radical solutions to a given problem.

Dedicated to
Ben, Phineas, and ShortRound

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This work on the history of the rudder was only made possible by the kind help of several people and institutions, who either provided me with information or allowed access to various documents and works of art.

I would like to thank John Coates of the Olympias Project, Martin Dean of the Scottish Institute of Maritime Studies, and John Pryor of the University of Sydney for their helpful replies to my inquires. I wish to thank David Valys of the Department of Physics for his help and suggestions concerning thestatics model for a tapered shaft. I would also especially like to thank Professor James Bradford of the Department of History at Texas A&M University who was kind enough to take pictures of art work while in Italy which were of significant help to my research.

I wish to thank the following institutions for their help during my research, and for their permission to study and photograph their materials: Archivo Municipal de Barcelona, Archivo Reino de Mallorca, Biblioteca de Catalunya, Biblioteca Episcopal de Vic, Biblioteca General de la Universidad de Valencia, Bridwell Library at Southern Methodist University, Cathedral of Lierda, Cathedral of Palma de Mallorca, Cathedral of Tarragona, Cathedral of Toledo, Cathedral of Zaragoza, Convento de Sant Francesc de Mallorca, Forest Products Laboratory at Madison, Museo de Arte de Catalunya, Museo Marítimo of Barcelona.

Finally, I wish to thank my committee members, Frederick H. vanDoorninck, Jr., J. Richard Steffy, and James C. Bradford, whose comments and suggestions were of the greatest help.

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CHAPTER I
INTRODUCTION

The one instrument which all ships, past and present, have in common is a rudder. It is the one device on a ship without which effective navigation and control would be impossible. Today, the custom of mounting the rudder on a vessel's stern is the common practice, and has been for so long that it is viewed as the only reasonable configuration for a ship. Yet until the 13th century A.D. rudders mounted on the stern quarters, known as quarter-rudders, were the primary system for controlling vessels. During this time vessels of virtually every shape and size, from Southeast Asia to the Baltic Sea, navigated with them. The long, continual use of the quarter-rudder suggests it was an effective device and yet it was eventually replaced by the pintle-&-gudgeon rudder. At first glance, this appears to have been a simple matter of a superior technology supplanting an inferior one, but the story is far more complex. It is not only the story of one system which had been successfully modified and adapted for centuries yet which was ultimately replaced, but also of another system which appeared because the technology it superseded could not evolve. Finally, this technological tale demonstrates how one technology can be dependent for its success on the convergence of several others.

The quarter-rudder appeared with the first ships at the dawn of history, partly because it was the simpliest solution to controlling a ship, and partly because it was a very effective device. By 2500 B.C. it had spread throughout the ancient world and had become highly developed (Basch, 1987: fig. 189; Casson, 1971: fig. 17). During the next two thousand years, the quarter-rudder underwent numerous changes and refinements, so that by the time of the Roman Empire it had evolved into an instrument capable of controlling very large ships. The Romans adapted the quarter-rudder to a variety of vessels by using a number of mounting schemes, most of which would survive through the medieval period. Our story concerning the history of the rudder will start in the Roman period by which time most of the mounting systems for the quarter-rudder had evolved.

Despite a long period of continual use, very few primary sources have come down to us concerning the mounting and use of the quarter-rudder. Most of the Classical references are simply one or two lines of text in literary works in which the rudder is only mentioned in passing and not discussed in any detail (Ammianus Marcellinus, 21.13.10; Euripides, *Helen* 1536; Heironymus, *Epistulae* 100.14; Lucian, *Navigium* 6; Lucretius 4.903-04; Manilius, *Astronomica* 4.280-83; Orpheus, *Argonautica* 276-77; Ovid, *Fasti* 3.593-94; Plato, *Alcibiades* 117c, *Cratylus* 390d; Seneca, *Epistulae* 90.24, *Medea* 346-47; Statius, *Silvae* 3.2; Virgil, *Aeneid* 5.858-60; Vitruvius, *De Architectura* 10.3.5; previous citations also given in Casson, 1971: 224-28). While these passages give some insights into the use of the quarter-rudder, they provide little or no information as to how the rudder was actually mounted. In his work *Mechanica* (850b-851a), Aristotle discusses why a rudder functions, but not the rudder itself.

The medieval period is also devoid of any major literary sources concerning rudders and their use. A few ship contracts do exist which give details about the rudder, but these do not discuss the system used to mount the rudder. One treatise on medieval shipbuilding mentions both pintle-&-gudgeon rudders and quarter-rudders. This early 15th century manuscript, universally referred to as *Fabrica di galere*,

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The journal used for format and style was *The International Journal of Nautical Archaeology*.

describes the construction of a Venetian galley for the Flemish trade. Unfortunately, this document was written towards the close of the Middle Ages, when the quarter-rudder was falling into disuse. The document gives both written descriptions and drawings of the rudders, but very little about their mountings. It was also written for a very specific type of vessel which makes the document of only marginal use when applied to other ship types, and thus gives no insights into the evolution of the rudder up to that time. The only real evidence that we have concerning the mounting and use of the quarter-rudder comes to us from ancient and medieval ship representations, and the few scattered remanents of quarter-rudders which have been uncovered.

This is not to say there has not been a great deal written on the above topic in the secondary sources. On the contrary, it is probably not an exaggeration to say that since the 19th century, as much ink has been spilt on this particular subject as any in the field of nautical archaeology. Opinions on the quarter-rudder, its effectiveness and the reasons for its ultimate demise, have run from one extreme to the other. Yet all of these works have had two major shortcomings. First, there has been no rigorous study of the quarter-rudder, and the different mounting techniques employed, based on an examination of all of the existing iconography. Previous works have used selected representations to bolster their premises without discussing all of the evidence available, and without considering the possibility that several methods of mounting may have been utilized within a given time period. Second, there has been no systematic appraisal of the quarter-rudder based on modern hydrodynamic research. At best, the hydrodynamic differences between the quarter-rudder and the pintle-&-gudgeon rudder have been discussed only in the most cursory manner.

The purpose of this work is threefold. First, it will review the forces which act on a quarter-rudder, and how rudder placement and shape effect them. Second, it will use the above hydrodynamic study in analyzing extant iconography to determine the different mounting methods employed by the Romans and then compare them to medieval methods in an effort to discover any evolutionary trends in mounting systems and/or rudder design. Finally, this work will look at the possible reasons why the pintle-&-gudgeon rudder appeared. The technical differences between the quarter-rudder and the pintle-&-gudgeon steering systems and the possible historical and economic influences that may have effected them will be essayed. Parenthetically, this study will offer some insights into how and why technologies evolve and decline, and humanity's general approach to technology.

Before discussing the hydrodynamic characteristics of rudders, a short word is necessary concerning terminology. The term *quarter-rudder* has been chosen for this work instead of the terms *side-rudder* or *steering oar*. The term *steering oar* was rejected since it is very imprecise. Not only does it fail to make a distinction between a device specifically designed to steer a vessel and a simple oar, but it also fails to denote whether the oar was affixed to the side of a vessel or hung from the stern, as on 19th century whaleboats. The term *quarter-rudder* was chosen over *side-rudder* simply because it denotes exactly where the rudder was placed, whereas the latter term is not quite as exact.

Concerning rudders mounted on the stern, the locution *pintle-&-gudgeon rudder* was chosen for the northern European mounting system because it both describes the method of attachment and implies attachment to the sternpost. The technology which eventually replaced the quarter-rudder was the pintle-&-gudgeon system, so that the use of the term is appropriate as well as accurate. The term *stern-mounted rudder* is too broad a definition. The Chinese for centuries used a rudder mounted on the stern, but they did not utilize pintles and gudgeons and, in fact, their ships did not have a sternpost to which to attach

them. The term could equally apply to a steering oar hung from the stern of a boat. The phrase *sternpost-mounted* also has some limitations. While, it adequately describes where and to what the rudder is attached, it neglects the method of attachment. A perfect example is the *mtepe* of the Indian Ocean. While the rudder is mounted on the stern and is attached to the sternpost, it is held in place by lashings which have little in common with the pintle-&-gudgeon system. For this reason, the term *sternpost-mounted rudder* will be used for describing those systems which do not use pintles and gudgeons. For simplicity and clarity, the abbreviation *PG-rudder* will be used in this work when referring to the system and rudder as a whole.

Another problem arising from terminology concerns the rudder tackle. As will be shown in later chapters, quarter-rudder tackle actually consisted of at least two different sets of tackle. One was used to hoist the rudder, while the other set acted to prevent the rudder from swinging too far to one side, to help control the rudder in rough weather, and to act as emergency steering gear if the tiller broke. This latter set of tackle was called the *rudder pendant* on vessels with quarter-rudders and, later, on ships with PG-rudders. Unfortunately, several authors have also used this term for the hoisting tackle. Because the term *rudder pendant* has had a consistent meaning from the 14th century onwards, it is inappropriate to use it in regards to the hoisting tackle of a quarter-rudder. For this reason, the hoisting tackle of a quarter-rudder will be referred to as the *rudder hoist*, and the term *rudder pendant* will be used to refer to the relieving tackle.

CHAPTER II
AN UNDEMANDING DEVICE

The actual methods for the mounting of quarter-rudders have been debated for over a century. The various discussions have usually revolved around one specific proposal, and have assumed only one technique was used for rudder mounts. In fact, a variety of methods were employed depending on the ship type and size. This flexibility in the types of mounts which could be employed resulted from the rather few and simple mounting requirements for a quarter-rudder. Before discussing the specific types of rudder mounts, the requirements and physical restraints effecting quarter-rudder installation will be delineated, and then reconciled with what few primary sources we have.

The first requirement for a quarter-rudder mount, regardless of the rudder's size, was that it hold the rudder in place at two points along its length and permit the rudder to rotate around the axis of the shaft. Several authors have argued that the quarter-rudder was affixed at only one point and was moved laterally like a sculling oar (Serra, 1891: 358-359; Lefebvre de Noëtes, 1935: 43; Adam and Denoix, 1962: 100; Morrison, 1968: 291-2). The passage most often produced to support this theory comes from Plato's *Alcibades* (117c) where the passage speaks of moving the tiller "inward or outward." Casson (1971: 225, n.5) shows that this passage can be interpreted several ways and is hardly conclusive proof. This proposal has also been attacked by Carlini (1935: 446) and Thurneyssen (1978: 76-77), who concluded that the rudder could only be controlled if it was attached at two points. Further evidence that the rudders were pivoted as modern ones can be seen in the passage by Vitruvius where he says: "Just as also the helmsman of a great merchant vessel holds the handle of the tiller, which is called the *oiax* by the Greeks, with only one hand, and moves it skillfully around the center where the fulcrum is tightly set, ..." (*de Architectura*, X.C.III.5).

The proponents of the lateral movement of quarter-rudders have ignored the constraints of scale. In order to turn a vessel, the ship's moment of inertia has to be overcome. While this method may work for small boats, it is totally impractical on even a small ship. A good example is the *Argo* replica which is only 16.5 m long but has a light displacement of over 3.4 metric tons (Mudie, 1986: 52). To turn the ship the helmsman would have to provide enough force to counter the moment of inertia of several tons using an oar only 4 meters long, and as noted by Lehmann (1978a: 96), he would also have to effectively control the torque applied to the rudder once the turn was initiated to keep it from veering from side to side. Even with the attachment point at the waterline, the best ratio for the amount of lever arm above and below the point a helmsman could hope for would be 1:1. With no mechanical advantage to assist him, the torque applied to the rudder under even moderate weather conditions would soon exhaust the strongest of helmsmen. When the theory is applied to larger vessels it becomes even more untenable. The quarter-rudders on larger ships would have weighed several metric tons, at least. To expect a man to control a multi-ton rudder, let alone a vessel with a multi-ton displacement, without any mechanical advantage, is ludicrous.

The second requirement for a quarter-rudder system was that it permit the rudder to be moved in a direction parallel to the axis of its shaft so that the depth of the blade beneath the water could be adjusted. The primary reason for this can be seen in Figure 2.1. As a ship takes on cargo or ballast its draft will change, which in turn effects the height of the rudder mount above the water. This would cause

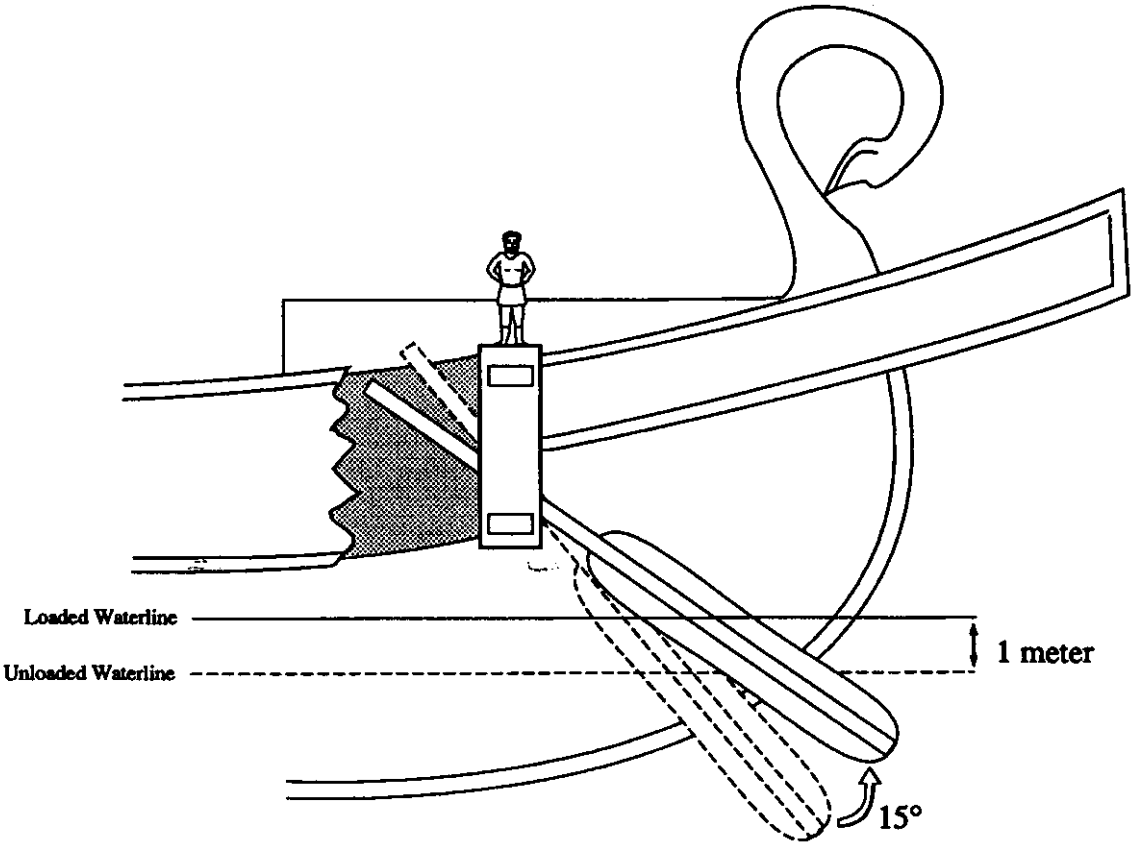

Figure 2.1 The effect the height of the rudder mount above the water has on the shaft angle of a quarter-rudder floating at equilibrium.

more of the rudder to become immersed and thus cause it to float at a shallower angle if supported at only one point. Since none of the Roman systems allowed for the shaft angle to be changed, the only effective solution allowing the rudder to be kept at the same angle and on its mount was to pull it upwards along the axis of the shaft. By pulling upward along the shaft, less of the oar was immersed. Because there was less rudder area submerged, there would be less bouyant force, so that the weight of the rudder would cause it to rotate downwards towards a vertical position. This ability to move the rudder along its axis would also permit adjustments for the opposite situation where the rudder would loose bouyancy due to the absorption of water. In this case, the rudder would float at too steep an angle, but by moving the rudder downward along the shaft more of the blade would be immersed so the rudder would float up to the proper angle.

The need to adjust the rudder along the length of its shaft is the reason that the system proposed by Tursini (Ucelli, 1950: 369-92) is unacceptable. Using the Torlonia Relief as evidence (Fig. 2.2), he suggested that the rope running from the deck was first passed through the end of a throughbeam jutting from the hull before being passed around the shaft just above the waterline. Carlini (1935: 446-47) proposed a similar arrangement where the cable passed through a ring on the hull and then around the

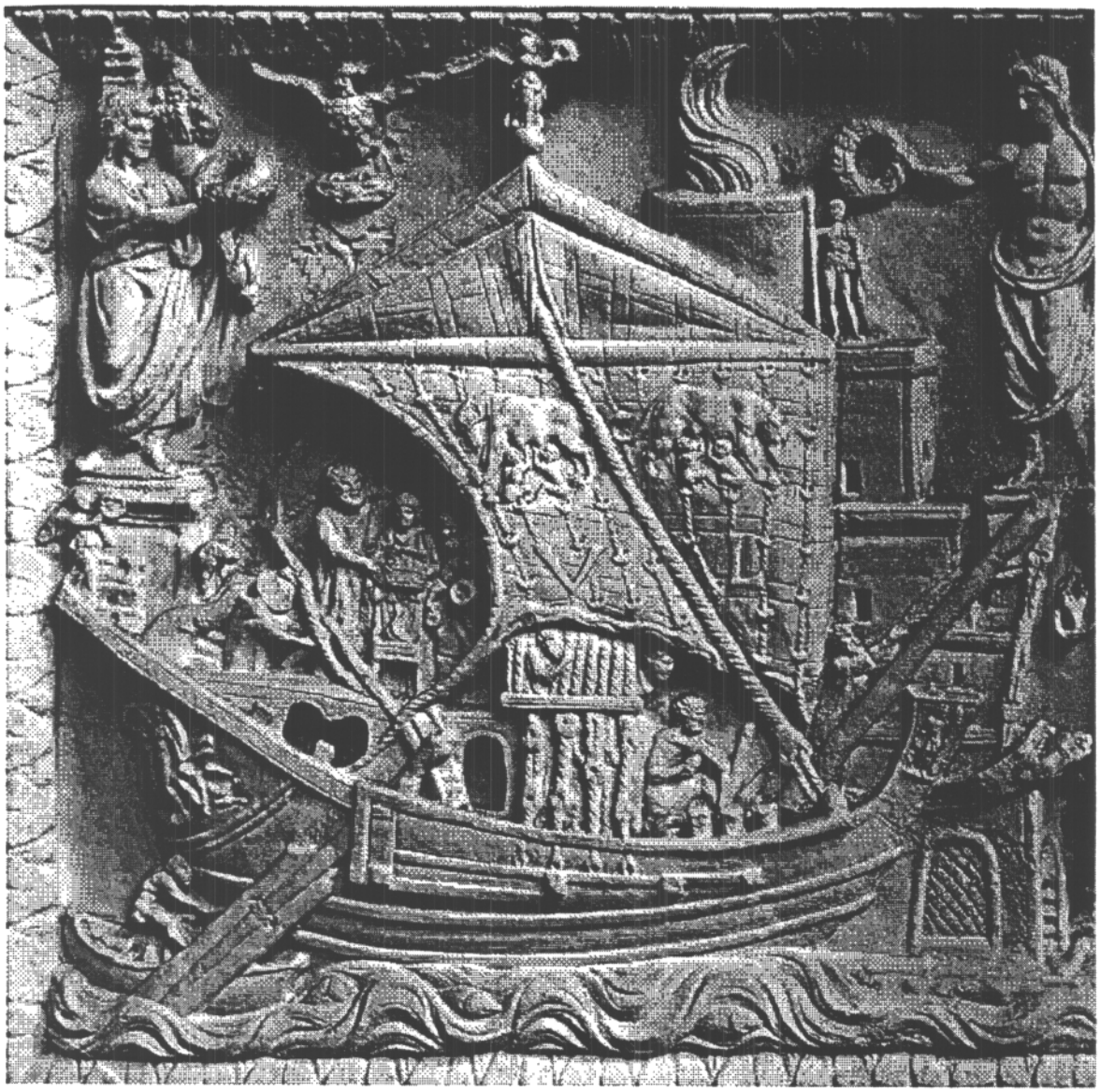

Figure 2.2 A detail of the Torlonia relief showing a ship entering the harbor of Ostia. Note the man in the boat helping to dismount the quarter-rudder from a braced mount. The relief is dated to the 3rd century A.D. (photo:Alinari).

rudder shaft. These hypotheses were heavily influenced by the discoveries of ships at burial sites in northern Europe and modeled after the Norse quarter-rudder system. Again, the problem here is one of scale. Whereas the northern vessels had a relatively low freeboard and therefore small rudders, the Roman vessels for which this system is suggested had high freeboards and heavy quarter-rudders. Based on Model 1 in Appendix I, these rudders averaged approximately 12 meters in length for the typical merchantman. As a merchantman took on cargo it would sit lower in the water and thus cause the rudder to tend to float upwards (Fig. 2.1). This meant that rudder would have to be forcibly held down by the cable. If the height of the beam was correctly placed for when the ship was fully loaded, then the cable would have to support the weight of the rudder when the ship was running light. In either case, the rope

would be under considerable stress even if the effect of swells passing under the ship is not taken into account. In such an environment the rope would stretch and fray rapidly, necessitating almost constant maintenance. The fact that the lower end of the rope would have been continually wet would exacerbate the problem of the rope stretching. That the problems of rope stretching, fraying and breaking would have made this type of system unfeasible can be inferred from the difficulties encountered on several Viking replicas using rudders attached with rope vastly smaller than those a ship the size of the one in the Torlonia Relief would have carried (Thorseth, 1986: 82; McGrail and Mckee, 1974: 14). It should also be noted that there is not a single ancient representation with even a hint of the existence of a throughbeam or ring for this purpose on the side of the hull (La Roërie, 1938: 329; Thurneyssen, 1978: 77).

Another advantage to pulling the rudder upwards from a point where it is floating at equilibrium is that of relieving pressure on the lashings or fixtures holding the rudder in place. The Greco-Roman mounting systems held the rudders at a fixed angle which was set by the position of the two attachment points. When floating at equilibrium the rudder would just touch the lower mount and the rudder's weight would be carried by the upper attachment point and the buoyancy of the rudder blade. In a static environment the rudder could be held to the lower mounting point by a light lashing. However, when the ship got underway the situation would change. Because of drag on the rudder from the water passing by it, the rudder would have a tendency to rise off its lower mount, thereby putting pressure on the lashings or attachment. This could be counteracted by partially pulling the rudder up. By doing this, the upward force due to buoyancy would be decreased causing the rudder to rotate back down onto the lower mount. By adjusting the amount of rudder in the water, the rudder could be made to sit firmly on the lower mount. The result of this is that under normal conditions the attachment would have little or no force on it due to rudder drag. Also, as will be seen in Chapter IV, the ability to pull the rudder partially out of the water could materially effect the speed of the ship.

Finally, a quarter-rudder system must allow the rudder to be dismounted and placed on board the vessel. This requirement was necessitated by the need to remove the rudder for repair or replacement. As will be shown, the ability to remove the rudder from the water also entailed other benefits. All of the systems used by the Romans allowed removal in one form or another. Most of the systems employed permitted the rudder to be rotated up to a horizontal position without removing it from the mount, while other systems required that the rudder be completely unshipped from its mount.

The most important factor influencing the design of the rudder mounts was the weight and size of the rudder. The weight of a given rudder was influenced by not only its overall size but also by its shape, and whether it was left constantly submerged or periodically removed and allowed to dry out. Besides determining the robustness of the mount, the weight and size of the rudder determined the type of mount used. A heavy, large rudder could break or damage a poor mount design due to the stress transmitted to it by the rudder. Under storm conditions, vibration and the working of the mount itself could harm the hull. These same vibrations and movements were noticed on an Indonesian *prahu* during a storm by passengers who noted that by putting their feet on the quarter-rudder support which ran through their cabin they could feel the whole ship "squirm and stretch like a fish" (Blair, 1988: 126). All of this had to be taken into account by the shipwright when building a vessel.

The reason that the weight of the rudder was one of the most important factors with regards to rudder mount designs is rather simple. While the increase in length of a quarter-rudder is by definition linear, the weight of the rudder increases by the cube. A small rudder could be essentially manhandled by

one or two men. As such it would not require a specialized mount or specific tackle to aid in adjusting or removing the rudder. A large rudder, on the other hand, such as found at Lake Nemi (Fig. 2.3), would require a reinforced mount, specialized tackle, and an installation design that could provide easy access for the handling of the large rudder during placement or removal. For very large ships a good mount and tackle would have been critical. Based on Appendix I, the Roman grain ship, the *Isis*, which was over 1,000 tons burden (Casson, 1971: 184-8), would have had quarter-rudders measuring over 18 meters in length and weighing well over 14 metric tons each. A significantly smaller vessel of only 375 tons burden, such as the Madrague de Giens wreck (Pomey, 1982: 146, fig.7), would still have required a rudder approximately the size of that found at Nemi (Fig. 2.3).

An example of the effect of rudder weight can be gleaned from a passage in *Stratagems* by Polyaenus. In the passage he describes how an Athenian commander, to aid steering during a storm, placed extra rudders on a trireme by passing them through the outrigger on each side (Casson, 1971: 226, n.7). To accomplish this, the rudders would have had to have been lifted nearly vertical before they could be passed downward through the crossbeams. Because the quarter-rudders for a trireme probably did not exceed 250 kg in weight several men could have manhandled the rudders into position without much difficulty, even in rough weather. This same undertaking would have been impossible had the rudder been much longer or heavier. The passage also demonstrates that because these quarter-rudders were relatively small, and therefore the forces and torques associated with them were small, they could be held in place by simple lashings and without a specialized mounting system. As will be shown, all of the different mounting systems used by the Romans were a clear reflection of the influence of rudder size and weight.

Most of the Classical passages dealing with quarter-rudders indicate that the rudders were lashed in place. In the *Argonautica*, Orpheus writes of the rudder being hung from the stern and then being bound tightly with thongs (Casson, 1971: 226, n.6). The other oft-quoted passage concerning lashings comes from *Epitoma rei militaris* where Vegetius suggests that a small boat could sneak up on the stern of an enemy galley and "without being observed cut the lines with which the enemy's quarter-rudders are made fast" (Casson, 1973: 226, n.6). The fact that the literature only mentions mounting systems that used lashings is an indication that lashings were the preferred attachment method. To prevent the rudders from slipping in their lashings, some of the rudder shafts appear to be tapered so that the shaft gradually becomes thicker towards the rudder head. This would prevent the rudder from appreciably slipping downwards even if the lashings became loose. While probably not all of the ancient systems used lashings, the numerous representations of ships with mountings requiring lashings supports the thesis that such systems were generally preferred to a gimbal or sleeve type of mount.

The mounts referred to in the literature appear to be very simple. A papyrus document in Greek refers to the rudder mounts simply as "brackets" (Casson, 1973: 227, 257). A passage from *Helen* by Euripides (1916: 1537) is even more instructive. The line states "And the rudders were let down into the crossbeam." The word for *crossbeam* in this passage is the same word used for the loop of the yoke of a harness. The yoke loops of the Classical period were simple curved pieces of wood into which fitted the neck of the horse (Singer, 1954: vol. I, 726-28; Vol. II, 542-43). This passage indicates that the "brackets" in the previous passage were probably no more than two throughbeams with rounded notches cut in them into which the rudder was fitted and lashed. Again, as in the case of lashings, these two passages are referring only to one or two systems out of several which were being used, but they are an indication that an adequate mounting system did not need complex equipment to provide functionality. It is possible that

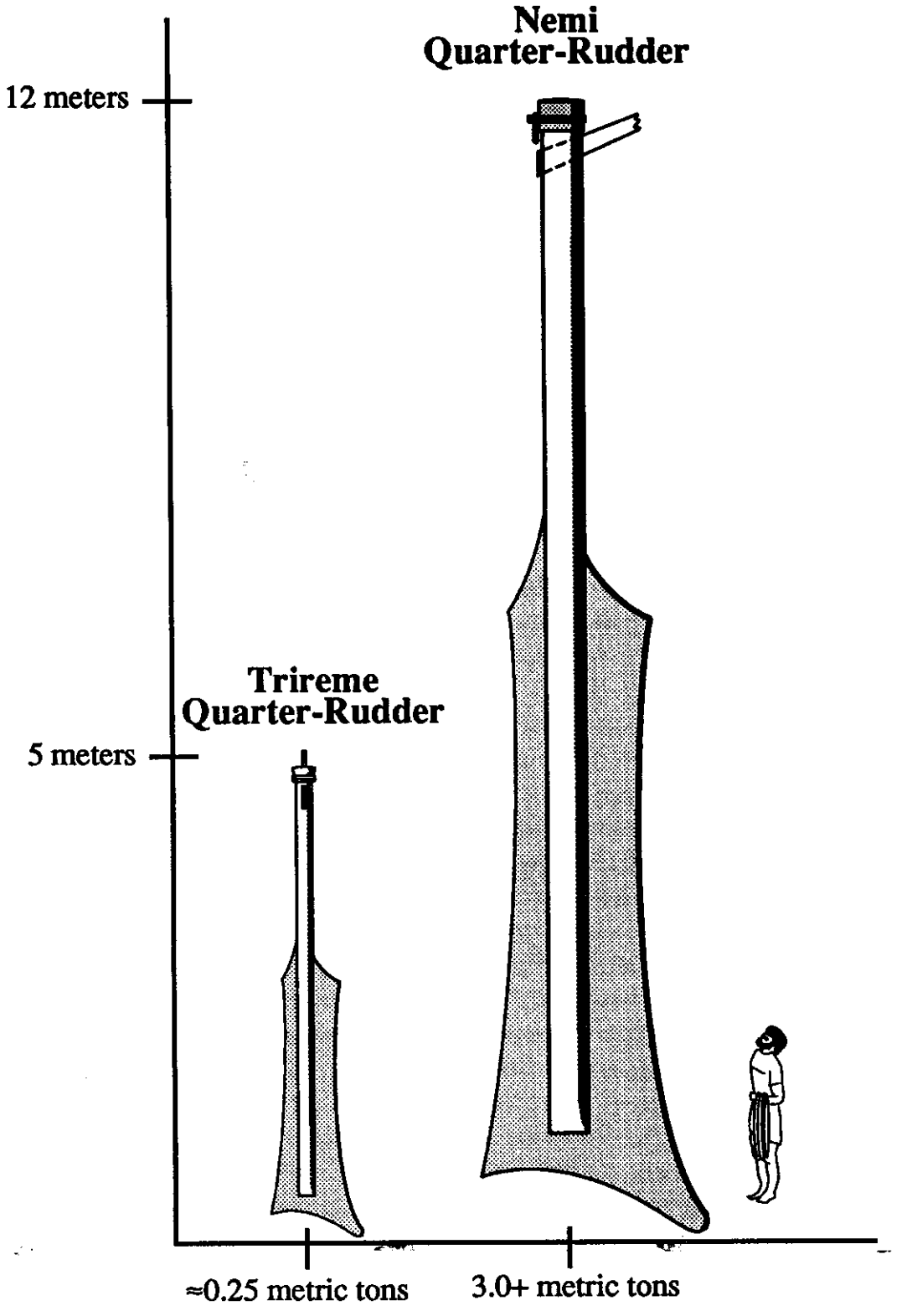

Figure 2.3 A comparison of Greco-Roman quarter-rudders, based on the ones used by the *Olympias*, and the quarter-rudder found at Lake Nemi.

larger vessels used a small wooden crosspiece at one point to prevent the rudder from pivoting. This arrangement will be seen later in a medieval fresco, but it would not be absolutely necessary. In the medieval period, there was a trend towards wooden collars, but except for the Roman box-mount there is no evidence the Romans employed them. It is not known if the mounts were lubricated or fitted with a gaskets to prevent wear on the rudder shaft and to decrease friction. Though the rudder on Indonesian *pinisi* are supported by two throughbeams, the rudders rest on rattan woven into cradles, presumably to reduce friction and wear (Blair, 1988: 107).

Roman ship representations reveal that quarter-rudders were mounted at an angle between 45 and 30 degrees from vertical. This range of mounting angles appears to be the most efficacious for several reasons. Within this range a significant portion of the rudder's weight is carried by the mount and not the lashings. This in turn permits a certain latitude in choosing mounting techniques. Angles beyond 45 degrees from vertical would cause the ratio of the depth of rudder immersed to the width of the immersed rudder, known as the aspect ratio, to decrease to eventually less than 1. As will be discussed in Chapter V, this would cause a decrease in hydrodynamic lift and an increase in turbulence and drag along the blade. At very shallow angles the mere act of rotating the blade would cause a large portion of the blade to lift out of the water so that even at large rudder angles very little water would be deflected. Mounting the rudder in a vertical position would also entail several problems. In a vertical position the lashings would have to support the entire weight of the rudder, which would be difficult and require heavy lashings. The lashings or mounting fixture would have to be so sturdy that should the rudder encounter a submerged object the shaft would probably break before the lashings; this would not be a desirable outcome.

If a rudder was lowered to the point where its buoyancy was supporting all of the rudder's weight, approximately 70% of the rudder, or more, would be immersed. This would leave very little rudder shaft to attach to the ship, especially if the vessel had any significant freeboard. The deep immersion would greatly increase drag, and the benefits from increased rudder force due to the increase of rudder blade in the water would appear to be only nominally useful. Also, the rudder is very unstable in this configuration. The loss of the lashings at either attachment point would cause the rudder to almost immediately rotate up to a nearly horizontal position. The rudder would also extend well below the hull, causing it to ground long before the hull was in danger of doing so. The fact that virtually all of the Roman ship representations have rudders mounted in a range of angle between 30 and 45 degrees from vertical is a strong indication that while they may not have understood all of the mechanics outlined above, years of observation had led them to the conclusion that this range of mounting angles were indeed the most efficacious.

In summarizing, any quarter-rudder system had to satisfy three requirements. It had to hold firmly the rudder at two points, or along a section of the shaft. It had to permit the rudder to be moved in the mount up or down in a direction parallel to the shaft, and it had to allow for the removal of the rudder for maintenance. The major factor influencing the type of system chosen for a ship was the projected weight, and therefore size, of the rudder. Finally, as several passages have indicated, a system did not need to be complex in design, and did not require specialized equipment for it to work. As will be shown in the next chapter, because the above requirements could be satisfied in a variety of ways, several distinctly different systems were employed, each satisfying a particular need.

CHAPTER III
VARIATIONS ON THE SAME THEME

As noted in the previous chapter, there are no written references concerning a specific type of quarter-rudder mounting system. However, by analyzing the existing iconography in light of what is necessary for a functional system, the actual types of mounting methods can be defined and categorized. All of the following quarter-rudder systems demonstrate that the basic requirements for mounting a quarter-rudder were rather simple, and all quarter-rudder mounting systems were essentially variations on the same theme. This in turn allowed a wide latitude in the actual mounts that could be employed.

How often a particular type of system appears in the iconographic lexicon for a specific time period is obviously not directly related to the frequency of use of that system. The record can be skewed by artistic styles and by the destruction or survival of particular styles or types of art. However, enough Roman art has survived to permit some gross generalizations about which method appears to have been favored, and on which types of vessels it appears to have been used. A review of the available representations indicates the Romans used five different techniques for mounting a quarter-rudder, and that all these fill the basic requirements for a successful design. The five systems will be discussed, starting with the one which appears most often in the iconography and then preceding to the less common systems. Names for the different systems have been devised by the author so that reference to the various mount designs can be easily made.

THE BRACED MOUNT

If the number of representations of ships using the braced mounting system is any gauge, then it was by far the most commonly employed mount during the Roman Period, and was placed on a wide variety of vessels. On Roman warships this system of mounting appears to have been used almost to the exclusion of all other systems. It is also found on virtually every other type of Roman vessel, from large cargo ships to coastal craft and fishing boats. Based on the iconography, the braced mount probably appeared sometime in the late 3rd century B.C. or earlier.

The lower mounting point was a throughbeam on which the shaft of the rudder rested. The upper end of the shaft was braced against a throughbeam which was aft of the shaft, unlike the lower one which was forward (Fig. 3.1). The best example of this type of mounting is in a sculpture of Ulysses' ship (Casson, 1971: fig. 170; Basch, 1987: fig. 803). The lower part of the mount has what appears to be a metal U-shaped bracket to keep the rudder from moving sideways or from unshipping if the rudder kicked-up slightly. The two throughbeams undoubtedly had rounded notches cut in them for the shaft to sit in. This same box-like structure can also be seen in the 3rd century A.D. mosaic of a merchant ship (Fig. 3.2). As with the sculpture, the rudder shaft is simply inserted between two throughbeams without the use of any specialized equipment.

The system is simple but elegant. Pulling the rudder upwards along its length would cause it to rotate downward thus pushing the end of the shaft into the upper throughbeam. This action would increase friction and tend to lock the rudder in place. The further the rudder was pulled up, the tighter it would sit in the mount because the rudder's bouyancy would decrease, thus causing the rudder to pivot downward around the lower beam and push the upper shaft into the upper throughbeam. The advantage

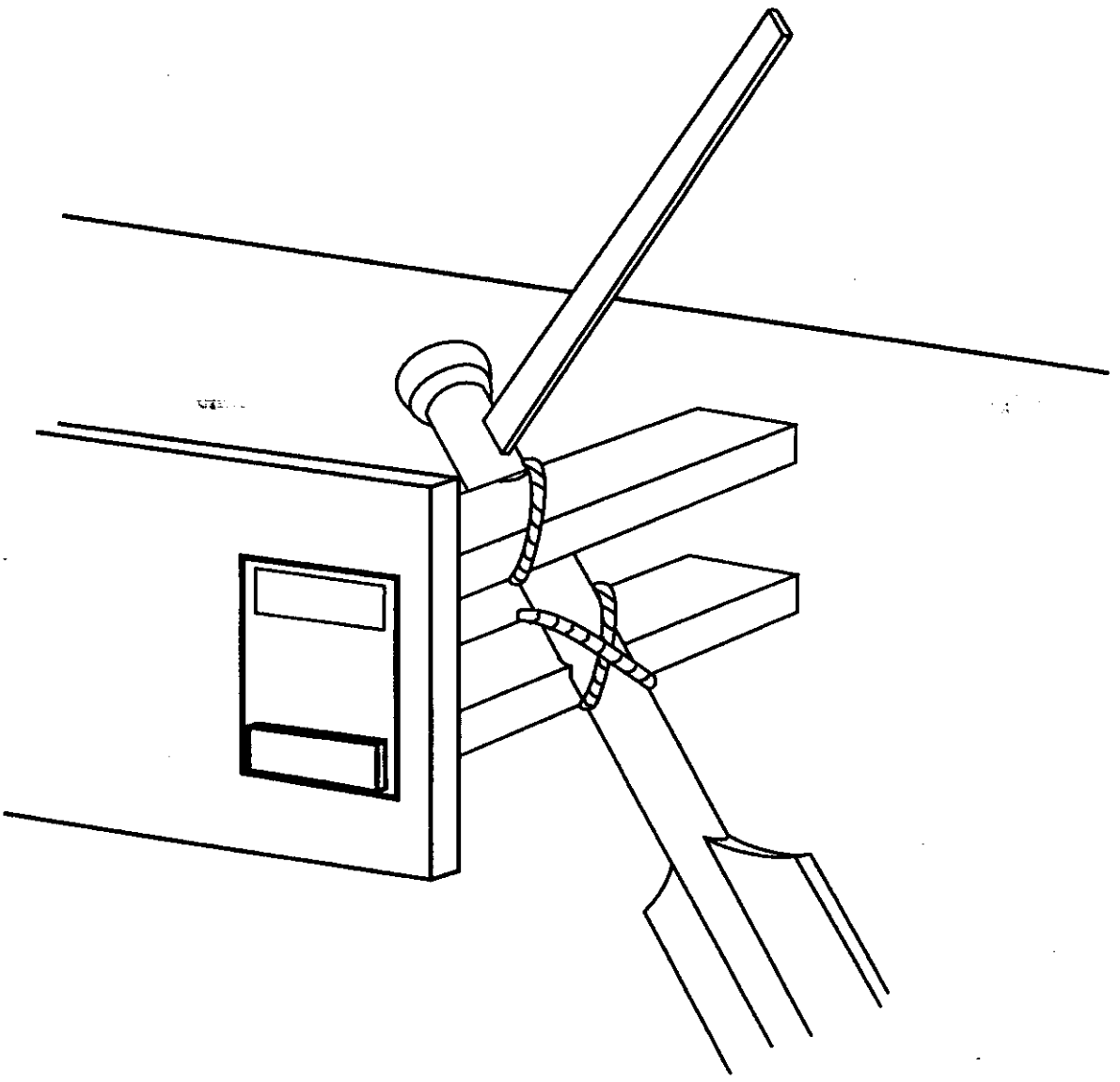

Figure 3.1 A view of a basic braced mount showing the rudder shaft inserted between the two throughbeams. While the lashings shown here are hypothetical, the upper lashing on a braced mount only had to be strong enough to prevent the rudder blade from rising up due to wave action, and could be light enough to break to allow the rudder to kick up if it struck a submerged object.

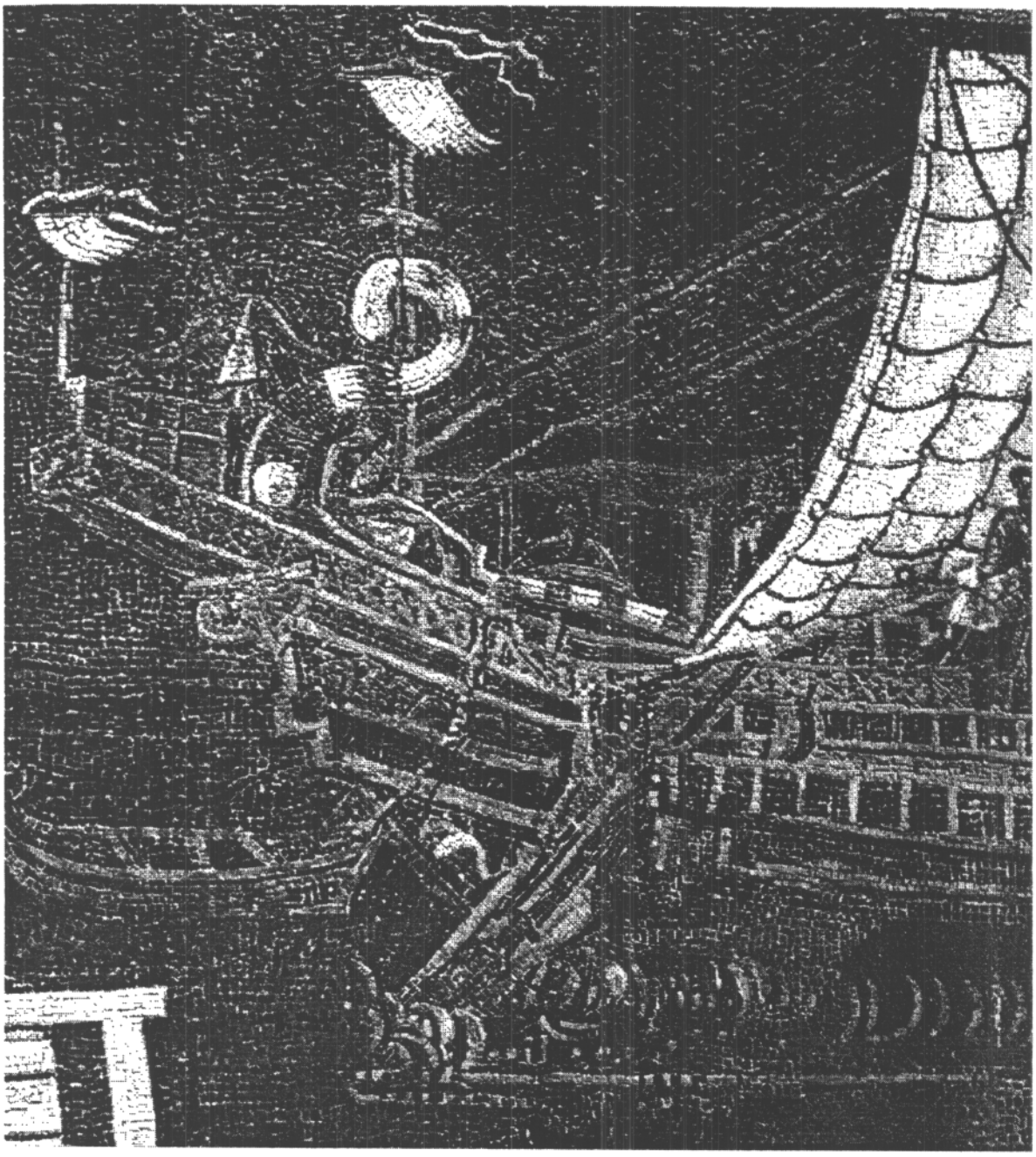

Figure 3.2 A 3rd century A.D. mosaic of a ship entering port with one rudder raised. The braced mount for the rudder can be clearly seen, with the shaft of the quarter-rudder passing between the two throughbeams which form the end of the side gallery. The mosaic also shows the pressure wave that builds up in front of a moving quarter-rudder and the turbulence associated with it (photo: Alinari).

of this is that it would require fewer lashings or, under certain conditions, none at all. If a wave caused the ship to roll and lift the rudder out of the water, the strain caused by the unsupported weight of the rudder would be taken by the two beams and not by the lashings used to hold the rudder in place.

This type of mounting system also had another advantage. By using a heavy lashing on the lower mount and light lashing on the upper beam, a safety mechanism for the shaft could be devised. The upper lashing could be adjusted so that if the rudder encountered a wave or submerged object which could break it, the upper lashing would break first, permitting the rudder to rotate upwards around the lower beam, and preventing damage to the blade or shaft. A system similar to this was used successfully by Thor Heyerdahl on the *Ra II* (Thorseth, 1986: 82). Obviously, this safety device would only work for forces applied to the forward edge of the rudder, and not for lateral torque applied to the shaft. This ability to easily rotate upwards would also facilitate carrying the rudder in a horizontal position. The rudder could be raised and secured by using a rudder hoist to pull the end of the rudder up. However, the main advantage would be that the rudder could be quickly lowered by simply loosening the hoist. If the rudder position was correctly adjusted, the rudder would lock itself into the mount and become immediately functional even before the installation of any lashings. With the other systems, the rudder would have to be moved into position and lashed before it could be used. This ability to raise and lower the rudder rapidly may be one reason this system was used, almost to the exclusion of all others, on Roman warships. However, in regards to actually dismounting or replacing a rudder, the braced mount system had some drawbacks compared to the aft-mounted system which will be discussed later.

The ship in the Torlonia relief (Fig. 2.2) has been one of the more controversial representations concerning quarter-rudder mounts, and has given rise to several proposals for mounting systems, two of which have been already discussed. Because the rudder appears to be held at only one point and to actually pass through the upper beam, the proposals invariably rely on a gimbal system to hold the rudder at the point where it touches the housing, and on the rudder hoist to actually support the rudder and prevent it from moving (Carlini, 1935: 446-47; La Roërie, 1937: 579; Daumas, 1970: 239). The position and angle of the rudder hoist is such that it could provide no support for the rudder, and even if repositioned to do so, it would not prevent the rudder from kicking-up every time a wave passed under the stern. More to the point, a gimbal system is totally unnecessary and overly complicated, as the trials of the *Argos*, *Kyrenia*, and *Olympias* replicas have shown. A close examination of the relief shows the rudder and hoist being attended by a man in a small boat. Casson (1971: 228, n.17) believed this to be a maneuver preparatory to docking, and the fact the rudder is only touching the ship at one point supports this interpretation. When the rudder position and housing are compared to other reliefs, there can be little doubt that the rudder is indeed being removed from its mount in preparation for raising and shipping it on board. The end of the rudder housing shows the reinforced box-like structure for a braced mount. Moreover, the stoutest throughbeam is the lower one, not the upper on which the rudder appears to sit. While for a gimbal system this extra beam would appear to be useless, for a braced system it makes perfect sense. In a braced mount the weight of the rudder is carried by the lower throughbeam, not the upper one. The placing of the rudder shaft so that it appears to pass through the upper beam is obviously a mistake by the artist. In all probability, the shaft should be placed below the upper beam so that when the rudder is raised the rudder can be pulled into the rudder housing.

The common occurrence of the braced mount in Roman art suggests that use of the system was widespread and that it could be easily adapted to different circumstances and ship types. It is also shows

Figure 3.3 A detail of a 9th century A.D. miniature in the bible of Charles le Chauve. This highly stylized depiction is the latest known representation which possibly shows the traditional Roman braced mount. The depiction is probably a copy of a much earlier representation (After Moll, 1929: G19 a9).

that the system must have performed its function more than adequately. Yet despite the obvious merits of the braced system and its general use throughout the Roman Empire, it did not survive into the medieval period. The latest examples of ship representations with the braced mount system date from the 9th century A.D. (Fig. 3.3). Even this example is probably copied from an earlier depiction. It is possible that the braced mount was used later, but there is simply no evidence, direct or indirect, that this was so.

THE AFT-MOUNTED SYSTEM

The aft-mounted system was probably the most commonly used method of quarter-rudder mounting on large merchant ships, after the braced mount. Unlike the braced mount, there are no representations from the Roman period which actually show the rudder mount itself. However, the features on several ship depictions demonstrate that the system was in use. Further evidence and information come from a modern analog still in use today in Southeast Asia.

The aft-mounted system consisted simply of two throughbeams with the lower one set aft of the other. The rudder shaft rested in notches or brackets on the aft side of each beam, and the rudder was held in place by lashing (Fig. 3.4). A similar mounting method can be seen today on the *pinisi* of Indonesia. The mount consists of nothing more than two notched beams on which the rudder rests. The upper end of the rudder is lashed to a kingpost around which the rudder can pivot. Under normal conditions, the rudder is held on the lower mount by its own weight and a Spanish windlass. The Spanish windlass is made of light rope and is there to keep the rudder from rising off the lower mounting point due to wave action. If the rudder encounters a submerged obstacle the rope breaks and the rudder swings upwards, thereby protecting it from serious damage. The system is very simple in construction, and as the *pinisi* and fishing boats of Southeast Asia demonstrate, it can be used on variety of vessels. On Roman vessels the rudder was probably lashed to the throughbeams, as there is no evidence that a kingpost was used by the Romans. Whether or not the Romans used kingposts as do the *pinisi*, the system they employed had to

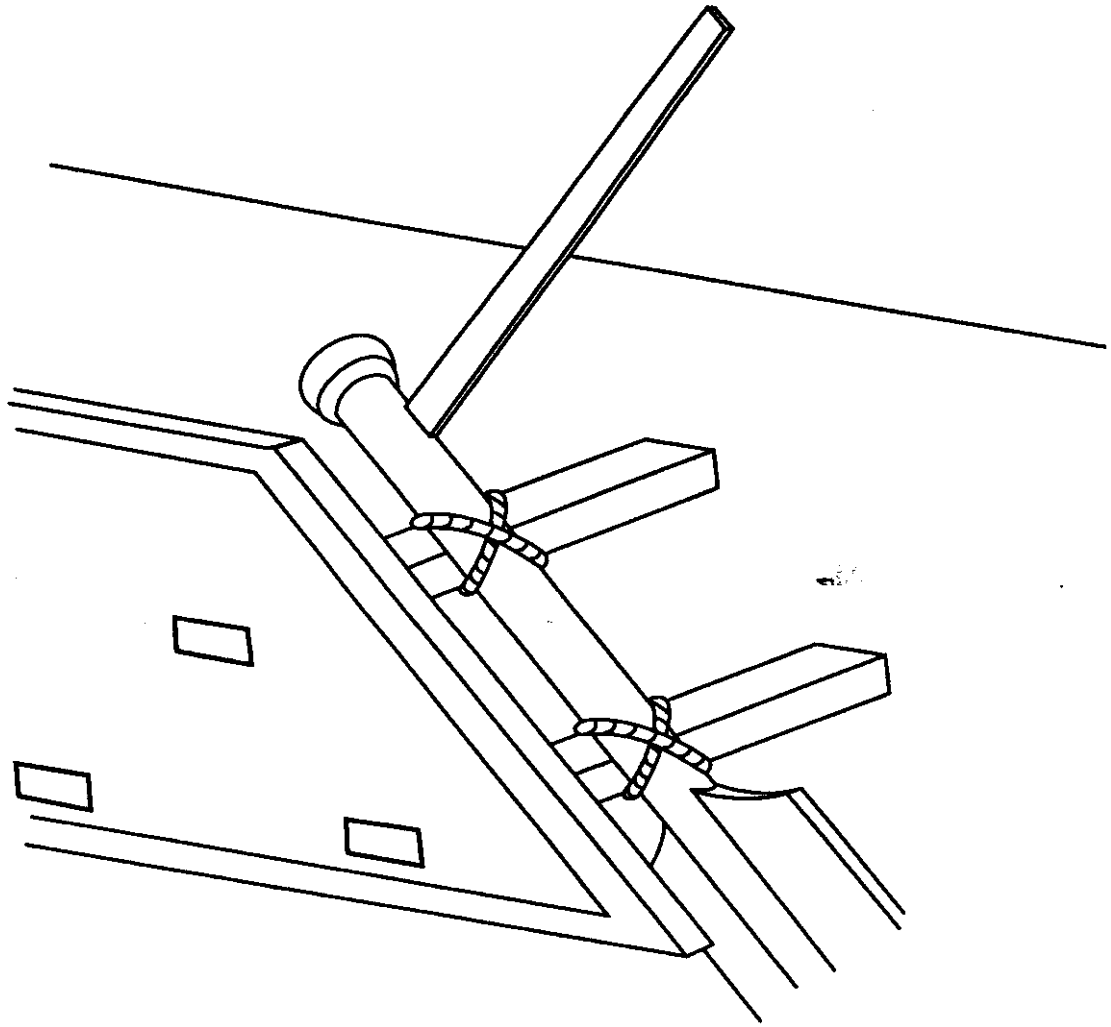

Figure 3.4 A view of a basic aft-mounted system showing the quarter-rudder shaft resting on the aft side of the two throughbeams forming the end of the side gallery on the ship. The lashings are hypothetical.

have been very similar.

The use of the aft-mounted system on Roman vessels can by inferred from iconography by the position of the throughbeams in the rudder housing and their relation to the position of the rudder shaft. The best examples of this can be seen in Figures 3.5 & 3.6. By extrapolating the position of the rudder shaft upwards in both of these examples, it can be seen that the shaft passes aft of both the lower and upper throughbeams and not between them. Another indication that an aft-mounted system is being employed is that the throughbeams are offset to form the proper angle for the rudder. In the examples of the braced mount system, the beams are not offset and there is usually a reinforced box-like structure joining the two beams.

The aft-mounted system did not have the advantage of being able to brace the rudder shaft between the two throughbeams. If the rudder was suddenly pulled clear of the water due to wave action

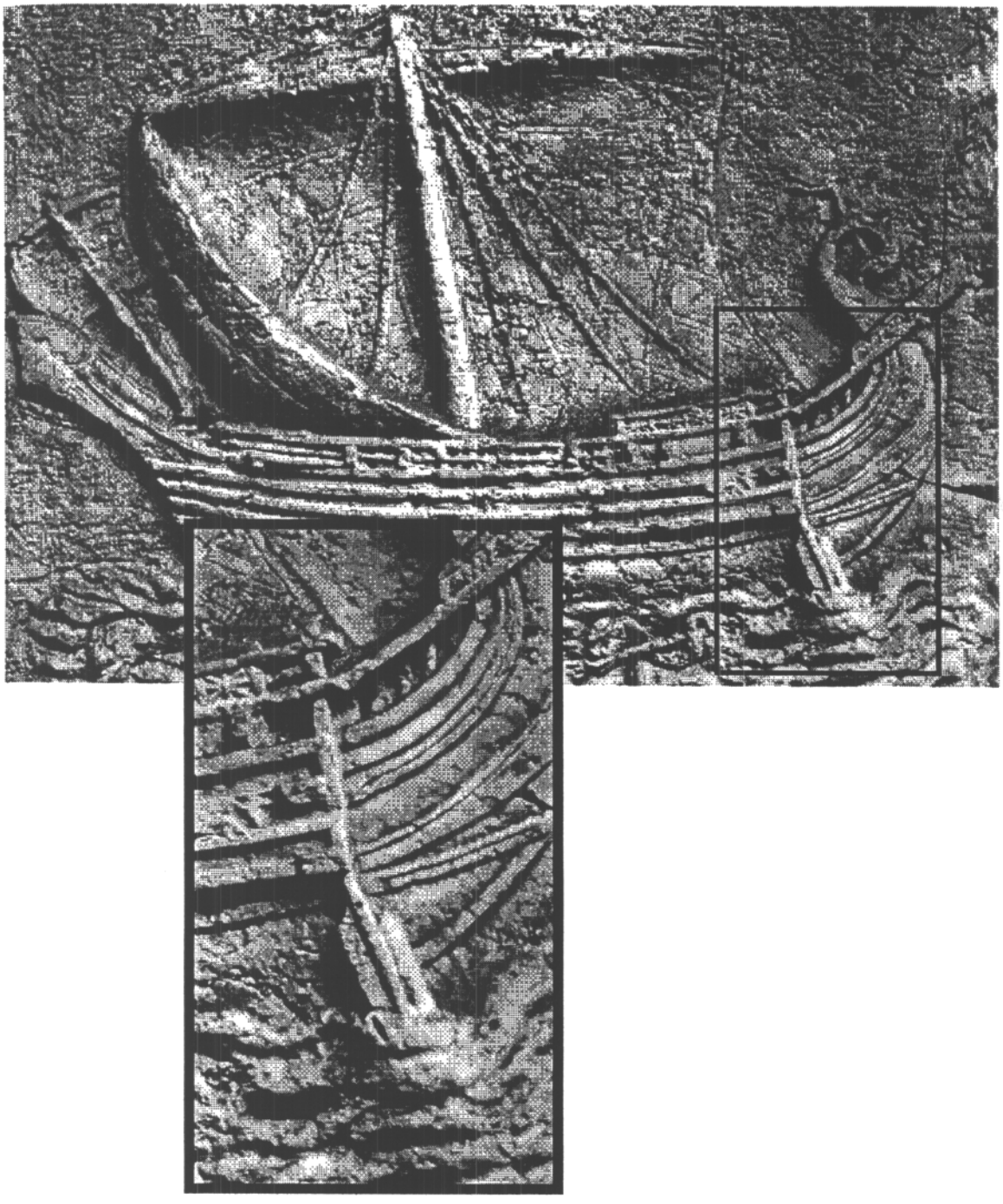

Figure 3.5 A 3rd century A.D. relief of a large Roman merchantman. The rudder shaft appears to pass aft of the two heavy throughbeams, indicating that the ship probably has an aft-mounted quarter-rudder (photo: Alinari).

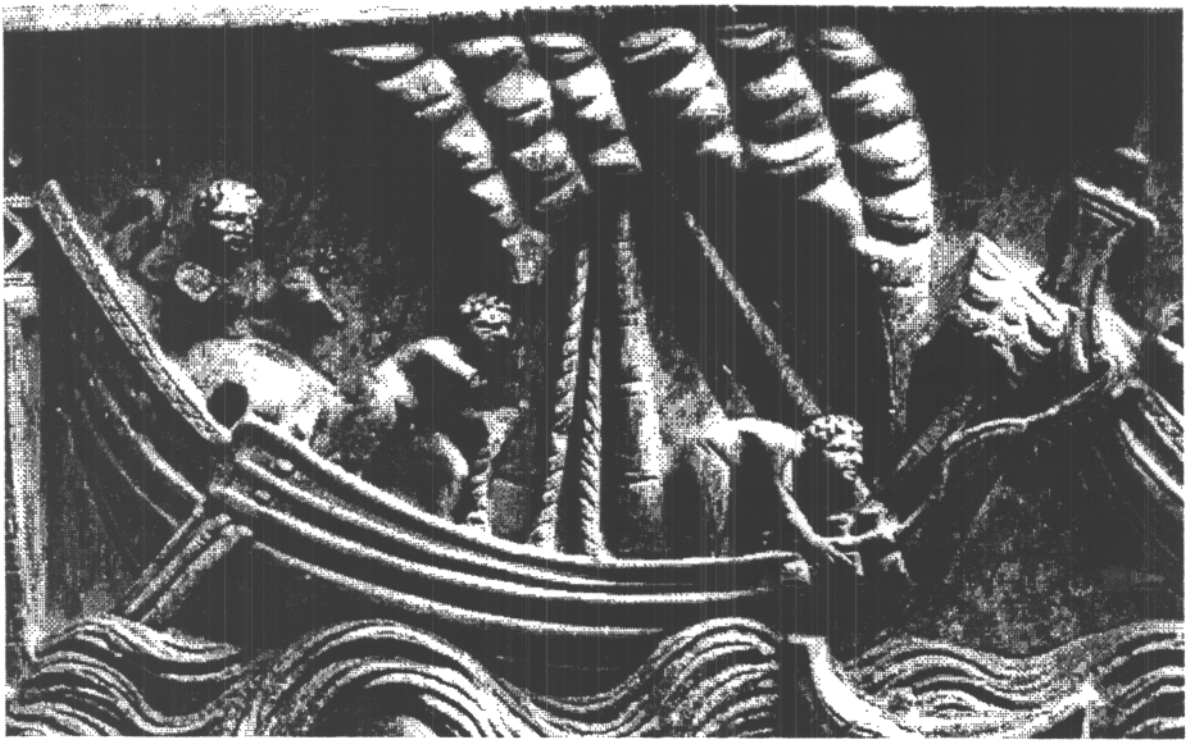

Figure 3.6 A detail of a 3rd century A.D. relief of three ships. The rudder shaft passes aft of both throughbeams. This, and the fact the throughbeams are offset, indicates that the vessel has aft-mounted quarter-rudders (photo: Alinari).

the downward force created by the weight of the unsupported rudder would have to be counteracted by the lashings instead of the throughbeams as in the case of the braced mount. As with the braced mount, upward force applied to the rudder due to drag, or swells passing under the ship, could be partially compensated by pulling the rudder up along its length so that it sat more firmly in the mount. However, unlike the braced mount, the rudder could not be pulled up too far. Pulling the rudder up would remove more of the rudder blade from the water thereby decreasing the bouyant force supporting the rudder. If the rudder was pulled up so far that the upward force on the blade, caused by bouyancy, drag or wave action, was substantially less than the downward force, the unsupported weight would cause the blade to drop and the rudder shaft to rotate downward around the lower throughbeam. In a braced mount the upper beam would prevent this, but on a aft-mounted system only the upper lashings could stop the rudder from pivoting towards a vertical position. For a large rudder, the force required to hold the shaft on the upper throughbeam would have been considerable and would have caused the lashings to stretch. Adding more lashings could compensate for this, but they might effect the ability to turn the rudder.

The reason for installing an aft-mounted system in preference to the braced mount system, which appears to have more benefits, is hinted at in both the previously mentioned representations. In both cases the ships are large merchantmen. The reason this type of mount was put on ships may have been related to rudder size and weight. In unshipping a rudder from a braced mount, the head of the rudder would have to be pulled completely out from between the throughbeams. This would entail pulling the rudder

aft until it was clear of the mount before it could be pulled on board. For small rudders this would present no problems, but for a large merchantman with a multi-ton rudder the proposition would have been more delicate. In a running sea there would be the problem of controlling the rudder as it was pulled aft and clear from the mount to prevent it from damaging itself and the ship. For the aft-mounted system, to pull a damaged rudder completely out of the water is much less involved. After loosing the lashings, the crew would simply need to attach tackle running from the mast to the head of the rudder. By pulling upwards the rudder would be pulled upwards and forward where it could be easily stowed, as is done today on the *pinisi*. The advantage is that the lashing could be left on the mount during the initial stages of raising the rudder, giving some nominal control over it during a crucial stage when the rudder could still be pushed around by wave action. The braced mount did not have this advantage. The procedure could also be used to simply rotate the rudder up to a horizontal position while in port, although this was not as easily done as in the case of a braced mount.

As we will see later, this system survived through the Middle Ages, though in a modified form. The simplicity of the system assured that it would be one of the few Roman systems to see use into and through the medieval period.

THE FORWARD-MOUNTED SYSTEM

The forward-mounted system is exactly the same as the aft-mounted system, except that in this system the quarter-rudder was placed forward of the two offset throughbeams (Fig. 3.7). While at first glance this appears to be an unlikely arrangement, the relief on a 3rd century sarcophagus leaves no doubt that the method was used. In Figures 3.8 and 3.9, the shaft of the rudder can be seen to pass forward of the lower throughbeam, and projection of the axis of the shaft upwards shows that it passes forward of the upper throughbeam. The actual arrangement for this system is clearly visible in a medieval representation (See Page 24). The upper bracket is a wooden U-shaped yoke, in which the rudder is held by a wooden pin placed in front of it. The lower mounting point is similar except that only a light lashing is used instead of a wooden dowel. If the rudder encountered a submerged object, the light pin would break before the shaft or mount, and rotate around the lashing on the lower bracket to a near horizontal position, and up and over the obstacle. The earliest examples of this type of mounting system all come from the 3rd century A.D., suggesting that it was developed by Romans.

In both the above examples, the forward-mounted system is used on relatively small vessels, but two other Roman representations show that the system was probably used on large merchant ships as well. In Figure 3.9 the rudder shaft passes forward of a heavy throughbeam indicating a forward-mounted system. The same arrangement is present on the ship in Figure 3.10. The rudder is placed forward of the two aft-most throughbeams in the quarter-rudder housing. There is a large gap in the spacing of the throughbeams forward of the rudder also indicating the presence of the forward-mounted system. The gap in the throughbeam spacing is wider than the rudder blade, and was necessitated by the need to pull the rudder out for repair or replacement. The gap would permit the rudder shaft some room in which to rotate in if the upper fastening broke due to the rudder striking an obstacle.

Why this particular mounting technique was used is unclear. The very nature of it prevented the common practice of rotating one of the quarter-rudders into a horizontal position. To pull one of the rudders out of the water would have essentially required completely unshipping it from the mount. This

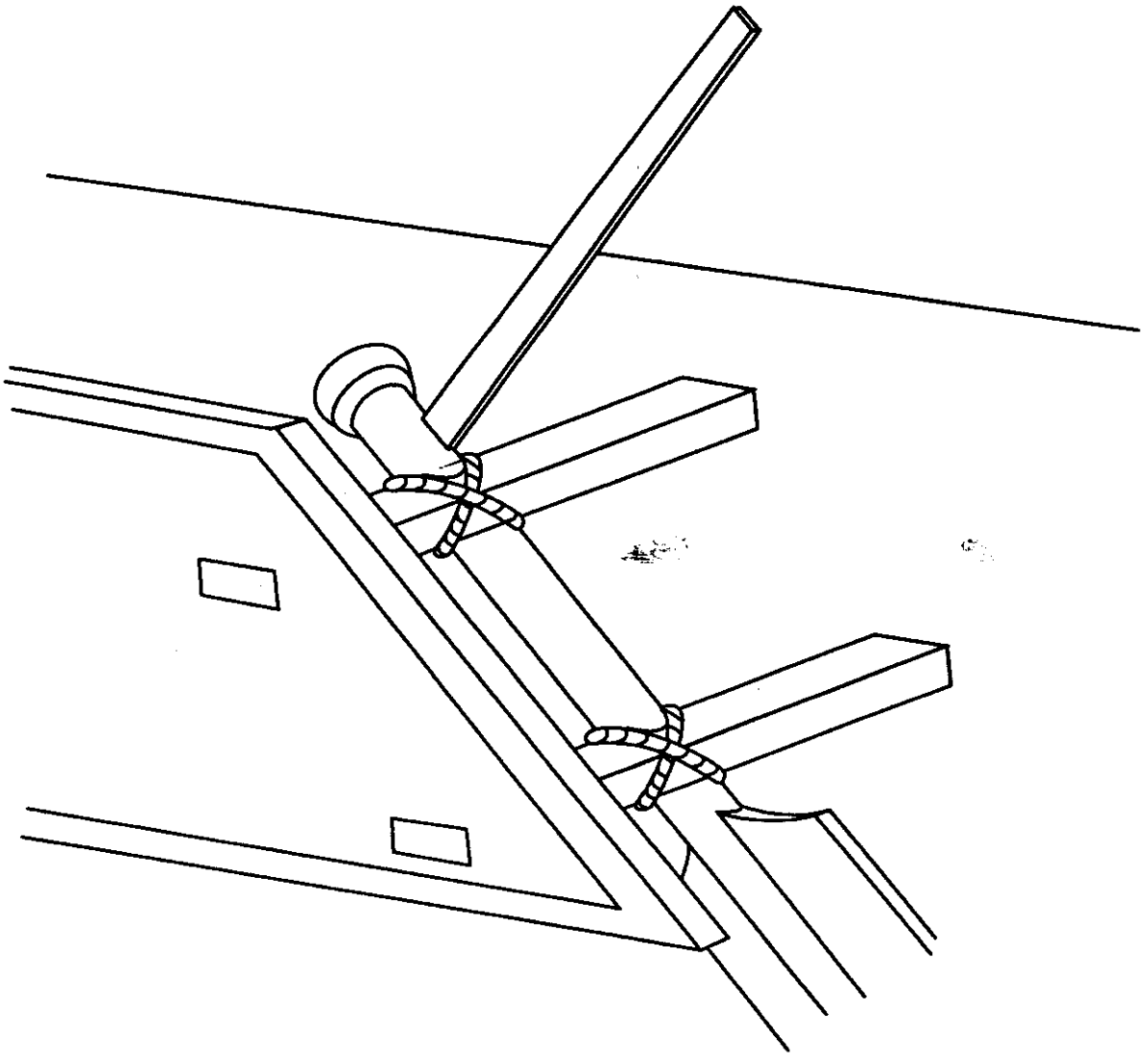

Figure 3.7 A view of a basic forward-mounted system showing the rudder shaft placed forward of both throughbeams. The lashings are hypothetical.

type of mount also would have made the actual task of dismounting the rudder while underway more difficult. Loosening the lower lashing and pulling the rudder up along its length would cause it to rotate forward to a vertical position, but the crew would still have to deal with removing it from between the beams in the rudder housing. To do so would require that the rudder be raised to a nearly vertical position, and to a considerable height, by tackle running from the yardarm or the mast. Again, this problem is a matter of scale. For small vessels, such as in the first two examples, the rudder was probably small enough to manhandle. For large ships the maneuver would have been more difficult as the crew would have had to control a large swaying mass essentially dangling from a rope.

The one advantage this system had was that the lower bracket took all of the stress from rudder

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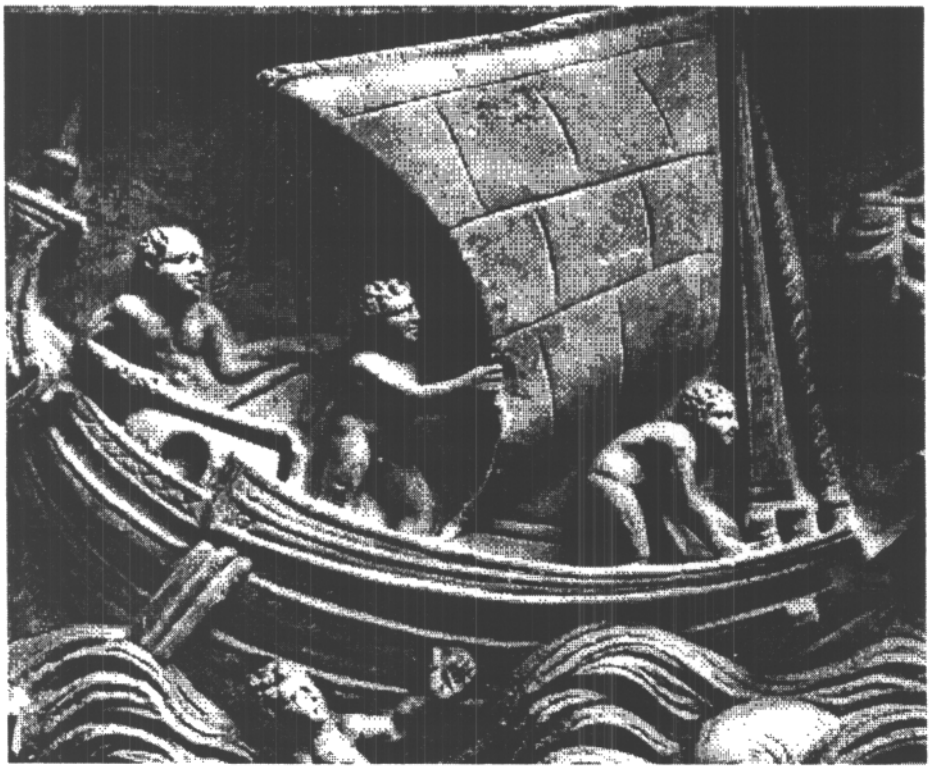

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Figure 3.8 **A.** A detail of a 3rd century A.D. relief of three Roman ships. The rudder shaft can be seen to be forward of both throughbeams(photo: Alinari). **B.** A detail of the ship's rudder housing showing the rudder shaft forward of the lower throughbeam (After Casson, 1964: fig. 74).

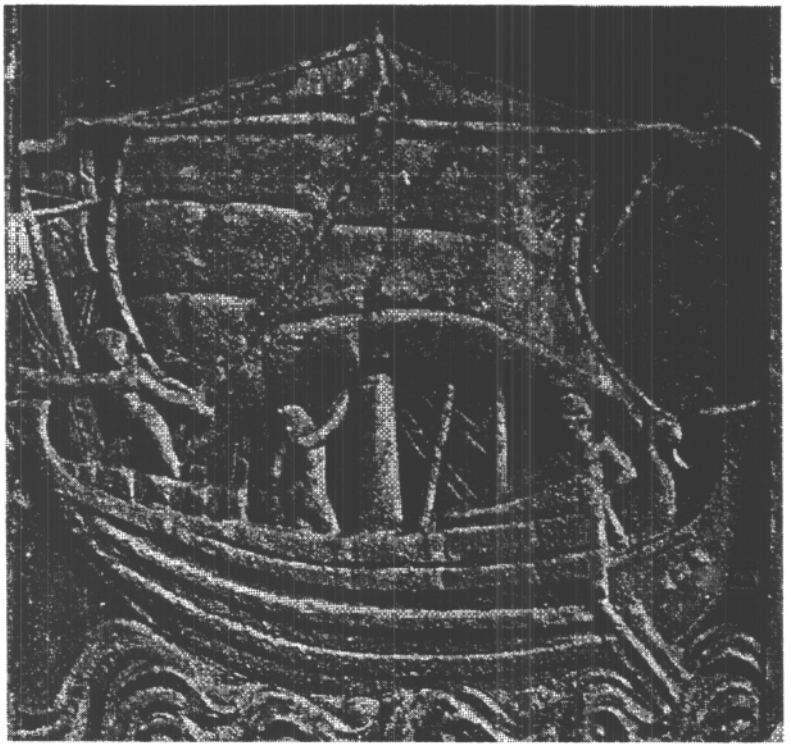


Figure 3.9 A 3rd century A.D. relief of a cargo ship which has forward-mounted rudders. The rudder shaft can be seen to pass just forward of the heavy throughbeam at the bottom of the rudder housing (photo: Alinari).

drag and waves, and not the lashings as in the braced mount or aft-mounted systems. This would eliminate the problem of the lashings stretching or fraying, and the upper lashing could be lighter. Because drag on the rudder would cause it to try and rotate around the lower bracket, the section of shaft between the lower and upper mounting points would act as a lever arm to help compensate against force applied to the submerged portion of the rudder. Only a light lashing would be required to hold the rudder to the lower bracket during times when the roll of the ship or waves would cause the rudder to pull out of the water and rotate forward. By having the main restraint or lashing on the upper mounting point, it could be easily accessed for maintenance. In the case lashings were used, having them on the upper bracket would have kept them farther from the water and thus drier, reducing stretching due to them becoming wet.

This system does not appear to have been in wide use after the Roman period. The only medieval example is the 14th century fresco of a fishing boat (Fig. 3.11). Because of the aforementioned drawbacks, it is very likely that the forward-mounted system was limited to small boats where the rudder size would not be a problem. This hypothesis is supported by the total lack of any medieval iconography of this system appearing on a large vessel.

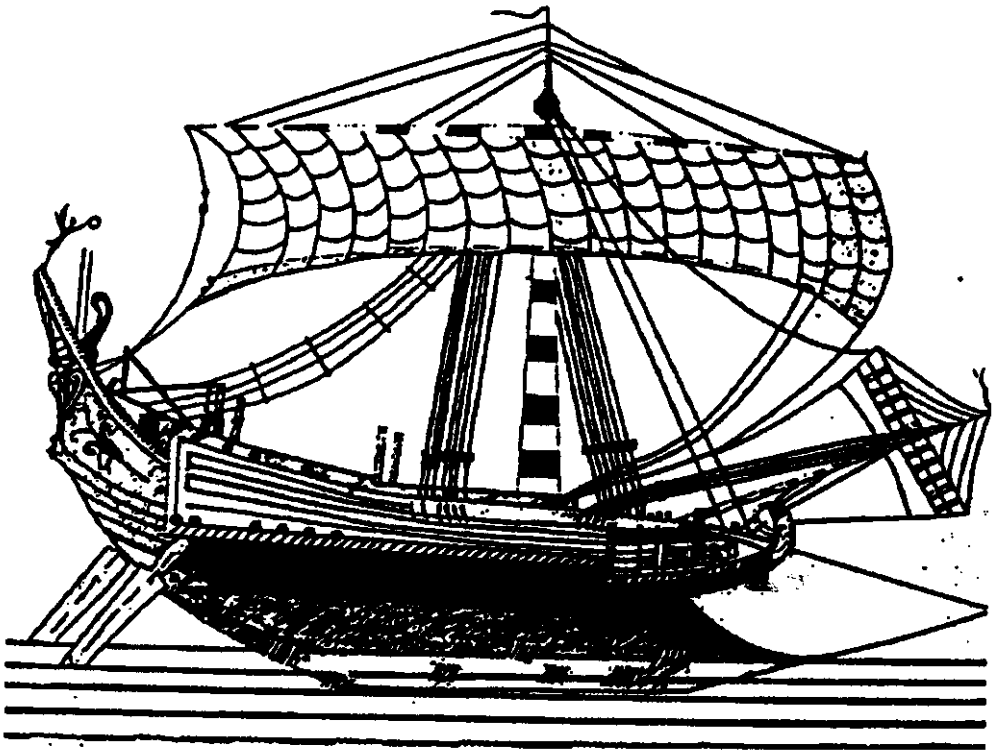


Figure 3.10 A ship in a 2nd century A.D. mosaic found at Thermetra in Tunisia. The ship probably carried forward-mounted quarter-rudders. The rudder shaft appears to pass forward of the two aft-most throughbeams, and there is a large gap in the spacing of the throughbeams forward of the rudder. This gap would be necessary for hoisting on board a forward-mounted rudder (After Foucher, 1967: 90).

THE BOX MOUNT

The box mount consisted of two closely-spaced throughbeams placed near the waterline. The spacing of the beams was just wide enough to permit the rudder shaft to pass between at an angle. The upper end of the shaft was either lashed to the caprail or was passed through a slot in the side of hull. The rudder shaft was prevented from moving sideways by wood crosspieces on either side of it. Together with the throughbeams, these crosspieces formed a box through which the shaft passed. By properly adjusting the spacing of the beams and the crosspieces, the box could be constructed so that it held the shaft tightly in place while allowing it to rotate freely.

This system was a radical break with ancient mounting traditions. All of the other systems were constructed to permit the rudder to rotate upwards to a horizontal position if the rudder struck an object. On the other hand, the box mount held the rudder firmly in place, preventing any movement; if the rudder struck hard nothing would prevent the shaft from breaking. At first glance, this would seem to be a major disadvantage. However, if the depth of the rudder was adjusted to keep the sole above the depth of the keel, there would be little danger of encountering a serious threat for a merchantman. On the other hand, not being able to easily remove or rotate the rudder to a horizontal position would be a major drawback

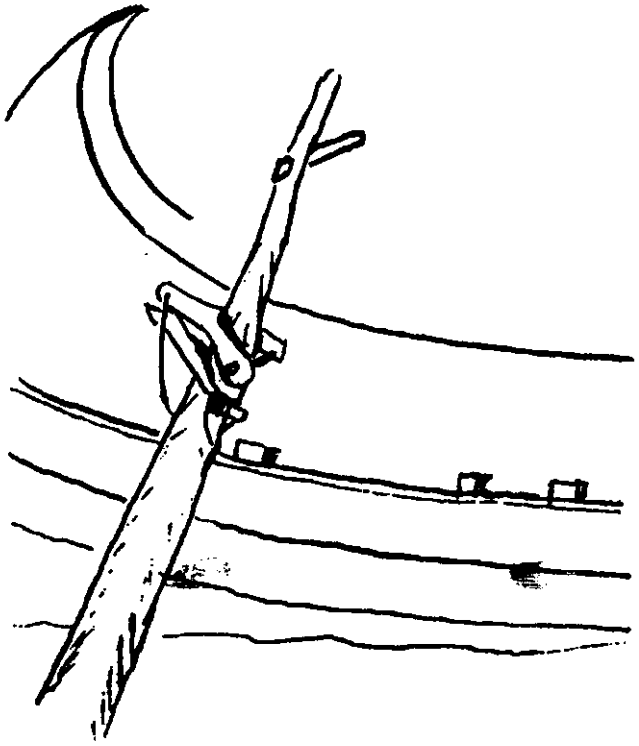


Figure 3.11 A detail of the forward-mounted quarter-rudder on a medieval fishing boat. The fresco was painted by Antoniazzo Romano in A.D. 1460. The rudder is held in place on the upper mounting fixture by a light wood dowel, instead of a lashing (After Vocino, 1951: 117).

on war galleys which traditionally beached stern-first. This is probably why there is only one Roman representation of a warship with the box mount (Fig. 3.12).

Despite some of the drawbacks, the advantages of the box mount were significant. The other systems used lashings to hold the rudder to the lower mounting point. This meant that the lower point had to be protected or moved away from the waterline to keep the lashings dry and to permit their repair or replacement due to stretching and fraying. Using a lower fixture which did not require lashings and maintenance meant that it could be placed near the waterline. This, in turn, decreased the distance between the mount and the rudder sole. By decreasing this distance, the amount of stress that could be applied to the shaft by an external force, such as a wave, was diminished because the lever arm was decreased. The end result was that the amount of force required to break the shaft would have been significantly greater than if the lower mounting point were higher up on the side of the ship. As with the other systems, changes in the ship's draft could have been compensated for by moving the rudder up or down parallel to the shaft.

A medieval representation (see Chapter VI) demonstrates that the system could be modified to permit the rudder rotate to a horizontal position. The system probably consisted of a removable wooden piece, either forward or aft of the shaft, which could be removed to create enough space between the beams to allow the shaft to rotate to a horizontal position. However, while underway, the wooden piece

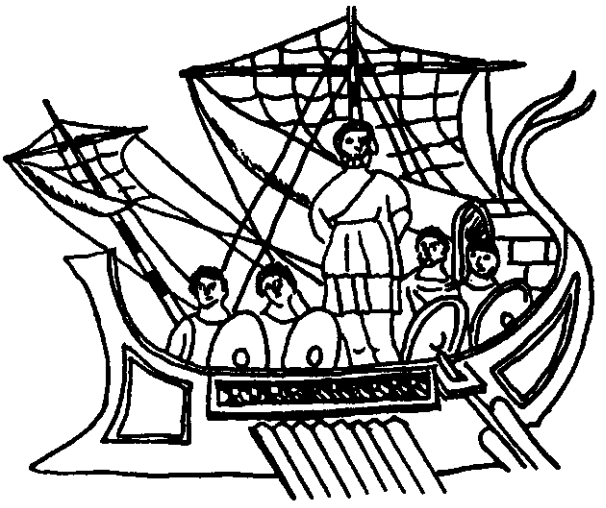
would have had to be in place to firmly hold the rudder. If not, wave action would have caused the shaft to rattle around in the box, eventually damaging itself, the box mount, or both. Also, the head of the rudder often passed through an opening in the side which would rule out the rudder being able to rapidly kick-up regardless how loosely it was held in the box. For removing the rudder, the outboard crosspiece was probably made so it could be removed.

Of all of the different mounting systems used by the Romans, only the box mount stayed in continual use through the Middle Ages without significant modification. The box mount first appeared in the 3rd century A.D. in a mosaic of a galley , and next in a mosaic from the 6th century A.D. (Fig. 3.12). The Roman box mount stayed in use until at least the late 15th century, and the basic design concept also gave rise to several variations during the Middle Ages.

SLEEVES AND GIMBALS

The use of sleeves and gimbals appears to have been very rare. There are only two examples of sleeve mounts in existence, and both come from the classical period. The first set of representations comes from an Etruscan sarcophagus circa 3rd century B.C. (Fig. 3.13). These depictions are highly stylized and are the only examples of this type of rudder mount. While it is very possible that they do not represent an actual system, the reliefs do provide a vehicle for discussing the problems inherent in any system where the quarter-rudder is solidly attached to a ship's side. In the reliefs, the rudder shaft can be seen to pass through a single fixed collar. This arrangement would have allowed the rudder to be moved up and down in the collar, but removal of the rudder from such a collar would have been difficult. The only plausible method would have been to remove the tiller and pull the rudder out from the bottom, which would have been nearly impossible feat while the galley was underway. As with the box mount, there would also be the problem of breaking the shaft if the rudder should ground. In the relief, the sleeve has been placed relatively high up on the side to allow the blade to be pulled clear before hitting the sleeve, which would have been necessitated by the common practice of beaching galleys stern-first to the shore. With the other systems, the rudder could simply be rotated to a horizontal position, but the sleeve would prevent that expediency. Because the sleeve had to be placed high enough to permit the blade to clear the water and beach, the actual distance between the sole of the rudder and the mount would have increased. The undesirable result would have been to increase the stress on the shaft by any force applied to the blade because of the increased lever arm. The use of such a sleeve system on a galley would have created more problems than it solved. In the Middle Ages, wooden collars were used but the rudder shaft was supported at a second point, and the the wooden collars were only used on merchantmen, not galleys.

The only other sleeve arrangement occurs on Trajan's Column (Fig. 3.14). The mount appears to consist of a simple fixed metallic sleeve. The rudder shaft rests at an angle in a curved wooden cradle with the sleeve fitted over it. While the reconstruction by Basch (1987: 453) is overly simplistic, in that it has the rudder in a vertical position and leaves out the wooden cradle, it is correct in placing the mount at the end of the outrigger, and not on the side of the hull. The sleeve mount is strictly limited to vessels which appear in river scenes, while the braced mount appears on both ocean-going vessels and river craft (Lepper, 1988: 81-84, 96, pl. XXV, XXVI, XXIV; Rossi, 1971: 148-49). This is the only Roman representation of a sleeve mount, and the presence of the sleeve mount on only river vessels suggests its use was rather restricted. The only advantage a sleeve could provide would be to prevent the dismounting of the rudder in combat since there would be no lashing to break or be cut. The disadvantages of the sleeve



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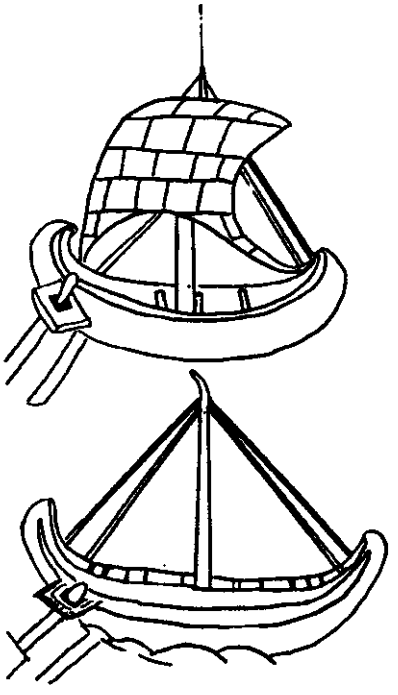

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Figure 3.12 Roman box mounts. A. A detail of a 3rd century A.D. mosaic found at Dougga, Tunisia. This is one of the earliest representations of a box mount (After Throckmorton, 1972: 85). B. Two ships from a 6th century A.D. mosaic from the church of Sant' Apollinare Nuovo at Ravenna. The representations clearly show that the mount had side pieces which formed a box-like structure to keep the rudder from moving laterally (After van Doorninck, 1972: 154).

Figure 3.13 A 3rd century B.C. relief from an Etruscan sarcophagus. The rudder appears to be held by only a wood collar at one point (After Moll, 1929: B.III b54).

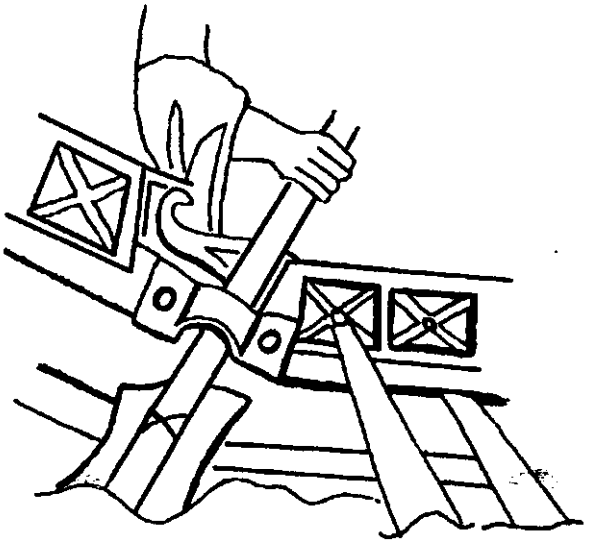

Figure 3.14 A detail of Trajan's Column showing a possible sleeve mount. These mounts are only found on ships in the river scenes (After Basch, 1987: fig. 999).

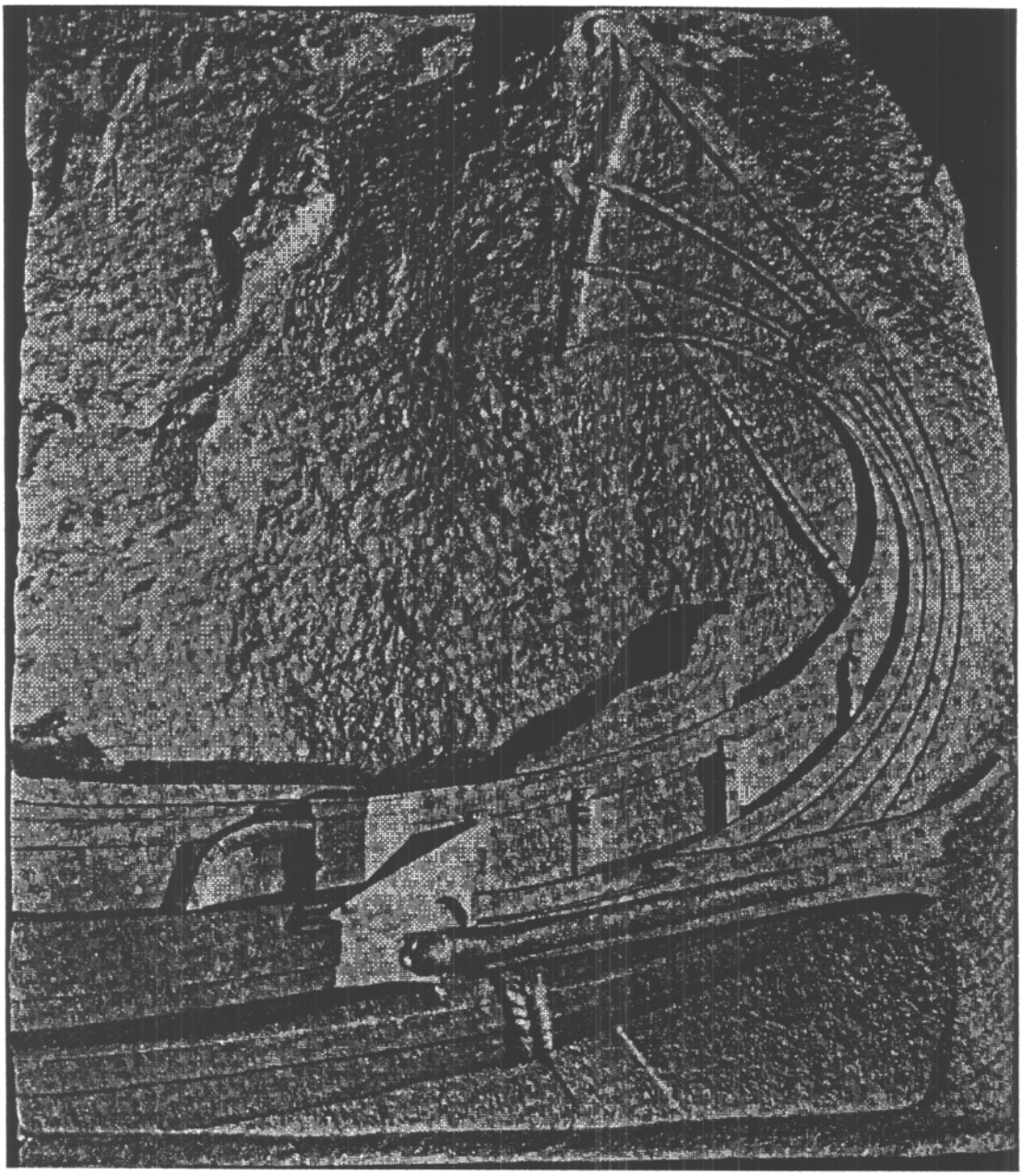

Figure 3.15 A cast of a relief from Lindos on the island of Rhodes showing the stern of a galley. The metallic sleeve can be seen where the rudder shaft enters the gallery on the ships side. A quarter-rudder with a gimbal or sleeve, as depicted above, would still require an upper point of attachment. The gimbal only protected the rudder and lower mounting point from battle damage, and removed the need to use lashings. The mount shown here is probably a braced mount, and the rudder appears to have an elliptical shaft. The depiction dates to circa 200 B.C. (Blinkenberg, 1938: fig. 3).

system far outweigh the potential benefits, and these are probably why the system had, at best, limited use.

The case for the use of a gimbal system is even more tenuous than that for sleeve mounts. There is not a single shred of evidence, written or iconographic, which indicates that a pure gimbal system was ever employed. The above is not to say that gimbals were not used, but the only example which clearly has a gimbal is using it in conjunction with a brace mount (Fig. 3.15). In the Lindos relief, a gimbal can be seen around the shaft where the rudder enters the hull. It appears to be a metallic sleeve through which the shaft passes. There are slots cast into the side of it so the gimbol can be set onto horizontal protruding pins. Despite the gimbol arrangement, the mount housing shows that if the rudder was lowered the upper end of the shaft would be stopped by the housing at about 35 degrees from vertical, which is about the average angle most quarter-rudders were set at. In any case only the Lindos relief provides an example that indicates some type of gimbol or metallic pivot was in use. The rarity of gimbols in the iconography indicates that they were certainly not in wide use.

The reasons for this apparent lack of use are not hard to find. First, as previously mentioned, there was simply no need for one. Virtually all of the rudder mounts in common use simply required two notched throughbeams set at the appropriate angle. The addition of a gimbal or special metal sleeve would have provided no material performance benefits. A gimbal, as in the Lindos relief, would have been an expensive luxury on a merchant vessel. If a rudder in a simple brace mount was lost in a storm, the only real damage which could occur would be to the rudder itself. However with a gimbal system there would be the chance the gimbal itself would be carried away with the rudder. In that case, not only the rudder would have to be replaced but also an expensive casting. Ship owners, from Classical times onwards, have been notoriously parsimonious when buying equipment for their ships. It seems highly unlikely they would have installed expensive devices which would provide little or no performance benefits.

The fact that the only possible examples of a gimbal system appear on warship representations supports the above assertions. While a gimbal would have little or no use on a merchant ship, a metallic fitting similar to the Lindos example could provide a useful benefit on warships. The gimbal or sleeve would prevent the enemy from detaching the rudder in battle by cutting the important lower lashing of a brace mount. The sleeve would also protect the shaft from battle damage at this critical junction with the hull. Another possible reason may be strictly cultural. While shipowners have been always confronted with financial limits, historically most military institutions have had nearly unlimited funds to work with and could afford relatively expensive and exotic hardware. However, even with these potential benefits the use of gimbals by the military does not seem widespread. Several ships on Trajan's column have no sleeve-like fitting for the rudder and are using a simple brace mount. The fact that Vegetius considered cutting the rudder lashings a viable tactic is a clear indication that even on warships gimbals were not a common occurrence.

RUDDER TACKLE

Evidence concerning the specifics of rudder tackle is sparse. The use of rudder hoists is suggested by a passage in *Silvae* by Statius where he invokes the sea goddess to "let down into the water the rudder that guides the curved vessel" (*Silvae*, 3.2). Another example comes from the voyage of St. Paul

where the crew loosens the pendants of the rudders in preparation for getting underway (Casson, 1971: 228, n.17).

There are few Greco-Roman representations actually showing the rudder hoists. As mentioned, the two most commonly cited are the Torlonia relief, and the mosaic from the Antiquarium (Figs. 2.2 & 3.2). In both these cases the rudder hoist is parallel to the shaft of the rudder. In both cases, it is attached to the rudder by passing it around the shaft and through holes cut in the blade. The positioning of the hoist would not be effective for rotating the rudder up and out of the water, but is exactly placed for adjusting the depth of the rudder by pulling it up in a direction parallel to its shaft. In fact, there are no Greco-Roman representations of a rudder being suspended from a vertical line. This suggests that a temporary line was looped around the rudder for this purpose, and then removed when the rudder was secured in a horizontal position. It is also possible that the position of the hoist was adjusted aft when it became necessary to raise the rudder. In any case, we have virtually no evidence as to what exact type of tackle was used for hoisting the rudders into a horizontal position.

As far as the use of relieving tackle, or rudder pendants as we know them today, there is only one clear example. St. Jerome speaks of a helmsmen releasing the "straining bonds of the rudders" during a quiet period in a storm. As pointed out by Casson, there is little doubt that these "bonds" were relieving tackle on the rudders to help the helmsmen control the rudders in rough seas (Casson, 1971: 228-29, n.19). Other than the above, there are no other passages mentioning rudder pendants. In fact, there is little evidence as to the actual terminology used during the Roman period concerning any of the rudder tackle. Saint-Denis (1934: 392) speculated that the word *habenae* referred to the hoisting tackle, but the evidence is indirect at best.

However, it does seems likely that a system of rudder hoists and relieving tackle were commonly employed to assist helmsmen in controlling massive quarter-rudders. The combination of hoisting tackle and rudder pendants was inherently necessary for controlling large quarter-rudders, especially under extreme weather conditions. Because the larger rudders would have required some method for assuring control, this combination would continue through the medieval period virtually unchanged.

The various mounting systems which were used by the Romans were a reflection of the various phenomena which effected the rudders and the ships. The relatively simple requirements of the quarter-rudder concept allowed for a variety of mounts to be designed which fulfilled the needs of different vessels. These mounting techniques were in turn influenced by the forces acting on the rudders and the ship. As we will see in the next chapter, not only did the rudders provide steering for ships, they also performed other functions as well.

CHAPTER IV
"WINGS" AND THINGS

Before the issue of quarter-rudder design can be addressed, a brief review of the forces that act upon a rudder is necessary. The factors which defined the hydrodynamic characteristics of an ancient rudder are still the same today. The mounting of rudders has changed, but the basic requirements and restrictions concerning the effectiveness of rudder design have not. Gillmer and Johnson (1982: 274) went to the heart of the issue of rudder evolution in stating, "In a technical sense, a great deal of improvement in the rudder as an effective control surface can be seen; but very little change in its basic nature and usage has taken place."

The Greeks very aptly refered to the rudder blade as the πτερυξ, which literally means "wing." A rudder is essentially a foil, and therefore can be described by the same definitions used to delineate various lifting surfaces in aerodynamics. The two major forces which act on a rudder are lift and drag (Fig. 4.1). Lift results from the Bernoulli effect and in the case of the rudder is caused by water on the leeward side of the rudder blade being forced to travel faster; this creates an area of low pressure, or lift. The low pressure created on the leeward side of the rudder produces the turning force, or turning moment, which actually turns the ship. Drag, which degrades lift, is the result of water friction and turbulence on the the rudder. The best rudder designs maximize lift and try to decrease drag as much as possible. For the following discussion of rudder forces and rudder shape, the basic definitions are those used by Gillmer and Johnson (1982: 274-75).

The fact that a rudder is a lifting surface has been long established by both theoretical and empirical methods. Unfortunately, this body of work has not completely put to rest the notion that the rudder acts as lever because of water which is pushing against it. This idea was first put forward by Aristotle (*Mechanica* 850b-851a) and repeated in Roman times by Vitruvius (*De Architectura* 10.3.5). In modern times, authors have continued to subscribe to this theory (Serre, 1891: 357-359, 369; Noëttes, 1935: 43-44). Recently, in an attempt to quantify this view Thurneyssen (1978: 75; 1980: 3-4) made the same mistake as his predecessors in that he basically restates the work of Aristotle. According to the equations he presents, the maximum resultant force produced by a rudder occurs when the blade is set at an of 45 degrees to the direction of movement. In reality however, most rudders *stall*, that is loose lift, well before reaching an angle of attack of 45 degrees. The work also totally neglects the dramatic effect that the aspect ratio of the rudder has on the critical angle and on lift, all of which will be discussed later.

The Roman quarter-rudder was no more than a single-plate, spade rudder which penetrated the surface of the water. The Greco-Roman design consisted of a central shaft with blade sections attached on either side by mortises and tenons. There is no evidence that the rudder shafts were of compound construction. However, to obtain the necessary width, the blades on the large rudders must have been constructed of two or more lines of planks joined edge-to-edge to form a complete blade. Because this would cause inherent weakness in the blade, metallic reinforcement bands may have been used to strengthen the rudder. Bands across the shafts of the rudders in Figure 4.2 and the presence of concretions found on the quarter-rudder fragments at Kyrenia (Steffy, 1985: 90) suggests that some rudders were indeed reinforced. These blades were thin and flat, and did not have a thick foil shape. These rudders behaved in a manner similar to what would be called today a single-plate rudder. The lack of a true foil

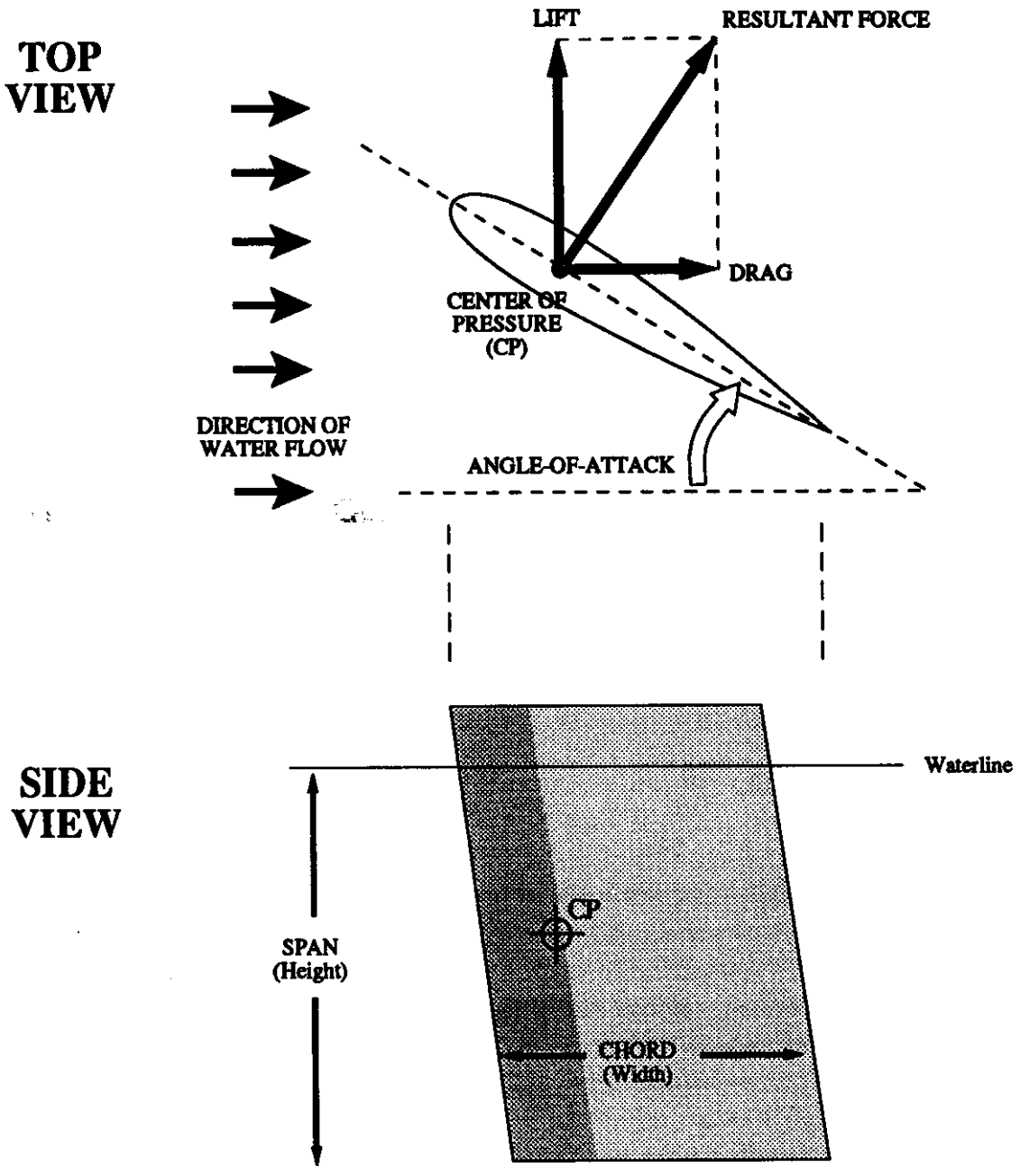

Figure 4.1 A diagram showing a basic foil-shaped rudder and the forces which act upon it. The aspect ratio of a rudder is the *span* divided by the *chord*. For irregularly shaped rudders, the mean span and mean chord are used. The aspect ratio affects the amount of lift a given surface area of rudder developes and the critical angle of the rudder. The critical angle of a rudder is the angle-of-attack at which the smooth flow on the leeward side begins to break up and becomes turbulent. An effective rudder design maximizes lift and decreases drag so the resultant force is directed laterally as much as possible.

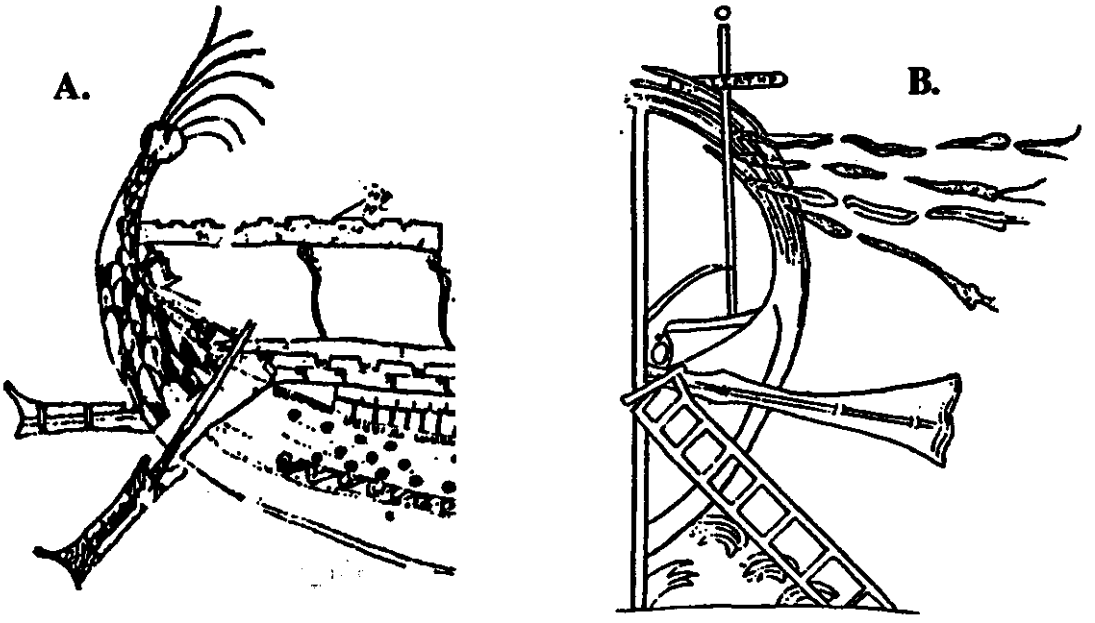

Figure 4.2 Greco-Roman rudders with reinforcemnet bands. **A.** A detail of a mid-3rd century B.C. fresco showing the stern of a galley (After Basch, 1987: fig. 1131). **B.** A early 3rd century B.C. depiction of a galley stern (After Basch, 1987: fig. 883). While there are no examples of Roman rudders using reinforcements, the employment of them by the Greeks, and their extensive use on rudders in the Middle Ages, suggests that Roman rudders probably used some form of exterior reinforcement.

shape was due in part to the construction technique of using a central shaft. While the Romans never used rudders with a thick foil cross-section, the advantages of this type of shape were not overlooked by the medieval shipwrights, as we will see later.

The choice of tiller arrangement appears to have been a matter of preference rather than one based on the size or type of ship. The simplest arrangement, with the tiller perpendicular to the blade, was used on rudders for both warships and merchantmen. This same arrangement has been used successfully on the *Olympias* where a single helmsman controls both rudders, except when the rudders have to be put hard over (Morrison, 1990: 53, fig. 29). The main advantage of this tiller positioning was that the tiller could be scarphed into the rudder shaft and there was no need for a tiller extension with a flexible joint.

The other position for the tiller was to place it parallel to the plane of the blade. This technique appears to have been common and is seen on a variety of craft (Figs. 2.2, 3.2 & 3.8). When Socrates speaks of moving the tiller "inward or outward", he probably has this tiller position in mind (Plato, *Alcibiades* 1.117C). When the tiller was placed parallel to the blade, either a tiller extension, similar to those used on modern yachts, had to be used or the helmsman had to stand next to or straddle the rudder shaft, as is done by *pinisi* pilots today. Roman iconography indicates that the former solution was preferred. In Figure 3.8A the tiller extension appears to be attached to the tiller by a simple cord.

In the ship representations, on the Nemi rudder, and on modern *pinisi* rudders, the tiller is not

perpendicular to the rudder shaft but angles upwards towards the rudder head at an angle of approximately 25 degrees from a perpendicular position. This placement kept the tiller close to vertical even when the rudder shaft was at a steep angle. This positioning is confirmed by the tiller slot in the Nemi rudder (Fig. 4.3), and this same tiller arrangement is still used today on *pinisi*. The advantage of this in conjunction with placing the tiller parallel to the blade was that the position of the helmsman was no longer restricted to an area close to the tiller heads. The vertical tillers allowed the helmsman to sit much higher and to sit farther aft, as can be seen in Figures 2.2 and 3.2. This positioning would give him a much better view of the ship and the sails.

Placing the tiller parallel to the blade had other advantages too. Probably the most important one is that the head of the tiller does not have to be as high as the caprail. The main effect of this is that the amount of rudder shaft above the upper mounting point can be reduced, or, if the tiller is placed between the two throughbeams, as on the *pinisi*, the rudder head can be at the same level as the upper throughbeam. Results from the model in Appendix II have shown that any part of the rudder shaft above the mount for the rudder acts as a counterbalance which causes the rudder blade to rise up. By decreasing or eliminating the shaft above the pivot, the rudder at equilibrium floats deeper than if it had the shaft extended to clear the ship's side. Furthermore, since the tiller is placed backwards directly over the shaft, the weight of the tiller moves the center of mass for the rudder towards the blade, causing the rudder to settle even lower than without the tiller. This tiller placement also allowed the rudder shaft to be placed in the side gallery when the rudder was raised without having to remove the tiller.

One factor which dramatically effects rudder performance in a variety of ways is the aspect ratio. The aspect ratio of a rudder is usually defined as the mean height, called the mean *span*, divided by the mean width, or mean *chord* (Fig. 4.1). Obviously, this definition only applies to the submerged portion of the blade. A rudder where the height is nearly equal to the width, so that the ratio approached 1, is considered a low-aspect-ratio rudder. Conversely, a rudder where the height-to-width ratio is greater than 2 is considered to be a high aspect ratio rudder. Because the depth of quarter-rudders could be adjusted, this meant that the aspect ratio changed as the rudder was pulled up or immersed deeper. As we will see, the aspect ratio of a quarter-rudder could dramatically effect its behavior.

In general, the rudders had nearly equal amounts of blade fore and aft of the shaft. The advantage of this was that the center-of-effort of the rudder was situated on or near the shaft. By "balancing" the rudder, the amount of effort required to turn it was negligible and could be easily handled by a man. The advantages of the design can be seen in the passage by Lucian (*Navigum* 6) where he writes: "And all of that {referring to the large merchantman, the *Isis*} one little old man just now brought through safely, turning the huge quarter-rudders with a fragile tiller." Another example comes from a rhetorical question by Aristotle (*Mechanica* 850b, problem 5) where he asks: "Why does the rudder, which is small and at the end of the ship, have so great a power that is able to move the huge mass of the ship, though it is moved by a small tiller and by the strength of but one man, and then without violent exertion?" From both these passages it is clear that the rudders were so constructed as to be nearly balanced when immersed so that little force was required to turn them under normal conditions.

It has been assumed by several authors that the Greco-Roman rudders were built perfectly balanced. However, votive rudders and large-scale reliefs showing the entire rudder indicate this was not the case. A close examination of Greco-Roman art shows that in fact they were actually semi-balanced, with the aft blade section having slightly more area than the forward one. In some cases the forward

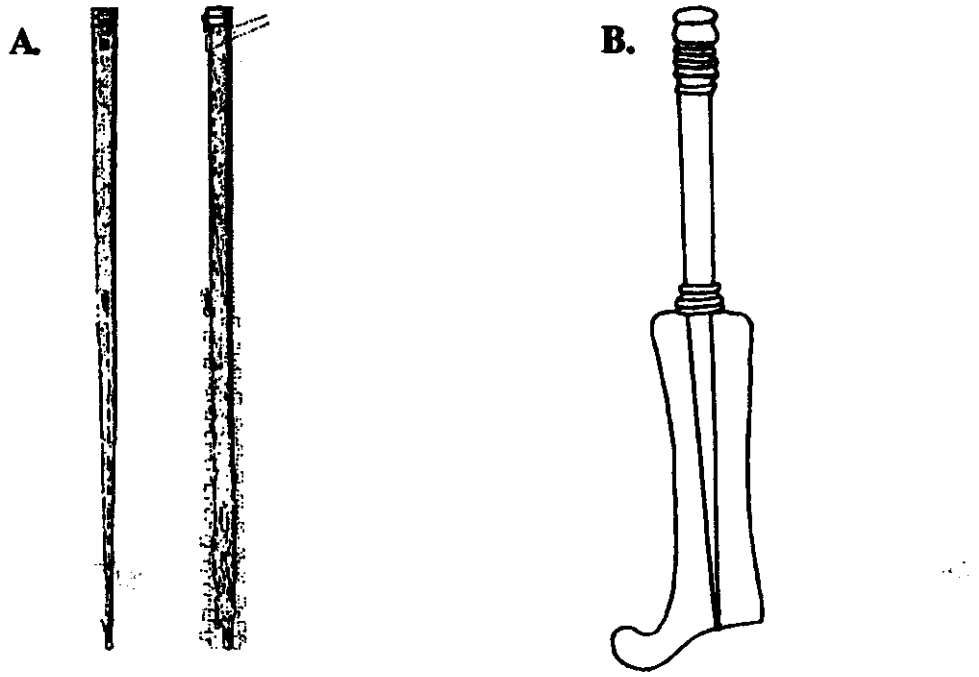

Figure 4.3 Two types of Greco-Roman rudder shafts. **A.** A drawing of the rudder from Caligula's barge found at Lake Nemi (After Ucelli, 1940: fig. 179). The tiller was placed parallel to the rudder blade as can be seen from the location of the tiller slot. The shaft is elliptical, with only the sections of the shaft which protrude from the surface of the blade being tapered. **B.** A drawing of a bronze votive quarter-rudder at Delos. The rudder has a conical shaft, which tapers equally on all sides towards the sole of the rudder.

blade area was uniformly narrower along the length of the blade, while on others a curved extension has been added to the aft blade tip. This extension, or "heel", is also found on Viking rudders. Experiments with Norse rudders has shown that the heel projection, causing the rudder to trail when left to itself, also causes the vortex created by aeration from the surface to be displaced aft of the blade, thereby decreasing drag and increasing rudder lift (Andersen, 1986: 216).

The reason for having a slightly unbalanced blade was to equalize the submerged blade area. For a quarter-rudder with equal amounts of blade on either side of the shaft, the natural stable position for it is at a rudder angle of 90 degrees! The reason for this is that when the rudder is placed at an angle in the water the amount of submerged area forward of the shaft is substantially greater than the amount aft. Under low flow conditions, the buoyancy of the forward section would be greater than the aft, causing the rudder to turn to a position where equal amounts of blade were submerged which occurs at an angle of 90 degrees. Under high flow conditions the problem is the same. Once the rudder was turned even slightly, the forward section would generate more force again causing the rudder to rotate 90 degrees to a neutral position. For these reasons the rudders were slightly unbalanced so that unattended the rudder would stay at a neutral position of 0 degrees under a wide range of flow conditions.

Obviously, someone building a rudder would have to weigh the need of having the rudder "balanced" so it could be easily turned against the necessity of having it slightly "unbalanced" so that it

naturally rested in a neutral position. Further complicating the deliberations would be the fact that as a rudder is turned the center of effort moves aft on the blade. The amount of displacement is higher on blades with a low aspect ratio. A rudder would have to be constructed to accommodate this drift of the center of effort so that it would be managable through a wide range of angles. If the rudder was built too unbalanced then at large rudder angles the rudder could become difficult to turn, while if too "balanced" the rudder would be unstable at the neutral position.

Another factor which had to be dealt with was that of the aspect ratio of the submerged section of the rudder. Modern research has shown that the aspect ratio of a rudder can dramatically effect its performance (Rossell, 1942: 203-4; Saunders, 1957: 709-10; Gillmer, 1982: 276-7). For rudders with equal areas, the rudder with a higher aspect ratio will develop the same amount of lift as one with a lower ratio at a lower angle of attack. While high-aspect-ratio rudders develop full lift at lower rudder angles, they also stall much earlier than rudders with a low aspect ratio. Because the flow conditions in the open sea are not constant or uniform, a rudder with a very high aspect ratio would stall at very low rudder angles. This situation occurs on some modern *pinisi* which have rudders with aspect ratios of over 6, causing them to stall at low rudder angles. This is probably why they are only used for fine control of these ships (Horridge, 1979: 32). In making the rudder, a decision would have to be made as to exactly how much of the blade was to be submerged, and then as to what proportions it should have so that the critical angle for the rudder would not be too shallow or too large. Based on the iconography and votive rudders, it appears that the aspect ratio for the submerged section of the typical Greco-Roman rudder was between 1 and 2, which means the critical angle for the typical Greco-Roman rudder was probably between 25 and 30 degrees (Gillmer, 1982: fig. 14-4). Because the rudder penetrated the surface of the water, aeration down along the low pressure side of the blade would decrease the angle and amount of lift somewhat. Turbulence caused by water flowing around the protruding shaft would also degrade the critical angle and lift.

While the quarter-rudder system might appear to be primitive, in fact it has several advantages over a sternpost-mounted rudder. In a sense they are still used today in the form of flanking rudders, which are no more than submerged quarter-rudders. Centuries ago it was recognized that quarter-rudders, being placed on the quarter of the ship outside the wake, had the advantage of being in a zone of relatively uniform flow which would increase their hydrodynamic performance (Vossius, 1685: 133-34; Charnock, 1801: 102-04, 367-68). Another advantage was that the use of two rudders provided an extraordinary amount of rudder moment which would greatly enhance a vessel's ability to rapidly maneuver in tight quarters. This would be particularly useful for large merchantmen in entering a harbor or a narrow passage. By using two rudders the quarter-rudder system permitted the use of rudders with reduced weight and size to achieve the same amount of rudder moment as could a much larger and heavier single rudder (Saunders, 1957: vol. I, 580). This latter advantage was partially offset by the common Roman practice of using only one rudder at a time, which would necessitate that each rudder be sufficiently large enough to control the ship by itself. Quarter-rudders would also act to stabilize the vessel and prevent it from rolling, much like bilge strakes on modern vessels. Furthermore, it has been suggested that by simultaneously turning the rudders in opposite directions that they would form an effective system for rapidly breaking a ship's speed (J.R. Steffy, 1990: personal comm.).

Indonesian *pinisi*, like the Roman and early medieval ships, have round sterns which lack any deadwood. On the *pinisi*, the quarter-rudders act not only as control surface, but also serve the function as

the fin on a faired, hollow stern in that they prevent the vessel from yawing excessively, particularly downwind (Blair, 1987). Since quarter-rudders on ships lacking deadwood act as an extension of the keel, it has been suggested that by varying the depth of the rudder penetration the pivot point of the ship could be changed and balanced with the sail plan (Adam and Denoix, 1962: 100). It is doubtful that the rudders could still have been effective control surfaces if they were pulled up to the point where the trim of the vessel would be materially effected. Also, several of the mounting systems used would not lend themselves to this type of evolution. Saint-Denis (1934: 394-95) has gone as far to suggest that this method was actually used for steering. As with the above suggestion, varying the rudder depth would not provide enough force to change the pivot point enough to provide adequate steering, and several of the Roman systems would not allow the rudder to be rotated up and down to vary the depth, as he has suggested.

While the use of quarter-rudders could materially affect the maneuverability of a ship, aspects inherent in the design could cause a significant decrease in a ship's maximum speed. The main cause of the loss of speed was the large amount of pressure drag induced by a quarter-rudder being placed away from the hull in a free flow of water (Fig. 4.4). If two quarter-rudders were in the water, then the induced drag would be doubled. The ancients used several methods to try and deal with this major problem. Trials on the *Olympias* have shown that the main source of drag caused by the rudder comes from the shaft and not the blade. Coates (1990: Appendix IV) has estimated that fairing the shaft could decrease resistance by up to one half. The resistance is probably due to turbulence induced by the protruding shaft which in turn would increase the tip vortices and drag. This turbulence would also adversely effect the lift of the rudder. The obvious solution was to taper the shaft so that it was faired into the blade. However, tapering would weaken the shaft, so that there was a certain trade-off between reducing drag and still maintaining sufficient strength in the shaft. This problem has been encountered in designing quarter-rudders for the *Olympias* (Coates, 1990: Appendix IV).

The earliest technique used to decrease shaft thickness was to simply symmetrically taper the shaft towards the rudder sole so that the lower half of the shaft formed a cone. This technique was commonly used by the Greeks and can be found in a number of depictions and models (Fig. 4.3). The main drawback to symmetrically tapering the shaft is that it significantly weakens as the tip of the rudder is approached. An alternate solution was to taper the sections of the shaft outside the plane of the blade (Figs. 3.15 & 4.3). By doing so the shaft maintained its thickness in the fore-and-aft direction, while the amount of shaft protruding from the blade surface was reduced. This design would not weaken a shaft nearly as much as the conical design, and it would significantly decrease the shaft profile with regard to the water flow.

Another method of decreasing drag caused by the quarter-rudders was simply to pull one of them out of the water. This practice was very common during the Roman period and can be traced back to at least the 6th century B.C. (Casson, 1971: fig. 73). Numerous representations show that the practice of using only one rudder at a time was common for both galleys and sailing ships (Figs. 3.2, 3.15, 4.2 & 4.5). The effectiveness of just one rudder is noted by Lucretius (4.903-4) when he comments that "one hand controls [a huge ship], no matter how great its speed, and a single rudder turns it in any direction." In the case of sailing vessels the leeward rudder was probably left down since heeling of the ship in the wind would keep it immersed, while the weather rudder would tend to be pulled out of the water. In order to reduce drag even further the ancient mariners probably pulled up the rudder in use as far as possible, leaving in the water only the minimal amount of rudder blade necessary for control. It is apparent that the

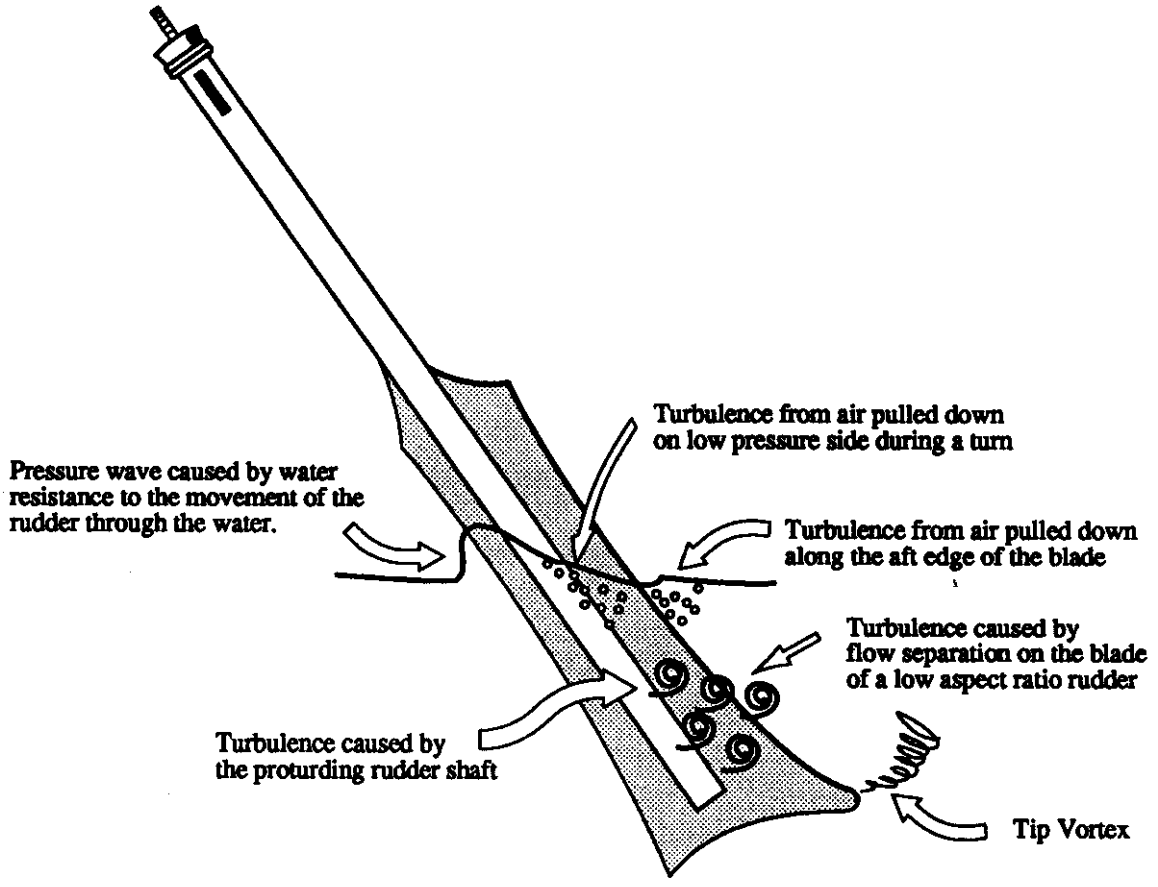

Figure 4.4 A diagram of a quarter-rudder showing the sources of drag and turbulence, which degrade a rudder's performance. By far the greatest source of drag is the water resistance to pulling the rudder through the water.

braced mount was by far the best system for either of these practices, which probably explains its wide use.

Another advantage of periodically pulling one or both of the rudders out of the water was that they could partially dry out. The benefit of this was that it prevented the rudders from absorbing large quantities of water and thereby substantially increasing in weight. Work on water absorption by planking shows that water absorption occurs at a very high rate and can significantly increase the specific gravity of wood (Peck, 1963: 7-9, figs. 4-7). In the case of white southern pine heartwood exposed to saltwater for 50 days, the specific gravity of the wood went from 0.65 to 0.88. Results for white oak were less dramatic but still significant, showing a change from 0.76 to 0.89. The tests were for ship planking, so only one side was exposed to water. In a case of total immersion several surfaces would be exposed, including the end-grain, which would greatly increase the rate of water absorption.

Once again, the issue is a matter of scale. For a small rudder only a few meters long the weight increase would have been relatively small. However, when considering the rudders on large merchantmen the problem of weight increase becomes a major issue. Using the southern pine results as a guide, we see that for a rudder the size of the Nemi quarter-rudder, the blade alone would have increased in weight by

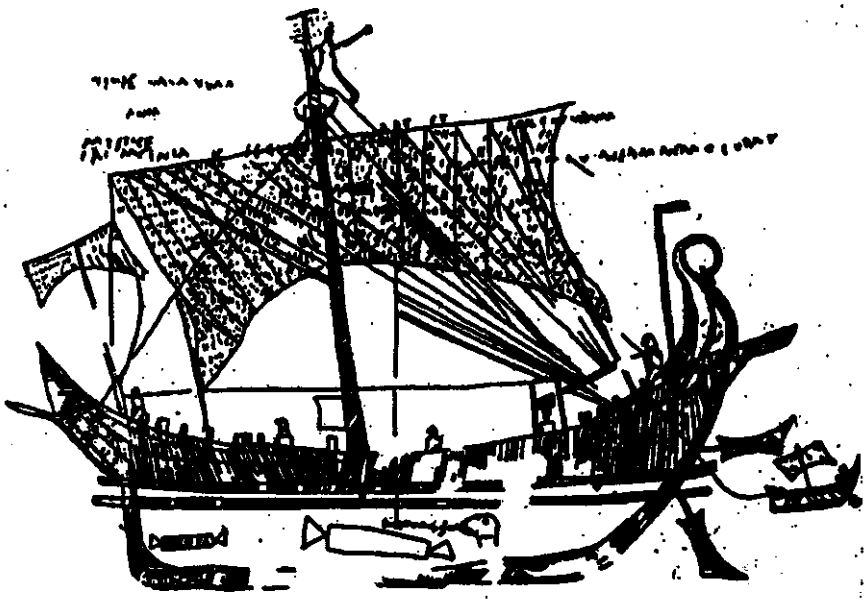

Figure 4.5 A 1st century A.D. graffito from Pompeii of a large merchantship underway. The ship is using only one rudder to steer with, while the other is raised (After van Doorninck, 1972: 72).

approximately half a metric ton. Since some voyages lasted over 65 days, the weight increase could have been substantial, even assuming a low rate of absorption. The water absorbed by the rudder would have caused a decrease in the buoyancy of the rudder initially, but after some absorption it would not have materially effected the displacement of the vessel while submerged since the water absorbed would have had the same density as the water around it. As long as the rudder was immersed, there would have been no noticable effects. However, once raised out of the water the increase in weight could have caused noticeable difficulties not only in handling the rudder, but also in ship handling. Put another way, hanging an extra half a ton or more off the stern quarter of a Roman ship would not have been likely to improve its sailing characteristics.

Alternately pulling one rudder out would also decrease wear and damage to the rudders (J.R. Steffy, 1990: personal comm.). Not only would it decrease damage to the leading edge of the rudder from floating debris, but it would also decrease erosion of the trailing edge caused by cavitation. The pitting associated with cavitation can be clearly seen on the trailing edge of modern *pinisi* quarter-rudders (Blair, 1987). The reduction of wear on the rudder, along with keeping the weight down and decreasing drag, are compelling reasons why, under normal cruising conditions, the Romans used only one rudder at a time. The rudders were probably changed on every tack, though on a long downwind run the rudders may well have been alternated without waiting to jibe the ship.

Rudders in the Classical and Roman periods appear to have been made under the direction of the helmsman: "The work of the carpenter, then, is to make a rudder under the supervision of the helmsman, if the rudder is to be a good one" (Plato, *Cratylus* 390D). As we have seen, in building a quarter-rudder the helmsman had to juggle a number of factors. First, he had to decide what size of shaft was needed, and what the overall dimensions of the rudder should be. If he decided to taper the shaft, he would have

to decide not only the shape, conical or elliptical, but also the degree of taper so that the shaft remained strong enough to withstand the rudder torque. He then had to decide on the shape of the blade, its size, and its positioning around the shaft. That building a workable quarter-rudder required no small amount of expertise is evidenced by the problems encountered on modern replicas. As previously mentioned, the problems encountered by the *Olympias* in regards to the rudder shaft shows that to taper the shaft correctly required a certain amount of skill and experience. The same can be said concerning the rudder shape. Tim Severin noted that the rudders they designed for the *Argo* were inefficient and prone to stall at low rudder angles (Mudie, 1986: 53).

The above is not to suggest that the ancients had advanced knowledge concerning hydrodynamics. The works of Aristotle and Vitruvius demonstrate they did not fully comprehend how a rudder works. However, all of the factors which have been discussed can be properly deduced and applied by employing simple empirical observation. Because the helmsman supervised rudder construction, the effects of any changes he made in the design would have been immediately apparent to him when the rudders were actually used. As the helmsman had to live with his creations, and would have been responsible to the ship's captain for their performance, there would have been a strong incentive to experiment until a utile design was arrived at. Changes in shape and placement of the blade would have been readily apparent not only in the handling of the rudder, but also visually, since the helmsman simply had to look over the side to see the effect the blade and shaft shapes had on turbulence and water flow. The effects of drag would also have been very apparent. Sailors quickly develop a fine sense for speed and distance over water, and changes in speed of only a half a knot become immediately noticeable. Obviously, the considerable drag induced by putting a quarter-rudder in the water would be immediately noticed. Likewise, the existence of tapered shafts from the Classical period onwards is proof that the ancients were well aware of the degradation in rudder performance and of the ship's speed that could be caused by shaft-induced drag and turbulence.

Because the rudder could have such a noticeable impact on a ship's performance, it seems likely there would have been ongoing experimentation in rudder design. Certainly the ability to directly observe the impact of any changes in rudder configuration facilitated experimentation, and the dramatic changes that occurred in quarter-rudder design during the Middle Ages demonstrates that shipwrights of the period were not as tradition bound as some believe. To the contrary, quarter-rudders during the Medieval period evolved to the point where the ultimate designs were radically different from their predecessors.

CHAPTER V
BUILDING THE BETTER MOUSE TRAP

The period between the 6th and 11th centuries is virtually barren regarding information concerning quarter-rudders. Because of the decline of civilization in the West and the iconoclastic emperors of the East there are few reliable representations of Mediterranean vessels from that time, and written references to ship construction and rudders are virually non-existent. All of this is particularly unfortunate since during those 500 years both mounting systems and rudder design changed radically. The change in rudder design was dramatic. The Greco-Roman rudder barely survived into the 13th century, and while the changes in the rudder mounts were evolutionary, not revolutionary, they were still a definite break with the Roman tradition. Why these changes occurred can only be guessed at, since we are confronted with the accomplished fact and lack any data concerning the technological or social developments which caused the adoption of the new techniques.

The changes which occurred may be part of the overall trend in ship construction during this period. The wider adoption of the lateen rig and the appearance of frame-first construction certainly indicate that the shipwrights and ship owners were willing to experiment with new techniques, especially if they were profitable. The changes in the rudder and mounting systems had to have been a result of both the change in the ship design brought on by the massive geopolitical upheaval in the Mediterranean, and the desire to improve existing systems. The political turbulence and lack of stability in the Mediterranean would have been significant stimuli for the search for improved construction techniques. While some knowledge may have been lost in the Latin West, the Roman traditions carried on uninterrupted in the Byzantine Empire, making it difficult to argue that the new designs appeared simply because the shipwrights had lost contact with the previous tradition. The changes in the quarter-rudder were the result of the pressure on shipwrights to build better vessels within the political and technological constraints of the time. The response was not to make a technological leap so much as to build the better mouse trap by improving tried and true techniques.

One of the more dramatic changes in quarter-rudder technology during the medieval period was the adoption of the high-aspect-ratio, foil-shaped rudder. The shift to this rudder design represented a major departure from the Roman philosophy of using a balanced rudder. Instead of a large rectangular blade which extended above the water, the new design had a narrow paddle-shaped or triangular blade which was almost entirely submerged. Moreover, in nearly all the medieval examples most of the blade area is placed aft of the shaft, meaning the rudder was intentionally unbalanced (Fig. 5.1). At first glance, these changes in rudder shape and blade placement would appear to be detrimental to the performance of the rudder, but in fact they represent a major breakthrough.

The Greco-Roman rudder design had served well for hundreds of years but had several design flaws which decreased its effectiveness. The use of a balanced rudder necessitated placing part of the blade forward of the rudder shaft. As previously noted, this meant that the shaft would protrude from the surface of the blade, causing turbulence which in turn would interfere with the rudder's lift. This turbulence also created drag which could seriously affect the speed of a ship. The Greco-Roman design prevented the blade from being shaped into a true foil form since the blade surface was broken by the protrusion of the shaft. Votive rudders indicate that the Greco-Roman rudder had been essentially what

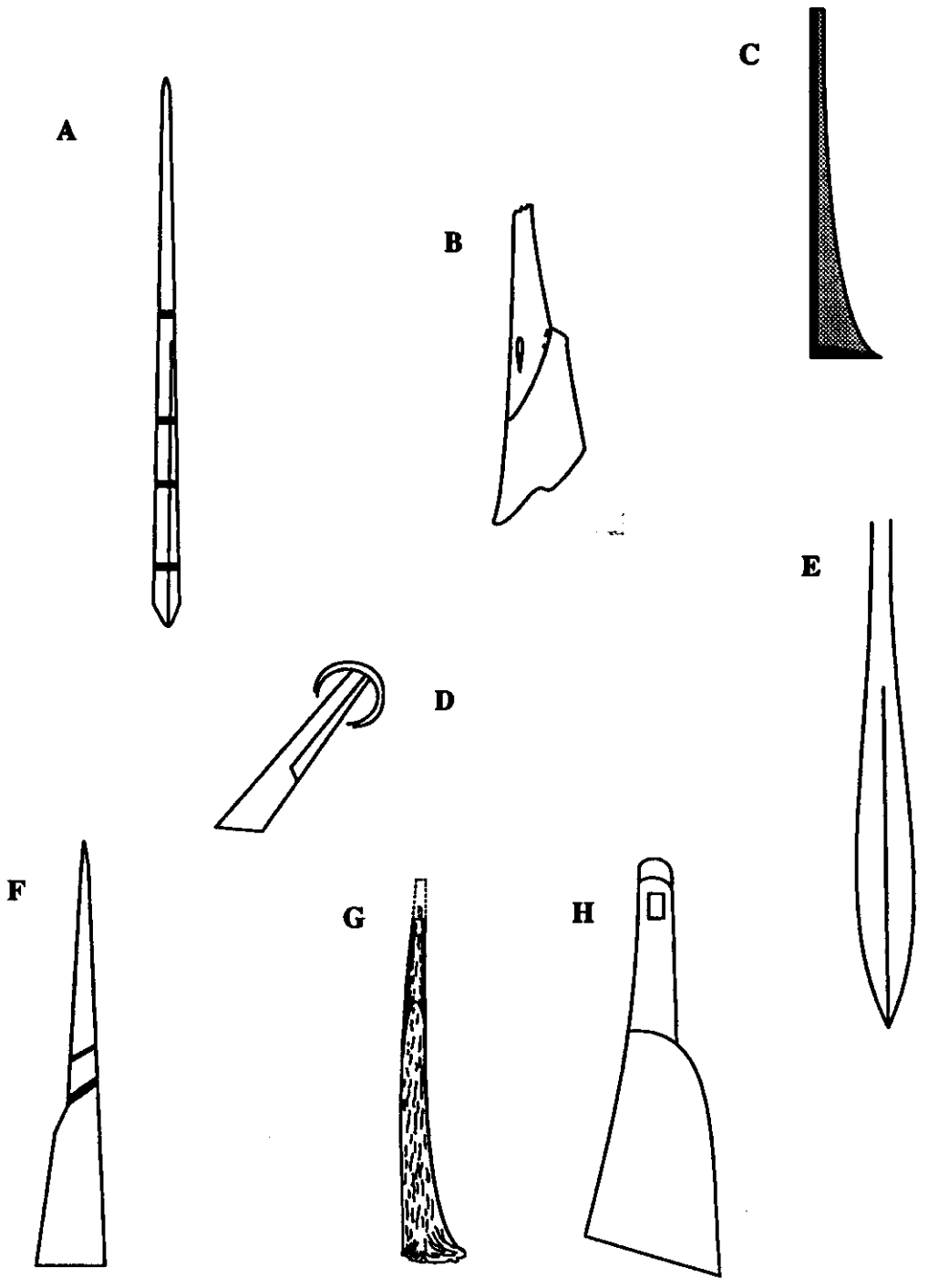

Figure 5.1 A comparison of different medieval rudder designs. **A.** A 12th century ship depiction in the Pala d'Oro. **B.** Venician manuscript (MS Gr. 17) at the Moriana Library, dated 1295. **C.** A 12th century mosaic at the church of San Marcos, Venice. **D.** The *Lapiderio* at El Escorial, dated 1260. **E.** *Publio Virgilio Maroon* (MS 768) at the University of Valencia, dated 1450. **F.** A 14th century fresco by Andrea da Firenze at in Santa Maria Novella, Florence. **G.** A 14th century rudder found off Rye (After Marsden, 1990). **H.** *Fabricca di galere*, dated to circa 1400.

would be called today a single-plate rudder since the blade was of uniform thickness across its entire width. By placing the blade aft of the shaft, the shaft of the medieval rudder could be tapered and faired into the blade so that a true foil shape was presented to the flow of water. The effect of this change alone would have been dramatic. The most important result of going to a foil design from the Roman plate configuration is that substantially more rudder force is generated while drag is significantly decreased (Rossell, 1942: v.II, 204-06: Gillmer, 1982: 277).

The change to a foil section also brought other advantages. As a rudder is turned, the flow around the rudder blade becomes disrupted causing turbulent flow to occur somewhere on the aft portion of the blade (Fig. 5.2). Any blade area effected by this turbulence is unable to provide lift for turning. The placing of the shaft forward of the blade meant that the leading edge of the rudder was somewhat blunt and thick compared to the thin leading edge of a Greco-Roman blade. Research has shown that rudders which have a blunt nose have cavitation and turbulence delayed on the leeward side during turning so that they occur much further aft on the blade. This means more area of the blade is availible to provide lift, thus effectively increasing the critical angle of the rudder and the amount of turning moment. The exact opposite is true for rudders with thin leading edges, like the Greco-Roman rudders, where the turbulence tends to form farther forward on the blade (Saunders, 1957: v.I, 539, 574). Another advantage of relatively thick foil sections is that the travel of the center of pressure aft on the blade is much smaller, compared to that for relatively thin sections (Rossell, 1942: v. II, 207). As the medieval rudders were semi-balanced at best, this last characteristic of foil behavior would have materially helped in suppressing unmanageable rudder torques as the critical rudder angle was approached. The change to a foil shape can be seen in medieval iconography (Fig. 5.1 B &C) and on a quarter-rudder retrieved off Rye, England (Fig. 5.1 G).

One problem with a fully streamlined rudder, which has a blunt nose and a blade which tapers aft to an edge, is that only a small amount of lift is generated at small rudder angles. Sometimes the amount of force generated at low rudder angles is too small for adequate steering, particularly where the speed of advance is slow and the rudder area is not large. The reason for this is that the sides of a tapered blade angle inwards towards the aft edge so that even after the rudder is put over a few degrees the leeward side is still roughly parallel to the flow and thus is deflecting little or no water. However, a way to increase lift at small rudder angles is to have the rudder sides at the aft edge of the blade be either parallel or slightly divergent. In these cases, the slightest movement of the rudder causes the water to be deflected because the blade sides are already parallel to the flow. While this technique slightly increases drag, it substantially increases lift at small rudder angles. Modern tugs and race boats make use of both of these phenomena by using rudders with either blunt or splayed tails (Saunders, 1957: v.I, 585).

A rudder with nearly parallel sides usually has a blunt trailing edge which creates an additonal advantage. A blunt trailing edge decreases drag during a turn. Sailing ships in the 18th and 19th centuries took advantage of this phenomena by putting a groove in the aft edge of their rudders to increase aeration at the separation zone and thereby decrease flow separation drag (Saunders, 1957: v. I, 585). Work with replicas of Norse rudders has confirmed this behavior (Andersen, 1986: 219). A survey of existing medieval quarter-rudders shows that shipwrights apparently were aware of this characteristic, and used it. Virtually all of the excavated rudders which used the Norse mounting method have a blunt trailing edge (Åkerlund, 1965: 256-57; Crumlin-Pedersen, 1966: 252-254; Dammann, 1983: pl. 6; Christensen, 1985: 154-55; Hutchinson, 1986: 220; McGrail, 1987: 249). The Rye quarter-rudder, which appears to have

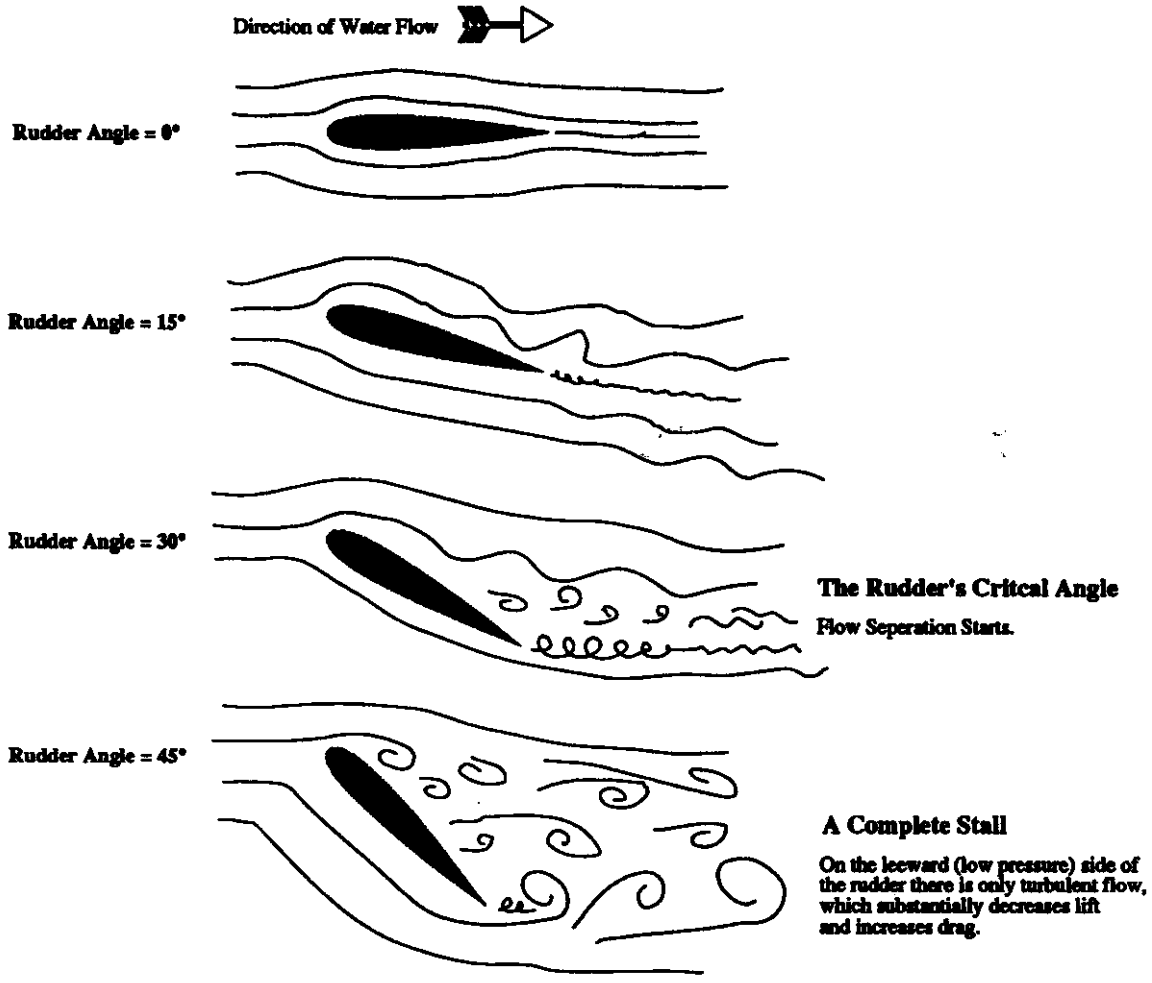

Figure 5.2 A diagram of the flow around a rudder as it is turned. The progression of a stall can be seen as the rudder angle, the *angle-of-attack*, approaches and then passes the rudder's critical angle. The above rudder is foil-shaped with a blunt nose. If the rudder was a single-plate rudder, as were the Greco-Roman rudders, then the stall would progress more rapidly and decrease the rudder's critcal angle. A foil shape delays the start of flow seperation thereby increasing the critical angle. A foil shape also generates more lift and creates less drag (After Gillmer, 1982: 276).

been mounted without using a withy hole, also has a blunt tail (Marsden, 1990).

It has been suggested that the trailing edge of these rudders had another piece of wood which fitted against the flat of the tail and the heel projection to give a thin streamlined aft edge (Salisbury, 1965: 360). Certainly the Zwammerdam steering oar and Bryggen rudder #91446 appear to support this contention. However, in both cases the second piece of wood appears to be a later addition and not an original part of the rudders (de Weerd, 1978: 17-18; Christensen, 1985: 154). Whether or not shipwrights in the Mediterranean employed a flat trailing edge is unknown, but the fact that northern ships were in the Mediterranean from at least the First Crusade onwards makes it likely they were probably aware of this design attribute.

The most significant change in regards to actual rudder construction came with the introduction of the high-aspect-ratio rudder. The rudder blades adopted tended to be in the shape of an acute triangle or that of an elongated ellipse with part of the blade actually forward of the axis of the shaft (Fig. 5.1 A & E). The elliptical-shaped blade would have allowed the rudder to have been balanced, but would have hindered the use of an efficient foil shape and the advantages it entailed. This may be the reason that, of the two shapes, the triangular configuration appears much more frequently in the iconography. Some representations of medieval triangular rudders have a small section of the blade forward of the shaft axis near the base of the blade in an attempt to make the rudders semi-balanced (Fig. 5.1 B & H). The narrow blade widths of both designs meant that the rudder could be placed close to the hull without the blade hitting it during a hard turn. This was particularly true for the triangular design whose blade would be actually behind the rise of the stern, and so the blade could actually be turned so it was under the ship's counter.

At first glance, it would appear that adopting a rudder configuration with a high aspect ratio would entail unacceptable penalties. Using the new configuration, the rudders would have been unbalanced and would seem to have a decreased rudder area. Yet the advantages the new design brought in terms of performance and rudder construction would have far outweighed the disadvantages. The large blade of the Greco-Roman design created substantial drag, which was a major problem with quarter-rudders. There can be little doubt that the drag induced by the quarter-rudders on a large ship materially impeded the ship's speed. Also, induced flow separation created during a turn tends to form on the blade of low-aspect-ratio rudders, whereas on high-aspect-ratio blades the eddying is delayed to an area behind the blade, thereby increasing lift and decreasing drag (Fig. 5.2; Gillmer, 1982: 276).

The new design reduced drag even further by decreasing the amount of rudder at the critical water-air interface. One major problem with any rudder configuration where the rudder actually penetrates the surface of the water is aeration. As the rudder passes through the water, air tends to get sucked down along the surface of the blade, causing substantial turbulence and drag (Fig. 4.4). Furthermore, this tendency for air leakage down along the blade surface is increased when the helm is put over, particularly on the low pressure side. This can destroy much of the rudder's lift (Rossell, 1942: v.II, 211; Saunders, 1957: v.I, 331; Gillmer, 1982: 279).

The design of the Greco-Roman rudders actually exacerbated the problem of aeration. The wide blades, with their protruding looms, were designs which virtually maximized the aeration effect. The advantage of the high aspect ratio rudders was that the amount of rudder at the air-water interface could be substantially decreased to the point where only the shaft broke the surface. The triangular blade configuration was best suited to take advantage of this. It allowed for a large blade area underwater and

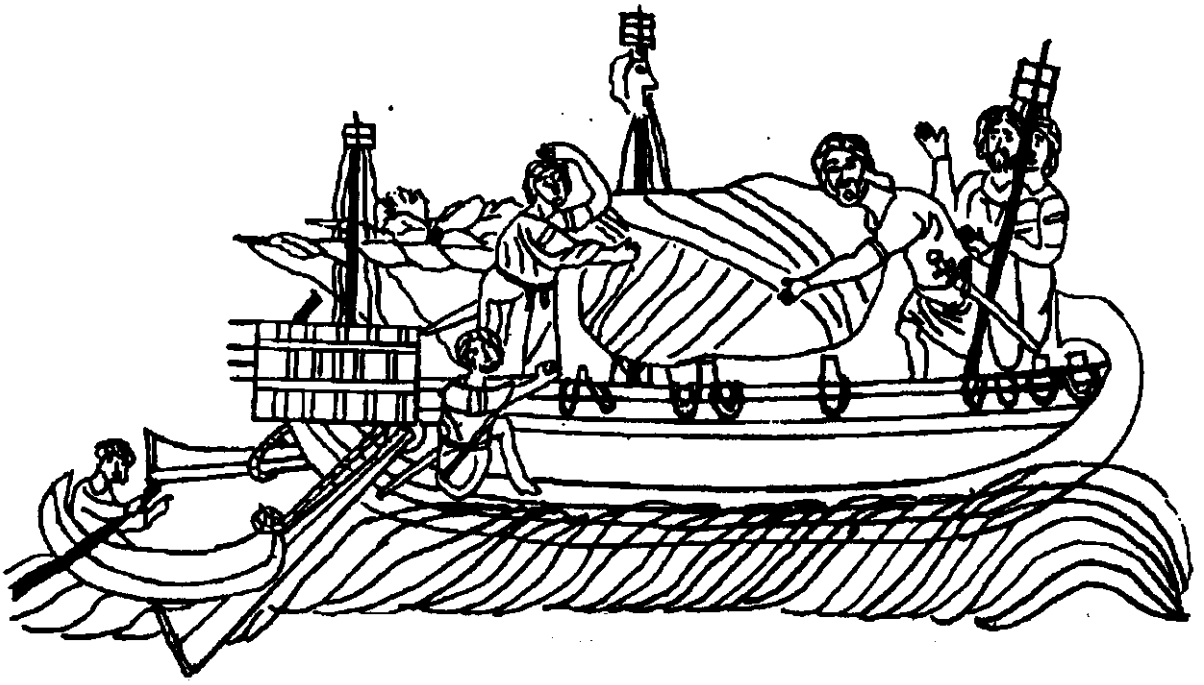

Figure 5.3 A 12th century A.D. mosaic at the church of San Marco, Venice. The ship has through-hull rudder mounts, and has one rudder raised. The mosaic shows the triangular, foil shape typical of medieval rudders (After Demus, 1984: fig. 65)

the use of a foil shape, while permitting the blade to be narrow at the surface. This practice of tapering the rudder upwards to prevent aeration is still practiced today (Saunders, 1957: v.I, 331, 574). The actual adoption of this design appears to have started in the Roman period. Two vessels depicted in a 3rd century A.D. relief (Casson, 1972: fig. 184) have triangular rudders that take advantage of narrowing the blade upwards, but the Greco-Roman method of attaching blades to the forward and aft sides of a central shaft is still adhered to.

The use of a foil-shaped blade in combination with a tapered blade probably resulted in an increase in rudder performance which more than compensated for the loss of rudder area. These design techniques in turn practically necessitated the adoption of the high-aspect-ratio rudder. Because the medieval rudders were essentially unbalanced, wide blades would have been unmanageable on large ships. Fortunately for the medieval helmsman, one attribute of aspect ratio in relation to a rudder is that the center of pressure moves forward on the blade as the aspect ratio increases. In general, the center of pressure is located one quarter chord from the leading edge of a rudder (Rossell, 1942: v.II, 207). The *pinisi* of Indonesia take advantage of this phenomena by carrying very high-aspect-ratio rudders which have the center of pressure located in line with the shaft. As these rudders are used to control ships with an average burden of 150 tons, the *pinisi* are modern proof that a balanced quarter-rudder is not required to control large vessels.

As mentioned in Chapter IV, the Roman rudders were essentially low-aspect-ratio rudders. The advantage was that the rudders did not stall until relatively large rudder angles were reached, and that with more overall blade area in the water more rudder force could be generated. If medieval sailors did

not extend the rudders below the keel, then to use high aspect ratio rudders would have necessitated a decrease in rudder area, and therefore a decrease in rudder force. It is possible that the decrease in overall rudder area required both rudders to be used at the same time, instead of alternately as was the Roman practice. Of all the medieval iconography I have seen there is no example of a ship with only quarter-rudders which has one of the rudders pulled up while underway. This may be due to a general need to have both rudders in the water to maneuver, as well as to the fact that several medieval mounting practices prevented it.

Arguing against the proposition that the medieval rudders did not extend below the hull are numerous ship representations where the quarter-rudders project far below the hull, similar to the practice on modern *pinisi* (Fig. 5.3). By extending the rudder deeper the medieval sailors could keep the same amount of rudder area while increasing the aspect ratio. Experimental results have shown that for rudders with the same area, the high-aspect-ratio rudder will develop more lift and have a lower drag coefficient than the rudder with a low aspect ratio (Rossell, 1942: v.II, 206). Much of the increased performance is due to delaying flow separation, and the turbulence associated with it, to a region behind the blade. Based on the iconography it would seem that, at the very least, some medieval shipwrights took advantage of this effect by extending the rudders below the keel. If this was the case then there would have been no need to use both rudders, while there would have been a strong incentive to pull one rudder up for the same reasons the Romans did. Pryor (1987: VII, 283) has speculated that the windward rudder was pulled up vertically, but at present there is no evidence in regards to this contention.

The exception to the use of high-aspect-ratio rudders were the auxiliary quarter-rudders used on a variety of ships during the 14th and 15th centuries. These rudders had wide, low-aspect-ratio blades, but still retained the triangular blade and foil shape so as to reduce drag. In some cases the blade widths are one half the length of the shaft (Fig. 5.1 H). As will be discussed in Chapter VIII, these rudders were primarily used in situations which required maximum control or maneuverability and were normally stowed until needed. The purpose of the low-aspect-ratio blades was to obtain the maximum amount of turning moment by putting the largest amount of blade area possible in the water. As the rudders from *Fabrica di galere* show, the forward edge of the blade was curved forward in an effort to compensate for the large rudder area aft of the shaft (Fig. 5.1 B & H). It is also possible that this design was preferred because the actual amount of space necessary for stowing the rudder was less than for a long, high-aspect-ratio rudder. This seems to be supported by the iconography. The low aspect ratio blades appear to be limited to small vessels, or ships with low freeboard, such as galleys, while larger ships carried the longer, high-aspect-ratio rudders.

All of the advantages of a deep, high-aspect-ratio rudder coupled with the introduction of a true foil shape would seem to be more than adequate to explain their use in preference to the old Greco-Roman design. But the new rudder design also entailed benefits in regards to the actual fabrication of quarter-rudders. One main advantage was that relatively large rudders, such as the Rye quarter-rudder, could be fabricated from a single tree. Besides simplifying rudder construction, such a rudder would be inherently stronger. Even larger rudders which required fabrication from several parts would have benefited. The Greco-Roman construction technique made it necessary to perforate the shaft on both the forward and aft sides; this would have substantially weakened the shaft. Since only the aft side of the shaft of medieval rudders had to be tampered with, the shaft remained more intact and therefore stronger. Furthermore, the high-aspect-ratio blade probably needed fewer pieces for its fabrication.

The material used for quarter-rudder construction seems to have been a regional or local preference, as there is a wide variation in the material actually used. The wood specified for rudder construction in Catalan contracts includes oak, holly, or elm, while contracts from Italian cities specify oak or walnut (Madurell y Marimòn, 1968: 186, 189; Lane, 1934: 218; Pryor, 1987: chap. VII, 292 n.70). All of the northern quarter-rudders, including the Rye rudder, were made of oak. Mediterranean quarter-rudders made extensive use of iron reinforcement. In some cases the iron was placed as horizontal bands around the blade, while in other cases an iron strap appears to have been wound around the blade in a spiral fashion (Fig. 5.1 F). In contrast to the Greco-Roman practice, the tillers appear to have been always placed perpendicular to the plane of the blades. There is is no evidence that the Roman practice of placing the tiller parallel to the plane of the blade survived into medieval times. Whether or not this happened because the mounting techniques changed is unknown. However, parallel tiller placement in the past was most commonly used with the Roman braced mount, and it may have gone out of use along with the braced mount.

Another change was that the construction of rudders appears to have been taken over by the shipwrights, and in the case of large facilities, such as the Arsenal at Venice, construction was undertaken by the foreman assigned to make masts and spars (Lane, 1934: 160). In some cases the rudders appear to have been fabricated at a one location and then transported to another (Appendix III: 6 & 7). In one 13th century contract the rudders were made in Marseille and then transported to Genoa (Blancard, 1885: v.II, 66). Another contract dated 1234 gives the dimensions of two rudders to be constructed and transported to Marseille, or at least as far as Arles (Blancard, 1885: v.II, 134). This last contract is important for several reasons. Not only does it stipulate the length and shaft diameter of the rudder, it specifies what the diameter should be where the shaft is to be fitted to the *luctatorio*, or lower mounting point. Since the rudders are being made in one location and transported to another, they could not have been made under the supervision of the shipwright constructing or refitting the ship. Because the blade width was not mentioned, it has to be assumed that there was a standardized formula dictating blade width for a given rudder length. More importantly, the contract implies that the position of the *luctatorio* on a ship was standardized. The contract demonstrates that by knowing the length of a rudder one knew by some formula exactly where the rudder mounts would be placed without having to be told. The contract shows that as early as the 13th century not only were there standardized formulas dictating rudder dimensions, but also formulas dictating the placement of rudder mounts on a ship for a given rudder length.

These two contracts also pose an interesting question. Why was it necessary to have such large objects as rudders built at one location and then shipped to another? It has generally been assumed that ships and their rudders were fabricated at the same yard. The two contracts show that this was obviously not always the case. If the issuse was simply one of having the proper lumber supply, then why were prefabricated rudders sent and not just the raw timbers? It would seem that it would be less expensive to buy the timber and fabricate the rudder at one's own shipyard than to pay someone else to do the work and then ship it. There is also the problem of transporting such large objects. In the case of the contract dated 1234 (Appendix III: 7), the rudder was nearly 16 meters long and weighed over 7 meteric tons. The problems and cost of transporting such an object must have been significant. At present, there is insufficient information to determine what was causing this trade in quarter-rudders, but the reason must have been compelling to create a trade in such large and cumbersome objects.

As to the actual proportions of the medieval quarter-rudder in the Mediterranean we have only

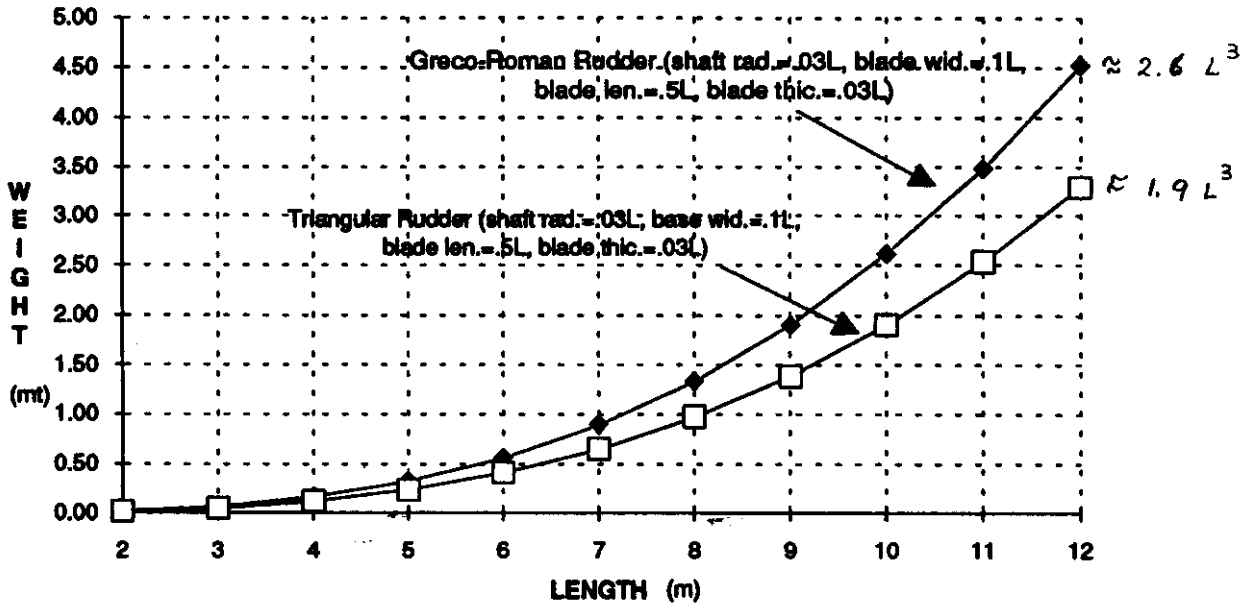

Figure 5.4 A chart comparing the weight of a Greco-Roman rudder versus a medieval triangular rudder.

the iconography and *Fabrica di galere* as examples. In most ship contracts, only the diameter, measured as the circumferance of the shaft, and the overall length are given (Appendix III: 1-15). Often, the contracts simply state that the rudders should be "good and sufficient" or "effective" (Appendix III: 5, 11, 14, 15). In *Fabrica di galere*, the proportion for the blade width for a *nave latina* is given as being one fifth that of the length of the rudder, and the height of the blade was set at one half the length of the shaft (Jal, 1840: v.2, 27, 92; Pryor, 1987: VII, 282). The medieval iconography tends to support these proportions, though as would be expected there is a certain amount of variation. The sole of the Mediterranean rudder usually was not perpendicular to the shaft, but angled downward at about thirty degrees, so that when the rudder was mounted at an angle the sole would be horizontal (Fig. 5.1 B, D & H). In regards to thickness, it is not known if the southern shipwrights followed the northern practice of tapering the rudder blades so that they decreased in thickness towards the rudder sole.

The medieval quarter-rudders of the Mediterranean attained considerable size in the 13th century. Construction contracts stipulate lengths up to 18 meters, and shaft diameters of over 70 centimeters (Appendix III: 2, 7). The weight of these rudders was considerable, and again the adoption of the high aspect ratio, triangular design played an important part. Consider two rudders, each 12 meters long, and identical in all respects except for the blade design. The rudder with the triangular shape would weigh approximately 25% less than the rudder with the Greco-Roman blade design. This is an important factor as the size increased, since the volume of the rudder increases exponentially with the linear increase in length (Fig. 5.4). The Rye quarter-rudder, which is only 6.7 meters long, still weighed nearly 1.5 metric tons even after it had dried out over a four year period (Marsden, 1990). A rudder constructed according to the stipulations in the above contracts must have weighed over 11 metric tons. The same

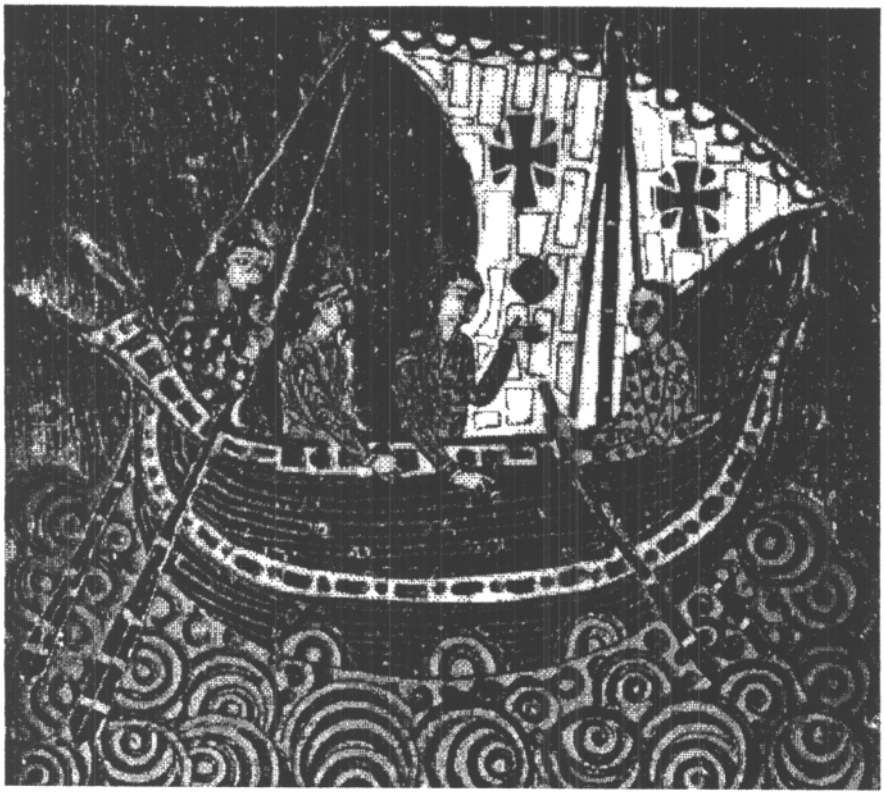

Figure 5.5 A 12th century mosaic in the Pala di Oro, in the Basilica of San Marco, Venice. The ship carries two quarter-rudders, and two bow sweeps to help it tack (photo: Alinari).

rudder with a Greco-Roman blade would have weighed close to 13 metric tons. Clearly, the new design was desirable if for nothing else than the decrease in the weight of the rudders.

Concerning actual rudder design, there are some minor but significant differences between the northern and southern traditions. Virtually all of the northern rudder examples, whether mounted with a withy as were Viking rudders or mounted following the southern tradition, have the foot of the rudder perpendicular to the shaft axis. Most excavated northern rudders also have a "heel", or projection, from the aft tip of the rudder. As mentioned in Chapter IV, besides making the rudder slightly under-balanced, the heel caused aeration turbulence to be displaced aft of the rudder. Interestingly, there are no representations from the Mediterranean of medieval rudders with this projection. This is somewhat curious since this design feature was common during the Classical and Roman periods. This is probably explained by the fact that Mediterranean rudders were inherently under-balanced and did not require it, whereas the Viking rudders, with the hole for withy near the center of the blade, were close to fully balanced.

Finally, some of the Viking rudders have asymmetrical foil shapes. Experimental work with Viking replicas indicates that it prevents the rudder from being sucked into the hull at high speeds (Andersen, 1986: 216). It has also been suggested that the airfoil shape created lift and thus turning moment opposite to that created by the drag of the one rudder on the starboard side (McGrail, 1987: 249). There is no evidence that Mediterranean shipwrights followed this practice, but based on the experimental evidence it would appear that there was no reason for them to do so. The first case occurs at the high

speeds attained by the light Viking hulls, but not at the slower speeds normally associated with medieval Mediterranean vessels. The second case also does not seem to be applicable since the drag created by the massive Mediterranean rudders would overwhelm any extra lift that an airfoil shape could produce at 4 or 5 knots.

The use of an improved quarter-rudder design did not necessarily guarantee adequate handling of a vessel. The overall steering characteristics of a sailing ship also depend on the hull shape and the type of rigging. Ships with a single square sail could have a particularly difficult time tacking if the ship did not have the ballast, sail plan, and rudder properly balanced. Evidence that bow sweeps were necessary to help tack certain vessels can be found on a number of representations, such as Figure 5.5. This has also been brought out in the sailing of Viking vessels, such as the two-thirds scale Gokstad replica which frequently needed to resort to bow sweeps (McGrail, 1980: 250). Bow sweeps were used in both the Mediterranean and the North. However, it should be noted that virtually all of the examples of vessels with bow sweeps date to the 12th century or earlier, and the representations which have them all depict rather small ships. Whether this is a reflection of later improvements in hull, sail, and rudder design, or simply that later the sweeps were stowed inboard and so not drawn by artists, is unknown.

These bow sweeps were nothing more than large oars used to push the bow across the wind when the ship was tacking. It has been suggested that they were in fact bow rudders. Harald Åkerlund suggested that bow rudders were used on medieval vessels, but Salisbury (1965: 361) objected arguing that such usage would create an unacceptable division of labor in regards to the helm. Scammell responded by citing a miniature, dated to 1150, which had bow sweeps fixed in oar ports, and used them as evidence that bow sweeps were permanently attached to the ship and so had to be rudders (Scammell, 1966: 200). This last argument appears to be rather weak considering oars were commonly placed through ports during this period, and that a steering oar in that position would be difficult to use at best. More to the point is the fact that modern research has shown that practically any type of bow rudder has little or no effect when used for ahead steering or maneuvering (Saunders, 1957: 578). Based on modern research and work with replica vessels, there can be little doubt that the oars in the bows of medieval ships were sweeps, not rudders, and should be referred to as such.

The advantages of the innovations in rudder design are clear and are no doubt the reason for the rapid change in quarter-rudder construction. What is less clear is what led medieval mariners to recognize the potential benefits from a particular design change. The change to a triangular blade can be traced back to the Roman period. It is quite possible that the change to a triangular blade inherently led to the adoption of an unbalanced, high-aspect-ratio rudder through experimentation with the new design. Certainly, the simplification in construction and the strength of the new configuration would have been obvious. The step of fairing the loom to the forward blade would have been logical, and in the tradition of the elliptically-tapered shaft. The end result would have been a foil shape, even if the builders had no initial concept of the properties it entailed. With these changes probably came the realization that these rudders could be made from a single tree, further simplifying construction and decreasing cost.

Whatever the reason for the appearance of the medieval rudder design, its introduction was one of the primary reasons for the longevity of the quarter-rudder. Not only did it permit the construction of stronger rudders, it also allowed for the development of mounting systems which would maximize the potential of the quarter-rudder.

CHAPTER VI
PUSHING A TECHNOLOGY'S LIMITS

The changes in quarter-rudder design that occurred before and during the Middle Ages were accompanied by the modification of two Roman mounting systems, and the introduction of two new mounting techniques. Unlike the Roman period, we do have a few contracts and chronicles which actually mention specific systems and their use. There is also a substantial body of medieval iconography depicting Mediterranean quarter-rudder systems. The modifications to older designs and the adoption of new ones were attempts to push Mediterranean quarter-rudder technology to its limits. This move to upgrade existing technology was brought on in part by the benefits derived from the new rudder designs, by the desire to correct the drawbacks in older systems, and by the need to develop mounting systems which would be effective on the large merchant vessels that were coming into use by the start of the 13th century.

Before discussing the new mounting systems, a brief review of the four Roman systems that survived is in order. Two of the systems, the forward-mounted and the braced mount, barely survived into the Late Medieval period, and were not in common use. The forward-mounted system apparently survived into the 14th century, but the only extant example of it is from a fresco of a fishing boat (Fig. 3.11). Considering the drawbacks of the system, it is not surprising that, based on the iconography, it does not appear to have been widely used, and was probably limited to small craft.

The braced mount also seems to have survived in a modified form until the 15th century , but again we have only one example (Fig. 6.1). In this case, the rudder mount is for an auxiliary rudder. Unfortunately, the drawing is small, and all that can be discerned is that the rudder is placed between two throughbeams, as in the Roman method, and held in placed by an angled piece of wood or metal connecting the ends of the two beams. As will be seem in the section on through-hull mounts, there is some circumstantial evidence that the braced mount survived in a modified form. In any case, the lack of any other iconography that could even remotely be interpreted as a braced mount suggests that this system was at best not preferred by medieval shipwrights and owners.

The two Roman mounting systems which not only survived, but also stayed in general use in one form or another, were the aft-mounted and box-mount systems. The reason for their widespread and continual employment was that both systems could be readily upscaled to meet the requirements of the increasingly bigger ships which began to appear at the end of the 12th century. As noted in Chapter 3, both these systems were used on larger ships during the Roman period, so it is not surprising to see them reappear during the Middles Ages. These two systems, and the modifications they underwent, will be discussed first, followed by an analysis of the mounting methods which were unique to the Middle Ages. It is important to remember that all of these systems had the same requirements, and the same constraints, on them as had their Roman predecessors. While some of the solutions to mounting quarter-rudders were different from those in the past, the factors effecting these solutions had not changed.

THE BOX MOUNT AND OTHER FIXED MOUNTS

Although several mounting systems had survived from the Roman period, the box mount was, by far, the most influential. In fact, the basic concept of the box mount was so successful that it gave rise to

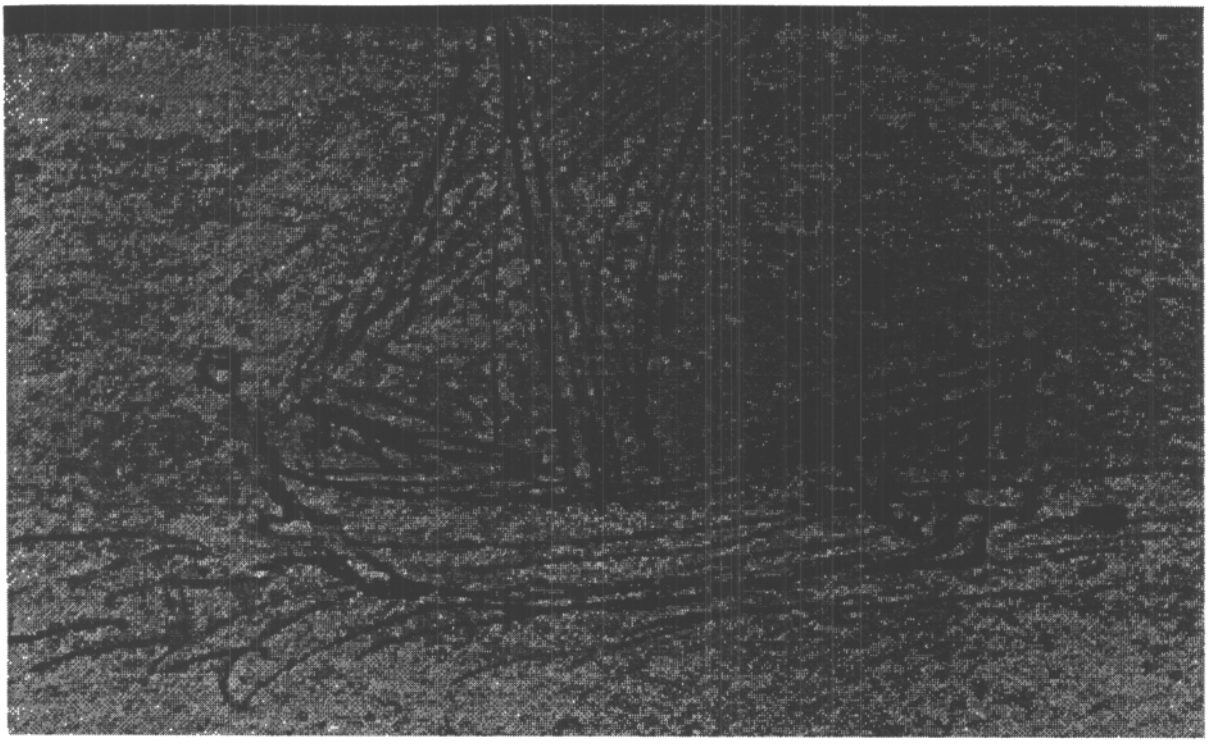

Figure 6.1 A small ship carring both quarter-rudders and a pintle-&-gudgeon rudder. The quarter-rudder mount appears to be a type of braced mount. The depiction comes from the *Llibre de les Ordinaciones de l'Administrador de les Places* (fol. 60R), and is probably very similar to the ship in Appendix III: 21. The page is dated January 26, 1405 (Archivo Municipal de Barcelona).

a variety of techniques for solidly attaching the quarter-rudder to the side of the ship. Several techniques have been put together here with the box mount because they all are a variation of the same theme; a rigid lower mounting point which prevented the rudder from moving both fore and aft, and laterally. All of these fixtures had the same drawbacks as the Roman box mount, including the fact that the rudders could not swing up to a horizontal position if they struck an object. Yet, despite this, fixed mounts became one of the most widespread types during the Middle Ages, if the iconography is any indication. This may have been due, in part, to the increased size of the rudders. It is very likely that, as quarter-rudders became more massive, simple lashings were unable to hold the rudders tightly on their mounts. While these systems were more secure, they robbed the quarter-rudder of several of its intrinsic assets.

Of all of the different mounting systems used by the Romans, only the box mount stayed in continual use through the Middle Ages without significant modification. One design was identical to those on the ships in the church of Sant Apollinare Nuovo, and was used on both merchant ships and war galleys. A miniature dated to 1450 shows that the box mount was in use at least until the late 15th century. In these examples the configuration of the box mount has not changed at all from those used during the Late Roman period (Figs. 6.2, 6.3, 6.4 & 6.5). It still consisted of a box-like structure through which the shaft of the rudder passed. In a painting by the Siena artist Giovanni di Paolo, a simple form of

Figure 6.2 A large roundship carrying quarter-rudder box mounts. The representation is in a 14th century mosaic in the chapel of San Isidoro in the church of San Marco, Venice (photo: Alinari).

Figure 6.3 A 14th century mosaic in the church of San Marco showing war galleys with box mounts for their quarter-rudders (After Moll, 1929: B.X. e147).

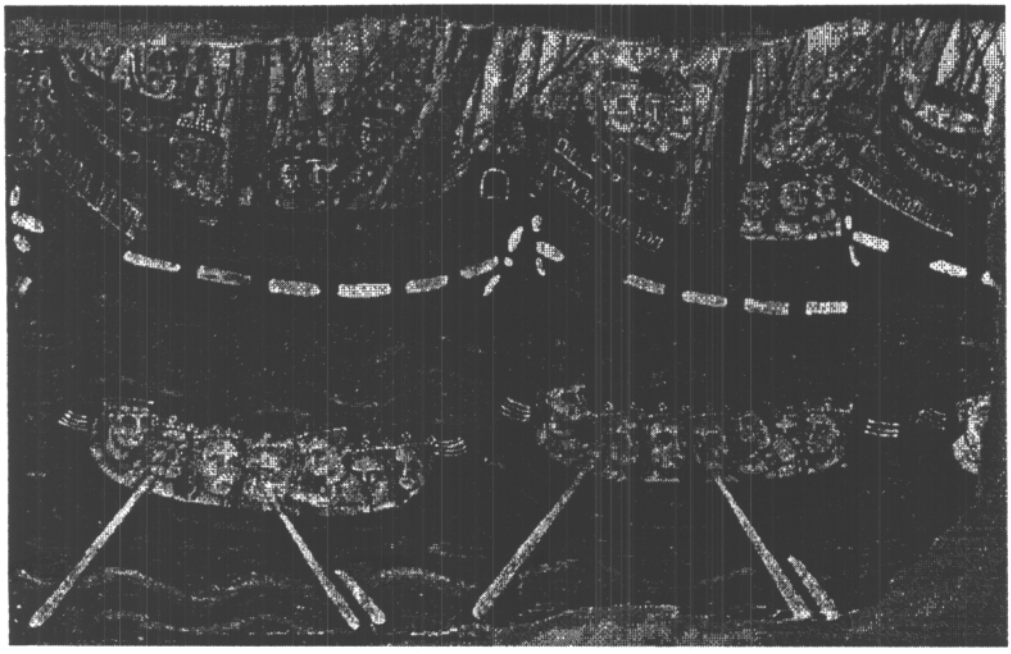

Figure 6.4 A detail of a 13th century painting of the voyage of Santa Ursula depicting large roundships with box mounts (Convent of Sant Francesc, Palma de Mallorca).

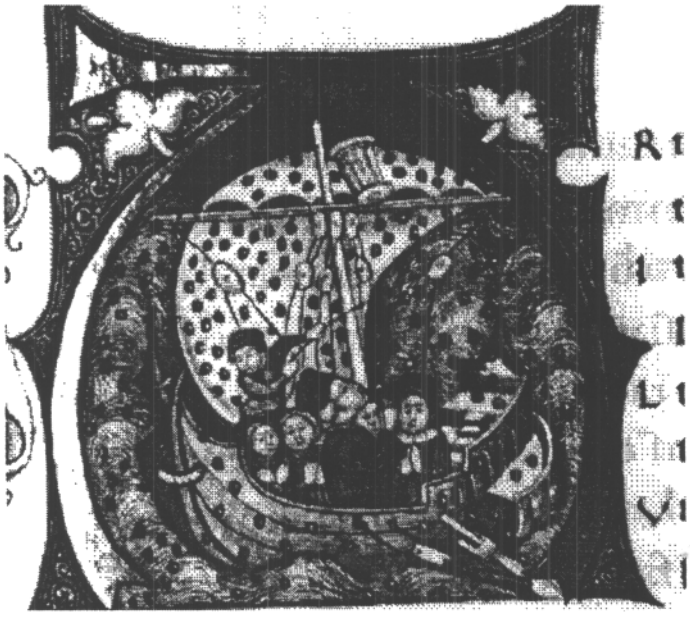

Figure 6.5 A minature from the *Publio Virgilio Maron* showing a ship with a quarter-rudder box mount. The manuscript was made in Naples and dates to circa 1450 (Biblioteca de La Universidad de Valencia, MS 768: fol. 58R).

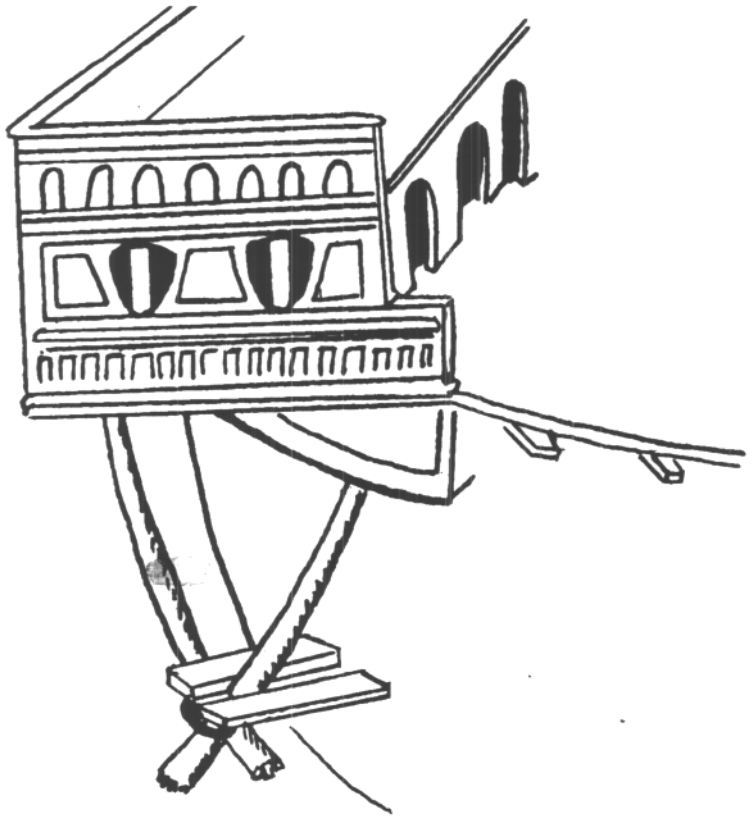

Figure 6.6 A detail of a painting of San Nicoló of Tolentino saving a ship. The work was painted by Giovanni di Paolo in 1455. The artist, who never saw a ship, has combined two different mounting systems; the box mount and the swing mount. However, the work is useful in showing that the box mount did not have to be complex, but could made from nothing more than two throughbeams (After Carli, 1956: fig. 115).

this type of mount can be seen to be nothing more than two throughbeams which form an open slot in which the rudder shaft sits (Fig. 6.6). Unfortunately, the usefulness of this particular piece of artwork is limited for two reasons. First, the ship has a conglomeration of two mounting systems which are direct opposites in regards to mounting philosophy. Secondly, the artist never left Siena, and so never personally saw a ship but had to copy from the work or descriptions of others (Carli, 1956: fig. 115). Regardless, the work does suggest that as even as late as 1455 the box mount was very simple in construction; it probably permitted the dismounting of the rudder through simple removal of a crosspiece at the end of the throughbeams. An indication of this can be seen in Figure 6.7, where an indentation can be seen on the box mount between its forward and aft ends.

A modified form of the Roman box mount appeared sometime in the 14th century. Because of drag on the rudder, under most conditions the aft throughbeam would receive most of the stress. To compensate for this, some medieval box mounts consisted of a thick reinforced wale extending forward from the stern and notched at the forward end to form a yoke for the shaft (Fig. 6.7, top). The forward end was closed off by a simple crosspiece. The advantage was that the mount was much stronger. If the rudder did ground hard and the shaft break, the reinforced wale would absorb the shock, whereas a simple

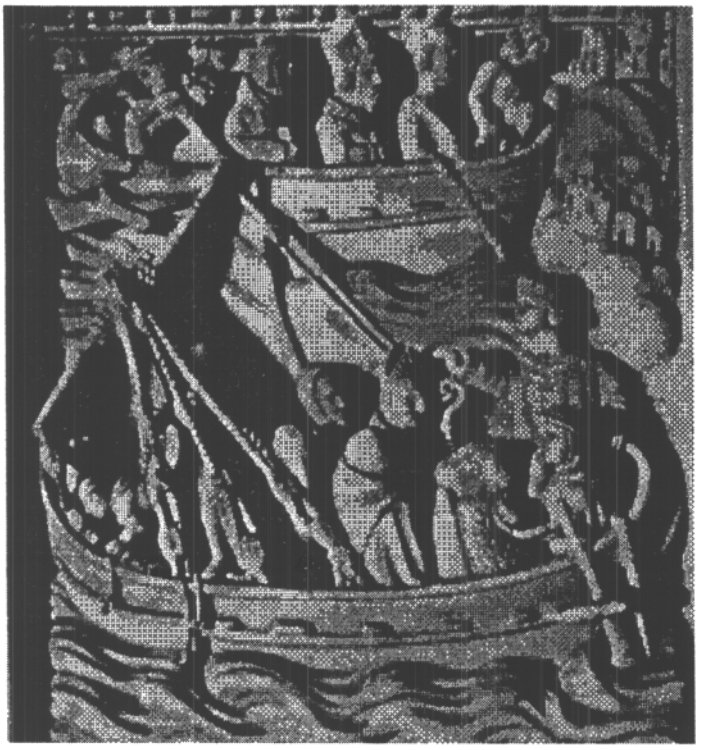

Figure 6.7 A 14th century relief of St. Peter in the Cathedral of Pavia. The work show two ships with different types of box mounts. The upper one is part of a reinforced wale extending from the side of the ship. The lower vessel appears to have a more simple type made of two throughbeams. Note the gap between the two beams (After Moll, 1929: F.a. 29).

throughbeam might be seriously damaged, hampering the mounting of a new rudder. Also, it is only in the case of this type of box mount that there are examples of a rudder raised up to a horizontal resting position.

Other modifications of the basic concept of permanently fixing a quarter-rudder to the side of the ship were more radical. One solution consisted of yokes which completely surrounded the shaft to form a wood collar at the lower mounting point (Figs. 6.8, 6.9 & 6.10). The concept of using a wood collar can be traced back to at least 1500 B.C., where one appears on a ship of Queen Hatshepsut (Casson, 1964: fig. 23). However, as previously noted, the use of a wood collar entailed several problems, and it was not widely used by the Greeks or Romans. After the Etruscan reliefs (Fig. 3.13), the next example of a wood collar for a quarter-rudder appears in the 12th century (Fig. 6.8). The principle difference between the medieval wood collars and the earlier sleeve mounts is that in the medieval design the bearing forms the lower mounting point, whereas the sleeve on the Etruscan tomb is the entire mounting system. The other examples of a wood collar come from the 14th century and 15th century, and all are from Italy. Whether this is due to a selective preservation of artwork, a particular regional artistic style, or to the fact that this was a mounting design indigenous to Italy is unknown.

Functionally, these wood collars were identical to the original box mount. All of the examples of this type of mount have a solid piece of wood with a circular hole for the rudder shaft, which would

Figure 6.8 A detail of a 12th century mosaic in the church of San Marco, Venice. This mosaic is one of the earliest medieval representations of a fixed mount using a wood collar (After Landström, 1961: fig. 213).

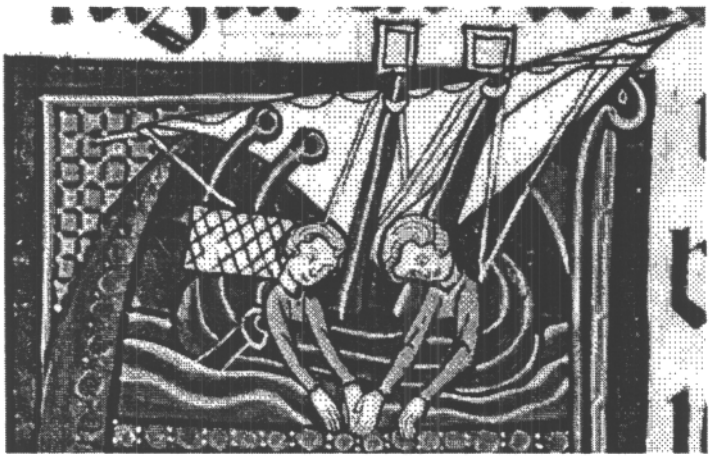

Figure 6.9 A detail of a miniature of Jonah being fed to the whale, from the *Biblia Sacre* at the Biblioteca Episcopal de Vic. The miniature shows a two-masted roundship with a wood collar for the lower mounting point. The bible is dated 1268 (Codice 3: fol. 351R).

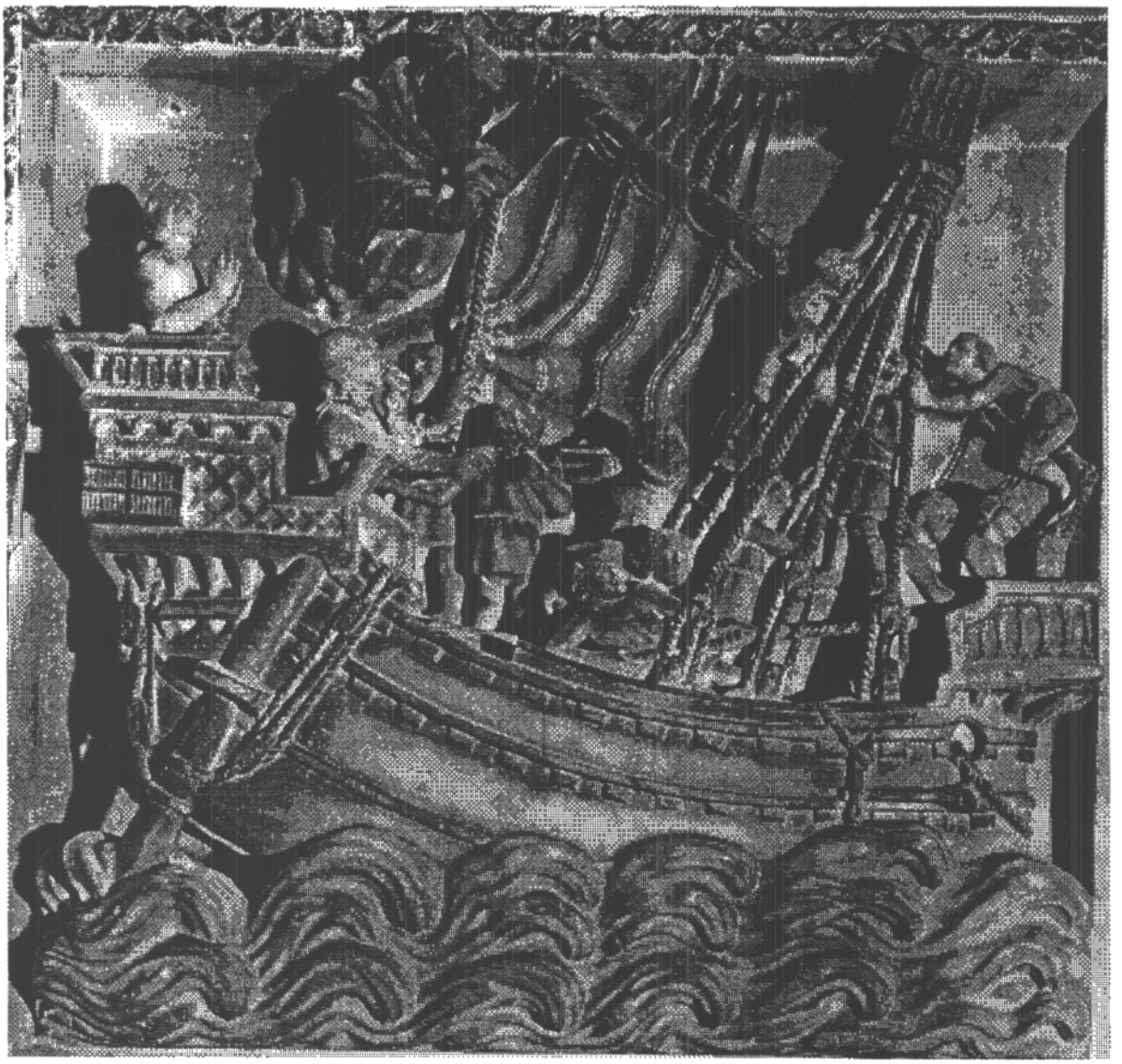

Figure 6.10 A sculpture in Milan of San Eustorgio saving a ship which has wood-collar rudder mounts. The sculpture was made between 1336 and 1339 (photo: Alinari).

suggest that the rudder could only be dismounted by removing the tiller and then pulling the rudder downward until the head of the rudder cleared the wood sleeve. This would be different from the other box mounts which appear to have either an open side, or removable crosspieces so that the rudder can be easily dismounted. There is the possibility that these wood fixtures could be detached from inside the hull and unshipped along with the rudder, but there is no information concerning this one way or the other. In any case, the limitations and advantages of this type of mount would be the same as those for the ancient sleeve mounts.

One of the most common devices used for the lower mounting point of fixed mounts was a simple iron ring. The earliest representation of a ring mount comes from the 12th century (Fig. 6.11). This mounting device appears to have been mainly used in the 13th and early 14th centuries (Figs 6.12,

6.13 & 6.14), but its use lasted well into the 15th century. The reason it is assumed that the rings in these representations are iron is that it would be virtually impossible to make a narrow wooden ring which could support a quarter-rudder weighing several tons without breaking along the grain. The obvious advantage of using an iron fixture instead of wood was the durability of the metal fixture. With both the box-mount and wooden-bearing designs, wear induced by rudder movement would eventually cause the slot or sleeve, in which the rudder shaft rested, to widen to the point where the rudder would not be held firmly. Using an iron ring would alleviate part of the problem. There would still be abrasion to the shaft of the rudder, but replacing rudder shafts must have been easier than replacing throughbeams.

The use of any of the above fixed-mount systems would have required the rudder shaft to have a specific diameter along the section which would be in contact with the lower mounting point. The required diameter must have extended along a section of the shaft so that the rudder could be raised or lowered to compensate for the draft of the vessel. An example of this comes from a contract dated 1248 which gives the required diameter of the rudder shaft for the lower mounting fixture (Appendix III: 7). The passage gives the required circumference of the shaft when fitted to the *luctatorio*, which is an indication that the rudder was not loosely fitted to the mount.

The term *luctatorio* has been assumed to refer to an iron ring (Bastard de Péré, 1972: 344; Pryor, 1987: chap. VII, 282; Villain-Gandossi, 1978: 292). However, there are no written sources connecting the word *luctatorio* with any mention of iron. The word, as used, could easily refer a box mount or a wooden collar, both of which would have required the rudder shaft to have a specific diameter at the lower mounting point. A more likely reference to an iron ring, is the word *ferreure*. A passage from a contract dated A.D. 1297 says "Pour ferreures a gouverniaux" (Villain-Gandossi, 1978: 287). The word comes from the Latin word *ferrum*, which in the 18th century meant the ironwork associated with a rudder. In this 13th century passage the word is used in the plural, and the passage refers to "rudders", which would indicate quarter-rudders and not a single sternpost-mounted rudder. The word could refer to iron reinforcement on the rudder, but later usage of the word always referred to the actual mounting fixtures for the rudder, and not iron fixtures in general. In any case, the term *luctatorio* can only be associated with a lower mounting fixture of some type, and not to a specific type of mounting system.

THE AFT-MOUNTED SYSTEM

The other system that survived along with the box mount until the 16th century was the aft-mounted system. This mounting system was used on both round ships and galleys at least until the end of the 13th century. There is only one medieval representation which clearly shows an aft-mounted system (Fig. 6.15). The rudder in this 12th century representation rests on a curved throughbeam. There appears to be no upper mounting point, but the size of the rudder and the ship would have required one. Despite this omission, there is no doubt that the rudder shaft is simply resting on an open beam.

Other evidence for the aft-mounted system comes from written sources. One hint that the aft-mounted system was in use on galleys of the 13th century comes from chronicles concerning the campaigns of Roger de Lauria. References are made to sailors in boats covertly moving between the galleys and cutting the lashings to the quarter-rudders (Serre, 1891: 372). This tactic would be much less effective against a braced mount or box mount system than the aft-mounted system, suggesting that warships of the period were using the latter. It is likely that the system was widely used on galleys as it was one of the few systems which would have accommodated the time-honored practice of beaching warships stern

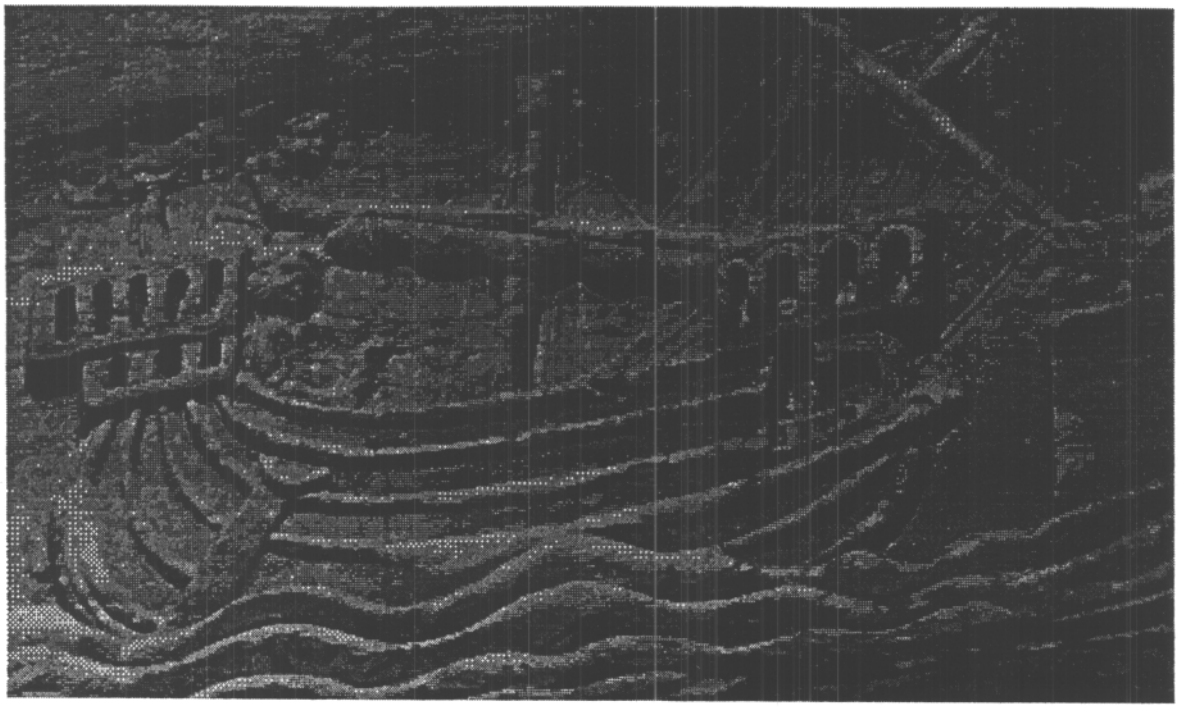

Figure 6.11 A 12th century relief on the side of the Tower of Pisa of a roundship with a ring mount for the quarter-rudder (Photo courtesy of Professor James Bradford, Dept. of History, Texas A&M University).

Figure 6.12 A detail of fol. 33 of the *Cantigas de Santa Maria* showing a roundship with a ring mount. The work dates to circa 1260 (By permission of the Patrimonio Nacional, Spain).

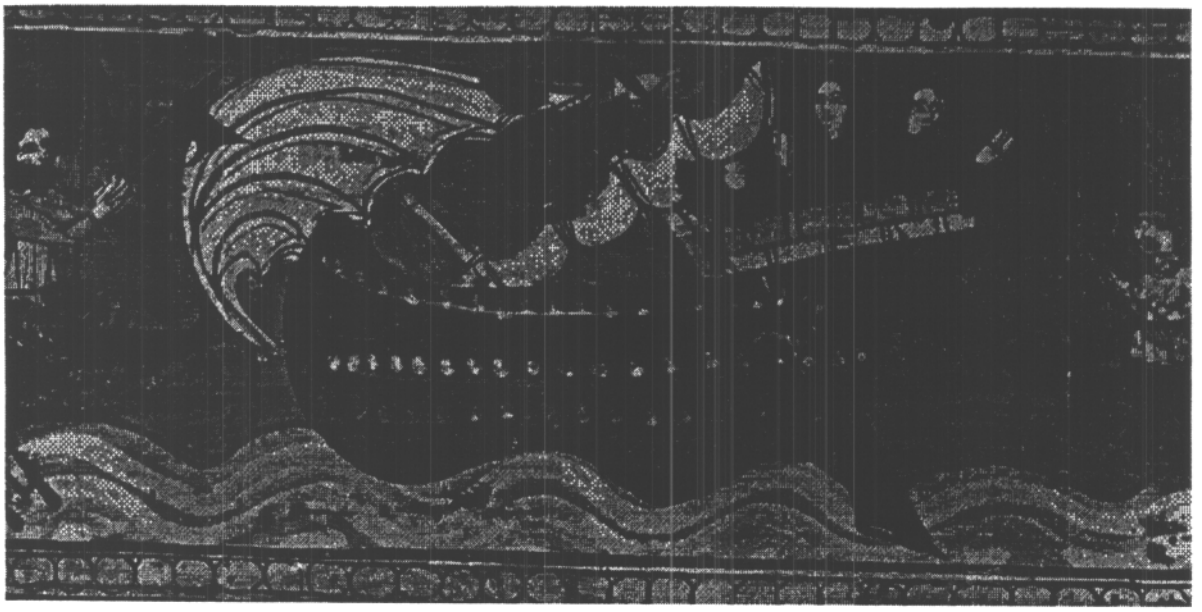

Figure 6.13 A painted wood beam showing a roundship with a ring mount. The ring appears as a faded white line around the upper portion of the rudder. The depiction is dated to the last quarter of the 13th century (Museo de Arte de Catalunya).

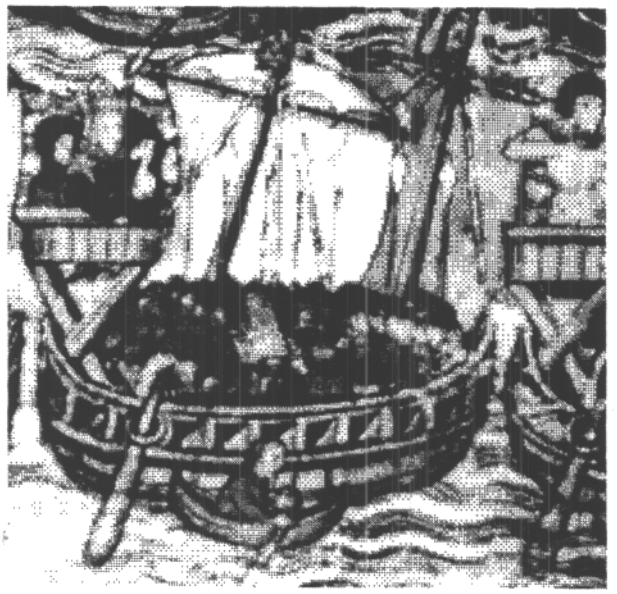

Figure 6.14 Detail of a miniature showing troop transports with ring mounts. The depiction is from the 14th century manuscript Les livres des histoires du commencement du monde (Bibliothéca Nationale, France: ms. fr. 301, f° 58 v°)

Figure 6.15 A ship with an aft-mounted quarter-rudder from the *Annales januenses*, dated 1187 (After Pryor, 1988: cover).

first.

Other evidence comes from *The Life of Saint Louis* written by Jean de Joinville in the 13th century (Pauphilet, 1952: 346). In one passage Joinville states:

> "En ces nés de Marseille a dous gouvernaus, qui sont atachié à dous tisons si merveillousement, que si tost comme l'en averoit tourné un roncin, l'en puet tourner la nef à destre et à senestre. Sur l'un des tisons des gouvernans se séoit li roys le vendredi ..." (On these ships of Marseille are two rudders, which are attached to two *tisons* so marvelously, with which as easily as one turns a horse, one can turn the ship to the left or right. The King sat on one of the *tisons* of the rudders on Friday ...)

The word *tison* is used several other places in the chronicle, and clearly from the context in those passages it is a generic word for a large timber or beam (Du Cange, 1954; Godefroy, 1969). The passage appears to indicate that each rudder was attached to nothing more than two large beams, which suggests that the aft-mounted system was used. Any other system could not have been so simply described.

Finally, there is a passage from *La Crónica de Don Pero Niño* written in the second quarter of the 15th century. The passage describes how during a storm both quarter-rudders were lost, but were then recovered and remounted (Diez de Games, 1940: 111, lines 10-16). The passage clearly shows that rudder hoists were being used. As will be shown, the rudder hoists were usually attached near the blade, meaning that when the rudder was pulled back on board it would have come blade first. The only mounting system which would have permitted manhandling the rudders into the correct position and the remounting of them during a storm was the aft-mounted system and its derivative the swing mount. All of the other mounts required that the head of the rudder be passed through either a collar or box-like structure which would have been nearly impossible in rough weather. With the aft-mounted system, the rudder simply had to be laid on the mount and lashed in.

The issue of rudder removal was an important one. It was common practice during the Middle Ages to require that a vessel which entered a harbor remove its rudders and turn them over to the port authority as security that the ship would not leave port until authorized. The earliest example of this practice dates to the 12th century where the Moslem commander of Alexandria ordered ships to turn over their rudders and yards so they could not leave without his permission (Lane, 1973: 72). A similar example is found under Heading 68 of the maritime statues of Ancone dated to 1397, which required all foreign ships to remove their rudders (Appendix III: 33). This appears to be the latest regulation of it's type. Another law from Pesaro dated 1532 has similar requirements, but appears to be a much older law (Appendix III: 34). Regardless of the potential problems these laws could cause, virtually all large merchantmen during the Middle Ages would have had to deal with this legal reality, and the rudder mounts would have had to be made to accomodate those laws.

As we have seen, the rudders of the large ships could be of considerable size and easily weigh between seven and eleven metric tons (Fig. 6.16). Handling these large rudders could not have been easy, especially on ships where the rudder had to be pulled out through an iron ring or wood collar. Further complications would arise for ships with fixed lower mounts which had the rudder head mounted inboard. Sometimes this amounted to simply placing the rudder heads inside the "wings" commonly found on medieval ships. However, many of them had the rudder passing upwards from the low mounting point through an opening in the side of the ship (Figs. 6.5, 6.8 & 6.11). During replacement the rudder would have to have been threaded through this opening. As always, the question is one of scale. Small ships would have had no problem with this, but handling an eleven-ton, eighteen-meter-long rudder would be a different matter entirely. The aft-mounted system, and its cousin, the swing mount, would have made the mounting and dismounting of rudders much easier. To mount the rudder the crew would have had to simply attach a line to the head of the rudder floating next to the ship and then hoist it up from the horizontal position, through the rudder guides, and on to the mounts.

While we have only one example of a true aft-mounted rudder, we do have several representations which show the mounting system of its direct descendent, the swing mount. There is little difference between the two mounting systems, except in the way the rudder is adjusted to compensate for ship displacement. The best example comes from *Peregrinations* by Breydenbach, dated 1486 (see Page 72). The mount is above the rudder at the forward end of the sterncastle. The upper mounting point is the forward most beam of the quarterdeck, and lower mounting point is formed by the aft edge of a beam below and aft of the upper one. The deck of the sterncastle has been removed between the forward deck beam and the next one aft to allow the rudder head to pass upwards between the beams. The rudder was

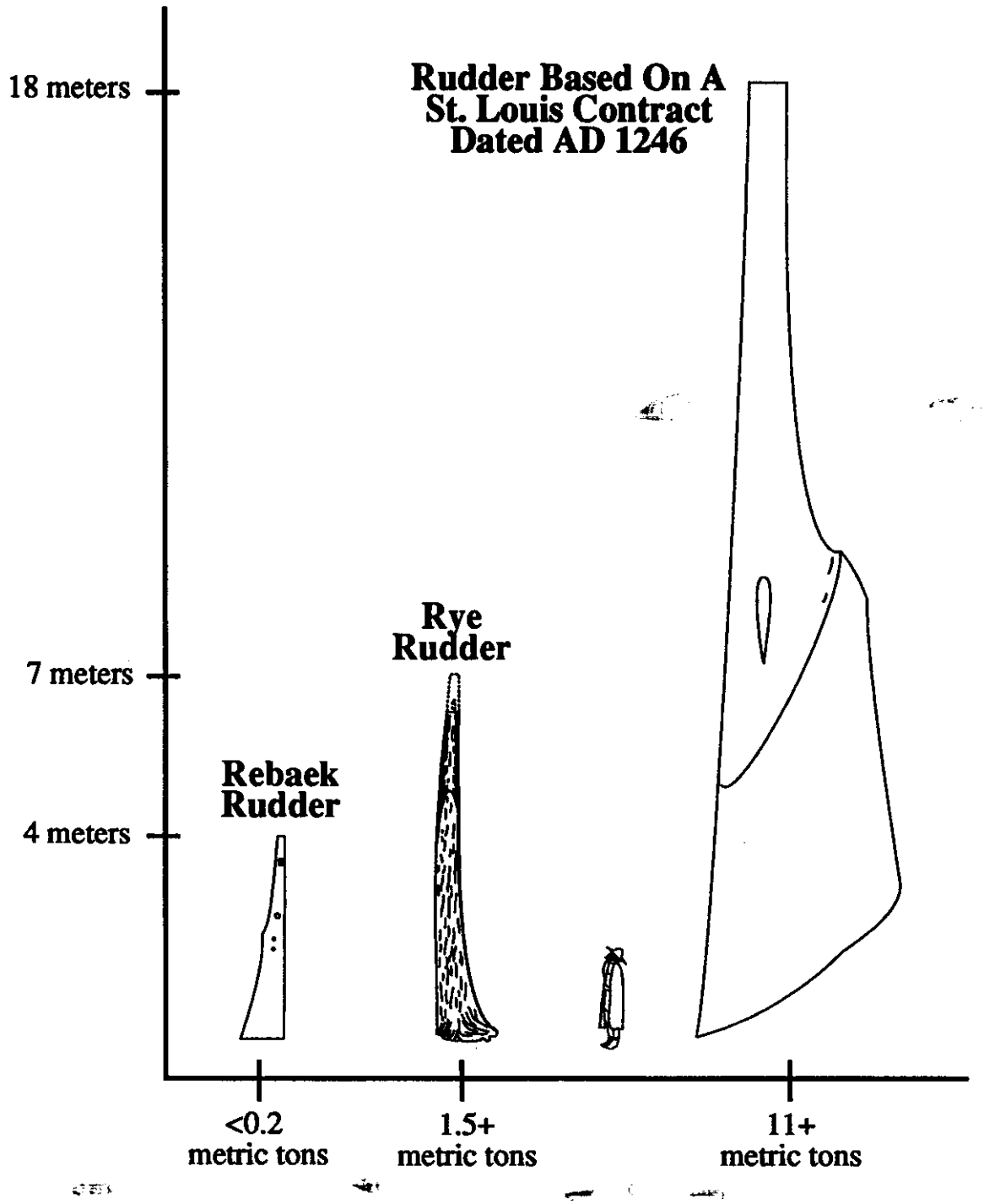

Figure 6.16 A comparison of the size and weight of different medieval rudders.

mounted by simply laying the rudder on the two beams and lashing it in place. Other variations are equally simple, such as where the upper point is again a simple beam, and lower mounting fixture is a metal strap bolted to the side of the ship in which the rudder shaft rests.

In medieval iconography, there are several representations of ships with the rudders extending from the overhang of the sterncastle. In these representations, there are no visible lower mounting fixtures (Figs. 6.17 & 6.18). The lack of a lower mounting point might be a simple omission by an artist, but the fact that there are several ship representations over two centuries which have this feature suggests that some rudders mounts were configured in this manner. The rudders on these ships may have been aft-mounted. The basis for this conjecture is the rather compact and elevated position of the rudder mounts. A structure of this type could easily be enclosed in the sterncastle of a large merchantman. Of course, this is merely speculation, and the mounting system might also be either a forward-mounted system or a braced mount. The only reason for favoring the aft-mounted system is that the other two methods appear to have been used very little by medieval shipwrights.

THE THROUGH-HULL MOUNT

One of the most interesting types of mounting systems to come into general use during the Middle Ages was the through-hull mount. Unlike all of the other mounting systems, this method had the entire mounting system inside the hull with the rudder protruding from an aperture above the waterline (Figs. 6.19, 6.20, 6.21 & 6.22). We have no evidence as to the internal arrangement for this system, but it would have to conform to the basic requirements of any quarter-rudder system. The through-hull mount was probably another solution to reducing torque on the shaft by putting the lower mounting point as close to the rudder blade as possible. It also removed the necessity of having to use lashings on the lower mounting point, which would have been a major advantage when mounting large rudders like those shown in Figure 6.16.

Initially, these mounts permitted the rudder to be raised as shown in the mosaic from the church of St. Mark in Venice (Fig. 5.3). To permit this, the rudder mount must have been configured in a way similar to a braced mount with the rudder head forward of the upper mounting point so it could be pulled down to bring the rudder up. It is unknown if this was practiced on larger vessels, but on large vessels it would have required an inordinate amount of free space in the hull that otherwise could have been turned to profit. It seems unlikely that shipowners would have employed a system that prevented the use of a substantial amount of potential space.

Why this particular system was employed is not clear, but it was used on both galleys and roundships (Figs. 6.19, 6.20, 6.21 & 6.22). The system did have the advantage of protecting the mounting system inside the hull, and would have permitted the servicing of both mounting points regardless of the weather conditions. The disadvantage was that considerable internal space must have been required for the rudder shaft and the mounting system. Another problem was that the opening in the hull for the rudder shaft would have been a potential source for leakage in rough weather. The shipwrights tried to counter this problem by putting a form of gasket around the opening. The gasket appears as a raised lip encircling the opening, and can be found on virtually every ship representation which has a through-hull mount (Figs. 6.19, 6.21 & 6.22). This raised lip may have also formed part of the lower mounting fixture.

The earliest representation for this system is dated to A.D. 1000 (Fig. 6.19), and the system appears to have come into widespread use in the 12th and 13th centuries (Figs. 6.20, 6.21 & 6.22). Ship

Figure 6.17 A ship with no visible lower rudder support. Note the foil shape of the quarter-rudder. A capital in the cloister of the Cathedral of Tarragona depicting San Nicolas de Barí, dated to between 1200 and 1250.

Figure 6.18 A ship representation on a bronze door, dated 1410. There is no visible lower rudder support, and the ship appears to have a PG-rudder as well (After Moll, 1929: F.a. 71).

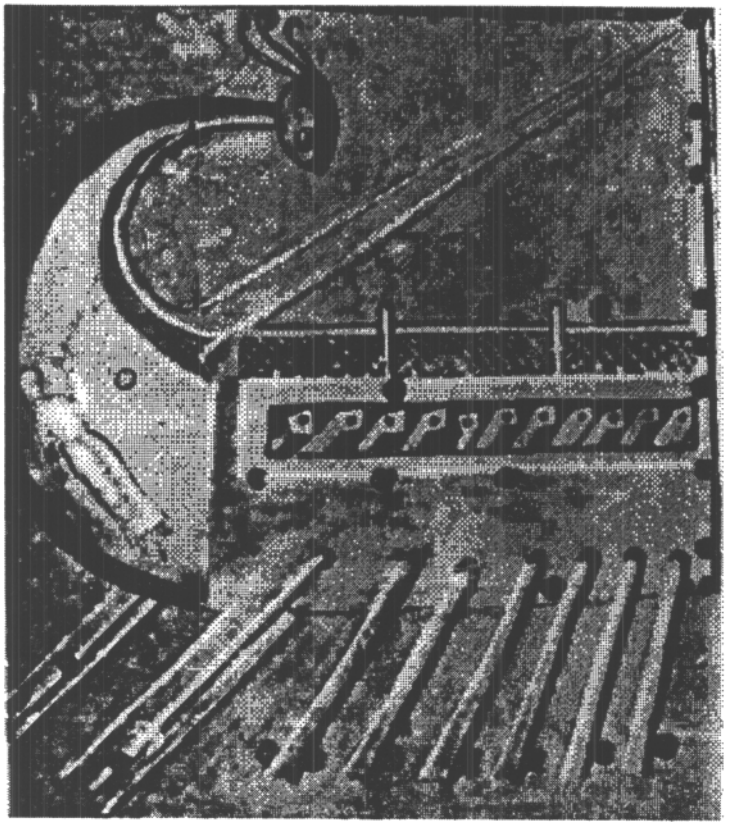

Figure 6.19 A fresco of a galley with a through-hull rudder mount. The painting is from Bologna, and dates to circa A.D. 1000 (After Moll, 1929: G. 8 i6).

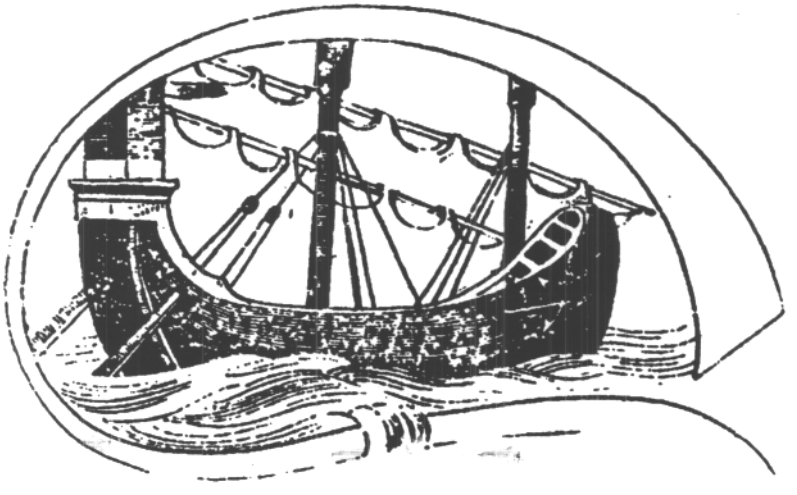

Figure 6.20 A roundship with through-hull rudder mounts. The depiction comes from *Capitolarium nauticum pro navis*, a Venetian manuscript dated to 1255 (After Moll, 1929: G. 16 r24).

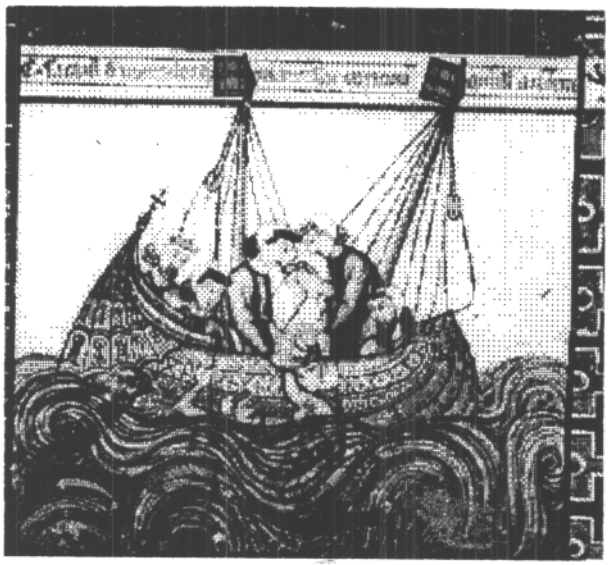

Figure 6.21 A detail of fol. 193 of the *Cantigas de Santa Maria* showing a roundship with a through-hull mount. The work dates to circa 1260 (By permission of the Patrimonio Nacional, Spain).

Figure 6.22 A detail of fol. 95 of the *Cantigas de Santa Maria* showing war galleys with through-hull mounts. The work dates to circa 1260 (By permission of the Patrimonio Nacional, Spain).

representations of the through-hull mount are common in the 13th century, but only one exists for the early 14th century, and none for the 15th century (Moll, 1929: G. 6 h13). The above iconography suggests that the system went out of general use by the end of the 14th century. The drawbacks of the system seem considerable, but the fact that it was in general use for at least three hundred years demonstrates that medieval seafarers found it more than adequate.

THE SWING SYSTEM

The other truly unique mounting system developed in the Mediterranean during the medieval period was the swing mount. Regardless of the design, all of the previous mounting systems had one thing in common. In order to keep a quarter-rudder firmly seated on its supports as a ship was loaded with cargo, it was necessary to pull the rudder up in a direction parallel to the shaft to prevent the rudder from pivoting upwards as the rudder mounts came closer to the water. Sometime during the 13th century, Mediterranean shipwrights hit upon an alternate solution which is still used today on the Indonesian *pinisi*. As previously noted, under normal load conditions the quarter-rudder mounts on the *pinisi* are used essentially as an aft-mounted system. However, when the ship is heavily ladened, instead of pulling upwards on the rudder head to compensate for the rudder's buoyancy, the rudder is allowed to float to a stable position and then is lashed into place (Fig. 6.23). The rudder pivots around a kingpost to which it is lashed and which holds the rudder on the upper mounting point. The rudder guide, which prevents the rudder from moving laterally, is formed by two horizontal beams running fore and aft, forming a slot in which the rudder sits. The inboard timber is solidly attached to the hull, but the outboard guide is lashed at the forward end to the kingpost which extends down to the lower throughbeam, and the aft end is suspended by rope from a framework on the stern. To prevent the rudder swinging outward, the outboard timber is lashed to the inboard one in front of, and behind, the rudder shaft. The forward lashing is generally heavier than the aft and forms the lower mounting point. The aft lashing is often light, being sufficiently strong to prevent the rudder from kicking up from wave action, but weak enough to break if the rudder should ground-out hard.

The best example of a swing mount comes from *Peregrinations* by Breydenbach, dated 1486 (Fig. 6.24). As mentioned above, what is depicted is essentially an aft-mounted system, but the curved timber running from the lower mount upwards to form a perfect arc shows that the system was indeed a swing mount. When the ship was heavily burdened, the rudder was allowed to swing up, and the shaft was then lashed to the curved rudder guide. Villain-Gandossi (1978: 300, n. 33) has suggested that these structures are rudder guards, and certainly these timbers would have fulfilled that function to a point. However, the fact that the timbers are curved is a strong indication they served another purpose. Also the position of the timbers would only provide marginal protection. Other indications come from the ships in Figures 6.25 through 6.29. The rudder mounts are covered by a housing, but the tell-tale signature of a swing mount can be seen in the curved form of the aft end of the mount housing. In these cases, the housing is so high that it could provide little or no protection to the rudder itself. If the only function of these timbers was to protect the rudders, then there would have been no reason to have them built always in the form of an arc.

The swing mount had a number of advantages over its predecessors. Probably the most important was that the rudder could be easily raised and removed in comparison to the other mounting systems. The fixed-mount systems which were in common use in the Middle Ages would only permit a rudder to

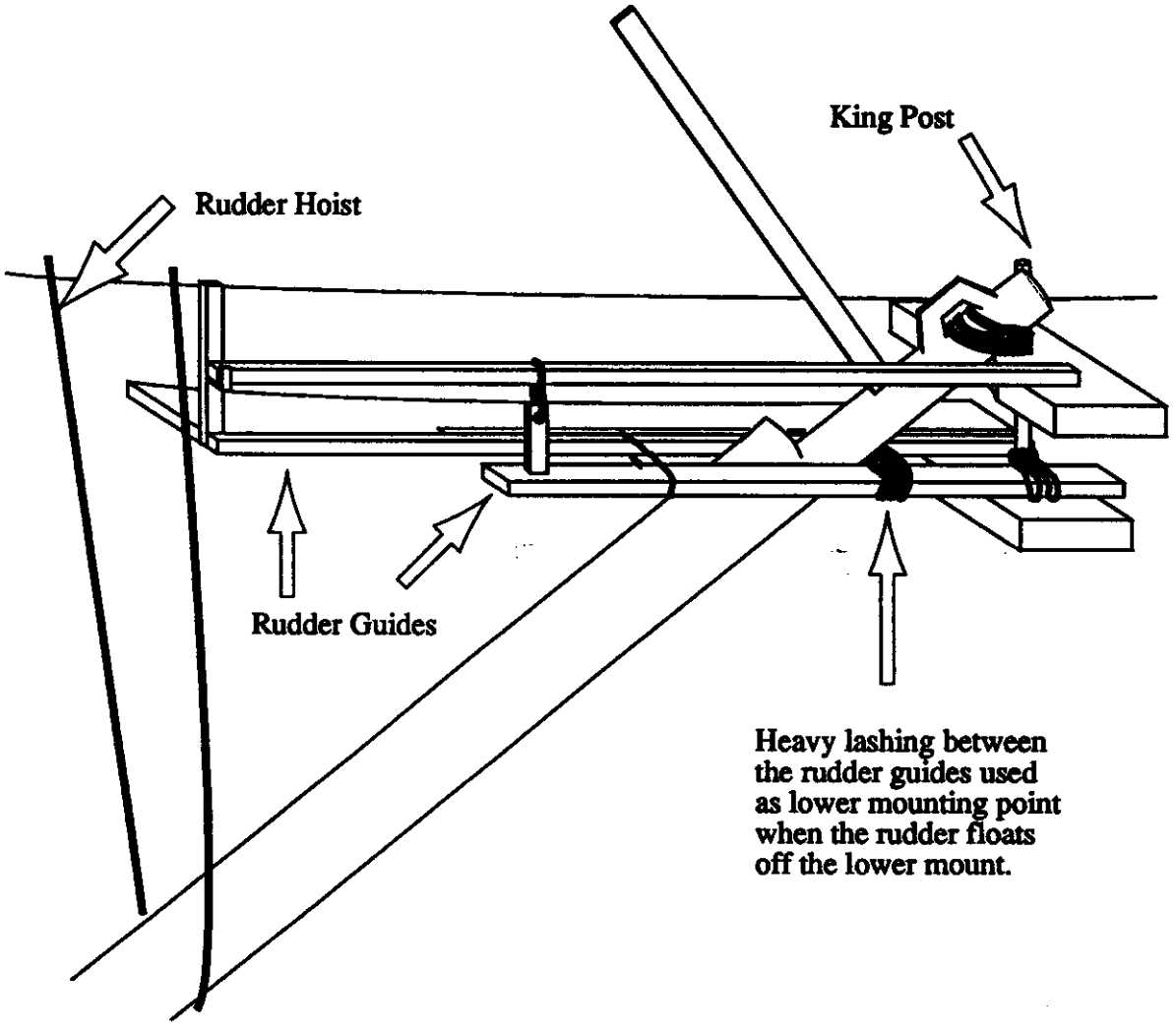

Figure 6.23 A diagram of the quarter-rudder mounting system found on Indonesian *pinisi*.

be pulled up to a point where the blade hit the lower box, collar or ring mount. The swing mount, on the other hand, would have facilitated the practice of shipping one rudder while underway by simply raising the end of the rudder, as was the old Roman practice, and as we have seen, actual removal and mounting would have been a far simpler task compared to what it was in other systems. Of course, the swing mount would have also permitted the rudder to kick up, like its modern analog, should it ground-out hard on an obstacle.

Two other advantages would have stemmed from the fact that, regardless of the load, the rudder head, and therefore the tiller, would always remain in the same place and at the same height. This would have allowed for the Indonesian practice of lashing the rudder through a ring on the shaft. The advantage of doing this is increased security. All of the other systems required that shaft be movable along its length so that the rudder could be raised or lowered to compensate for the ship's load, or for shallow water. Since the swing mount, by design, did not require the shaft to move, the rudder head could be lashed solidly to a kingpost around which it would pivot. This would prevent the shaft from slipping in the

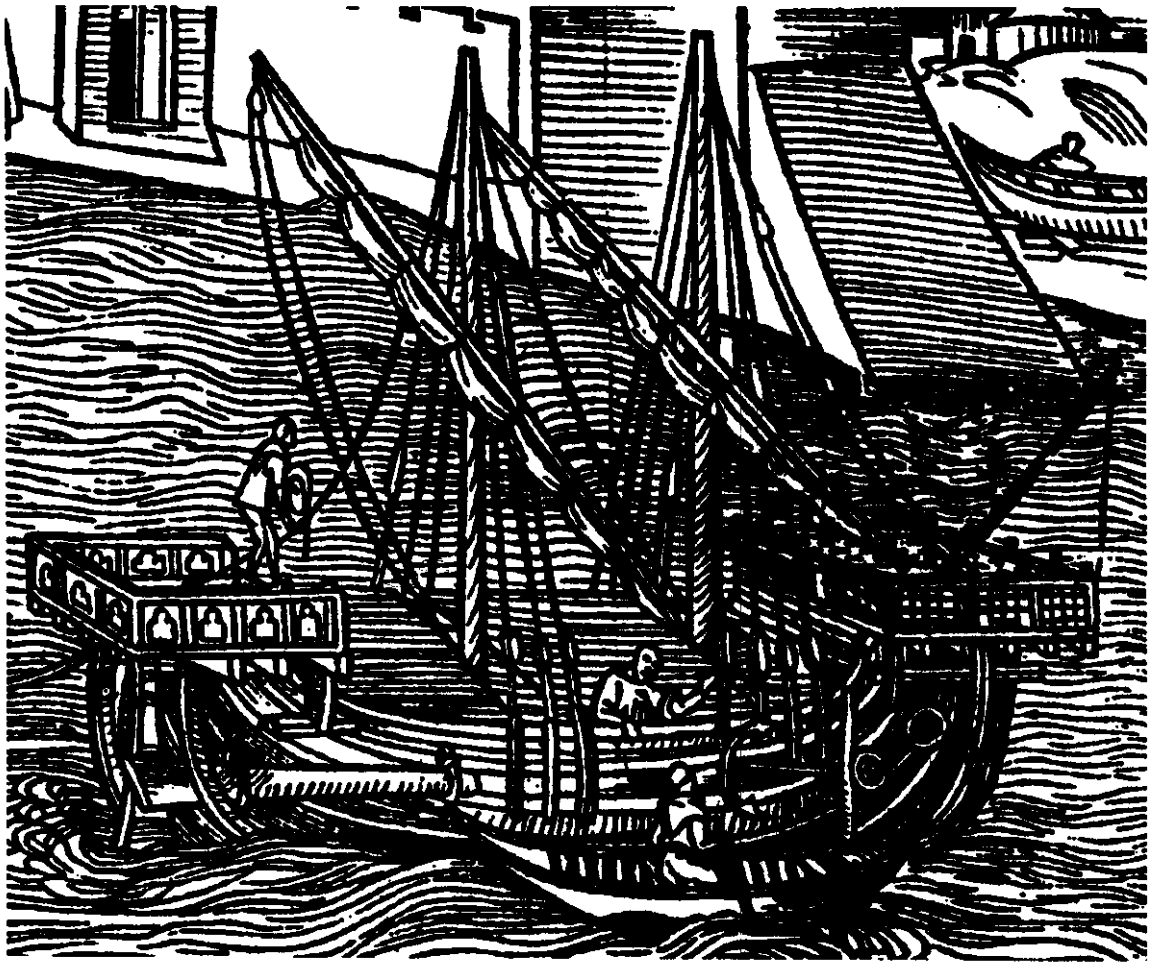

Figure 6.24 A woodcut from *Peregrinations* by Breydenbach, dated 1486. The ship carries both a pintle-&-gudgeon rudder and swing-mounted quarter-ruddders. Note the foil-shaped quarter-rudder hung from the stern quarter of the ship (From the collections of the Bridwell Library at Southern Methodist University).

mount due to rough weather and made it much more difficult to loose the rudder.

The earliest example of a swing mount comes from a Venetian manuscript dated to approximately 1295 (Fig. 6.25). The upper mounting point is not visible, but the lower one appears to be a large bushing of some kind for holding the shaft. There is also an inboard guide which is either part of the bushing or simply a fender between the hull and the shaft. The requirement for a large bushing may be a reflection of the ship's size and the rudder it was carrying. A similar arrangement can be found in a fresco at the Plazzo Publico in Sèina which is dated to circa 1400 (Fig. 6.26). The lower mounting point can not be seen but is covered with a housing. The function of the housing is unclear, but it may have served to protect a bushing similar to that in the previous example. It also may have covered an access port through the side which would have permitted servicing the lashing and the bushing while the ship was underway.

The above examples demonstrate that some rather elaborate arrangements were devised for the swing mount, but they were certainly not necessary. The system could be quite simple, with the rudder

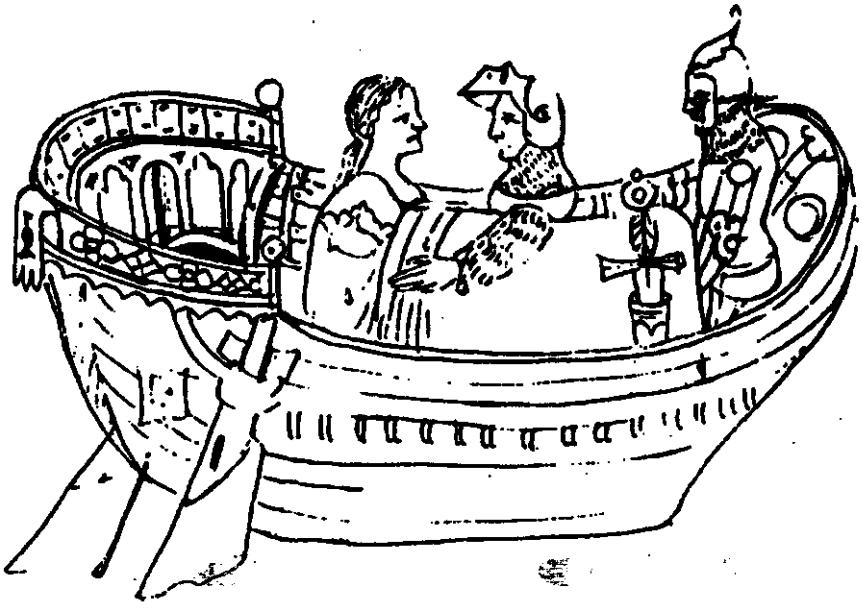

Figure 6.25 A ship with swing mounts. Note the large bushings for the rudder at the lower mounting point. The rudders have part of the blade forward of the shaft to give the rudder more balance. The drawing comes from the Marcaina Library at Venice (MS Gr. 17, fol. 20) and is dated 1295 (Courtesy of Lillian Ray, Nautical Archaeology Program, Texas A&M University).

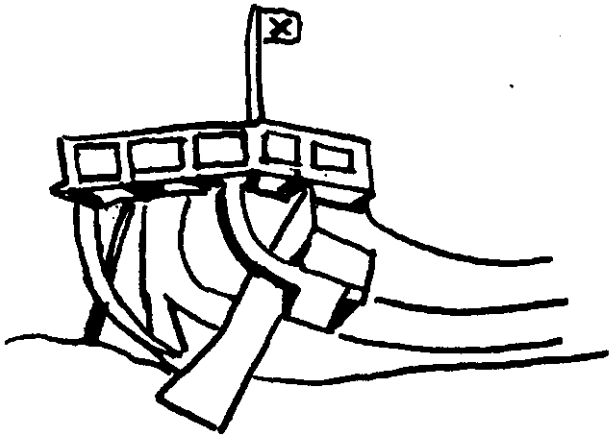

Figure 6.26 A stern of a ship with swing mounts and elaborate housings for the lower rudder mounting point. A detail of the fresco *Ingresso di Papa Alessandro III a Roma* by Spinella Aretino, painted circa 1400 (Courtesy of James Bradford, Dept. of History, Texas A&M University).

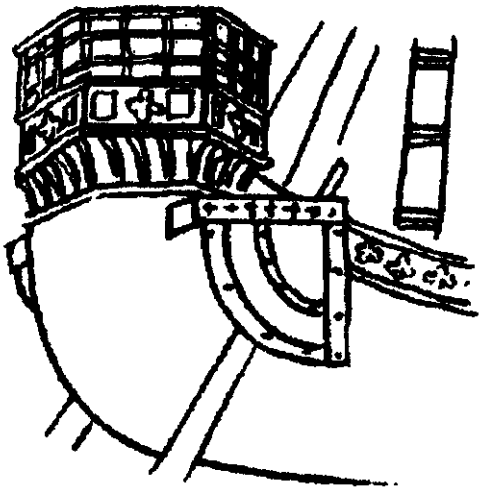

Figure 6.27 A ship with swing mounts for the rudders from a mid-14th century A.D. painting by Ambrogio Lorenzetti (After Landström, 1962: fig. 234).

Figure 6.28 A medieval grain ship with quarter-rudders in swing mounts. A detail from a painting entitled *The Life of San Nicolo of Bari* by Ambrogio Lorenzetti, painted between 1333 and 1335 (photo: Alinari).

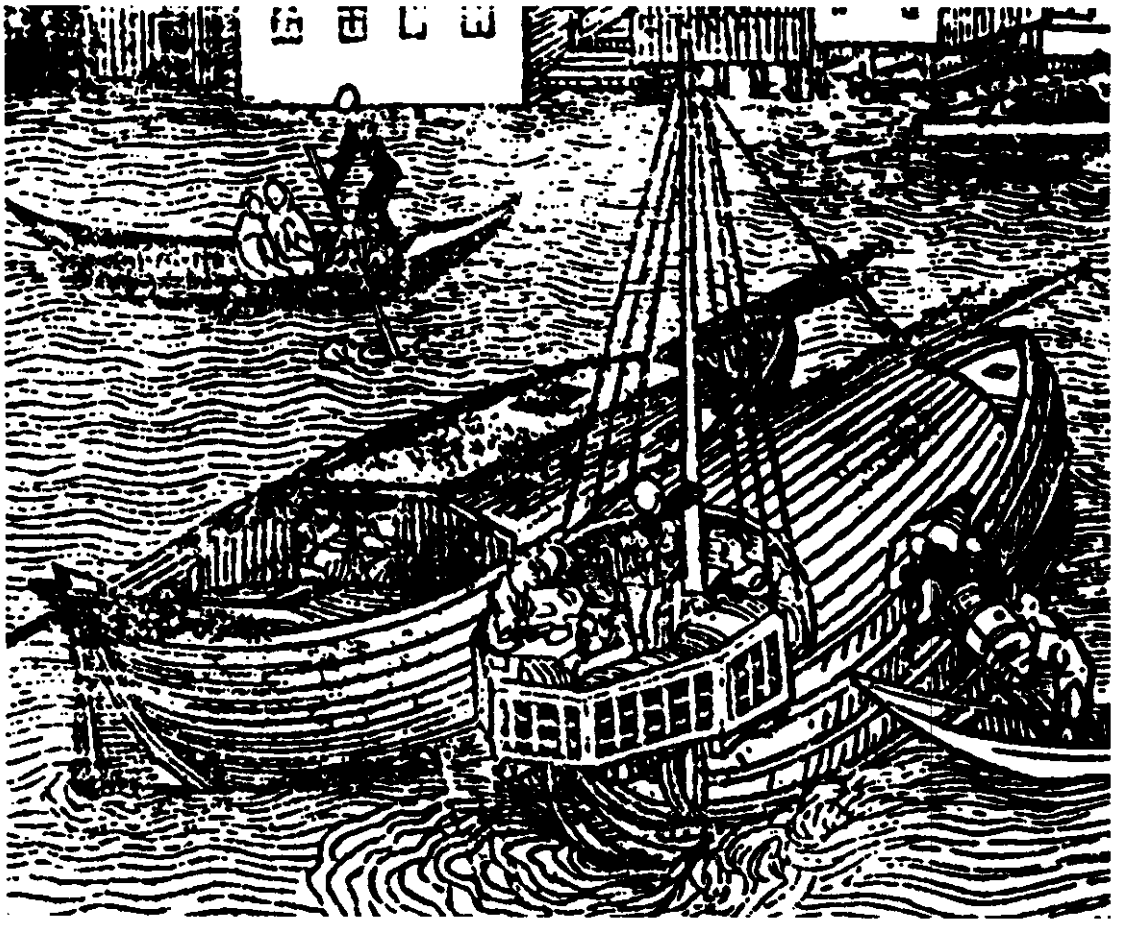

Figure 6.29 A view of the sterns of two vessels in the harbor of Venice. The one on the left has a pintle-&-gudgeon rudder, while the one on the right has quarter-rudders, as can be seen from the presence of the two rudder guides for the swing mounts. The woodcut comes from *Peregrinations* by Breydenbach, dated A.D. 1486 (From the collections of the Bridwell Library at Southern Methodist University).

resting on two beams (Fig. 6.24), or held on the lower point by an iron strap. Some of the ships in the 14th century had rather elaborate decorations which covered both the mount and the rudder guide (Figs. 6.27 and 6.28). It is probably the simplicity and flexibility of the system which explains why it remained in use into the 16th century. In fact most of the reliable examples of quarter-rudders at the end of the 15th century are of those with swing mounts (Fig. 6.29). The swing mount was the last system in the Mediterranean to come into widespread use and represented the culmination of the centuries of refinement of the quarter-rudder. The utility of this system was such that it remained in use on galleys into the 17th century.

RUDDER TACKLE

Rudder tackle during the medieval period appears to have been more varied than during Roman times (Fig. 6.30). What little evidence for rudder tackle we have for the Roman period shows a rudder

hoist looped around the shaft, and oriented parallel to it (Figs. 2.2 & 3.2). The visible medieval tackle normally consisted of a single rudder hoist attached to the blade. Usually the attachment point was at the top and aft side of the rudder blade (Fig. 6.30 C). However, there are examples of the hoist attached to the leading edge of a paddle-shaped blade (Fig. 6.30 B & E). The other common arrangement for rudder tackle consisted of two hoists, one attached to the leading edge and the other to the trailing edge (Fig. 6.30 D). The obvious advantage of this is that there would be more purchase for raising the rudder. Depending on the size of the vessel, the hoists could be a simple line attached to the rudder or an elaborate system of blocks and tackle.

It has been widely assumed that these hoists were used to hold the rudder up. However, like the Roman tackle, these arrangements, particularly the latter, would have prevented effective use of the rudder if the tackle was pulled taut. Also, as explained in the second chapter, there would be no need for it as the rudder would naturally stay in the mount if properly adjusted. The medieval tackle served the same function as their Roman predecessors: to adjust for a change in vessel draft or when approaching shallow water, and to pull one rudder up while underway. The one exception to the above is the use of a line which is looped around the rudder with both ends running up to deck (Fig. 6.30 A). The rudder is cradled in the loop and can be raised or lowered by pulling on one or both ends of the line. This arrangement is used on the *pinisi* when the ship is passing through shallow waters, or if the rudders hit bottom. This technique would only work for swing mounts since the other types do not have rudder guides to prevent the rudder from moving laterally. It also requires an asymmetrical blade since any blade forward of the shaft would interfere with the line. One of the ships in St. Mark's cathedral appears to be using this technique (Fig. 5.3).

Several medieval contracts and inventories mention items which are for the rudders (Appendix III: 25-28). Unfortunately, we have little idea as to what these items are. The most common word appearing in reference to rudder tackle is *baron*. Jal (1848) considered this to be a Catalan variation of the Castilian word *varon*, and that it referred to pendants for the rudder. This is probably partially true. However, a French manuscript refers to a line for the *barons*, which suggests that the word may refer to the actual blocks and fairleads of the rudder tackle (Appendix III: 28). Garcia de Palacio (1587:132) defined the word as a thick cable that was attached to the rudder to prevent its loss if it became unshipped. Later, O'Scanlan (1831) defined the word as tackle on either side of the rudder to prevent its loss, but also to stop the rudder from swinging too far to either side, and finally, to serve as emergency steering gear if the tiller was lost. Barcia in his work on Spanish etymology (1902) also used the latter definition.

The word *talles*, from the Catalan word *talla*, also appears in the contracts, but never with the word *baron*. As will be shown, this is an important point. The word first appears in 1351 in nautical documents (Corominas, 1980). Garcia de Palacio (1587: 154) gives several definitions for the word *talla*. A secondary meaning given is identical to the definitions given by O'Scanlan and Barcia for the word *baron*. O'Scanlan (1831) gives rudder pendant as a secondary meaning as well. He also lists the word *talle*, but the usage has no relation to rudders or their tackle. Based on the above information it would appear that during the medieval period the word *talles* was simply another word for *barons*, or rudder pendants. The fact that, as we will see in a moment, the word *estantares* is always associated with one or the other, but not both words, seems to support this contention (Appendix III: 26, 27 & 29). The *barons* or *talles* probably served to help control the quarter-rudders, particularly if the tiller, the *timonera*, broke. If they were similar to later rudder pendants, they could have been tightened to prevent the rudders from

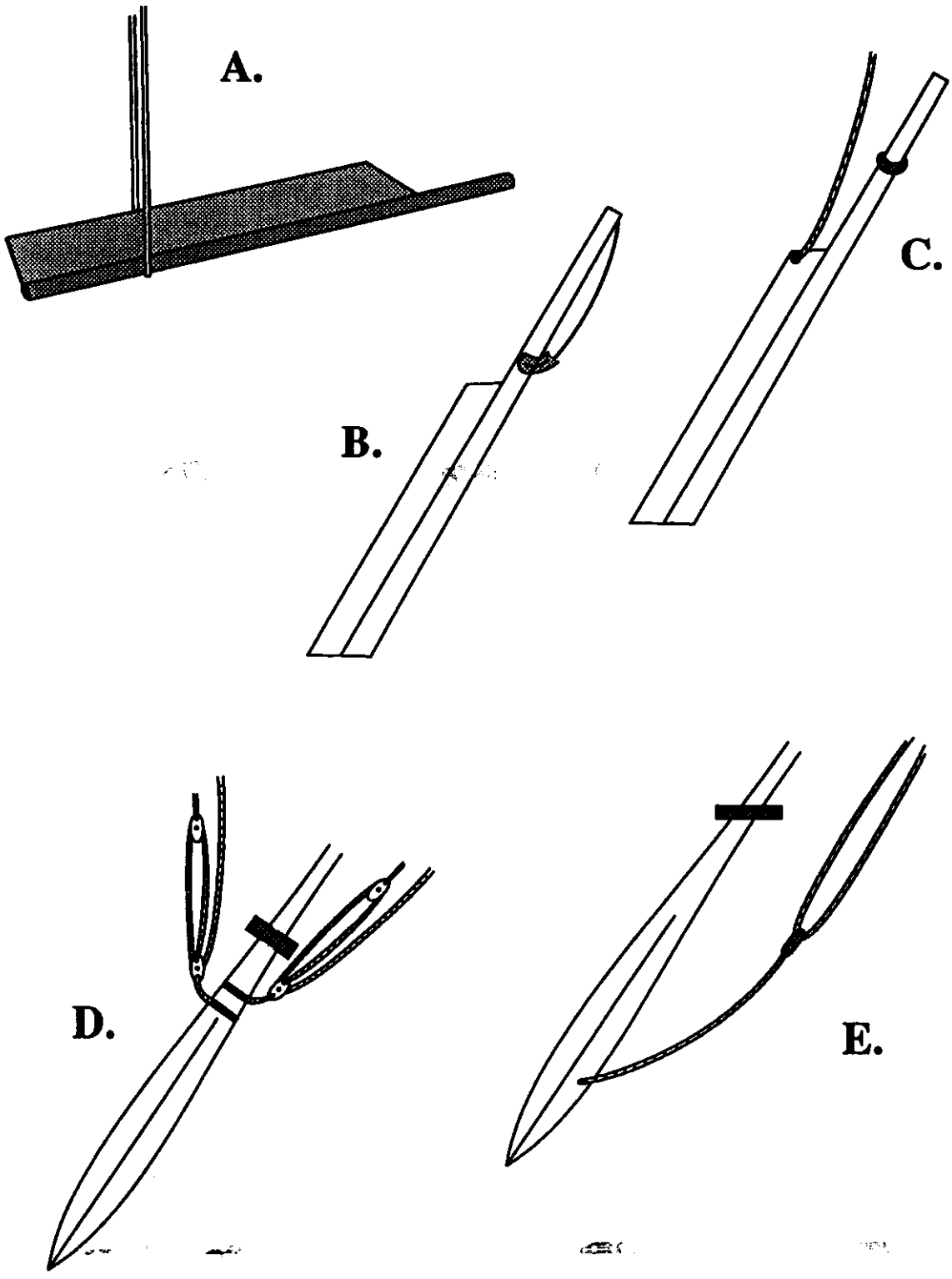

Figure 6.30 A comparison of the different types of rudder hoists used during the Middle Ages and a list of their dates. A. 12th century. B. 1187. C. 1260. D. 1339. E. Circa 1450.

swinging wildly from side to side during storm.

The one word which commonly appears in relation to quarter-rudder tackle and the words *barons* and *talles*, is *estantares*. The word appears to be a variant of the verb *estancar*, which comes from the Latin verb *stagnare*. The word is used as a noun and has the *c* replaced by a *t*, which is not uncommon (Corominas, 1980). The word generally signified the stopping or the holding back of running water, or the staunching of flowing blood. However, the verb also had a figurative meaning of to hold back, to detain, and to suspend something (Real Academia Española, 1732; Barcia, 1902; Corominas, 1980). Jal (1848) felt the word possibly referred to the metal fixtures for attaching the pendants to the rudders, but acknowledged that this was only a guess. There is no doubt the word refers to part of the rudder tackle, but it has such an obscure nautical meaning that there is no direct evidence as to what exactly it signifies. It was in use as late as 1380, but by the time of Garcia de Palacio's work it had dropped out of usage (Appendix III: 29). The word disappeared about the same time the quarter-rudder falls out of common usage on large vessels, and yet the two words associated with it, *barons* and *talles*, continued in the nautical vocabulary. If the latter two words are essentially references to rudder pendants, then it is probable that *estantares* refers to the tackle used to move the rudder up and down, the rudder hoist. Whereas rudder pendants would be necessary on either sternpost-mounted rudders or quarter-rudders, rudder hoists, *estantares*, would only be required by quarter-rudders. In fact, the word only appears in relation to quarter-rudders, and is not found in reference to PG-rudders. All of the above is circumstantial, yet the relationships strongly suggest that the word *estantares* signifies the hoisting tackle for a quarter-rudder.

The Middle Ages saw the modification and perfection of the quarter-rudder. It had been successfully adapted and used on every type of vessel, and had proved itself to be adequate for controlling ships of over five hundred metric tons burden. The reason the quarter-rudder was so widely used through the 15th century was probably due to its adaptability. The requirements for mounting a quarter-rudder were rather simple and allowed for several solutions to the problem of a good rudder system for a particular size and type of vessel. The very nature of Mediterranean quarter-rudder systems permitted them to be upscaled for use on even the largest ship. The quarter-rudder system also performed a secondary function by stabilizing a ship's movements. If the Mediterranean shipwrights had wanted to replace the quarter-rudder they would have had to find a system which satisfied several functions, not just one. Because of the flexibility and adaptability of the quarter-rudder, there was no impetus to create a totally different solution to the problem of ship control.

While the Mediterranean shipwrights had the luxury of simply refining an existing technology to meet their needs, their northern counterparts were facing a technological deadend. The solution which they would eventually reach would change not only the way ships were steered, but also their very construction.

CHAPTER VII
DEADENDS AND NEW SOLUTIONS

While the Mediterranean shipwrights were perfecting the southern quarter-rudder, a completely different tradition had arisen in the north. The Roman tradition of rudder mounting had been introduced to England, as evidenced by the small rudder excavated at the fort at Newstead (Curle, 1911: 313, pl. LXIX). Yet, for whatever reason, after the collapse of Roman government in the northern provinces at the beginning of the 5th century A.D., the southern shipbuilding tradition, along with the Mediterranean quarter-rudder system, totally disappeared. The northern solution to the problem of ship control which finally emerged was as far removed from its predecessor as could be possible while still using a quarter-rudder. The steering system, and the ships which they were used on, had evolved from a Scandinavian shipbuilding tradition largely untouched by the Romans. With the collapse of the empire, the Scandinavian shipbuilding techniques move southward with the numerous migrations which followed. The vessels which would replace the Roman designs were already in existence before the demise of the Roman empire, as is clearly shown by the Nydam ship which has been dated to between A.D. 350-400 (Marsden, 1972: 163). The northern quarter-rudder system which had been evolving in the Scandinavian countries would dominate northern shipbuilding from the fall of the Roman empire until the upper Middle Ages.

The only thing that can be said to be common to both the southern and northern quarter-rudder systems is that both used rudders which were hung from the side of the ship. Beyond that superficial similarity, the philosophies of the two systems were radically different. The southern tradition employed two quarter-rudders which were held to the side of the ship by a variety of methods, but they were never physically bolted or fixed so that they could not be pulled up, or rotated freely. In otherwords, they were not permanently attached, and even the largest rudders could be easily removed to accommodate local maritime laws. On the Mediterranean mounts, the lashings only served to prevent the rudder from slipping or becoming dismounted in extreme circumstances. The rudder was held in place by the actual mounting fixtures, and by its own weight. Any torque applied to the rudder was resisted by the mount itself, and not the lashings.

The northern philosophy was the exact opposite. The most basic difference is that while the southern ships traditionally carried two rudders, the Viking vessels only used one, usually carried on the starboard side. As early as the Nydam ship, the rudders were fixed to the side of the ship by a lashing at the caprail and, at the waterline, by a line or withy which passed through the rudder and hull so as to physically hold the rudder in place. The upper mounting usually was a simple leather thong holding the shaft to the side. The lower mounting fixture consisted of a rounded oak boss nailed to the side of the ship (Fig. 7.1). A withy, or rope, was passed through a hole in the rudder, through a hole in the center of the boss, and then into the ship where it was tied. The withy had to be strong enough to hold the rudder, yet sufficiently flexible to allow the rudder to rotate around the rounded end of the boss. In this system, the withy carried the weight of the rudder and had to resist any torque put to it. Unlike the southern mounting systems, there were no mounting structures to absorb the stress and transmit it to the hull. The Kvalsund ship demonstrates that by 700 the northern method had reached a form it would keep until its demise. The distinction between the two philosophies is subtle but important. Because the Mediterranean

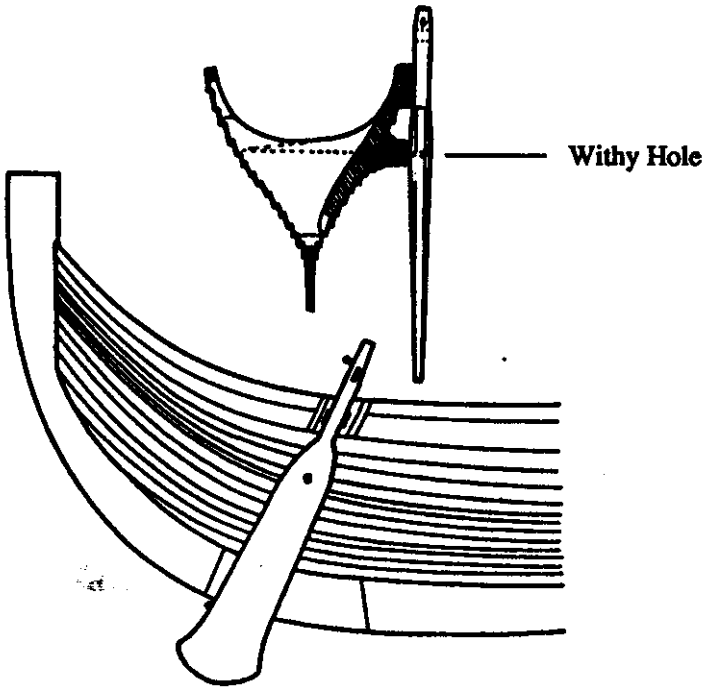

Figure 7.1 A typical northern quarter-rudder system, based on the Gokstad ship. The drawing shows the mounting hole for the withy or rope which passes through the rudder, the boss, and the hull (After McGrail, 1987: fig. 12.34).

quarter-rudders were supported and held by structures which were integral to the hull, the hull helped absorb any stress applied to the rudder. The lashings holding the rudder were important, but they only had to resist a fraction of the force on the rudder, not all of it. On the other hand, the northern system required the withy to withstand all of the force required to overcome the moment of the vessel, as well as any external forces applied by wave action.

The problem of stress causing the withy to fail has been a recurring theme throughout the trials of various Viking replicas, which is not surprising since the northern system required the withy to accomplish two diametrically-opposed tasks. The withy had to be strong enough to hold the rudder securely to the ship, and yet be flexible enough to allow the rudder to rotate. Achieving this fine balance must have been a difficult task. The numerous excavations of Viking vessels with part or all of their steering gear intact have provided detailed information concerning the mounting system, and the numerous replicas which have been built have allowed close scrutiny of its behavior. Yet, with all of the primary evidence and trial data, the withy system has yet to be adequately mastered. Virtually all of the larger replicas have had to eventually resort to the use of rope, usually nylon, for the withy (Crumlin-Pedersen, 1966: 257; McGrail, 1974: 14; Thorseth, 1986: 82). The problem with hemp rope is that as it is wetted, it tends to stretch thus allowing the rudder to start working back and forth. This problem was encountered on the replicas of the Gokstad *faering* and the *Saga Siglar* (McGrail, 1974: 14; Thorseth, 1986: 82). The problem was partially relieved by the use of relieving tackle running from the rudder head to the sternpost. There is evidence that such tackle existed, but as McGrail has pointed out this was a matter of correcting the symptom and not correcting the problem (Dammann, 1983: pl.6; Andersen,

1987: 216; McGrail, 1987: 250). Undoubtedly, part of the problem is that we have lost certain skills necessary to perfect the system, but the consistent pattern of problems surrounding the use of the withy points to some serious flaws in the system.

The Scandinavian system had another problem as well. By placing a hole in the centerline of the blade, an inherent weakness was introduced which would permit the rudder to split in two if enough pressure was applied by the withy. In one case in a heavy sea the stress on the withy was so great the knot fixing it to the rudder was pulled through the hole causing the rudder to break (Crumlin-Pedersen, 1966: 257). Crumlin-Pedersen (1966: 254) noted that the Vorsa rudder was probably relatively new when it was lost; this again points to a problem of the withy either breaking or pulling itself through the hole.

The question of rudder loss was much more important for the northern vessels than their southern counterparts. The tradition of carrying two quarter-rudders permitted the Mediterranean mariner to simply lower the second rudder into the water while he dealt with the problem of retrieving and remounting the lost rudder. The Scandinavian sailor did not have this option. Ragnar Thorseth stated the inherent danger in this when he wrote:

> "One of the things I am most afraid of is losing the rudder again, then we should be in trouble. Now of course we shall carry a spare rudder, but it is still not a good thing to have happen in an open boat. If the rudder goes, we have to take down the sails and cannot sail away from the wind and the waves" (Thorseth, 1987: 82).

With this system, the crew would have had hold the rudder in place, in a heavy sea, while another threaded the withy through the rudder and the boss. It does not take much imagination to see that this would have been a difficult and dangerous task. However, it should be noted that this was not an impossible task, and if the ship carried a spare rudder, there was virtually no damage which could be incurred with loosing the rudder which could prevent the new rudder from being mounted.

The above comments are not to suggest that the Scandinavian system was completely inutile. The voyages of the Vikings to the Mediterranean, and even North America, demonstrate that the system in competent hands could, and did, function adequately for the vessels on which it originally appeared. Yet the above data strongly suggest that the system had serious flaws which would make themselves apparent as the system was required to be employed on ships which were becoming increasingly larger. The Baltic shipwrights had reached a deadend with the technology they were accustomed to using. Unlike the southern shipwrights, the northern builders were confronted with a technology which would not allow itself to be upscaled.

The withy system could not withstand the demands of large rudders. The fact that all of the above problems occurred on ships with rudders less than 4 meters in length supports this contention. The largest quarter-rudder found is the Byggren rudder #92738 which is 6.7 meters long (Christensen, 1985: 229). This rudder appears to be the exception, and in fact, the next two largest rudders ever found which used a withy for attachment are the rudder from Rebaek which is only 4.1 meters in length and the Southwold rudder which was only 3.9 meters (McGrail, 1987: 245; Hutchinson, 1987: 220). These are a far cry from the Mediterranean quarter-rudders which attained lengths of up to eighteen meters and weighed well over eleven metric tons (Fig. 6.16). The archaeological evidence suggests that a length of four meters was near the upper limit for rudder length that the withy system could sustain. Probably beyond that length there was no material which the shipwrights could have used which would not have

stretched and yet been supple and strong enough to hold the rudder. The withy system had sufficed for relatively small vessels with low freeboards, but economic developments were demanding larger vessels the old steering mechanism could not accommodate.

The impetus to find a new steering system came from the increase in trade between the Baltic, England, and the Low Countries. By the start of the 12th century trade had been well established between England and German cities such as Bremen and Cologne (Dollinger, 1970: 6). Other groups, such as the Scandinavians and Frisians, were also actively pursuing trade. With the increase in trade in the 11th century came the necessity of transporting bulk cargoes. By as early as the 10th century such bulk goods as wheat, wine, and fish were being carried between France and the Baltic countries (Lewis, 1985: 106). The increasing demands of trade gave rise to vessels which were substantially different from their Viking predecessors: the *hulk* and the *cog*. They differed from the Viking *knarr* in that they were larger and had higher freeboards. As time progressed, they would also continue to steadily grow in size so that by 1250 an average *cog* would have over five times the capacity of a typical Viking vessel of 1000 (Unger, 1980: 139).

The increase in ship size and vessel freeboard during the 11th and 12th centuries taxed the withy system, and rudder loss during a voyage must have been a constant danger to larger ships. The technological problems, along with the probable demand by shipowners, captains and merchants for a more reliable steering mechanism to safeguard their investments, would have provided a strong incentive for shipwrights to develop a new system.

The northern shipwrights were in a curious position, in that they were technologically isolated from other societies from which they could borrow. Borrowing a technology from another society requires at least one of two things; either verbal or written transmission of sufficient information concerning the desired technology to allow its construction, or an actual example which can be studied and copied directly. In the first case, it is very unlikely that the northern shipwrights were exposed to the necessary technical information. During the early 11th century, trade with the Mediterranean was just beginning to revive, and virtually all of it was carried out over land. The merchants who were braving the trek certainly did not have the required expertise, and there would have been no incentive for individuals with a nautical background to leave home for a dangerous overland trip to a land with strange customs and languages. It is unlikely that any of the travelers who made the journey at this time could have provided any useful information. To describe adequately to a shipwright an alien steering system, be it a quarter-rudder or a sternpost-mounted rudder, required not only an intimate knowledge of how the system worked, but also an understanding of the nautical vocabulary of both societies so the data could be transfered. It is doubtful that the individuals making the trip across Europe possessed one, much less both, of these requirements. An example of the problem can be seen in the *Chronicle of Joinville*. As mentioned previously, he uses the word *tison* to describe a large beam supporting one of the quarter-rudders on his ship. He also uses the same word for the keel of the ship, and also for the beams in a torture machine (Du Cange, 1954). In the latter two examples, Joinville knew exactly what the two items were and how they functioned, but he lacked the vocabulary to describe them precisely. The point is that though a person, like Joinville, could read and write, he probably lacked the technical vocabulary to describe a complex system, such as a quarter-rudder, to the point where a shipwright could make any use of his description.

Another source of technological information is an actual example of the desired item to study.

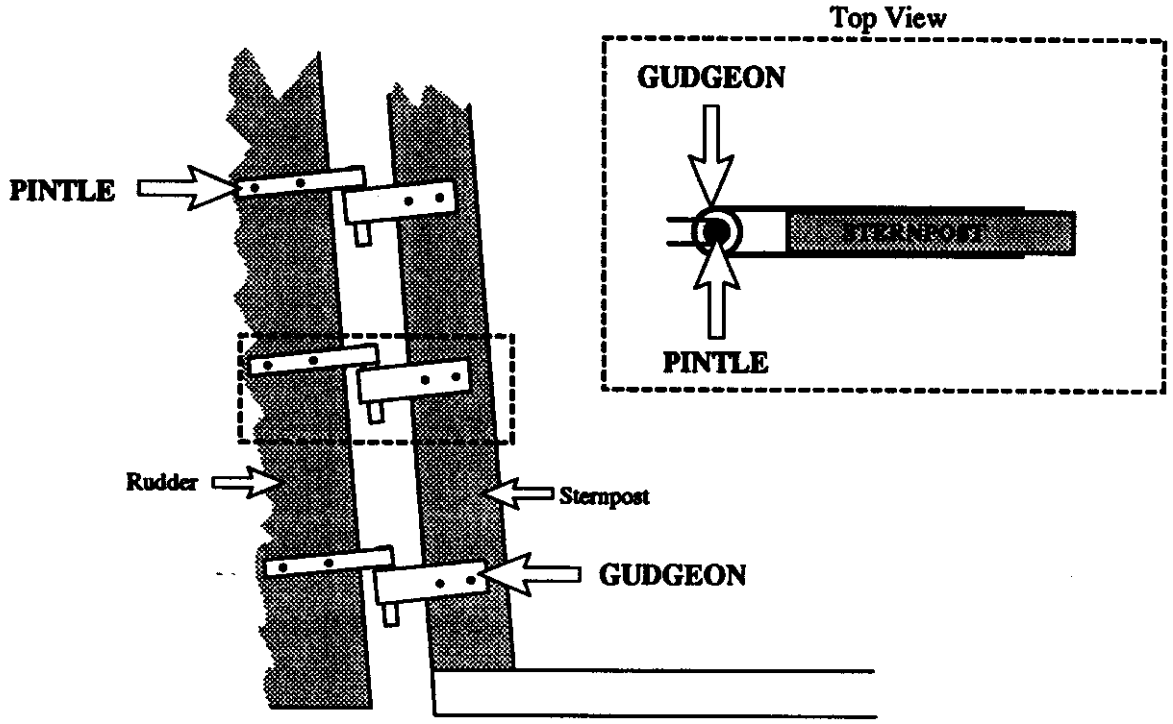

Figure 7.2 A diagram showing the basic components of a pintle-&-gudgeon system.

Yet here again, the northern shipwrights had only limited access to this potential source of information. Because of a strong surface current running west to east in the Straits of Gibraltar, ships could easily enter the Mediterranean but could only leave it with great difficulty. This problem was exacerbated by the rise of Moslem naval power in the strait (Lewis, 1976: 144-45). A vessel wishing to leave the Mediterranean would have had to battle not only the strong current, but also a substantial Moslem naval force in the strait. The difficulty of sailing out of the Mediterranean is attested to by the fact that all of the participants in the northern naval expeditions which entered the Mediterranean, from the pilgrimage of Count Robert the Frisian of Flanders in 1089 until the fall of Sevilla in 1249, returned home by land, and there is no evidence that any of these northern ships ever sailed out of the Mediterranean (Lewis, 1976: 144, 151). While this situation did not absolutely preclude Mediterranean ships from traveling to northern waters during the 11th century, it must have significantly limited the number to the point where there would have been few examples for the northern shipwrights to study and copy. It should also be noted that simply copying an item does not guarantee success if the principles which underpin the technology are not understood.

The above circumstances virtually insured that the northern shipwrights would be technologically isolated just as they were being forced to find a new solution to ship control. Exactly when this technological crisis was reached in the north is unknown. The earliest iconographic evidence for a PG-rudder are the celebrated Winchester and Zedelghem baptismal fonts dated between 1150 and 1180 (Brindley, 1927: 86; Sleeswyk, 1982: 282). There is also the first seal of Ipswich which dates to 1200 which clearly shows a sternpost-mounted rudder (Jewitt, 1895: II, 331). These dates suggest that the sternpost-mounted rudder had probably been in existence since at least the early 12th century since it

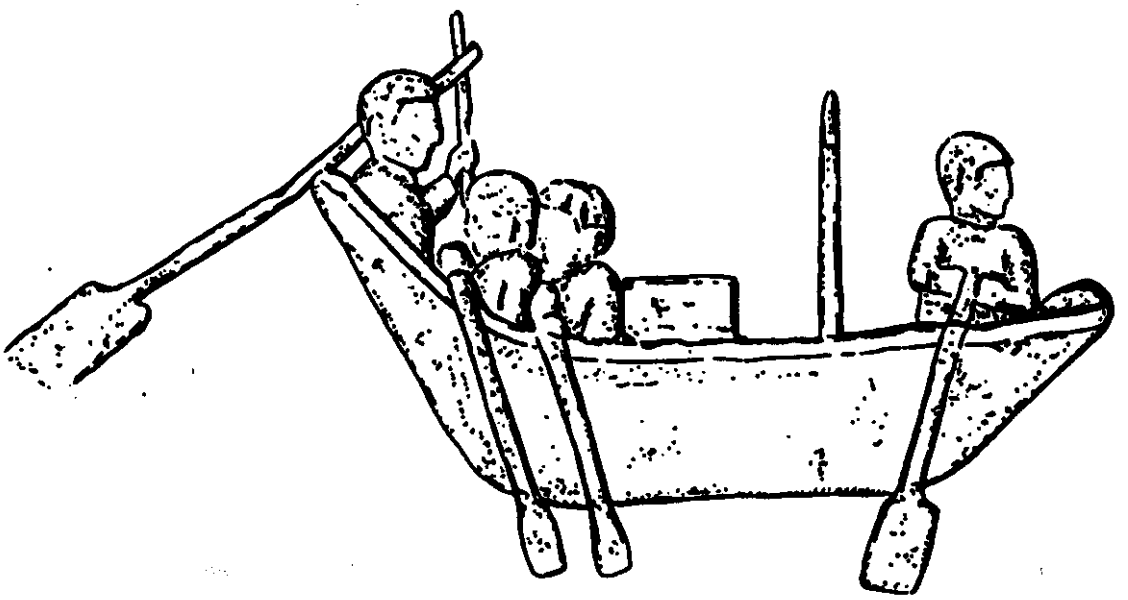

Figure 7.3 A 1st century A.D. relief of a boat with a stern-mounted steering oar similar to that found at Zwammerdam. The depiction comes from a monument at Mainz dedicated to Blussus (After McGrail, 1987: fig. 12.32).

usually takes a number of years for a new technological device to appear in artwork. The placing of the origin of the sternpost-mounted rudder to the very early eleventh century would also coincide with the increase in trade and ship size.

The northern shipwrights in the late 11th century were working in technological isolation, and since they had reached a deadend in the technology they were currently using, they were free to adopt a system which was not bound by tradition. The solution which they eventually arrived at was strong and relatively simple. The system mounted the rudder on the stern of the vessel and consisted of two parts, an vertical iron spike attached to the forward edge of the rudder, the pintle, and a ring attached to the sternpost into which it fit, the gudgeon (Fig. 7.2). Hung in this way, the rudder could rotate freely and yet be held tightly to the ship. This new steering system was not in itself a major technological jump, as much as a melding of several technologies which were already in existence. All aspects of the PG-rudder which have been viewed as unique or revolutionary had been in existence well before the PG-rudder evolved. The genius of the new system was the interweaving of these existing technologies to produce a new one.

The use of a single rudder from the stern would not have been as great of a conceptual leap for northern shipwrights as it might appear. Certainly they were not hampered by a traditional baggage of having previously used two rudders to steer the ship. All the evidence indicates that the use of a single rudder was the traditional standard. Whereas the idea of only having one rudder may have been viewed with some skepticism in the Mediterranean, it probably was not even considered an issue in the north. The concept of using a single rudder mounted off the stern of a vessel was certainly not new either. In fact a relief from the Late Roman period demonstrates that idea of using a single rudder from the stern had been in existence for some time (Fig. 7.3). An example of a steering oar, like that in Figure 7.3, was

uncovered at Zwammerdam along with several barges; it is dated to A.D. 150-225 (de Weerd, 1978: 15, 19-20). This rudder was probably mounted off the stern of a barge in a fashion similar to that depicted by the relief. The use of these barges on the Rhine from the Late Roman period onward suggests that the northern shipwrights were well aware of the idea of using a single rudder mounted on a vessel's stern.

The problem with mounting a steering oar off the stern was that a significant portion of the rudder was unsupported. By its very nature, this arrangement prevented any fittings for rudder reinforcement below the caprail on which the shaft rested. Any force applied to the blade would have had a significant mechanical advantage due to the long length of shaft below the caprail so that the shaft could have been broken with the application of little force. What was needed was a method of fastening the rudder to the hull along its entire length, and the pintle-&-gudgeon system provided the means.

As with rudder placement, it was not a question of creating a new technology as much as it was of simply finding a new application for an existing one. The use of hinges in northern Europe dates back to the Roman period, and iron hinges on churches in England goes back to the early 11th century (Singer, 1956: II, 425). The technology necessary for hanging a stern-mounted rudder by iron hinges had been well established long before the rudder crisis occurred. It has been argued that the PG-rudder was the direct result of improvements in iron technology which, until the 12th century, had not advanced enough to make the pintles and gudgeons. La Roërie (1937: 579) dismisses this argument by pointing out that the Romans had the technology to make them, and yet did not.

Iron had come into widespread use in northern Europe by the early 11th century for window bars, hinges, and door reinforcements on even small churches, demonstrating that the ability to make pintles and gudgeons had been present for some time (Singer, 1956: II, 424-25; Sleeswyk and Lehmann, 1982: 287). Pintles and gudgeons were very simple affairs. The pintle was nothing more than an iron spike with a U-shaped strap bent around the blunt end of the spike. The gudgeon differed only in that the spike was replaced by an iron ring. Moreover, they could be easily made on an open forge out of wrought iron. Archaeological examples show that, even by the mid-16th century, pintles and gudgeons for large ships were still being made exactly the same way (Arnold, 1978: 234-37; Keith, 1987: 175-81).

Certainly, affordable iron was an important factor. Had the cost of the iron fittings been too high, the PG-rudder would not have been adopted. The new fittings would have been an added expense to the cost of a ship, and the owners adopted them because they had to out of necessity, not because they wanted to. If anything, the cost and specialized nature of the fittings did not spread the use of the new system, but instead dampened enthusiasm for its adoption. However, this was partially mitigated by the fact that the new device could be made by any reasonably talented blacksmith.

A major factor which certainly aided the development of the PG-rudder was the introduction of the *cog* and its straight sternpost. A straight sternpost would have made mounting the new system infinitely easier than on a curved one. The problem of mounting a PG-rudder on a curved sternpost was quickly overcome, but during the initial stages of development the straight sternpost of a *cog* must have made the task of formulating a functional hinging system much easier. Hanging a straight rudder on a straight sternpost was no different than hanging a door, and so was much easier for the shipwrights to conceptualize. The arrival of the *cog* and its straight sternpost at approximately the same time the PG-rudder appeared is strong circumstantial evidence that in the initial stages the design of the *cog* was instrumental in the development of the PG-rudder.

The new system was a major advance over the one it replaced. Both the northern and southern

quarter-rudder systems suffered from the problem that a significant section of the rudder was unsupported. As noted in Chapter IV and V, the section of rudder shaft below the lower mounting point created a leverarm which amplified at that point any force applied to the blade: a number of mounting systems tried to alleviate this problem by lowering the mount. But this solution was essentially restricted to the hull above the waterline. Because a significant portion of the rudder was unsupported, rudder breakage due to rough seas must have been a problem, particularly for the large Mediterranean ships. On the *Ra I* both quarter-rudders were broken on the first day of the voyage. During the voyage of the *Ra II* the single steering oar, which was described as being "much thicker than a telephone pole," was snapped clean off by one wave (Thorseth, 1987: 82). Another indication that shaft breakage was an inherent problem with the quarter-rudder system comes from 13th century ship contracts. In a number of these contracts the only dimension specified for the rudders is that of the shaft diameter. The only logical reason for making this stipulation in the construction contract is that the buyer was worried about rudder breakage and felt it necessary to put a specified diameter in the contract to assure a sufficiently strong shaft.

The new system addressed this problem by essentially putting mounting points along the entire rudder. The distribution of the hinges equally along the length of the rudder resulted in a very mechanically strong system (Adam and de Noix, 1962: 106; Sleeswyk and Lehmann, 1982: 284). Because even the earliest vessels habitually used three or more pairs of pintles and gudgeons, unlike the Viking quarter-rudder, the PG-system would not fail if one of the attachment points broke. The pintle-&-gudgeon system did require that the sets be evenly spaced along the rudder. By evenly spacing the sets, any potential leverarm was eliminated, so that any force applied to the rudder would not have a mechanical advantage. If too much rudder extended below the bottom pintle and gudgeon, then any force applied to that part of the rudder would have sufficient leverage to bend or break the pintle. The metal technology of the period simply did not have the means to supply pintles strong enough to survive the kind of torques one could expect in the above situation.

Sleeswyk and Lehmann (1982) have suggested that early *hulks*, and later Mediterranean ships, only had pintles and gudgeons above the waterline because submerged ones could not be inspected for corrosion. Their thesis has several problems. In the case of hulks, they argue that the pintles and gudgeons on a mid-15th century miniature of a *hulk* can only be seen above the water line, thus proving their point (Sleeswyk and Lehmann, 1982: 282, fig.2). However, this is hardly proof considering that the artist omitted the hull and rudder sections below the waterline. Also, the northern ships could have been inspected on tidal flats. Their argument that this could only be done in the case of flat-bottomed *cogs* is not supported by the common maritime practice over the last five centuries of beaching vessels which have a steep deadrise on tidal flats. In the Mediterranean, inspection would have been easily accomplished by sending a diver over the side while the ship was anchored.

They later use the Mataro model, circa 1450, as further proof that Mediterranean shipwrights followed the practice of using pintles and gudgeons above the waterline. But to arrive at this conclusion they use a rather strange argument. They state that the lower hull proportions are distorted, thus placing the lowest pintle above the waterline, but then argue that the rest of the hull is proportioned correctly (Sleeswyk and Lehmann, 1982: 292-293). The fact is there are numerous 14th and 15th century ship representations which clearly show pintles and gudgeons below the waterline. There are also several ship contracts from the 15th century which call for eight to ten sets for a rudder (Bellabarba, 1988: 117). It seems ludicrous to think they were all crowded above the waterline.

The PG-rudder had several other advantages besides better rudder attachment. By placing the rudder on the stern, it was made less vulnerable to damage from ship collisions during a naval engagement. The tactics of disabling the rudder by slashing the rudder lashings and tackle would have been of no use against a PG-rudder. It would also be much more difficult to disable the rudder through tampering since the rudder would have to be unhinged or the iron fastenings destroyed. At the end of the 13th century, Mediterranean war galleys rapidly adopted the PG-rudder because the helmsman could be protected from missile fire by placing him at the stern under a protective covering. The helmsman would also be protected from the elements in this position. His position away from the sides would have afforded some protection from boarding seas, and with the introduction in the north of sterncastles in the 13th century, he received further protection by being placed underneath them.

This last point concerning tiller placement and the location of the helmsman was not as easily arrived at as one might think. The obvious solution was to cut the sternpost low enough so that the rudderhead was above it and the tiller could be extended over the sternpost. Yet, at first, this solution was not universally adopted. The problem was that traditionally northern vessels were built with extended sternposts, and for whatever reason many northern shipwrights appear to have been loath to cut them down to accommodate the new system. A temporary solution was have a tiller which was attached to the rudder and the sternpost by hinges and curved around the sternpost. By pushing to port or starboard on the tiller the helmsman could control the rudder. This same arrangement can be seen on a miniature dated to between 1321-1330 (Fig. 7.4). Later, this system was modified. A tiller perpendicular to the blade was attached the rudder. A tiller extension which extended inboard was then fixed by a flexible joint to the end of the tiller allowing the rudder to be turned by pushing aft or pulling forward on the tiller extension (Jal, 1858: 250; Serre, 1891: 375). This latter system continued in use in the north through the 19th century. While these ingenious arrangements partially solved the problem, the solution of a low sternpost was by far simpler and more accepted.

One last advantage derived from the PG-rudder had to do with the rake of the rudder. Rudders placed on either straight or curved sternposts had their bottom raked forward. The result of this is that the overall ship behavior is improved in a following sea (Saunders, 1957: II, 589). Because the *keels* and *cogs* to which the new PG-rudder was attached were essentially double-ended, this characteristic was enhanced. Sailing vessels up to the present have taken advantage of this phenomena. Quarter-rudders would have had the opposite effect. Because the ends of the rudders trailed behind the ship, they would tend to "catch" as a large wave passed under the stern causing the ship to yaw. Also, because the rudders were exposed to a following sea and would have been impacted before the hull by a large wave coming from the stern, there would have been the tendency for them to break.

While the PG-rudder had several advantages, it also entailed several disadvantages. The primary problem associated with the new system was that of decreased rudder effectiveness due to turbulence caused by the unfaired stern sections of medieval ships. This was a particular problem with *cogs* and *hulks* which had very bluff sterns (Figs. 7.5). As noted in previous chapters, turbulent water significantly decreases the amount lift of a rudder. The only way to compensate for this is to increase the rudder area. Extending the rudder below the keel to increase area was not an option because of the nature of the PG-rudder. That left increasing the width of the rudder until at least part of it was clear of the turbulence as the only means for increasing rudder area.

The problem with this solution is that the center of pressure moves aft on the rudder blade which

Figure 7.4 A miniature, dated to between 1321-1330, showing a PG-rudder being controlled with a tiller using a hinge arrangement allowing the tiller to curve around the sternpost. The miniature is from an exact facsimile of the *Breviculum Llullia* (Biblioteca de Catalunya).

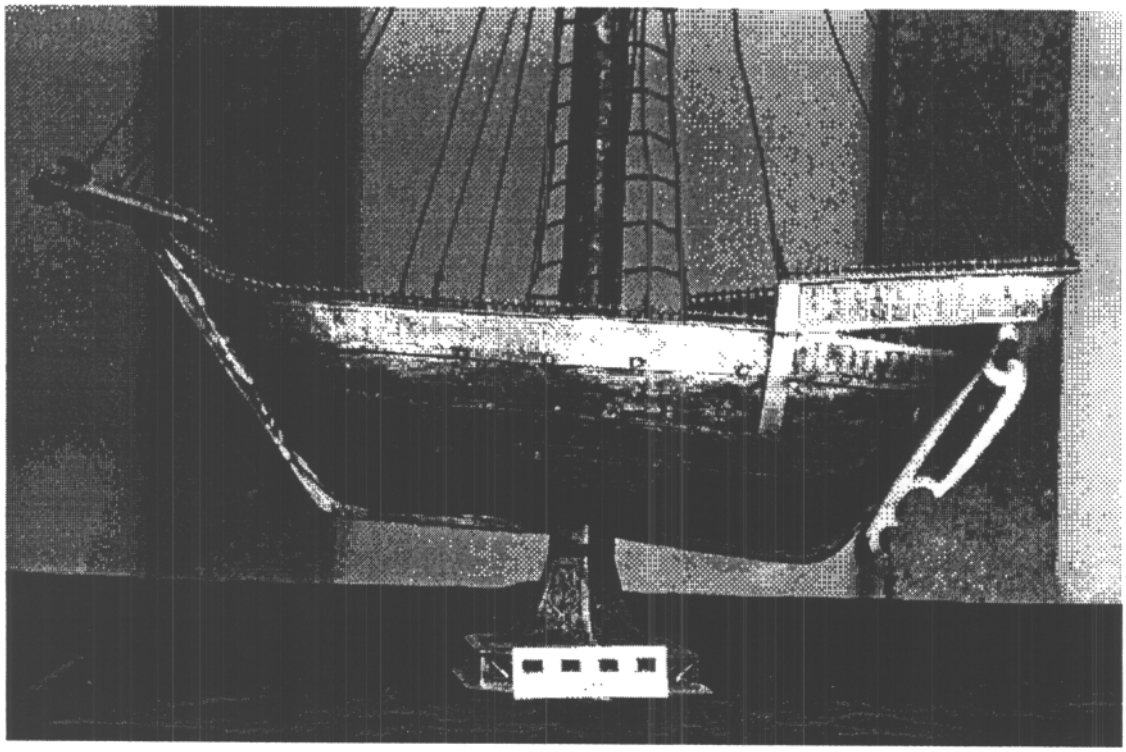

Figure 7.5 The *Relicario de San Blas*, made in the form of a *cog*, showing the typical blunt stern and absence of any fairing into the rudder. The relicary, dated to between 1377 and 1399, is a rather accurate representation, down to the lap-strake construction of the hull (Catherdal of Toledo).

would increase the torque necessary to turn it. Because the rudder was unbalanced the actual increase in rudder torque could have been substantial. The way to compensate for this was to increase the length of the tiller so as to give the helmsman sufficient leverage to control it. That this was a problem is indicated by the extreme length of tillers found on ship representations from the 13th and 14th centuries. In some cases the tiller extends as far as one-quarter the length of the ship. The problem of the helmsman having to control a massive rudder and tiller would only become worse as ships became larger. The above solutions did not, however, solve the problem of the turbulence. Even a wide rudder would have decreased lift, because the turbulence would cause it to stall at relatively shallow angles. In overall performance, a quarter-rudder with an submerged area equal to that of a PG-rudder would have produced more turning moment and have had a larger critical angle.

Another problem with the PG-rudder was presented by the pintles and gudgeons themselves. The cost of them must have been initially almost prohibitive. The metal fastenings would have required quality forging and welding which could not have been cheap. As noted, ship owners through history can never be accused of having been spendthrifts, and they must have certainly eyed the added cost of the new fittings with some distaste. But the problem of the PG-system went beyond the issue of cost. Adam and Denoix (1962: 107) noted the problem when they observed that while the PG-rudder was more solidly attached to the ship, it was harder to repair when damaged. If either the pintle or the gudgeon

became damaged during an accidental dismounting, the rudder could not be remounted. A bent pintle or gudgeon would have prevented proper realignment and mounting, even if the other pairs of fittings were completely undamaged.

Even if the rudder could be brought on board there was the problem of having the necessary tools and parts to either repair or replace it. The new ironwork required a specialized technology which was not normally found on board early medieval ships, leaving the captain to face the prospect of not having a rudder even if the damaged one could be recovered. This why medieval ships habitually carried a spare rudder, which was often mandated by law (Appendix III: 19, 22, 23, 24, 32). Aligning the pintles and gudgeons at sea must have been a significant problem, and is probably the reason only three or four sets were used on vessels through the 14th century. The use of any more would have made the task of alignment almost impossible in even gentle swells.

Because the protruding spike of the pintle was the weakest part, it was always mounted on the rudder, and the sturdier gudgeon strap was attached to the sternpost. The reason for this is rather simple but important. The stronger gudgeon straps were placed on the sternpost because the ironwork attached could not be effectively repaired at sea. As noted above, if the ironwork on the rudder was damaged, the rudder could be hauled on board. However, if one of the gudgeons was damaged then there would be no hope of remounting the rudder. The temperature of the northern waters can kill a man in minutes, which would effectively prevent the use of divers to repair the gudgeon. And, regardless of the water temperature, trying to repair a submerged gudgeon during a storm would have been suicidal for the diver. This meant that in a storm a northern ship faced almost certain destruction. Because they carried only one sail, the ship could not balance its sail plan to run downwind. Any attempt to run before the storm without a rudder would cause the ship to eventually roundup into the wind and take a series of "knockdowns" from which it might well not recover. Also with only one square sail and no rudder it would be difficult to heave to. All of this points to a central fact: The PG-rudder was an inherently stronger and more durable mounting system than its predecessors, but it was much more difficult to repair at sea, and a major failure during a storm could lead to the loss of the ship.

The city seals from England and the north coast of Spain demonstrate that the problems associated with the PG-rudder were sufficient to justify the continued use of quarter-rudders on *knarrs* and *keels* until the second half of the 14th century (Morcken, 1988: 399). The city seals of Faversham and Winchelsea indicate that most of these vessels continued to use the withy system, but the City Seal of Dover, dated 1305, shows a rudder mounted using the southern tradition, indicating some technological transfer from the south by that time (Fig. 7.6 & 7.7). The continued use of the quarter-rudder can be partially ascribed to the clinging of shipwrights to older tradition, but the fact that it continued in use in the north for over three centuries after the introduction of the PG-rudder is a clear indication that superiority of the pintle-&-gudgeon mounting by itself was not as great as has been suggested by some authors. The pintle-&-gudgeon system had some advantages, and certainly was an inherently stronger means of attachment than the withy system. Yet by itself, the system was not that much of an improvement over the one it replaced. The PG-rudder was the result of the ingenious combination of several technologies, but it lacked two important developments to make it the preeminent steering system in Europe. The two critical pieces of technology which it lacked were to be found in the Mediterranean, to which we will now turn.

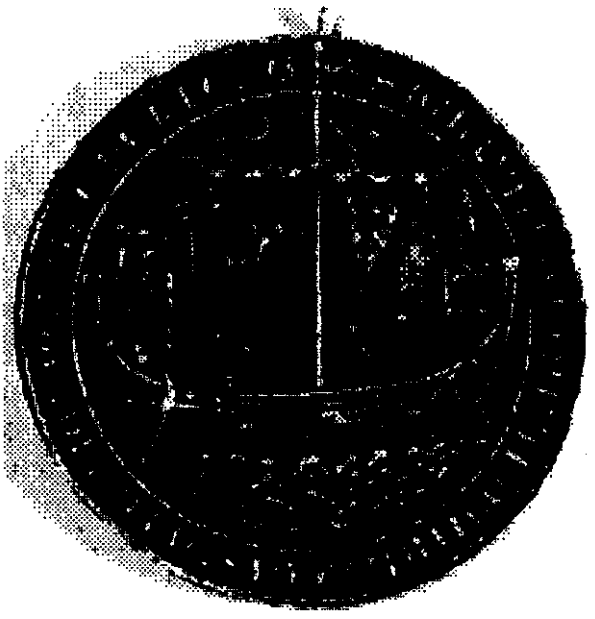

Figure 7.6 The City Seal of Winchelsea, dated 1274, showing a large *keel* using a quarter-rudder mounted with a withy or rope.

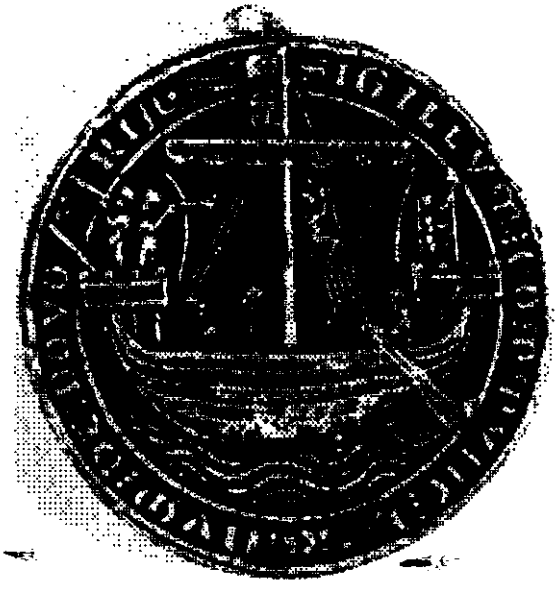

Figure 7.7 The City Seal of Dover, dated 1305. The ship, a *keel*, carries a quarter-rudder which rests on a throughbeam, and, as in the case of the Rye rudder, it is apparently mounted without a withy. The Rye quarter-rudder is shaped like that in the seal, and it may have come from a similar ship .

CHAPTER VIII
A COMBINATION OF INNOVATIONS

The introduction of the PG-rudder into the Mediterranean was one of the milestones in maritime history. Not only did it change the way ships were steered, it eventually changed the construction of the ships themselves in a profound manner. In discussing the effects of the PG-rudder on Mediterranean naval architecture, the question of exactly when it was introduced and adopted arises. Along with this question comes the issue of from where the sternpost-mounted rudder was introduced. Several authors have argued that the sternpost-mounted rudder came from the Arabic maritime tradition, and possibly from as far away as China. Before the impact of the PG-rudder on Mediterranean ships can be discussed, the issue of the source of its introduction has to be addressed, as this will also shed some light on when actually it arrived.

It has been argued by Needham (1971: 651-52) that the concept of mounting the rudder on the stern came from China and was transmitted to the Arabs by Chinese sailors. He has also suggested that the idea may have been carried to the Baltic by Russian traders (Needham, 1971: 651). Concerning this last suggestion, the problem is one of transmission. As was noted in the last chapter, verbal transmission is not very reliable, and the simple idea of mounting a rudder from the stern was not new in itself. With regards to the transmission of the sternpost-mounted rudder to the Indian Ocean, while the concept of mounting the rudder on the stern may have come from Chinese traders, it was so modified and changed that it hardly resembles its origins except in the grossest sense. As noted by Needham (1971: 653), Chinese vessels did not have a sternpost to which the rudder could be attached. Instead, it was suspended and held in place by an elaborate system of tackle. The idea of attaching the rudder to the sternpost in a relatively permanent fashion, therefore, must have been an Arab invention independent of the Chinese. Also, whereas the Chinese used tillers, Arab vessels used lines to control the rudder and did not adopt the tiller until the arrival of the Portuguese (Bowen, 1963: 304; Ministry of Info. of Oman, 1981: 112). This raises the question as to why the Arab sailors did not adopt the more effective tiller and yet borrowed the idea of a stern-mounted rudder. The above shows that the only actual concept which can be claimed to have been transmitted from the Chinese is the idea of a stern-mounted rudder, and not its method of attachment nor the manner in which it was controlled. Since that idea of putting a rudder on the stern can be traced back to the models found in Egyptian tombs, the need to have the concept brought into the Middle East is questionable at best. There is no evidence to support the contention that the sternpost-mounted rudder came from China, and no need to call on exterior sources for its introduction into the Mediterranean.

While there is virtually no evidence to suggest that the sternpost-mounted rudder was introduced from China, there is a strong body of evidence to suggest that the sternpost-mounted rudder was developed in the Indian Ocean and Middle East independently of, and possibly before, the PG-rudder appeared in northern Europe. The earliest evidence for a sternpost-mounted rudder comes from the *Ahsan al-Taqasim fi Marifat al-Aqalim* (The Best Divisions for the Classification of Regions) written by al-Muqaddasi in 985. In his book he writes:

> "The captain from the crow's nest carefully observes the sea. When a rock is espied, he shouts: "Starboard!" or "Port!" Two youths, posted

> there, repeat the cry. The helmsman, with two ropes in his hand, when he hears the calls tugs one or the other to the right or left. If great care is not taken, the ship strikes the rocks and is wrecked." (Collins, 1974: 151)

Though the above narrative was written in the 10th century, it is a perfect description of the steering tackle used to this day on the Arab *boum*, *badan* and *baggarah* (Tibbetts, 1981: 54-55; Ministry of Info. of Oman, 1981: 35, 112). On these ships the sternpost-mounted rudder is controlled by two lines, each attached to a crosspiece mounted on the rudder head perpendicular to the plane of the rudder blade. The above passage perfectly matches this steering system. On the other hand, it is very hard to imagine two quarter-rudders being controlled by two simple lines.

Descriptions of Arab sternpost-mounted rudders are also to be found in 13th century chronicles. John of Montecorvino wrote in the second half of the 13th century, "And they have a frail and flimsy rudder, like the top of a table, of a cubit in width, in the middle of the stern" (Hourani, 1963: 98-99). Marco Polo made a similar observation concerning the ships at Hormuz around 1272 when he later wrote, "And the ships have only mast and one sail and one rudder and have no deck" (Moule and Pelliot, 1938: I, 124). Both these descriptions have been dismissed by Johnstone and Muir as being unreliable (Johnstone and Muir, 1962: 62; Muir, 1965: 358). They state that the descriptions could be of a single steering oar, not a sternpost rudder. Their arguments neglect the fact that these narratives accurately reflect Arab construction techniques, both past and present. This is particularly true of the account of Marco Polo which describes construction features, such as sown hulls and treenail fastenings, which can be seen today on Arab ships.

Iconographic evidence for an Arab sternpost-mounted rudder comes from the *Suwar al Kawakib* (Book of Fixed Stars) written by al-Sufi around 1130 (Fig. 8.1). The stern of the vessel clearly has a sternpost-mounted rudder, along with two quarter-rudders. Another example comes from the *Maqamat of al-Hariri*, which dates to around 1235 (Fig. 8.2). The rudder yoke has been drawn in as two wood pieces projecting from either side of the rudder. Again, Johnstone and Muir reject these depictions as "fanciful", neglecting the fact that they closely match modern Arab rudders (Bowen, 1963: 303). In the former case, they argue that the ship has quarter-rudders, and so could not have a sternpost rudder. This argument, as will be shown, completely ignores the fact that Mediterranean vessels carried both types of rudders for over three hundred years after the PG-rudder appeared.

All of the above evidence points to the conclusion that Arab vessels were using the sternpost-mounted rudder by the end of the 10th century. Pryor and Bellabarba (1990: 107) reached a similar conclusion in writing that the sternpost rudder was in use in Mesopotamia, the Persian Gulf, and the Red Sea during the 11th through 12th centuries. Christides (1984:46) has suggested that the Byzantine navy was using the sternpost-mounted rudder by the 11th century. However, the textural evidence from Basil's *Naumachica* that he produces to support his argument is not conclusive. As pointed out by Pryor (1988: 60), the use of the singular of the word for *rudder*, instead of the plural, is hardly evidence that the rudder was mounted on the sternpost. He noted that the reference could easily apply to a stern-mounted steering oar, the use of which on galleys can be dated by iconography and written sources to the 11th and 12th centuries (Pryor and Bellabarba, 1990: 100, 106-107; Mott, 1990b: 103). It has also been pointed out that the cited passage refers to rowing oars and has nothing to do with quarter-rudders (Frederick van Doorninck, Jr., 1990: personal comm.). Furthermore, the iconography produced by Christides to support

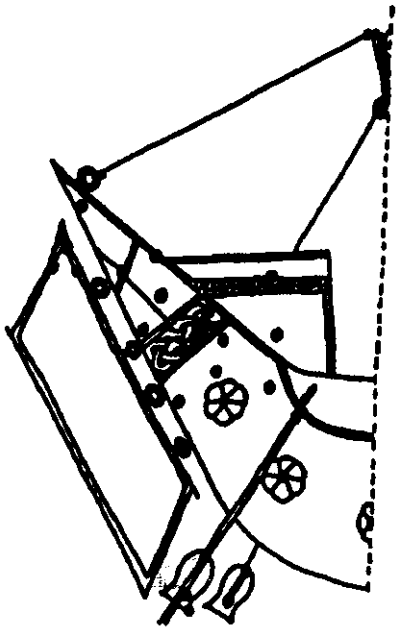

Figure 8.1 A depiction of an Arab vessel with both a sternpost rudder and quarter-rudders. This representation has been dismissed because the ship carries two kinds of rudders. However, medieval ships commonly carried both types. The picture comes from the *Suwar al Kawakib* (The Book of Fixed Stars) and dates to 1131 (After Nicolle, 1989: fig. 15).

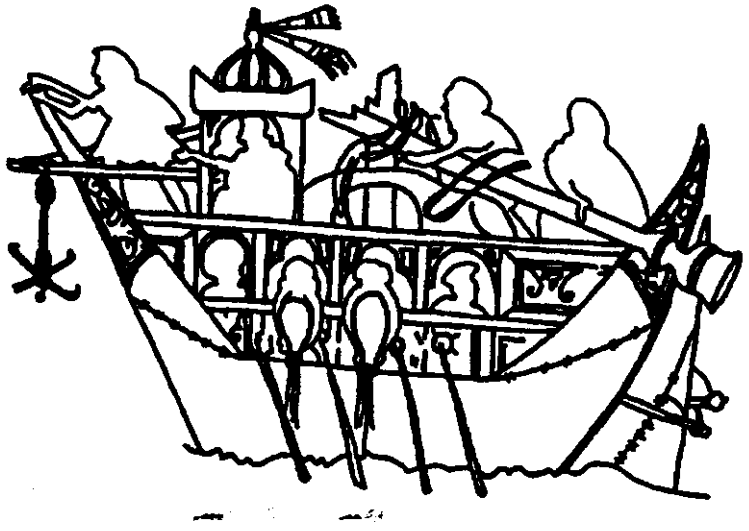

Figure 8.2 An Arab ship with the traditional lashed sternpost rudder, and the steering yoke with its associated control lines. The steering yoke, as seen above, can still be found today on Arab ships in the Persian Gulf. The representation comes from the *Maqamat of al Hariri* and is dated between 1225 and 1235 (After Nicolle, 1989: fig. 23).

his contention cannot be dated accurately, and more resembles ships from the 14th century than the 11th century (Pryor, 1988: 60-61). At present, there are no iconographic representations of Latin or Byzantine ships with sternpost-mounted rudders before the second half of the 13th century.

The above facts present an interesting paradox. There can be little doubt that Arab ships in the Indian Ocean were using the sternpost-mounted rudder by the 10th century, and yet its use does not appear to have spread to navies and general shipping in the Mediterranean. There can be little doubt that the sternpost-mounted rudder was introduced into the Mediterranean by Muslim shipwrights, but the fact remains it was not widely adopted, or even used. This would seem to indicate that the sternpost-mounted rudder, by itself, was not the panacea of navigation that its proponents have made it out to be. The reason that the Arab sternpost rudder was ignored can be traced to the method of its mounting. As noted by Marco Polo, the Arab shipwrights did not use any iron in the construction of their ships, which meant that it had to be fastened to the sternpost by lashings. As with quarter-rudders, lashings have to be constantly maintained, particularly if they are constantly submerged or wet. Furthermore, there is abrasion due to normal use. The problem with the Arab system was that the only way to inspect the fastenings was to send a diver over the side. All of this combined to create a mounting system which was inherently weak.

Evidence that Arab rudders were unreliable comes from both medieval and modern sources. In the *Umda*, Sulaiman al-Mahri wrote, in 1511, that the rudder must be checked every day, and repeated this warning in the *Minhaj* where he wrote, "It is desirable therefore that the pilot should examine his rudder every day and similarly all the equipment of the ship. Another grave danger for the rudder is being hit broadside by large waves." This admonition to constantly check the rudder was later repeated by Sidi Celebi (Tibbetts, 1981: 390). In the voyage of the Arab dhow replica, the *Sohar*, it was necessary to stop and send divers over the side to repair the rudder lashings before the vessel had even left the Indian Ocean (Severin, 1982: 27). The above indicates that the Arab sternpost rudder could not withstand much punishment and was a constant source of concern. If nothing else, it appears to support the contention of John of Montecorvino that the Arab rudders were "flimsy." The lack of a suitable mounting method for the Arab sternpost rudder probably is the reason it was virtually ignored by Mediterranean shipwrights. The *Sohar*, which had problems with its rudder, had a displacement of only 58 metric tons. The difficulties encountered with a lashed rudder must have increased with the size of the vessel to the point where it would have been unusable.

The steering system which was used on Arab ships was not particularly suited for large ships either. The system of controlling lines has persisted in the Persian Gulf, but only on relatively small vessels. Today, the larger vessels use the tiller, which was introduced by the Portuguese in the 15th century (Bowen, 1963: 304; Ministry of Info. of Oman, 1981: 112). Both the method of attachment and the control system prevented the Arab rudder from being adopted on the large vessels which were being used in the Mediterranean. Compared to the quarter-rudder systems in use, the Arab sternpost rudder offered no advantages and was therefore ignored.

The early use of a sternpost-mounted rudder, the problems with its attachment and control, and the overall indifference to it by Mediterranean mariners points to a central fact. The adoption of the sternpost-mounted rudder in the Mediterranean is an issue concerning not only the effectiveness of the rudder itself, but also the method of attachment. Clearly, the reason for the sternpost rudder not evolving in the Mediterranean is not due to a problem of developing the concept. Models with single steering oars mounted on the stern have been found in Egyptian tombs dating to 2000 B.C., and Roman river craft are

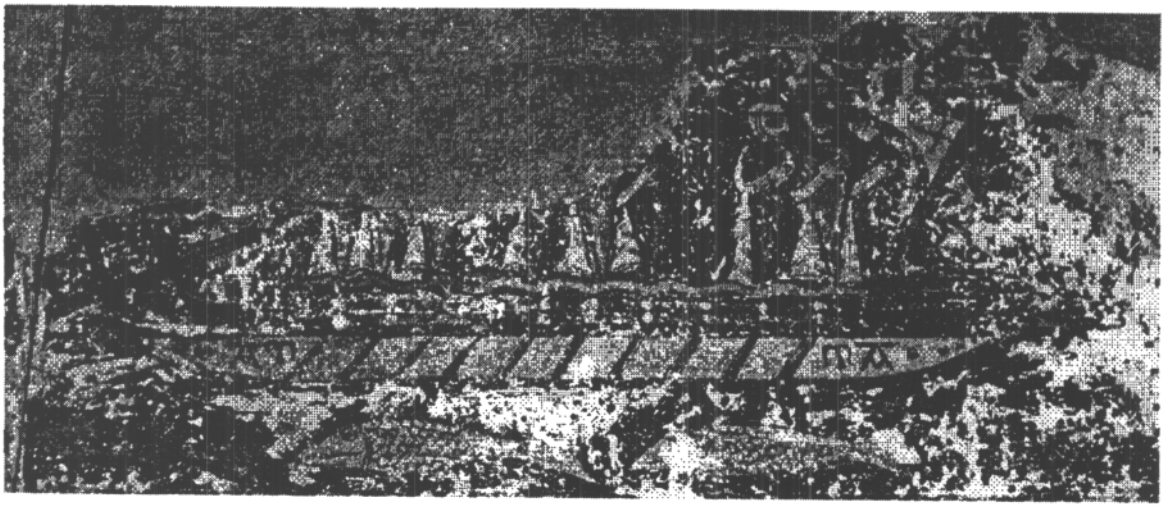

Figure 8.3 A mural showing a light war galley using a single steering oar. The mural comes from a castle near Lerida, Spain and is dated to circa 1200 (Museo de Arte de Catalunya).

known to have employed a similar system. Mediterranean sailors had been using single, stern-mounted steering oars to control small vessels since Roman times and were commonly employing them on light war galleys in the 12th and 13th centuries (Fig. 8.3). The Latin mariners would also have been exposed to the Arab sternpost rudder through trading contacts and the Crusades. Therefore, the question concerning the widespread adoption of the sternpost-mounted rudder in the Mediterranean should not be when it was introduced, but when the pintle-&-gudgeon system was introduced into the Mediterranean.

Exactly when the PG-rudder was introduced into the south is difficult to determine. However, even using the date of the Westminster font as the earliest possible appearance of the PG-rudder, it is very probable that it was carried into the Mediterranean at the start of the Second Crusade in 1147 by one of the 190 ships which set sail from the north (Unger, 1980: 129). With the PG-rudder coming into common use in the north by the end of the 12th century, there can be little doubt that it had been introduced during the Third Crusade of 1190 and the Fourth Crusade in 1204. Since the PG-rudder was intimately associated with the *cog*,, the above contention is supported by the fact that Jaime I used *cogs* in the invasion of Mallorca in 1229 (Lewis and Runyon, 1985: 74). Iconographic evidence for the introduction of the PG-rudder by *cogs* in the 13th century comes from the Cathedral of Palma de Mallorca. Graffiti of *cogs* in the belltower have been dated as having been made prior to 1367 and stylistically match cog representations on seals dating to the mid-13th century (Mott, 1989: 14). Based on the above, it is clear that PG-rudder was in use in the Mediterranean by the mid-13th century, if not earlier.

It has been a general truism that the PG-rudder was introduced into the Mediterranean at the start of the 14th century and that it quickly replaced the quarter-rudder system on virtually all vessels (Lane, 1934: 37; Lefebvre des Noëttes, 1934: 40-41; 1935: 107; Sleeswyk and Lehmann, 1982: 301; Lewis and Runyon, 1985: 74-75). This belief has been predicated on the fact that there is a dearth of both iconographic and written sources regarding the PG-rudder through the 13th century and then a virtual explosion of data at the beginning of the next century. Yet the evidence indicates that the PG-rudder had been in the Mediterranean for nearly a hundred years before the 14th century. This suggests the PG-rudder was only gradually adopted and did not come into widespread use until the start of the 14th century. Not only does

this indicate that mounting the rudder on the stern was not in itself a major technological breakthrough, but it also calls into question other assertions concerning the superiority of the PG-rudder.

One of the most persistent claims made concerning the quarter-rudder was that it could not be mounted on large vessels, and therefore an increase in ship size was prevented until the introduction of the PG-rudder. As a corollary to this contention, it has been argued that the great voyages of discovery were not possible until the introduction of the PG-rudder (Vaughan, 1913: 136; Lefebvre des Noëtes, 1933: 631-32, 647; Moulinier, 1933: 39-41; Lefebvre des Noëtes, 1934: 32-36; Saint-Denis, 1934: 396; Lefebvre des Noëtes, 1935: 69-71; Bernard, 1968: 277). These authors proposing this thesis either neglect or dismiss the fact that Roman grain carriers exceeded in size most ships of the 16th century. From the 5th century B.C. onwards, cargo vessels of 350-500 tons burden were not uncommon. These vessels were much larger than the ships that made the voyages of discovery (Casson, 1971: 172). The crusader transports demonstrate that during the 13th century quarter-rudders were commonly used on vessels over 350 tons burden. In comparison, the *Santa Maria*, which crossed the Atlantic Ocean, only had a capacity of around 120 metric tons (Martínez-Hidalgo, 1976: 27). There are also representations of large merchant ships with quarter-rudders up through the 15th century (Figs. 6.5 & 6.24). The above indicates that the quarter-rudder system was sufficiently flexible to permit its upscaling for use on large vessels. The voyages made by large transport ships during the crusades demonstrates that the quarter-rudder was certainly not an absolute hinderence to ship size or voyage duration. The same observation can be made for the northern ships which sailed to the first three crusades.

Yet the tremendous weight of these rudders must have created difficulties. The problem of attaching adequately to the hull these large, heavy devices by only two points, and yet allowing them to turn freely, must have strained all of the availible mounting systems. The quarter-rudder had probably reached the upper limits in regards to size by the mid-13th century. At the time this was probably not a major problem, since the ships on which these 19-meter-long monsters were being used were exceptional in size compared to the average medieval ship. The average-size Venetian ship working the Black Sea at this time was rarely larger than 500 tons (Bryer, 1966: 4). However, as time progressed, the average ship size did increase, so that by the 15th century the ability of the pintle-&-gudgeon system to securely attach a large rudder to a ship must have been appealing and probably contributed to the eventual demise of the quarter-rudder.

Certainly, handling a quarter-rudder weighing several tons entailed its own set of problems. However, if size, weight and reliability were the only controlling factors in regards to the adoption of the PG-rudder, it would seem reasonable to expect the change to the new system to have occurred in the early 13th century. It would appear, then, that there were other factors impacting not only the acceptance of the PG-rudder, but also the continued use of the quarter-rudder long after the former's introduction.

A solution to this riddle comes from the sailors who are still using quarter-rudders to this very day. Not only does their response suggest why the quarter-rudder persisted so long after the appearance of the PG-rudder, but also on why it was eventually replaced. When asked why they preferred using quarter-rudders even though they could easily have used a PG-rudder, the captains of Indonesian *pinisi* invariably answered that they could be repaired at sea; they required no iron fittings; they lifted over shoals; they could be easily shipped when the vessel was aground or hauled out; and most importantly, the ships simply handled better than when fitted with a PG-rudder (Horridge, 1979: 32). Each one of these points is as valid for the 13th century as it is for today.

The first and second responses are not surprising considering the simplicity of the quarter-rudder systems. While all the various mounting schemes had a system of tackle associated with them, the fact remains that the only part which could be permanently damaged was the rudder itself. Even the fixed mounts were no more than heavy, modified throughbeams which were so robust that even if the rudder was impacted so hard that it broke, the chances of the mount itself being damaged were small. In the case of swing or aft-mounted rudders, the damage was probably no more than broken lashings and tackle. A case in point is the *Chronicle of Pero Niño* dated between 1431 and 1449. Concerning a storm they were caught in, his standard-bearer wrote:

> "Todavía se metía el viento màs fuerte, e con la grand fuerça de las olas trocàronse los timones de caxa en la galera del capitàn, e hera la galera a unto de se perder. Llamando todos a Santa María que los acorriese, cobraron los timones, e amaynaron la bela, e lançaron toda la gente so sota, e hecharon las escotillas al escandelar e a todas las çentinas" (Diez de Games, 1940: 111). (The wind became stronger still, and with great force the wave broke loose the quarter-rudders of the captain's galley, and it was at the point of being lost. Everyone called upon Santa María to succor them, and then they recovered the rudders, and lowered the sail, and sent everyone below, and fastened the hatches of the *escandelar* and all the other cabins.)

The above passage, while showing that quarter-rudders were susceptible to being lost in a storm, also demonstrates that the rudders could be recovered and remounted. Such a feat would have been impossible with a PG-rudder. Moreover, even though the rudders were ripped from the ship, there was no collateral damage to prevent remounting them.

Even if the rudders were damaged, the quarter-rudder system had a distinct advantage in that a temporary quarter-rudder could be made out of any spar on board the ship. This is directly alluded to by a 13th century law from the *Consolat del Mar* (Appendix III, 31). The law in question states that an owner has to reimburse the captain if he has to use another part of the ship to make repairs. As an example the law uses the case of having to utilize one of the yards as a quarter-rudder. Because a spar could be shaped to make a quarter-rudder, and mounting it required no special fittings, making repairs while underway was not a particularly debilitating task, especially since the vessel would have had the other rudder to control the ship. This was certainly not the case for the early PG-rudders.

The curved sternpost was a traditional feature of Mediterranean ships dating back thousands of years. A PG-rudder could be fitted to a curved sternpost, but there were several limitations to doing so (Fig. 8.4). The major drawback to mounting a rudder on a curved sternpost is that only two sets of pintles and gudgeons can be used. The advantage of the northern *cogs* was that with a straight sternpost numerous sets could be used, resulting in a very strong mounting system. The use of a curved sternpost meant that only two sets of pintles and gudgeons had to bear the weight of the rudder and absorb any forces applied to it. This weakened one of the main advantages which had initially brought the PG-rudder into use. Moreover, probably to facilitate mounting, PG-rudders mounted on curved sternposts had the lower pintle mounted on the hull, not on the rudder. Because the pintles were more susceptible to damage during an accidental dismounting, this meant there was a greater likelihood of the ship being unable to remount a rudder in case of an accident. On top of all this, to facilitate mounting, the lower pintle-&-

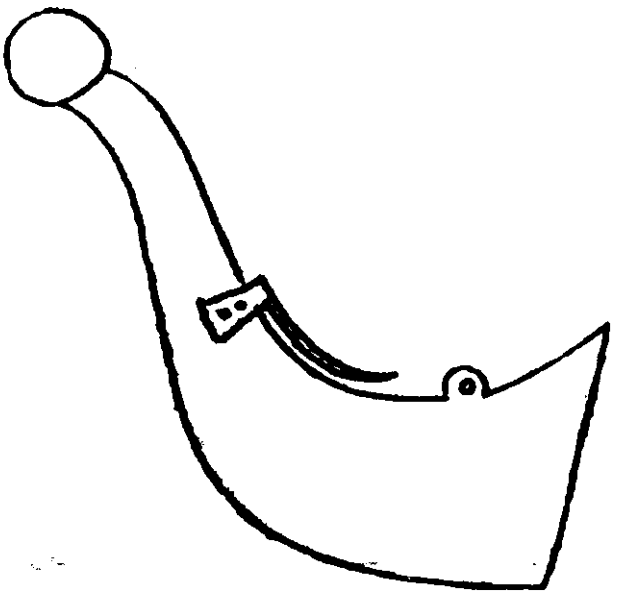

Figure 8.4 A drawing of a curved pintle-&-gudgeon rudder from *Fabrica di galere* (fol. 13). The drawing shows how this type of rudder had only two fastenings, and that one of the gudgeons was mounted on the rudder itself (After Sleeswyk and Lehmann, 1982: fig. 9b).

gudgeon set was not placed at the sole of the rudder, but nearly a third of the rudder's length up from the sole. As mentioned in the previous chapter, the absence of a set at the sole would have added a further weakness to the system.

As noted by *pinisi* captains, the lack of iron in the quarter-rudder system means that the tools and skill required for repairs are much less. The use of iron in medieval PG-rudders was extensive. Not only were the fittings iron, but the rudders had to be reinforced extensively with iron. Heavy reinforcement was necessitated by the wide rudder blades which were required to adequately control the ships (Fig. 8.5). The wide blades required composite construction and, therefore, numerous reinforcement bands to hold them together. Not only did this add to the cost of fabrication, it also virtually precluded the manufacture of a spare rudder on board a ship.

The need to carry a spare rudder is made apparent in a passage from the *Libre dels Feyts* (fol. CLXXIX v.) written by Jaime I El Conquistador describing an incident on his trip to Palestine in 1269:

> "E quan vench aquel dia, vim la nau del Temple sobre nos, e envians messtage que el timo havia trencat, e quens pregaven quels en dessem I. E nos voliem lo ls, e dix nos En Ramon Marquet que no u faessem, car la nostra nau no devia anar menys de I timo que haja sobrer."
> (And when that day came, the ship of the Templars came upon us and sent a message that the rudder had broken, and then begged that we give them one. And we wanted to give it to them, but En Ramon Marquet told us not to do it because our ship should not go without an extra rudder.)

In the above passage, the writer makes an important distinction in that he speaks of *the* rudder, and not *a* rudder. This strongly indicates that some ships were using a PG-rudder by 1269. If the ship had not been using one, there would have been no immediate need to beg for a spare rudder, as the ship would have had the other quarter-rudder. Because temporary quarter-rudders could be made out of any large spar, the need to find another rudder would not have been as great as the passage indicates. The refusal of Ramon Marquet to give his only spare rudder to the Templars indicates that his ship had a PG-rudder; if he had quarter-rudders, the fear of giving up the only spare would not have been so critical. The passage also hints that rudder loss was common enough to make it unsafe to give up the only spare rudder.

Ease in lifting the rudder in shallow water is also an important point. As can be seen in Figure 8.5, the curved rudders, particularly on galleys, commonly extended below the keel of the vessel. This meant that a ship sailing in shallow waters ran the risk of having the rudder ripped off the sternpost if the vessel passed over a shoal that was deep enough to miss the keel but too shallow for the rudder to clear. It also forced the crew to remove the rudder every time the ship was careened. The quarter-rudder systems did not have this flaw. If the ship was passing through known shoal waters, the rudders could be raised until their soles were above the keel. In the case of the swing mount, the rudders would simply pivot up if they struck an underwater obstacle. However, with the advent of the fixed mount, many medieval shipwrights seem to have given up this latter advantage.

The final point made by *pinisi* captains is that the ships handled better with quarter-rudders than with a PG-rudder. The *pinisi* have curved sternposts much like the Roman and early medieval ships. Because the vessels lack any deadwood, the quarter-rudders act as an extension of the keel to prevent excessive yawing by the ship. The two quarter-rudders also provide more turning moment than any single rudder could. These factors were accentuated on medieval ships. The curved and round-tucked sterns lacked any deadwood to prevent yawing, and were very blunt, which caused a great deal of turbulence behind the ship. As with the northern *cog*, this turbulence substantially degraded rudder performance to the point where wide rudder blades had to be used (Fig. 8.5). This turbulence would also prevent even the wide rudders from providing the same degree of lateral stability that quarter-rudders would have. An excessively wide rudder to control the ship forced the use of a long tiller to compensate for the increased torque created by the wide blade. All of this combined so that overall, quarter-rudders would have provided better handling and stability than a PG-rudder.

Because of the numerous drawbacks involved in using a PG-rudder, it is not surprising that initially it was not widely accepted in the Mediterranean. Yet there is substantial evidence that it was used on some ships during the 13th century. There were probably several reasons why southern shipwrights experimented with the PG-rudder despite its flaws. It was probably first used on *cogs* which were built as copies of the ones that sailed into the Mediterranean from the north. As the shipwrights and shipowners became familiar with the new device, they perceived several advantages for using it. Probably the biggest advantage was the increase in speed which the vessels using a PG-rudder gained versus ships using quarter-rudders. The increased drag caused by even one large quarter-rudder must have been substantial, and shipowners must have been at least passingly interested in a device which would increase ship speed and decrease transit times. There is no present test data to quantify exactly the increase in speed the use of a PG-rudder versus a quarter-rudder would entail, but the difference must have been very noticeable, if the results from the *Olympias* trials are any gauge (Coates, 1990: Appendix IV).

The other possible reasons for interest in the PG-rudder system involve the actual construction of

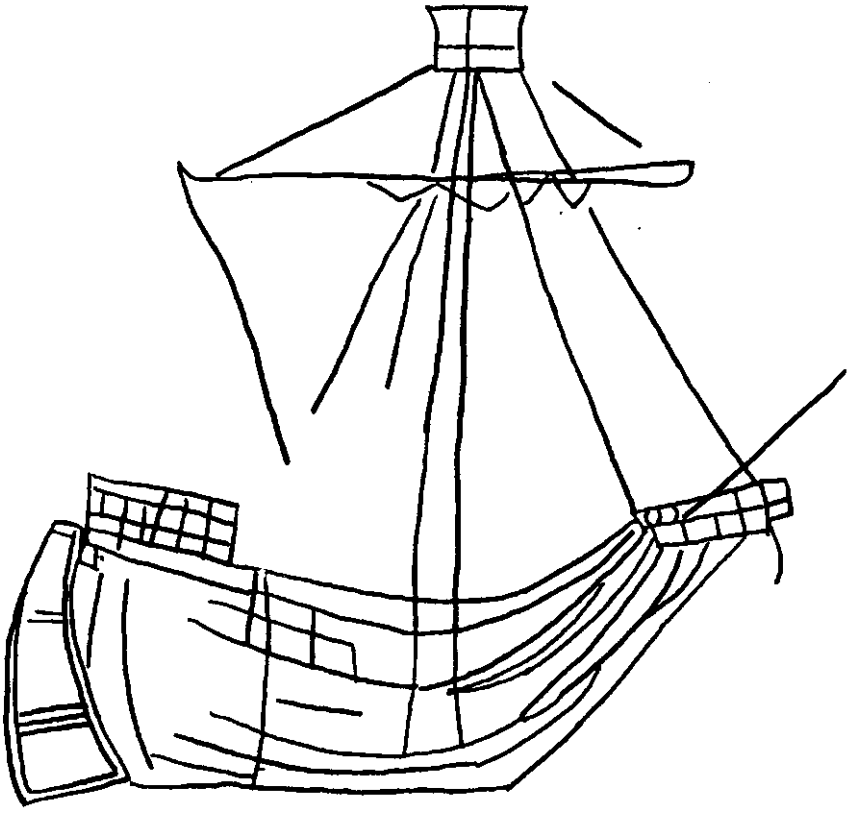

Figure 8.5 A tracing of a graffito of a large medieval ship from the belltower of the Cathedral of Palma de Mallorca. The drawing shows the wide rudder required to overcome the turbulence caused by the unfaired, rounded stern. The depiction was definitely made sometime before 1367. Other ship depictions associated with it suggest that the drawing probably dates to the late 13th century.

rudders and their mounts. While the use of the PG-rudder required specialized parts such as the pintles and gudgeons, the additional construction necessary to operate it was actually small compared to a quarter-rudder system. The PG-rudder simply required the pintles and gudgeons themselves, and an opening in the stern for the tiller. On the otherhand, a quarter-rudder system required not only the fabrication of two rudders but also numerous specialized construction features. Heavy throughbeams and supports had to be added, specialized wood collars had to be made for fixed mounts, or rudder guides for swing mounts, and galleries or platforms added for the upper support and the helmsman. The savings gained by the elimination of these parts alone may have provided enough savings for shipowners that they were willing to overlook the potential problems created by the new system.

A decreasing ability to find suitable trees to make rudder shafts also may have played a part. The written documents show that oak, mahogany and holly were the main woods used for rudder shafts. These species do not grow particularly straight in the Mediterranean, and as the length of quarter-rudders increased, finding a straight piece of oak up to 19 meters in length and 73 centimeters in diameter must not have been an easy task. There is some iconographic evidence that the large quarter-rudder shafts were of composite construction (Fig. 5.1 A, B, C, D, F & H). If so, this would have weakened the rudder con-

siderably, as well as adding to its cost. While composite construction would have increased the shaft's resistance to bending, it would have weakened the shaft with regards to a twisting motion such as created by rudder torque. The PG-rudder had the advantage that it could be made out of several pieces of wood and bound together with iron straps. While some quarter-rudder blades were made this way, it was a difficult proposition to make a long shaft out of several short pieces of wood which could withstand considerable torque.

Finally, the tendancy of quarter-rudders to break in rough weather conditions must have played a part. As we have seen, most replicas which have used the southern quarter-rudder encountered this problem, and no amount of tinkering would solve the problem resulting from a significant portion of the rudder shaft being unsupported. We have no information from which the frequency of shaft failure can be gleaned, but the problem must have become more frequent as rudder size increased. This, coupled with the massive weight of the large rudders, must have induced some shipwrights to look for an alternative.

All of the above reasons give some clues as to why some shipwrights may have changed to the PG-rudder in the 13th century, but the fact remains that it did not come into widespread use until the start of the 14th century when it suddenly began to replace the quarter-rudder on many ships. The PG-rudder, as originally configured, had too many drawbacks for it to be widely accepted, and had to await the introduction of a construction technique which would greatly improve its performance. When looking at the differences between ships of the 13th and 14th centuries, the one which perhaps is the most striking is the straight vertical sternpost found on many of the latter vessels. The introduction of this design feature not only changed the way the rudder could be mounted but also profoundly changed the handling characteristics of the ships themselves.

Putting a vertical sternpost on the traditional southern hulls created advantages which were unforseen by the shipwrights who employed the new design. Initial use of the vertical sternpost probably arose from the desire to strengthen the rudder attachment by using more than two sets of pintles and gudgeons. The advantage of using a vertical sternpost, instead of an inclined one as found on northern *cogs*, was that mounting and dismounting a PG-rudder with several sets of pintles and gudgeons was substantially easier. The rudder simply had to be lowered onto the gudgeons, whereas a rudder mounted to an inclined straight sternpost had to be pulled up under the ship, which made mounting considerably more difficult. It must be remembered that the laws concerning the dismounting of rudders while in port applied equally to PG-rudders as well as to quarter-rudders. La Roërie (1937: 580) suggested that ship owners were encouraged to use the PG-rudder as a means of circumventing these laws. However, Statue LXVIII of Ancone, dated 1397, clearly refers to a single rudder, not to a set of quarter-rudders. This indicates that, regardless of the type of steering device, every ship was expected to comply (Appendix III: 32). A vertical sternpost allowed more fastenings to be fitted and facilitated mounting.

While the vertical sternpost facilitated both strengthening and mounting of the PG-rudder, the consequence of its adoption was considerably greater. The only way that a ship could have a round-tucked stern with fair lines and have a straight vertical sternpost which extended to the depth of the keel was by filling in the area between the level of the keel and the rising frames with deadwood or thin, wineglass-shaped frames. The deadwood and narrow frames formed a fin and gave a vessel a fine run to the rudder, even if the ship had a full stern like the Mataro model (Fig. 8.6). Compare this to the bluff stern of the *reliquerio de San Blas* which is made like a cog down to the lapstrake construction (Fig. 7.5). In the latter case the hull is not faired into the rudder, which would have created a great deal of turbu-

lence. Even on ships where the deadwood formed only a small fin, the effect on ship behavior would have been dramatic.

The effects of a fine run at the stern were probably best described by John Charnock (1801: III, 368) when he wrote:

> "The action of the rudder, which is certainly one of the most material discoveries in aid of navigation, depends in great measure on the clearness of the vessel's run, that is to say, on the after body being so tapered, that the fluid through which it is forced, either by impulse of the wind, or by artificial means, shall have such a clear and unimpeded passage, that the inclination of it may act upon it with the greatest force, and produce the effect required in the government, or steerage of the vessel. Those nations which, from peculiarity of construction, founded either on a local partiality for certain principles, or, in general, from necessity itself, have thought proper to deviate from this rule, have found it necessary to construct the rudders of their vessels much broader than would be necessary among a people less bigoted to absurdity, or less dictated to by powers they are unable to resist."

Rankine (1866: 95) made a similar observation:

> "It is also necessary that the rudder should be immersed, not in a mass of eddies dragging behind the ship, but amongst particles of water whose motion, relatively to the ship, consists in a steady astern. Hence the same fairness and fineness of the waterlines and buttocklines of the afterbody which are essential to speed and economy of power are essential to good steering also."

Both the above passages demonstrate the beneficial effect of clean, non-turbulent flow across the rudder and hint at several other advantages as well.

When a rudder is hung as a flap at the end of a fin structure formed by narrow frames and deadwood, the differential pressures created by turning the rudder not only act on the rudder itself but also extend along the deadwood, thus increasing the amount of turning moment and transmitting it directly to the hull (Rossell, 1942: II, 208; Saunders, 1957: I, 572-573). The upshot of this is that a rudder hung on the end of a fin formed by deadwood can be much narrower than a single isolated rudder and still produce the same amount of turning moment. Furthermore, the center of pressure moves forward on the rudder so that the rudder torque decreases. The decrease in rudder torque along with the decrease in rudder width allowed placement of the PG-rudder, still manually controlled, on large vessels. Finally, the addition of deadwood decreases the response time of the ship to turning by increasing turning resistance. The fin the deadwood forms under the hull, much like the feathers on an arrow, provides resistance to turning by forcing water to flow around it during a turn. While this makes a vessel turn slower, it also increases lateral stability. Experience has shown that ships with little or no deadwood tend to yaw badly in a heavy sea (Rossell, 1942: II, 208; Saunders, 1957: I, 572-573; Gillmer and Johnson, 1982: 279).

The adoption of the vertical sternpost, and the fin which the narrowed frames and deadwood created gave all of the benefits that had been associated with the quarter-rudder and more. The new ar-

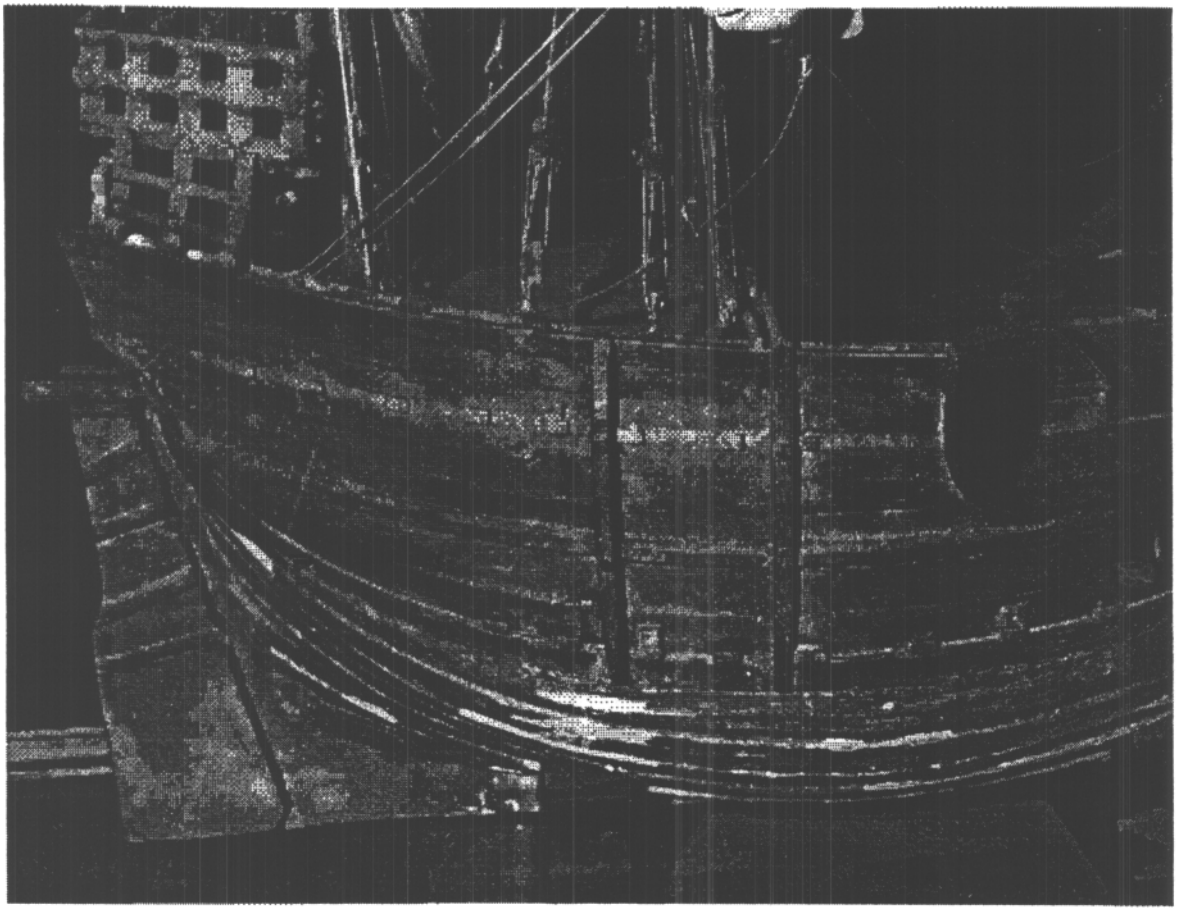

Figure 8.6 A view of the stern of a replica of the Mataro votive ship showing the vertical sternpost and the extensive deadwood leading up it (Museo Marítimo, Barcelona).

rangement not only provided lateral stability and increased rudder performance, but it also reduced overall drag on the vessel and provided a relatively strong mounting system. It is no coincidence, then, that as the PG-rudder comes into widespread use at the start of the 14th century, the vertical sternpost becomes a common feature on Mediterranean vessels. One of the earliest examples of the use of a nearly vertical sternpost comes from the cover of *Lletres Conunes,* dated 1342 (Fig. 8.7). Other examples are the sarcophagus from Cardona, Spain, dated to circa 1350, and the relief of *The Life of Santa Ursula*, dated to 1360 (Figs. 8.8 & 8.9). By the 15th century, some ships were making use of extensive deadwood sections as can be seen on the ship in Figure 8.10.

It is quite possible that the vertical sternpost came from the north at the end of the 13th century. There are several indications that near-vertical sternposts, and their associated deadwood, were in use before the 13th century and were used on the *knarrs* and *keels* of the north. Northern shipwrights kept the traditional curved stempost but adapted the vertical sternpost of the *cogs* to their clinker-built vessels. A graffito from Gotland, dated to the early 13th century, clearly shows these characteristics (Fig. 8.11). Other medieval examples are the first Seal of Sluis, dated 1293, and the ship on the tomb of Alexander

McLeod in Scotland (Figs. 8.12 & 8.13). One of the best archaeological examples is the 13th century Kalmar boat found in Sweden in 1932 (Landström, 1961: 74-75).

There is no way of knowing whether or not the vertical sternpost was introduced from the north, but a passage by Giovanni Villiani written in 1304 may be a hint that it was. He wrote:

> "At this time some people passed through the Strait of Sevilla (Gibraltar) with their ships, called cogs, with which they pirated on this sea and caused much harm. Since then the Genoese, the Venetians, and the Catalans have begun to employ cogs for their seafaring, and have abandoned the use of their own larger ships in order to secure the seaworthiness and reduced costs of the cogs. This circumstance has constituted a substantial change in our concept of sailing" (Mott, 1990a: 18-19).

Villiani's statement has been called into question, mainly because both the *cog*, and its square rig, had been introduced into the Mediterranean long before the 14th century. It has also been shown that the "cogs" he was writing about were, in fact, probably *keels* from the north coast (Mott, 1990a: 18-19). Yet, despite these discrepencies, the fact remains that at the turn of the century there was a dramatic shift in ship construction in the western Mediterranean. His statement is supported by the fact that there is no indigenous Spanish art work which can be dated later than the last quarter of the 13th century that contains a traditional roundship. The ships on which Villaini commented were probably larger and more seaworthy varients of the northern ships which first came into the Mediterranean over a century before. There is no evidence for or against the proposition that these vessels carried PG-rudders mounted on vertical sternposts, but there is no denying that at the time Villiani was writing his chronicle the ships of the western Mediterranean underwent a dramatic change, including the widespread adoption of the PG-rudder and a vertical sternpost.

Another factor which greatly facilitated the employment of the PG-rudder was use of multiple masts. Ships in the Mediterranean had been using multiple masts for centuries. The main advantage of two or more masts was that the sail plan could be balanced so that the rudder was only needed for minor course corrections (Baker, 1983: 50). Even if the rudder was lost, as on the ship of the Templars, the vessel could still be controlled by adjusting the sails. Modern *pinisi* captains often use this technique to sail with the rudders completely shipped in order to demonstrate their sailing prowess (Horridge, 1979: 32). Because of the advantages of having a balanced sail plan were so obvious, it is not surprising that it was immediately applied to the new ship designs at the start of the 14th century (Bellabarba, 1988: fig. 18). By at least 1406, full-rigged ships with three masts had appeared (Fig. 8.14).

The last addition, which would combine with the PG-rudder to create a superior steering system, was the introduction of the spritsail towards the end of the 15th century. It further enhanced the ability of the crew to balance the sails so as to increase control and decrease reliance on the helm. The mizzen sail was useful for balancing the helm for a ship going to weather, but was nearly useless if the ship was sailing with a quartering wind. During the voyage of the Mayflower replica, the mizzen sail was often taken in when the wind was from the beam or astern (Charlton, 1957: 128, 151). Under these same conditions the spritsail provided enough force to control the ship. Captain Villiers noted that "the spritsail proved to be a fine maneuvering sail" and also noted that it offset the substantial windage of the ship's

Figure 8.7 A ship on the the cover of *Lletres Conunes*, dated 1342. This is one of the earliest depictions of a Mediterranean ship with a vertical sternpost (Archivo Reino de Mallorca).

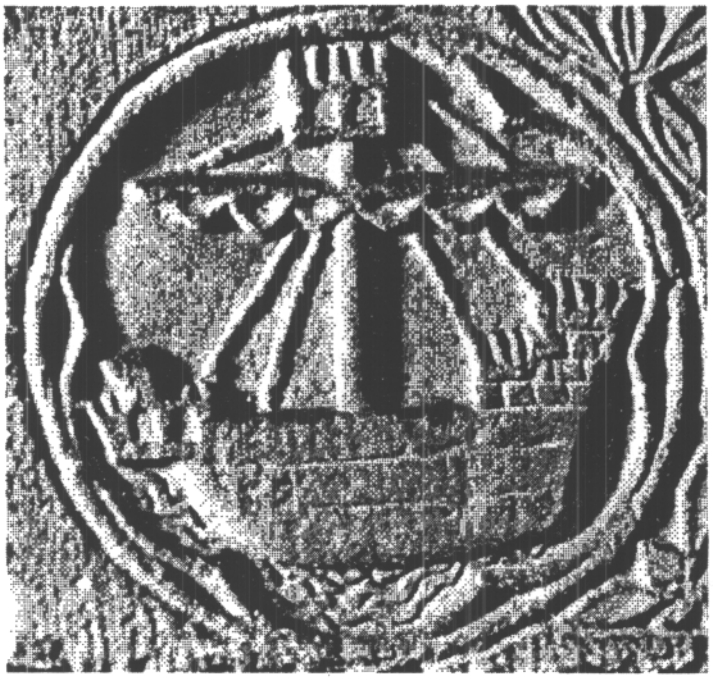

Figure 8.8 A sarcophagus from Cardona, Spain, dated to circa 1350, showing a ship with a straight sternpost (From the photo archive of the Museo Marítimo, Barcelona)

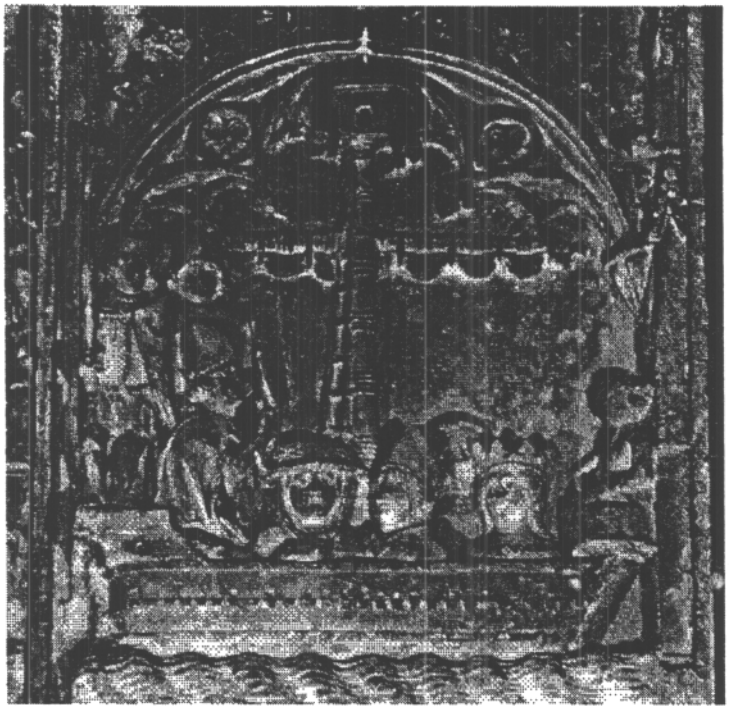

Figure 8.9 A relief entitled *The Life of Santa Ursula,* dated to 1360, at the church of San Martin in Lerida, Spain.

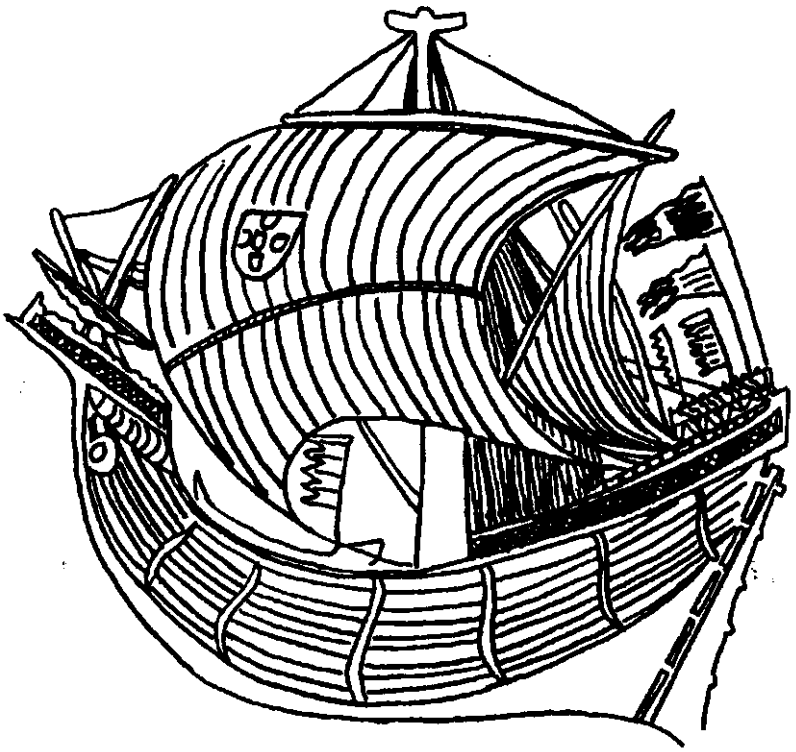

Figure 8.10 A ship from an early 15th century plate. The ship has all of the innovations to make the PG-rudder effective: a foremast, mizzenmast, and extensive deadwood forming a fine run to the rudder (After Landström, 1961: fig. 255).

high poop (Villiers, 1962: 144). With the addition of this second maneuvering sail, the full-rigged ship had all of the necessary instruments to fully control the largest of vessels.

Despite all of the advantages the new combination of sail and hull design brought, the quarter-rudder persisted into the 17th century for a variety of reasons. A major factor was that the various changes were not introduced together, but slowly over a period of two centuries. The change in hull design was not fully adopted for over two centuries, as can be seen in Figure 8.15, where the ship still carries a rudder for a curved sternpost. Excavations have shown that the *nave latina* with its curved sternpost and bluff stern continued to be used into the mid-16th century, which virtually assured that the quarter-rudder would continue to be used also (Bonino, 1978: 18-21). Without the straight sternpost and deadwood a ship would have better control and stability from two quarter-rudders. Undoubtedly, the retention of the older hull design can be attributed to tradition, but also in part to the needs of particular vessel types. Many of the ships which continued to use the quarter-rudder were small coasters which required a high degree of maneuverability (Fig. 8.16) Another factor in their continued use was that these vessels were relatively small and therefore did not require large, massive quarter-rudders.

The quarter-rudder persisted, even on sailing ships that had PG-rudders, up to the start of the 16th century (Figs. 6.1 & 6.24; see pages 113 & 114; Appendix III: 21). The use of both rudder systems on one vessel was influenced by several realities. It was probably initially prompted by the early short-comings of the PG-rudder. The early examples of this combined system show ships with a curved PG-

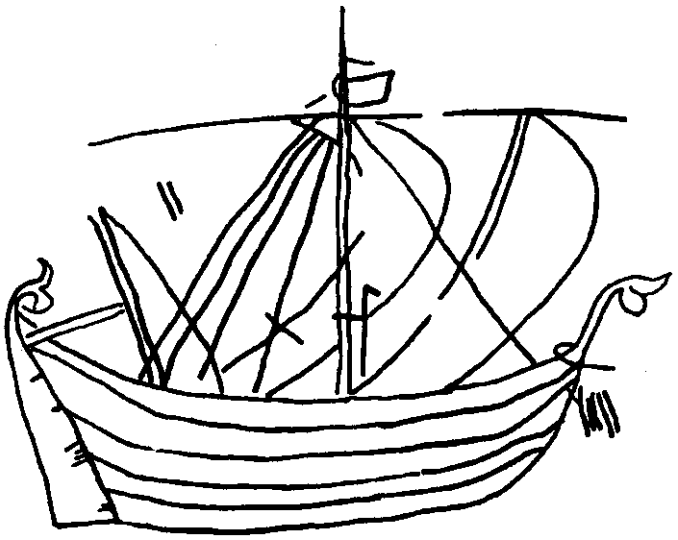

Figure 8.11 A tracing of an early 13th century graffito in a church in Gotland. Besides having a straight sternpost, the ship appears to have a tiller which curves around the sternpost (After Landström, 1961: fig. 174).

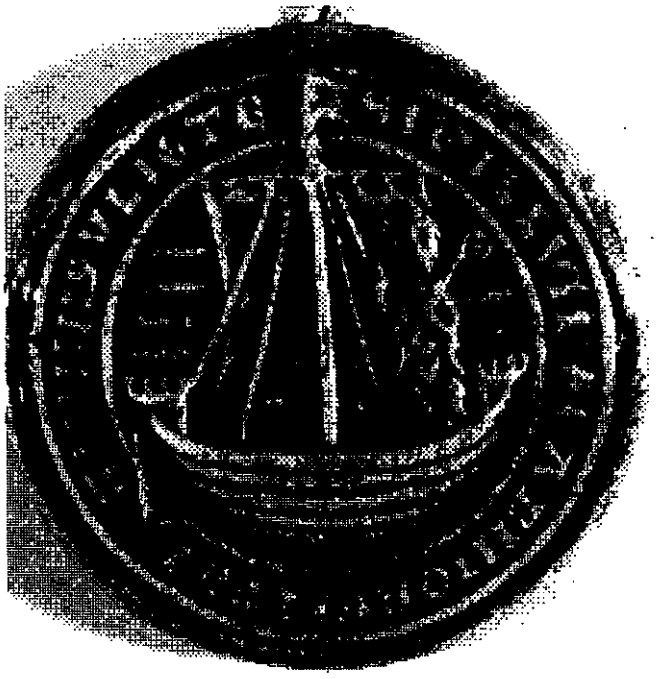

Figure 8.12 The first Seal of Sluis, dated to 1293. Though the hull is patterned after the traditional *knarr*, the ship carries a vertical sternpost.

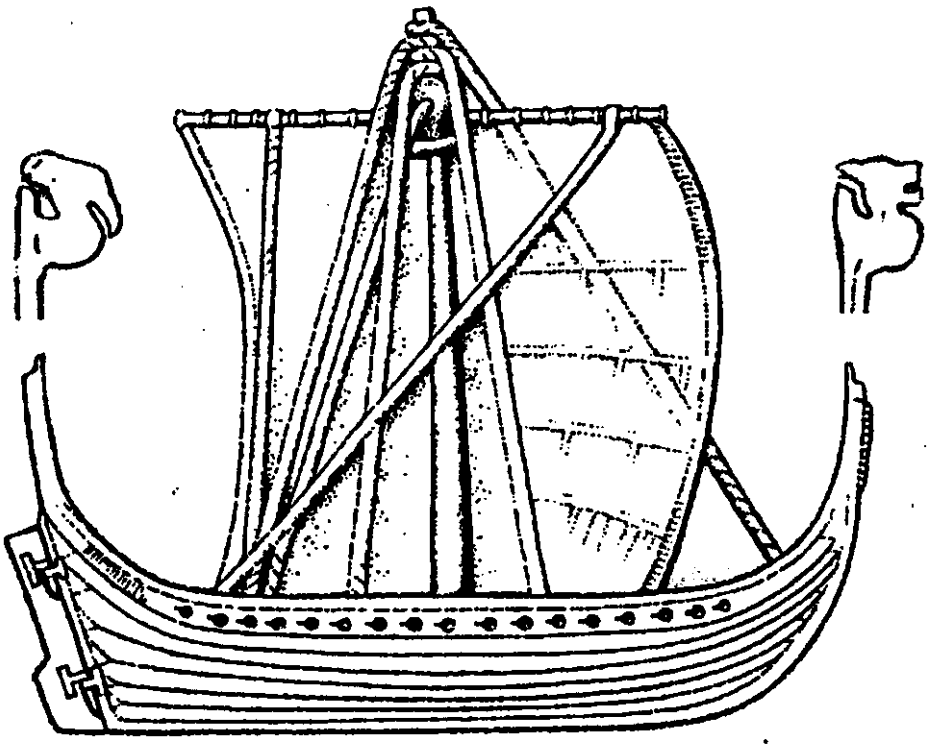

Figure 8.13 A medieval relief from the tomb of Alexander McLeod in Scotland. The hull of the ship is faired into the sternpost to form a fin, as indicated by the narrow hood ends at the base of the sternpost and the flared ones towards the top (After Christensen, 1985: fig. 16-11).

rudder, and the auxiliary quarter-rudders gave the ship a spare steering system if the PG-rudder became damaged. Even after the introduction of the straight sternpost with its multiple sets of pintles and gudgeons, the PG-rudder was still not completely reliable. Statute XXXIV of Ancona, which was written for ships with PG-rudders, states that a large ship should carry two spare rudders for the safety of the ship (Appendix III: 32). The fact that this statute had to be written into law is a clear indication that rudder loss was more than a minor problem. Also, many of the inventories show that the vessels carried spare PG-rudders, but no spare quarter-rudders (Appendix III: 19, 21, 22, 23, 24). An example of how frequently rudder loss occured can be found in the log of the first voyage of Columbus, during which the *Pinta* lost her rudder twice while sailing from Spain to the Canary Islands (Morrison, 1942: I, 210-211).

The retention of the quarter-rudders was necessary not only as emergency steering gear, but also for the added turning force they could deliver in a tight situation. Two quarter-rudders could still deliver more turning moment than a single PG-rudder, and captains and owners of coastal vessels took advantage of this. When not needed they could be puffed out to give a ship a better turn of speed. The addition of deadwood actually increased the need of more turning force for these vessels, which explains why quarter-rudders were retained after the introduction of the vertical sternpost (Figs. 6.1 & 6.24). The above factors explain why the quarter-rudder continued to be used on sailing ships up into the 16th century. It is also probably no small coincidence that the quarter-rudder went out of general use at the same time the combination of the new hull designs and sail plans were becoming perfected and widespread.

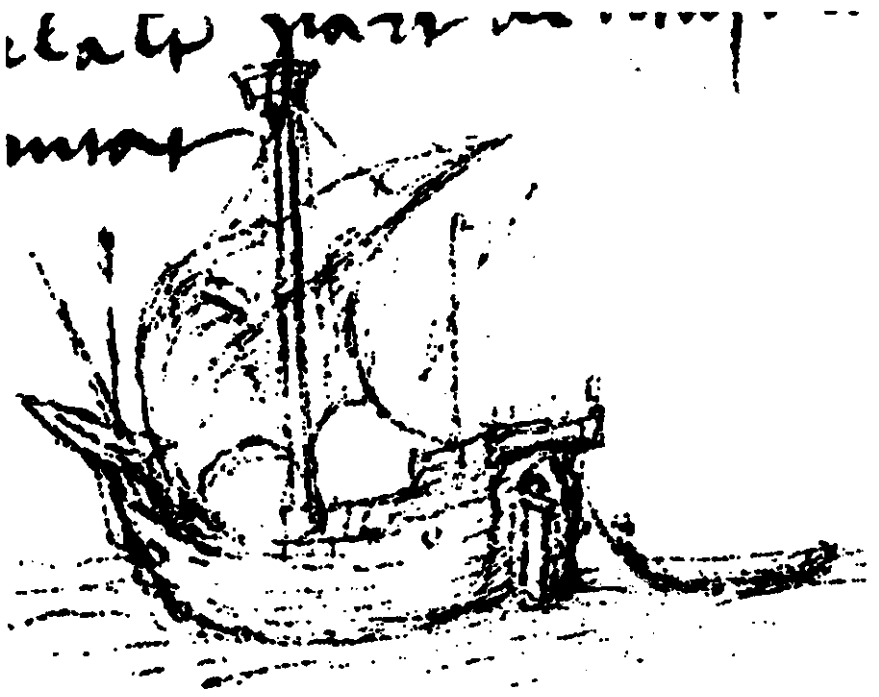

Figure 8.14 An ink drawing of a full-rigged ship, dated 1409. The drawing comes from the *Llibre de les Ordinaciones de l' Administrador de les Places* (fol. 67R), and is one of the earliest depictions of a full-rigged ship (Archivo Municipal de Barcelona).

While the quarter-rudder fell into general disuse on large sailing ships around 1500, it remained common equipment on large galleys into the 17th century. The quarter-rudder was retained on the Newcastle galleys of 1295, where they were referred to as *liberia Gubernilia* (Anderson, 1928: 239; Tinniswood, 1949: 297-298). Inventories for galleys from the 14th century onwards commonly list both *timones latin* or *timones de caxa* along with a PG-rudder, usually called the *govern*, or *timon de roda* (Appendix III: 17, 18, 19, 21, 22, 23, 24).

The reason for its continued employment on galleys, either by itself or in conjunction with a sternpost rudder, involves the hull configuration of galleys in general. Their long, narrow hulls required substantially more force to turn compared to the typical roundship, and unlike the typical sailing vessel, excessive yawing was not a problem. The PG-rudder was almost immediately adopted on war galleys as a means of protecting the helmsman during combat, and the quarter-rudders were stowed on the quarter of the galley until needed (Figs. 8.19 & 8.20). However, while the PG-rudder was rapidly accepted, a faired stern with a vertical sternpost and deadwood was rarely employed on galleys. The reason for this omission is that the addition of deadwood would make a galley even harder to turn than was already the case. The PG-rudder gave a galley the necessary control for fair sailing conditions, but the quarter-rudders were still necessary for rapid maneuvering and a maximum of control. In the *Crónica de Don Pero Niño*, every time the galley was confronted with a storm or treacherous waters the auxiliary quarter-rudders were lowered, demonstrating that the PG-rudder alone was insufficient to control the galley (Diez de Games, 1940: 111, 136, 188, 190, 277). The practice of carrying two rudder systems was common throughout the 16th century (Figs. 8.21 & 8.22). On the larger galleys, the rudders were stowed in a series

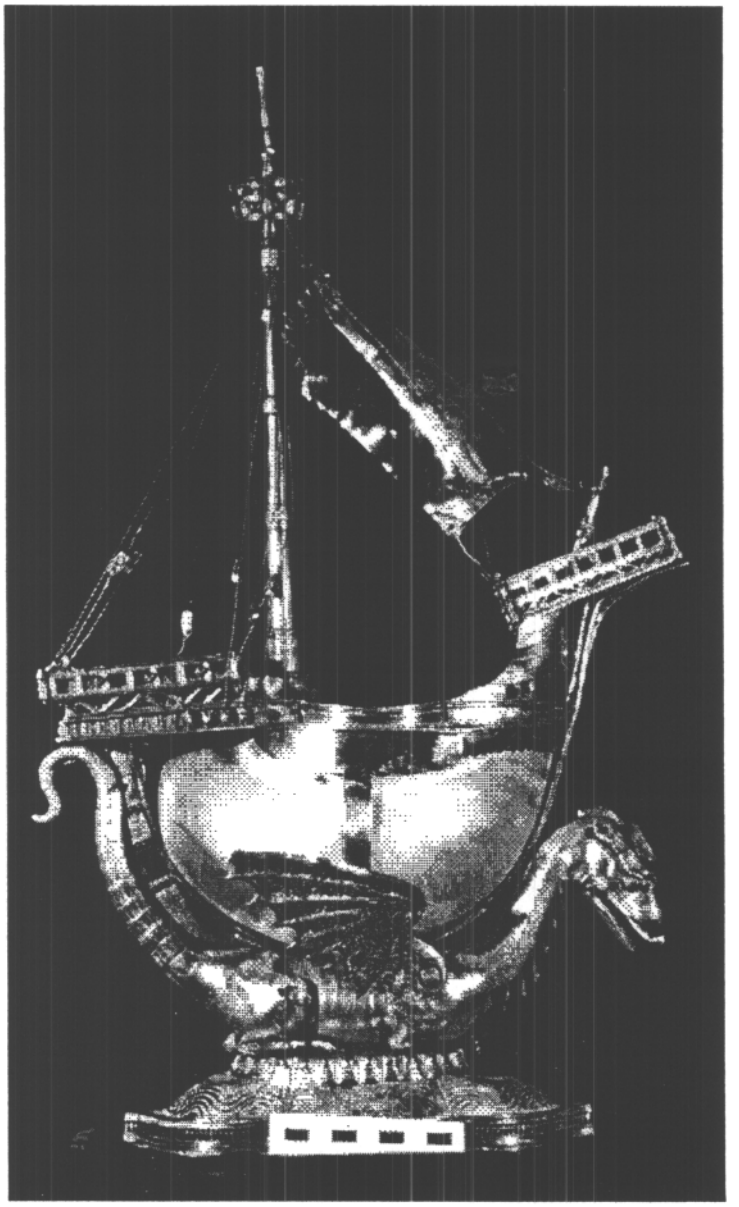

Figure 8.15 A naveta donated to the Cathedral of Zaragoza in the last third of the 15th century. The small ship depicted has a curved sternpost and rudder. The naveta indicates that traditional ship building techniques persisted long after the introduction of the vertical sternpost.

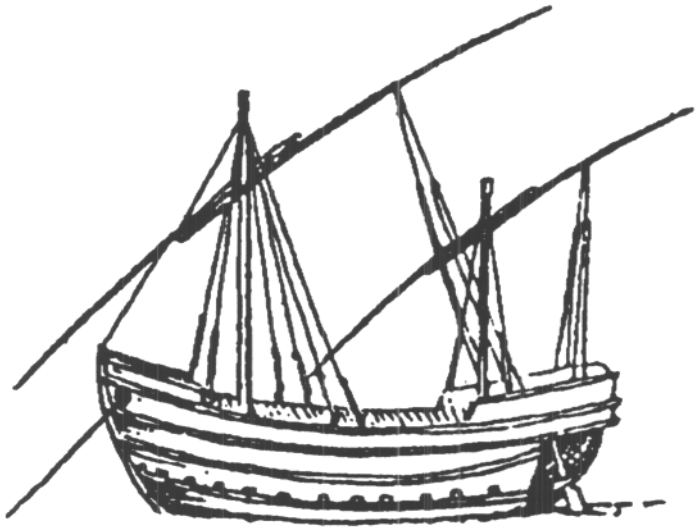

Figure 8.16 A woodcut of an Adriatic coaster with quarter-rudders by Jacobo di Barbari, dated to 1500 (After Nance, 1955: fig. 21).

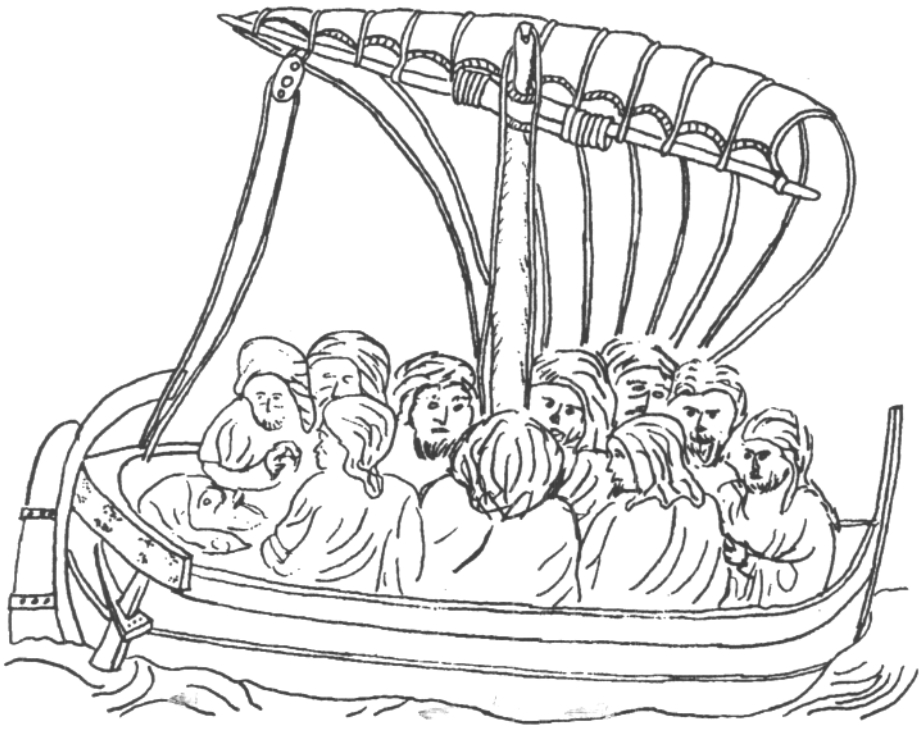

Figure 8.17 A relief of a small ship with both box-mount quarter-rudders and a PG-rudder. The depiction is from the altar of the Cathedral of Pistoria and is dated 1370 (After Moll, 1929: F.a. 22).

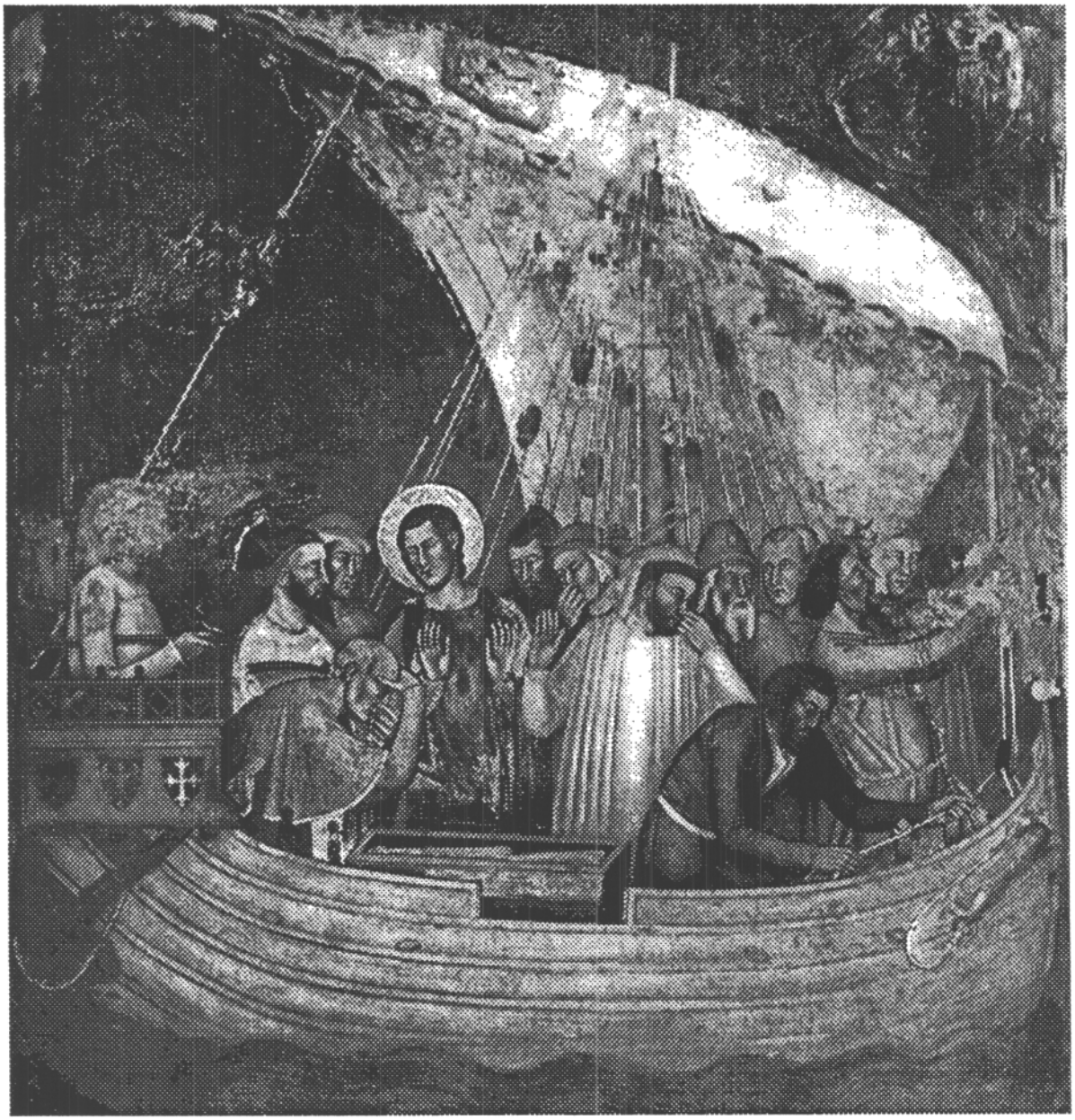

Figure 8.18 A mid-14th century ship with both quarter-rudders and a PG-rudder. The tiller for the PG-rudder can be clearly seen under the arm of the helmsman. The quarter-rudders are held by a swing mount. The picture is a detail of a fresco entitled *The Life of San Ranieri*, painted by Andrea da Firenze (photo: Alinari).

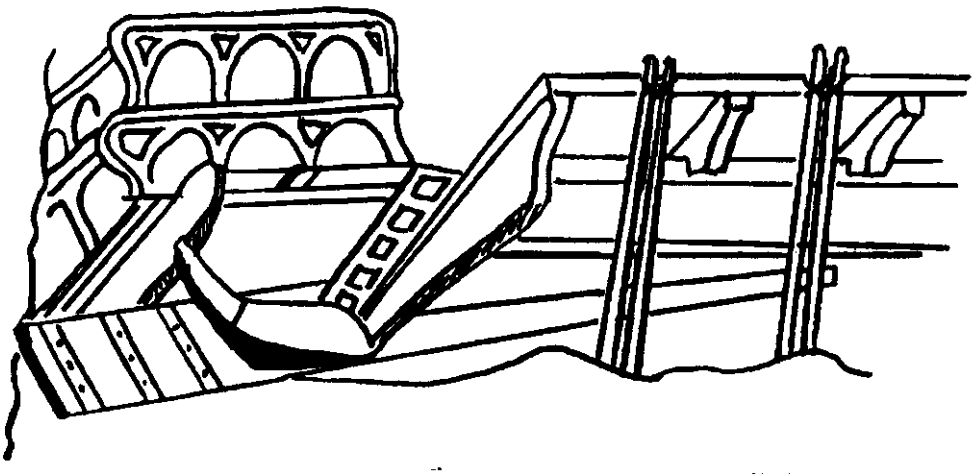

Figure 8.19 A tracing of the stern of a war galley with the quarter-rudder stowed, dated 1406. Note the spiral reinforcing bands on the rudder blade. The drawing is from a fresco, in the Palazzo Pubblico at Siena, depicting the defeat of Barbarossa by Venice (Courtesy of Professor James Bradford, Dept. of History, Texas A&M University).

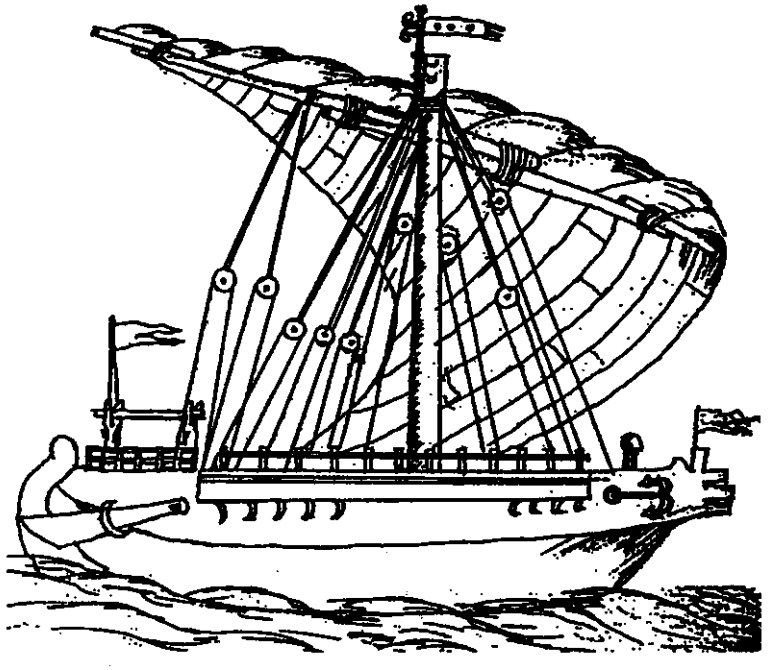

Figure 8.20 A merchant galley carrying both quarter-rudders and a PG-rudder. The drawing comes from *Fabrica di galere* and dates to the early 15th century (Courtesy of Lillian Ray, Dept. of Anthropology, Texas A&M University).

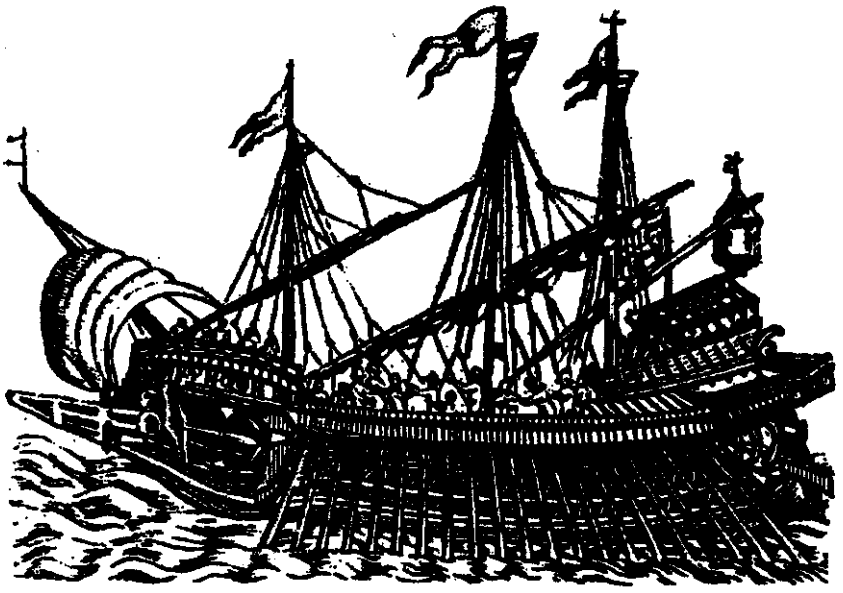

Figure 8.21 A late 16th century *gallera grossa* with its quarter-rudders stowed (After Scandurra, 1972: 211)

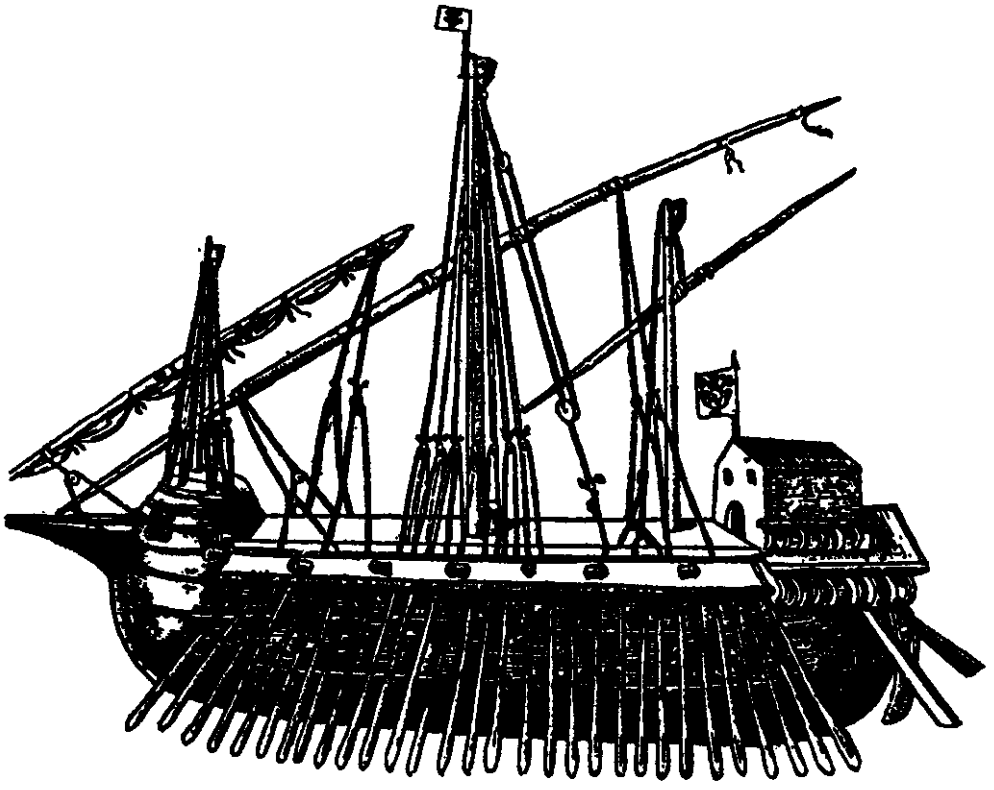

Figure 8.22 A galleass from *Nautica Mediterranea* by Bartolomeo Crescentio, dated 1606. Note the curved timbers under the sterncastle for stowing the quarter-rudders (After Artiñano, 1920: 43)

CHAPTER IX
CONCLUSION

The evolution of the rudder, in a narrow sense, provides a number of insights into why a given technology develops and persists, while others are eventually replaced. If nothing else, the history of the quarter-rudder shows that the replacement of one technology by another is not a straight line event, but is often a complex affair which is influenced by a variety of factors. The truism that the quarter-rudder was replaced simply because a rudder mounted on the stern was more efficient has been shown to be erroneous. Rather, a number of factors were involved which had little to do with the rudder design itself.

The quarter-rudder persisted for centuries because the technology had few physical requirements concerning its use. Because it was not overly complex, the technology proved flexible and therefore could be adapted to fill various needs. The variety of mount designs demonstrate that the system was sufficiently flexible to be employed on virtually every type of ship from antiquity through the Middle Ages. It was also simple in concept, and as a consequence did not need complex hardware to support it. The ability to fashion an adequate rudder from any large spar on the ship is a reflection of the overall simplicity and utility of the concept. Finally, the quarter-rudder system fulfilled several needs and did not require major changes in ship or sail design for its use. The flexibility and simplicity of the concept insured its continued use for centuries after the introduction of an alternative which would eventually replace it. The history of the quarter-rudder indicates that the technologies which are inherently simple will survive in the face of a more advanced solution because they entail low economic costs, they can be readily adapted to different situations, and they do not require a major modification of the surrounding technologies which they support. On the other hand, the PG-rudder required a radical change in hull designs before it became truly effective. If this appears to be stating the obvious, it should be remembered that this central fact has been previously overlooked with regard to the history of the rudder.

The history of the pintle-&-gudgeon rudder is the antithesis of that of the quarter-rudder. Unlike the quarter-rudder, the pintle-&-gudgeon rudder resulted from the combination of several unrelated ideas and technologies. The new steering system arose not from the implementation of a single new technology, but from the amalgamation of several ideas, some of which had been present for centuries. The iron hinge, the concept of stern-mounted rudder, and the straight sternpost of the cog had all been present before the pintle-&-gudgeon arrived. It is an example of a radical solution arising, not from the conception of a single, totally new technology, but from the application of several existing ones to a new problem.

By itself, the sternpost-mounted rudder offered few advantages over it's predecessor. Initially, it provided less turning force and failed to provide the vital function of preventing excessive yawing of the ships it was placed on. Not only did it marginally fulfill the task of ship control, the mounting devices themselves required the relatively expensive technology of iron to support them. Furthermore, while the new mounting system was stronger than that of the quarter-rudder system, it was infinitely harder to repair if it became seriously damaged. Until the start of the 14th century A.D., the history of the pintle-&-gudgeon rudder is classic example of the introduction of an essentially immature technology and explains why the quarter-rudder persisted as long as it did. Unlike the quarter-rudder, the pintle-&-gudgeon rudder required dramatic changes in the technologies it supported before it could reach its full

potential. Only after the introduction of the straight vertical sternpost, and later the full-rigged ship, did the pintle-&-gudgeon rudder become an effective device. Like several modern devices, it had to wait for developments in other technologies before it could be adequately utilized.

In a very broad sense, the history of the rudder gives some clues as to how humanity approaches and deals with technological issues. The evolution of the rudder from the Roman period through the Middle Ages shows that shipwrights and shipowners were not as tradition bound as has been suggested. The major design changes in the quarter-rudders, and the development of new mounting systems such as the swing mount, demonstrate an inherent trait in man to try and improve on existing technologies. In several cases the existing devices appear to have functioned more than adequately, but they were still modified. Undoubtedly, economic considerations, along with the need to correct perceived flaws in the existing technology, were major stimuli to this constant drive of technological evolution. Yet all of the innovations in the rudders and the mounts were nothing more than a modification of an existing technological system, and not the creation of a totally new solution to the old problem of ship control.

This last point brings up an interesting question. Do radically new technologies arise from an innate human desire to experiment, or do they occur because technological crises force man to search for them? The development of the pintle-&-gudgeon rudder resulted because the northern shipwrights were forced to find a completely different solution. Unlike the Mediterranean shipwrights, they did not have the option of refining an existing technology but were forced to seek alternatives. The southern shipwrights had all of the tools necessary to develop it, yet they did not. The iron hinges and the single stern-mounted rudder were not alien to them, which means that the reason they did not develop the pintle-&-gudgeon rudder was because they saw no imperative to do so. The history of the rudder suggests that major new technologies may arise not from an innate human drive to experiment, but because a society is forced, by economics or war, to find a new solution to a problem after reaching a technological deadend.

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APPENDIX I
MODELS FOR QUARTER-RUDDER FLOTATION BEHAVIOR

The following are mathematical models for defining the angle at which a quarter-rudder floats at equilibrium around a pivot of a given height above the waterline. The models will allow various sizes of quarter-rudders for a given ship reconstruction to be tested to see at what angle the rudder would float, to what depth it would penetrate, and to predict the minimum height for the upper rudder support. The first model is written for a Greco-Roman quarter-rudder which has equal blade area on either side of an untapered shaft and whose blade is not tapered in the vertical direction. The second model is similar to the first except that the section of shaft to which the blade is attached is a tapered cone decreasing downward towards the bottom of the blade to a specified diameter.

As these are equilibrium models and do not involve hydrodynamics, rudders with blades which taper towards their edges can be modeled as long as the blade volume can be approximated by a rectangular box. The models are not valid for rudders with a blade attached only to the forward or aft portion of the loom.

The shaft has been divided into two parts, an upper section which constitutes the portion of the shaft above the blade, and a lower section which passes through the blade. By dividing the shaft into two sections, the effects of density changes due to water absorbtion in the lower shaft can be simulated.

The models require the following information: densities for the three parts of the rudder (upper shaft, lower shaft, and blade), shaft diameter (and tip diameter for Model #2), upper and lower shaft lengths, and the dimensions of the blade. Given these values, either the rudder flotation angle or the pivot height can be calculated if the other value is provided.

The limits of the models are zero degrees from vertical and approximately 75 degrees from vertical. The latter limit occurs when the top of the blade becomes immersed, thereby violating an assumption in the models that the entire top of the blade is above water. This limit is somewhat variable as it depends on the values of density, shape, and volume chosen for the model. Other assumptions or limits will be discussed with each of the models.

The purpose of the models is to allow one to calculate the angle at which a given quarter-rudder will float, the depth beneath the surface it will penetrate, given its shape, volume, density, and the height of the upper mounting point. The upper mounting point is used in the calculation, since using the second lower mount would always result in the rudder being at equilibrium at a shallower depth and greater angle from vertical than if it was allowed to pivot around the upper mounting point. Obviously, the rudder could be forced deeper through attachment to a lower support below the angle of equilibrium. However, for reasons discussed earlier, this is not likely.

The variable which appears to have the most dramatic effect on the flotation of the rudder is the density of the wood. Relatively small changes in the wood density resulted in gross changes in the flotation angle. The amount of rudder shaft above the pivot also has significant impact on the rudder angle, though this is dependent to a certain extent on the densities chosen for the various parts of the rudder.

MODEL 1: Greco-Roman Rudder with an Untapered Shaft

Upper Shaft

Mass (M_1) = $\rho_1 V_1 = \rho_1(\Pi D^2/4)l_1$

Center of Mass ($\chi cm1$) = $0.5l_1$

Lower Shaft

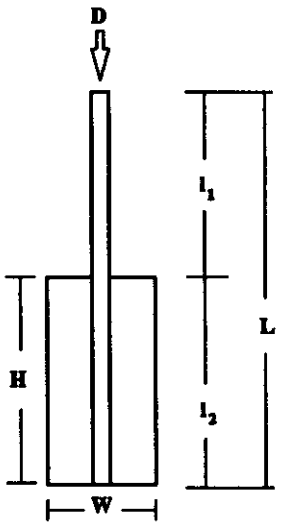
Mass (M_2) = $\rho_2 V_2 = \rho_2(\Pi D^2/4)l_2$

Center of Mass ($\chi cm2$) = $0.5l_2+l_1$

Blade

Mass (M_3) = $\rho_3 V_3 = \rho_3(l_3 WT-DTl_3)$

Center of Mass ($\chi cm3$) = $0.5l_2+l_1$



Rudder Mass and Center of Mass

$M = M_1+M_2+M_3$

$X = (M_1\chi cm1+M_2\chi cm2+M_3\chi cm3)/(M_1+M_2+M_3)$

T = Blade Thickness

W = Blade Width not including Shaft Diameter

Sum of Torques = $\Sigma\Gamma = 0$

$\Sigma\Gamma = -Mg(X-l)SIN\Theta+\Gamma_{BOUYANT} = 0$

$F_{BOUYANT} = \rho_{H2O} V_{DISPLACED} g$

$\Gamma_B = F_B \xi SIN\Theta$

$V_D = S(\Pi D^2/4)+(STW-STD)$

$COS\Theta = H/\upsilon \Rightarrow \upsilon = H/COS\Theta$

$S = L-l-\upsilon = L-l-H/COS\Theta$ (l = Section of shaft above the pivot)

$V_D = (L-l- H/COS\Theta)TW + (L-l-H/COS\Theta)\Pi D^2/4 - (L-l-H/COS\Theta)TD$

$= (L-l-H/COS\Theta)(TW+\Pi D^2/4-TD)$

$F_B = \rho_{H2O} g(L-l-H/COS\Theta)(TW+\Pi D^2/4-TD)$

$-Mg(X-l)SIN\Theta = -\Gamma_B$

$Mg(X-l)SIN\Theta = F_B \xi SIN\Theta$

$\xi = \upsilon+S/2$

$\xi = H/COS\Theta+½(L-l-H/COS\Theta) = L/2-l/2+H/2COS\Theta$

$\xi = ½(L-l+H/COS\Theta)$

$$Mg(X-l)SIN\Theta = \rho_{H2O}g(L-l-H/COS\Theta)(TW+\Pi D^2/4-TD)\tfrac{1}{2}(L-l+H/COS\Theta)SIN\Theta$$
$$M(X-l) = \rho_{H2O}\tfrac{1}{2}[(L-l)^2-H^2/COS^2\Theta](TW+\Pi D^2/4-TD)$$
$$2M(X-l)/\rho_{H2O}(TW+\Pi D^2/4-TD) = (L-l)^2-H^2/COS^2\Theta$$
$$(L-l)^2 - 2M(X-l)/\rho_{H2O}(TW+\Pi D^2/4-TD) = H^2/COS^2\Theta$$

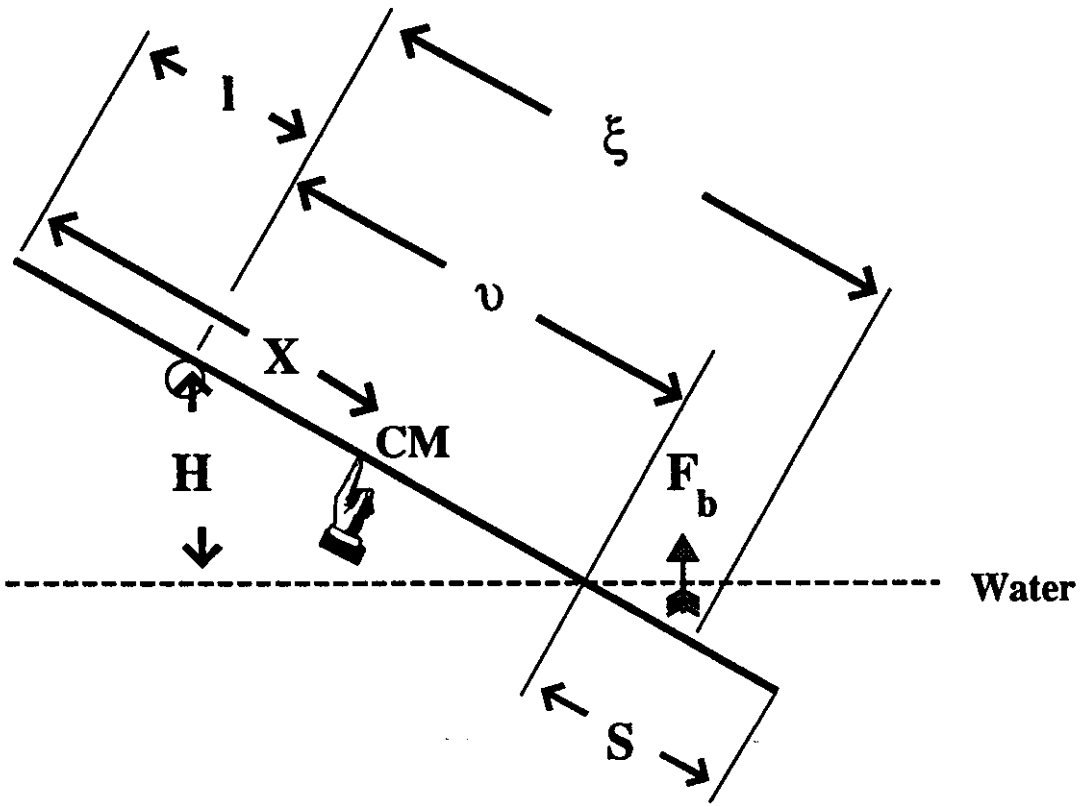
$$H = COS\Theta\sqrt{(L-l)^2 - 2M(X-l)/\rho_{H2O}(TW+\Pi D^2/4-TD)}$$

$$COS\Theta = H/\sqrt{(L-l)^2 - 2M(X-l)/\rho_{H2O}(TW+\Pi D^2/4-TD)}$$

Length of Blade Submerged

Length of Shaft between the Pivot and Water = H/COSΘ

$$L_{sub} = (L-l) - H/COS\Theta$$



MODEL 2: Greco-Roman Rudder with an Tapered Shaft

Upper Shaft

Mass $(M_1) = \rho_1 V_1 = \rho_1(\Pi D^2/4)l_1$

Center of Mass $(\chi_1) = 0.5l_1$

Lower Shaft

Center of Mass $(\chi_3) = \frac{\int \rho_3 x dV}{\int \rho_3 dV}$ (Solid Cone)

$\int \rho_3 x dV = \int \rho_3 A(x) dx$

$A(x) = \Pi D^2/4(x)$

$(y_2-y_1) = m(x_2-x_1)$ (Point Slope Formula)

$y = mx+b$ (Slope Intercept)

$m = (D_1-D)/(L-l_2)$

$b = y-Mx$

$b = D_1-ML$

$D(x) = mx+b = mL+b$

$A(x) = \Pi/4(m^2L^2+2mbL+b^2)$

$$\int \rho_3 x dV = \int_{L-l2}^{L} \rho_3 L\Pi/4(m^2L^2+2mbL+b^2)dx$$

$$= \rho_3\Pi/4 \int_{L-l2}^{L} (m^2L^3+2mbL^2+b^2L)dx$$

$$= \rho_3\Pi/4 \left[\frac{m^2L^4}{4} + \frac{2mbL^3}{3} + \frac{b^2L^2}{2} \right]_{L-l2}^{L}$$

$$= \rho_3\Pi/4 \left[\frac{m^2L^4(1-1/16)}{4} + \frac{2mbL^3(1-1/8)}{3} + \frac{b^2L^2(1-1/4)}{2} \right]$$

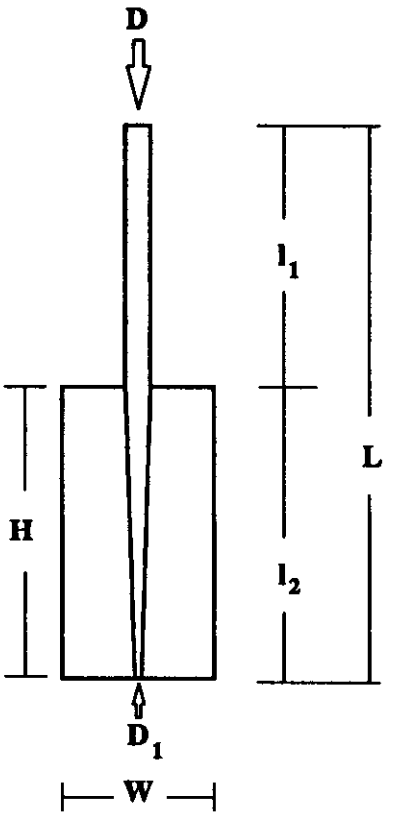
$$= \rho_3\Pi/4 \left[\frac{m^2L^4 15}{4(16)} + \frac{2mbL^3 7}{3(8)} + \frac{b^2L^2 3}{2(4)} \right]$$

$$= \rho_3\Pi/32 \left[\frac{m^2L^4 15}{8} + \frac{2mbL^3 7}{3} + b^2L^2 3 \right]$$

$$\boxed{\int \rho_3 x dV = \rho_3\Pi/32 \left[\frac{m^2L^4 15}{8} + \frac{2mbL^3 7}{3} + b^2L^2 \right]}$$

$\int \rho_3 dV = \int \rho_3 A(x) dx$

$= \int_{L-l2} \rho_3\Pi/4(m^2L^2+2mbL+b^2)dx$



T = Blade Thickness

W = Blade Width not including Shaft Diameter

$$=\rho_3\Pi/4\left[\frac{m^2L^3}{3}+\frac{2mbL^2}{2}+b^2L\right]_{L-l2}^{L}$$

$$=\rho_3\Pi/4\left[\frac{m^2L^3(1-1/8)}{3}+2mbL^2(1-1/8)+b^2L(1-1/8)\right]$$

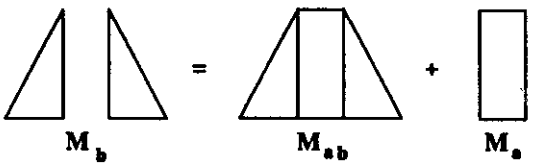
$$=\rho_3\Pi/4\left[\frac{m^2L^3 7}{3(8)}+\frac{2mbL^2 3}{4}+\frac{b^2L}{2}\right]$$

$$\boxed{\int\rho_3 dV \quad =\rho_3\Pi/8\left[\frac{m^2L^3 7}{12}+\frac{2mbL^2 3}{2}+b^2L\right] = \text{Mass of Lower Shaft } (M_3)}$$

$$\chi cm3 = \frac{\int\rho_3 x dV}{\int\rho_3 dV}$$

For a Blade in Two Pieces

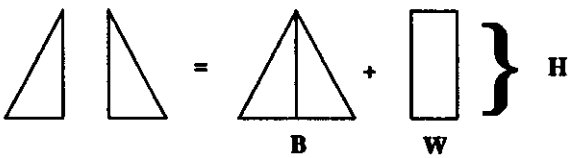
$$\chi cm4 = \frac{M_a\chi_a+M_b\chi_b}{M_a+M_b}$$



$M_{ab} = \rho_2(\tfrac{1}{2}BHT+HWT)$

$M_b = \rho_2\tfrac{1}{2}D\Pi_2$

$M_a = \rho_2 D_1 T l_2$



$\chi_a = l_1+\tfrac{1}{2}l_2$

$$\chi_4 = \frac{\int\rho_2 x dV}{\int\rho_2 dV} = \frac{\int\rho_2 x dV}{M_b}$$

$$\int\rho_2 x dV = \int_{L-l2}^{L}\rho_2 x B_{(x)} T\,dx \qquad B_{(x)} = mL+b$$

$$= \int\rho_2 xT(mL+b)dx \qquad x = L$$

$$= \rho_2 T\int mL^2+bL\,dx$$

$$= \rho_2 T\left[\frac{mL^3}{3}+\frac{bL^2}{2}\right]_{L-l2}^{L}$$

$$= \rho_2 T\left[\frac{m^2L^3(1-1/8)}{3}+\frac{b^2L(1-1/4)}{2}\right]$$

$$= \frac{\rho_2 T}{8}\left[\frac{7m^2L^3}{3}+\frac{b^2L}{2}\right]$$

$$= \frac{\frac{\rho_2 T}{8}\left[\frac{7m^2L^3}{3}+\frac{b^2L}{2}\right]}{M_3}$$

$\chi_{ab} = (M_a\chi_a + M_b\chi_b)/(M_a + M_b)$

$\chi_2 = (M_{ab}\chi_{ab} + M_{Blade}\chi_{Blade})/(M_{ab} + M_{Blade})$ $\boxed{M_{Blade} = M_2 - M_{ab}}$ $\Rightarrow$ Mass $(M_2) = \rho_2 V_2 = \rho_2(l_2 WT - DTl_2)$

$\chi_2 M_{ab} + \chi_2 M_{Blade} = M_{ab}\chi_{ab} + M_{Blade}\chi_{Blade}$

$\chi_{Blade} = (\chi_2 M_{Blade} + \chi_2 M_{ab} - M_{ab}\chi_{ab})/M_{Blade}$

$X_{TOTAL} = (M_{Blade}\chi_{Blade} + \chi_1 M_1 + M_3\chi_3)/(M_{Blade} + M_1 + M_3)$

Sum of Torques = $\Sigma\Gamma = 0$

$\Sigma\Gamma = -Mg(X-l)SIN\Theta + \Gamma_{BOUYANT} = 0$

$F_{BOUYANT} = \rho_{H2O} V_{DISPLACED} g$

$\Gamma_B = F_B \xi_5 SIN\Theta$

$V_D = STW$

$COS\Theta = H/\upsilon \Rightarrow \upsilon = H/COS\Theta$

$S = L-l-\upsilon = L-l-H/COS\Theta$ (l = Section of shaft above the pivot)

$V_D = (L-l-H/COS\Theta)TW$

$= (L-l-H/COS\Theta)(TW + \Pi D^2/4 - TD)$

$F_B = \rho_{H2O} g(L-l-H/COS\Theta)TW$

$-Mg(X-l)SIN\Theta = -\Gamma_B$

$Mg(X-l)SIN\Theta = F_B \xi_5 SIN\Theta$

$\xi = \upsilon + S/2$

$\xi = H/COS\Theta + \frac{1}{2}(L-l-H/COS\Theta) = L/2 - l/2 + H/2COS\Theta$

$\xi = \frac{1}{2}(L-l+H/COS\Theta)$

$Mg(X-l)SIN\Theta = \rho_{H2O} g(L-l-H/COS\Theta)TW\frac{1}{2}(L-l+H/COS\Theta)SIN\Theta$

$M(X-l) = \rho_{H2O}\frac{1}{2}\{(L-l)^2 - H^2/COS^2\Theta\}TW$

$2M(X-l)/\rho_{H2O}TW = (L-l)^2 - H^2/COS^2\Theta$

$(L-l)^2 - 2M(X-l)/\rho_{H2O}TW = H^2/COS^2\Theta$

$$H = COS\Theta\sqrt{(L-l)^2 - 2M(X-l)/\rho_{H2O}TW}$$

$$COS\Theta = H/\sqrt{(L-l)^2 - 2M(X-l)/\rho_{H2O}TW}$$

Length of Blade Submerged

Length of Shaft between the Pivot and Water = $H/COS\Theta$

$$L_{sub} = (L-l) - H/COS\Theta$$

Model 2 has one limit. The diameter of the upper end of the lower shaft section must be ≥ 2 times the blade thickness.

In this model the entire submerged portion of the blade is assumed to contribute to $F_{BOUYANT}$ and the section of blade which would be replaced by the shaft is included, whereas the lower shaft is assumed to not contribute to $F_{BOUYANT}$. If the lower shaft and the blade have similar density values then the effect of this assumption is negligible. The thin rounded slivers of shaft on either side of the submerged blade were assumed to contribute to such a small portion of the bouyant force that they were not included. If the lower end of the shaft tapers down to where the diameter is equal to the blade thickness this assumption is reliable. However as the diameter of the shaft end increases towards the maximum shaft diameter this assumption is not as valid. As the diameter approaches the maximum, Model 1 will give more reliable values for a slightly tapered shaft, since the submerged section of shaft on either side of the blade will have sufficient volume to significantly effect $F_{BOUYANT}$.

APPENDIX II
RESULTS OF TEST OF FLOTATION MODELS

To test the validity of using the mathematical models to predict quarter-rudder floatation behavior, a series of tests were performed using a rudder replica. The results from the tests were compared to values predicted by mathematical model 1, for a rudder of the same size as the replica, to see if the predicted results were similar to those observed from the test rudder. The test rudder consisted of an untapered shaft whose lower end was slotted to fit a single blade. The upper shaft had a series of holes drilled along it's length so a steel pin could be passed through the shaft at various intervals to form a pivot. The holes and the pin were greased to reduce friction. The wood for the blade and shaft were then weighed and measured to obtain their densities. The rudder parts were painted with clear polyurathane to prevent the absorbtion of water. Water absorbtion would have effected the results by changing the density of the submerged parts over time.

The rudder mount consisted of two vertical square posts which had matching pairs of holes drilled at different heights. The rudder was mounted by placing the shaft between the two posts and then putting the steel pin through one post, a hole in the shaft, and finally the post on the other side. This apparatus was placed on top of a tank filled with water, so that the lower end of the rudder was allowed to float to a position of equilibrium in the water. By varying the position of the pin along the shaft and along the posts, the effects of mounting the rudder at different heights with the pivot point at different locations along the shaft could be observed. The angle of the shaft was measured by a level protractor hung from the pin.

The models were tested with the pivot pin placed at 2.0, 2.5, and 3.0 cm from the end of the shaft. Three readings of the angle were taken for each height. The average of the three readings was then recorded, along with the height. The results are listed and plotted at the end of this appendix.

The values of the observed and predicted heights are very close with an averaged error for the three cases of less than 3%. It should be noted that the term error is here being used to signify the percentage of the data not explained by the model. As can be seen in the tables, the actual % error for each case varied from 1.6% to 3.5%. This variation is probably due to the methods used for measuring the angle and the height of the pivot. The angle could only be read accurately down to about 1 degree, and the height only to 1mm. The model itself is sensitive to values below the above limits. A change of one half of a degree can change the predicted pivot height by as much as 7mm. The inability of the recording methods to read degrees of angle to the sensitivity threshold of the model is probably the source of random error in the results.

One consistent difference in all three test cases was that the observed values were always lower than the predicted. This result is probably due to water absorbtion by the wood. Although the rudder had been painted to prevent this, the end grain on the blade edges and on the shaft base proved impossible to completely seal. It was visually apparent that the blade edges began absorbing water almost immediately on immersion. Case 3 was the last case run, and the rudder had absorbed water continuously all through the tests. The largest seperation between the values of the predicted and observed data occur in the last test, and the percent error is over 1% higher than for the previous tests. These results are most probably due to the significant uptake of water by the blade.

Overall the mathematical model accuratly predicted the behavior of test rudder. The average error for the entire test was 2.4% and the highest error for an individual case was only 3.5%. Moreover, the plot of the observed data closely follows the curve for the predicted data (see graphs of test results). If the model was not valid, then the curves would not conform in shape and would probably cross at some point.

The results conclusively demonstrate the validity of the model and show that the models can be useful tools in determining the rudder size and the height of the upper rudder mount on ancient ship re-constructions.

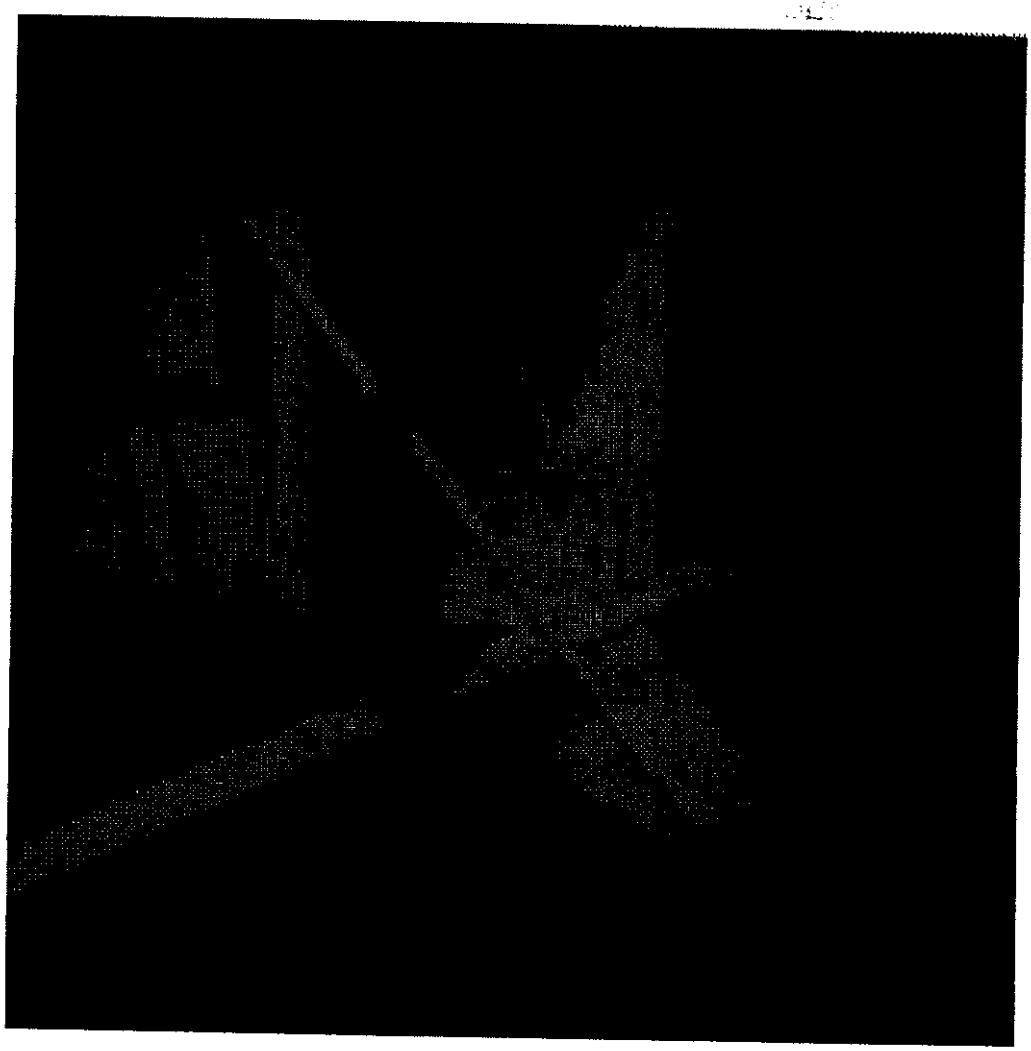


Figure A.1 The test apparatus for testing the statics models for flotation equilibrium of a quarter-rudder with an untapered shaft.

TEST CASE 1: Table of Results

	Meters
Rudder Length =	1.1
Shaft Diameter =	0.018
Upper Shaft Length =	0.493
Lower Shaft Lenth =	0.607
Blade Length =	0.607
Blade Width =	0.150
Blade Thickness =	0.007

Mass of Upper Shaft = 0.096
Ctr Mass Upper Shaft = 0.247

Mass of Shaft Loom = 0.084
Ctr Mass Lower Shaft = 0.797

Mass of Blade = 0.444
Ctr Mass Blade = 0.797

Shaft Above Pivot = 0.15

Center Mass Rudder = 0.71

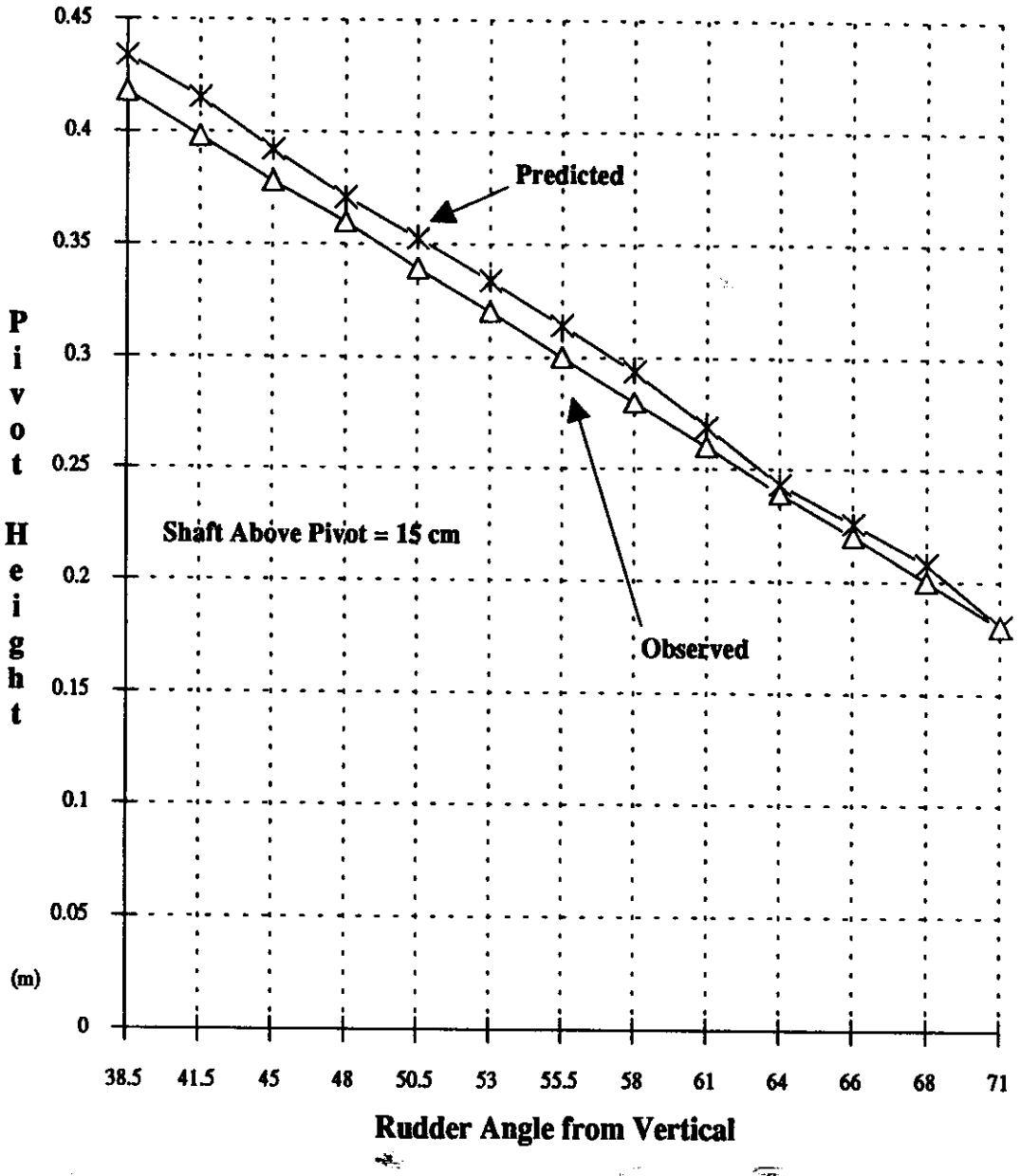
Total Mass of Rudder = 0.624

Shaft Angle from Vertical	Pred. Height	Observed Height
38.5	0.434	0.418
41.5	0.415	0.398
45	0.392	0.378
48	0.371	0.36
50.5	0.353	0.339
53	0.334	0.32
55.5	0.314	0.3
58	0.294	0.28
61	0.269	0.26
64	0.243	0.239
66	0.226	0.22
68	0.208	0.2
71	0.181	0.18

Mean = 0.299385
SSE= 0.001823
Total Vari. = 0.081625

% Error = 2.2

TEST CASE 1: Plot of Results



TEST CASE 2: Table of Results

	Meters
Rudder Length =	1.1
Shaft Diameter =	0.018
Upper Shaft Length =	0.493
Lower Shaft Lenth =	0.607
Blade Length =	0.607
Blade Width =	0.150
Blade Thickness =	0.007

Mass of Upper Shaft = 0.096
Ctr Mass Upper Shaft = 0.247

Mass of Lower Shaft = 0.084
Ctr Mass Lower Shaft = 0.797

Mass of Blade = 0.444
Ctr Mass Blade = 0.797

Shaft Above Pivot = 0.25

Center Mass Rudder = 0.71

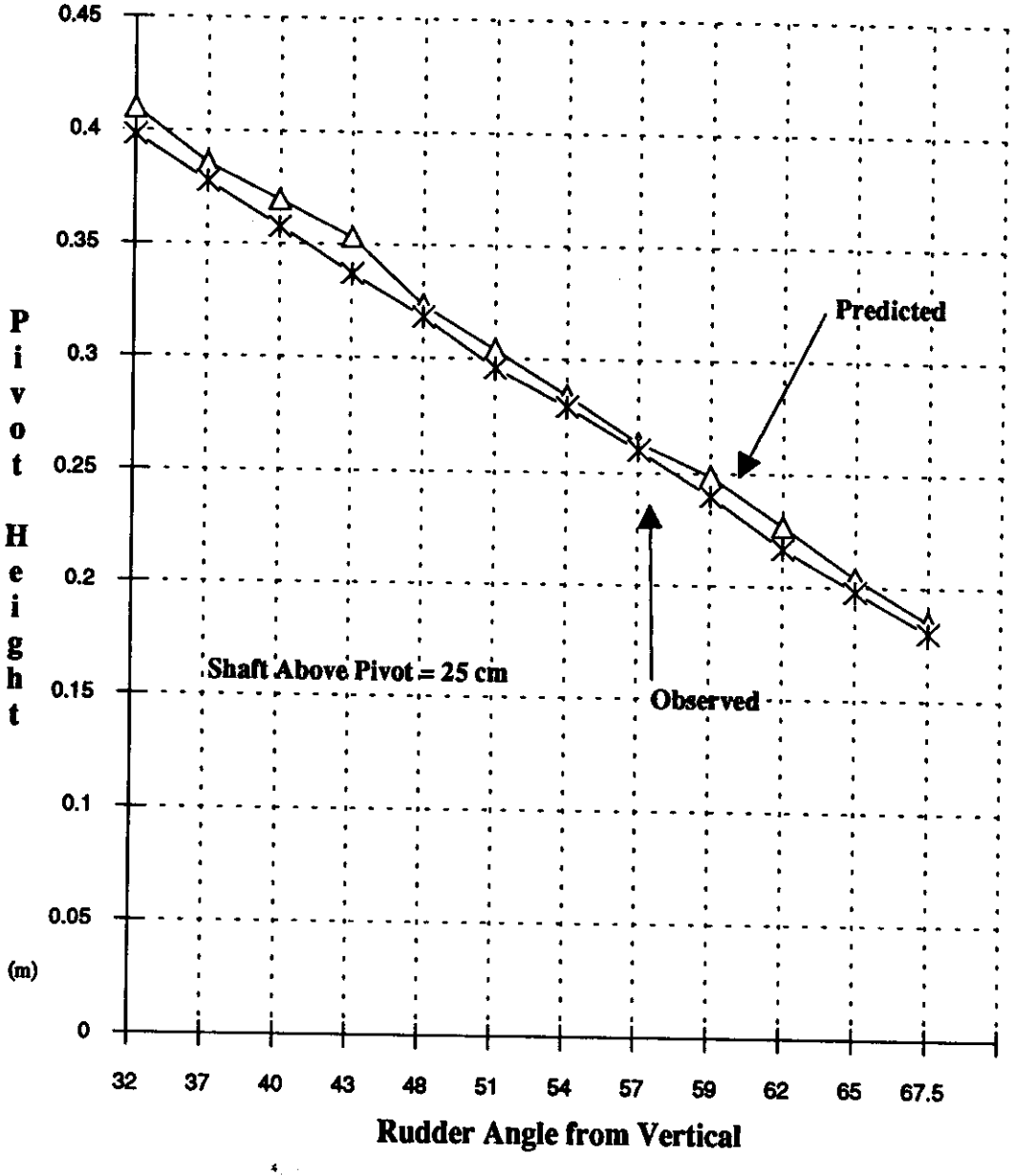
Total Mass of Rudder = 0.624

Shaft Angle from Vertical	Pred. Height	Observed Height
26	0.434	0.418
32	0.410	0.398
37	0.386	0.378
40	0.370	0.358
43	0.353	0.337
48	0.323	0.318
51	0.304	0.296
54	0.284	0.279
57	0.263	0.26
59	0.249	0.24
62	0.227	0.217
65	0.204	0.198
67.5	0.185	0.18

Mean = 0.298231
SSE= 0.001231
Total Vari. = 0.078109

% Error = 1.6

TEST CASE 2: Plot of Results



TEST CASE 3: Table of Results

	Meters
Rudder Length =	1.1
Shaft Diameter =	0.018
Upper Shaft Length =	0.493
Lower Shaft Lenth =	0.607
Blade Length =	0.607
Blade Width =	0.150
Blade Thickness =	0.007

Mass of Upper Shaft = 0.096
Ctr Mass Upper Shaft = 0.247

Mass of Lower Shaft = 0.084
Ctr Mass Lower Shaft = 0.797

Mass of Blade = 0.444
Ctr Mass Blade = 0.797

Shaft Above Pivot = 0.300

Center Mass Rudder = 0.712

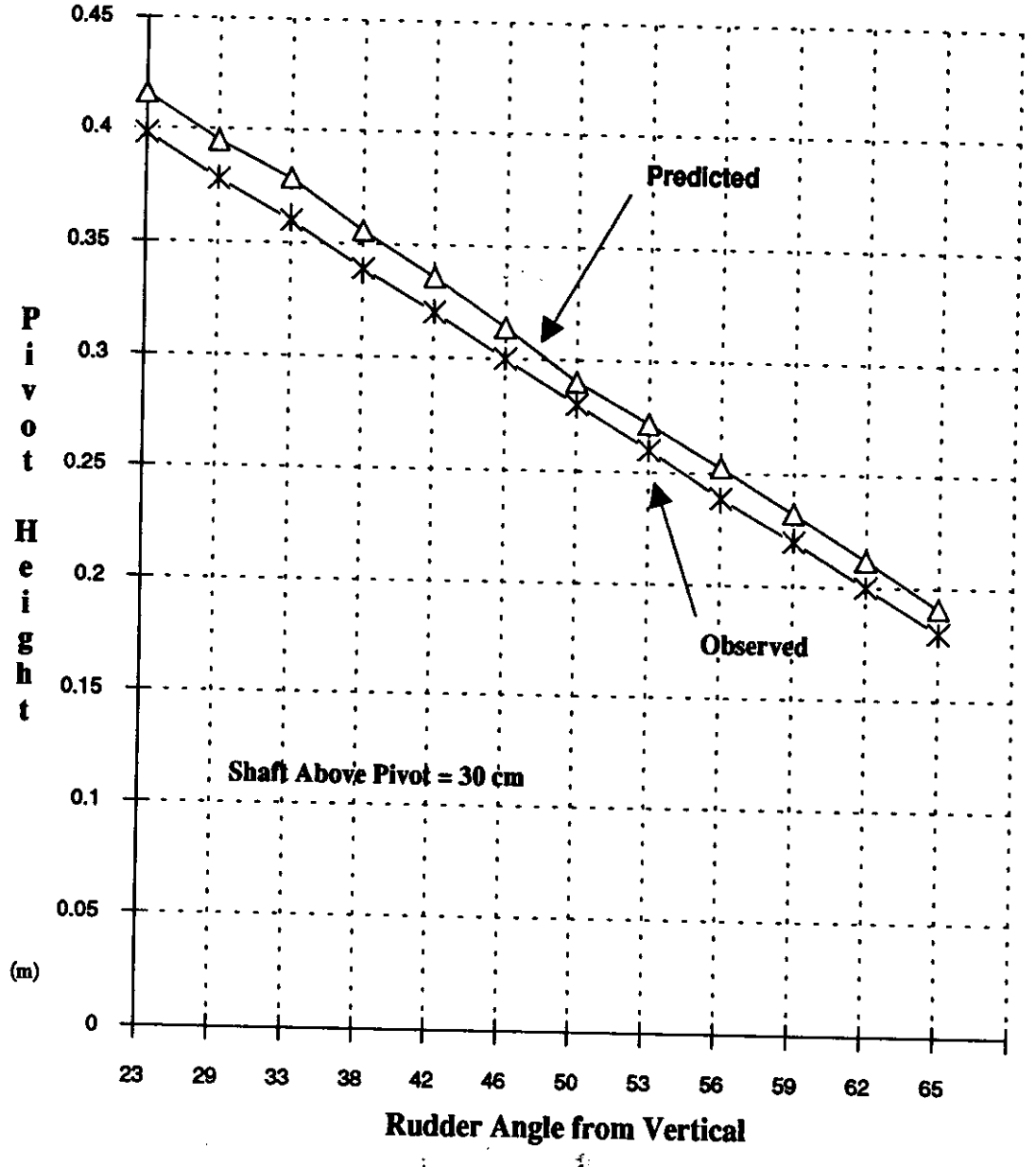
Total Mass of Rudder = 0.624

Shaft Angle from Vertical	Pred. Height	Observed Height
15	0.436	0.418
23	0.416	0.398
29	0.395	0.378
33	0.379	0.36
38	0.356	0.339
42	0.335	0.32
46	0.314	0.3
50	0.290	0.28
53	0.272	0.26
56	0.252	0.239
59	0.233	0.22
62	0.212	0.2
65	0.191	0.18

Mean = 0.299385
SSE= 0.00281
Total Vari. = 0.079223

% Error = 3.5

TEST CASE 3: Plot of Results



APPENDIX III
MEDIEVAL CONTRACTS, INVENTORIES AND LAWS

Appendix III is a compelation of selected contracts, inventories and laws which relate to the history of the quarter-rudder. These various citations are intended to provide insight into the construction, size, and use of the rudder during the medieval period. For a full a full listing of nomenclature used in relation to the rudder one should refer to *Glossaire Nautique* by Jal, and the work by Villain-Gandossi (1978).

CONTRACTS FOR THE CONSTRUCTION AND/OR TRANSPORT OF QUARTER-RUDDERS

1 Sunt etiam necessari ad unam navem tres timoni, scilicet duo in capcia et unus superfluus, habentes longitudinis XVI goas et latitudinis IX palmos. (A 13th century Marseille contract. Jal, 1848:1454)

2 Item tymones duos et affaiticos, grossitudinis palmorum IX et dimidii, longitudinis cubitorum XXIIII. (Proposal by Louis IX to the Council of Genoa for the construction of 3 naves, dated March, A.D. 1246. Champollion-Figeac, 1841: 55)

3 Item timones duos pro qualibet navi, videlicet pro quolibet longitudinis cubitorum XXII. grossitudinis palmorum IX. (Proposal by Louis IX to the Council of Genoa for the construction of an unspecified number of naves, dated March, A.D. 1246. Champollion-Figeac, 1841: 57)

4 Item timones II grossitudinis palmorum VII. (Proposal by Louis IX to the Council of Genoa for the construction of 30 naves and naulizandum, dated March, A.D. 1246. Belgrano, 1859: 15)

5 Item timones dous bonos et sufficientes. (Proposal by Louis IX to the Council of Genoa for the construction of 12 tarides, dated March, A.D. 1246. Belgrano, 1859: 22)

6 Eodem die & loco. Ego Aubertus Piola confiteor et recognosco tibi Bonavia Calafato me habuisse & recepisse a te II timonos portandi apud Januam. precio seu loquerio XXXI l. confiteor me a te habuisse et recepisse, renuncians, etc. Testes: suprascripti proximi. (Contract for the transport of two rudders from Marseille to Genoa, dated A.D. 1248. Blancard, 1885: v. II, 67)

7 Eodem die & loco. Ego W. Riqueti vendo tibi W Alberti II temones de robore grossitudinis VIII palmarum cum fuerint aptati in luctatorio & longitudinis de XX gosis usque ad XXI quilibet, precio LXX l. vianensium, de quibus confiteor me habuisse & recepisse X l., renuncians etc.; quos timones promicto tibi per stipulacionem portare & tradere tibi in Massilia cum propriis expensis meis, hinc ad festum Sancti Johannis Babtiste, vel ad minus adducere in dicto termino apud Arelatem et ab Arelate ducere apud Massiliam, quamcito fuerit ibi et tempus fuerit

oportunum in civitate Massilie adducendi, et omnes expensas et dampna et interesse que tu vel tui faceretis etc.; obligans etc.; renuncians etc.; et ego dictus W. Alberti promito tibi dicto W Riqueto tibi dare et solvere LX 1. vianensium que restant tibi de dicto precio ad solvendum infra VIII dies postquam adduxeris dictos temones apud Massiliam, obligans etc.; renuncians etc. Testes: Guitelminus de Tarascone, W. Benedictus, Isnardus Fusterius, Armandus Vaquerius. (Contract for the construction and transport of two rudders to Marseille, or at least as far as Arles, dated May 4, 1248. Blancard, 1885: v. II, 133-34)

8 Et thimones duos roboris grossitudinis parmorum octo in mensuratore. (Contract for the ship *Sanctus Nicolaus*, dated April 7, 1268. Belgrano, 1885: 218-19)

9 Item timones duos qui debent esse laborati et effetai, palmorum novem. (Genoese contract for the construction of two unnamed naves, dated November 26, 1268. Jal, 1841: 520)

10 Timonibus duobus sannis, grossitudinis palmorum octo pro quolibet. (Genoese contract for an unnamed navis, dated November 28, 1268, in Jal, 1841: 601)

11 Timonibus duobus bonis et convenietibus dicte navi, ... (Genoese contract for the ship *Sanctus Nicholaus*, dated June 4, 1269, in Jal, 1841: 566)

12 Item, velas cotoni novi quinque et timones duos grossitudinis (sic) palmorum septem pro quolibet. (Genoese contract for an unnamed navis, dated June 4, 1269, in Jal, 1841: 570)

13 Timonibus duobus, grossitudinis palmorum septem pro qualibet sanis et convenientibus dicte navi; (Genoese contract for the ship *Bonaventura*, dated June 8, 1269, in Jal, 1841: 552)

14 Timonibus duobus sannis et convenientibus dicte navi. (Genoese contract for the ship *Sanctus Spiritus*, dated June 8, 1269, in Jal, 1841: 583)

15 ac temonibus bonis et sinceris..... (Undated document from the reign of Jaime II of Aragon (A.D. 1291-1327) for the construction of the ship *Sancta Maria de Natzare*. Bofarull y Sans, 1898: 68)

DOCUMENTS LISTING QUARTER-RUDDERS AND A PINTLE-&-GUDGEON RUDDER

16 quoqueta coperta trium timonorum. (A.D. 1353. Villain-Gandossi, 1978: 284)

17 Primerament timons fornits....II Item govern....I. (Inventory of the uxer *San Pedro de Roma*, dated April 26, 1354. Bofarull y Sans, 1898: 77)

18 Primo II timons de timoner et unum govern. (Contract for the *Saint Antoine*, dated November 16, 1381. Jal, 1848: 797)

19 Primo corpus unius gallee. Item timones duos latinos. Item timones duos baonensses. (Inventory of a galley, dated A.D. 1402, in Villain-Gandossi, 1978: 284)

20 Est assavoir 3 gouvernailles, ... (Inventory of the galley *La Gaillarde*, dated September 29, 1450, in Lehmann, 1978b: 16)

21 timó de roda e II timons de caxa ab la timonera, III o IIII. (Contract of the construction of a caravel, dated A.D. 1464. Archivo Histórico de la Ciudad de Barcelona, Notariales IX-10 "Construcció de Naus")

22 II timos de roda et II timos de caxa. (A.D. 1465, in Villain-Gandossi, 1978: 284)

23 Primero, II timones de rueda, y II de caxa. (Inventory of the Galera Real *San Johan Baptista y San Johan Evangelista*, dated May 15, 1503, in Capmany, 1787: 29-30)

24 La referida Galera Real, entre otros muchos artículos, que por comunes se dexan aquí, llevaba II timones de rueda, y otros II de caxa. (Inventory of the Galera Real *Santa Trinidad*, dated March 12, 1529, in Capmany, 1787: 38)

25 Hanno (speaking of galeasses) il timone alla navaresca, cioè ad uso di nave et a i fianchi del timone portano doi gran remi, che aiutano à far girar' il vascello più presto. (Pantero-Pantera, 1614: 44)

DOCUMENTS LISTING RUDDER TACKLE

26 Item timons latins .....II, Item barons e estantares dels timons. (Inventory of the galley *Santa Catalina*, dated September 20, 1352, in Rubio i Lluch, 1947: 267)

27 Estantares ab ses talles. (A.D. 1354, in Villain-Gandossi, 1978: 293)

28 Apparaux de galée bailles et delivres à Jehan Tartarin, patron de la gallee Saint Victor ... une corde pour ses barons pour tous ses gouvernaux appelée hoste de pouppe. (French manuscript, dated A.D. 1359, in Villain-Gandossi, 1978: 293)

29 Item reebere timos fornits ab estantares e ab barons... Item troç de sagola del govern. (A.D. 1380, in Villain-Gandossi, 1978: 293)

MEDIEVAL MARITIME LAWS CONCERNING RUDDERS

30 Et si aliquam magagnum scivero in arboribus ipsius navis, vel timonariis, timonibus, ipsam

magagnum nauclerio, et penasio, et quinque naulizatis, si tanti fuerint naulizati in ipsa navi, et si tantinon fuerint, illis qui erunt, quam cicius potero, dicam et manifestabo. (Venetian maritime law LI requiring each ship to be provided with certain necessary equipment, including rudders and tillers. Normally it would seem that a rudder would be supplied with a ship leaving port, but obviously some ship owners did not see to this if this had to be written into law. *Capitulum sacramenti quod faciunt marinarii*, dated A.D. 1255, in Pardessus, 1839: v.V, 35)

31 E si cas és que ans que hajen comprada la dita exàrcia, havien tallada entena per fer timó o timoneres, o altre lenyam necessari a la nau per falta de exàrcia, los mercaders són tenguts de pagar la dita antena. E lo senyor de la nau deu comprar altra antena en esmena de aquella. (Chapter CCXXXI of the *Libro Del Consulado* requiring the ship owner to pay for replacement of equipment, such as a yardarm that had to be made into a rudder. The law probably dates to the last quarter of the 13th century A.D.. Capmany, 1965: 195)

32 Statuto è, che ciaschuna barcha da otto milliara in su, porta doi timoni per salvamento de la barcha, e de la nave. Et chi contrafarrà, paghe in nome di bando C soldi de anchonitanj piccioli. (Maritime statue XXXIV of Ancona requiring large ships to carry two rudders, dated A.D. 1397, in Pardessus, 1839: v.V, 145)

33 E el chapitanio del porto debia levare acciascheduno navilio de forestierj, che serà nel porto d'Anchona li timonj, overo [richiedere] buona sigurà, che ellj non debia chargare de pelegrinj nel porto de Ancona, nè d'Alaspia, Affiumegino, defino attanto che li navilij d'Ancona non sia chargati. (Maritime statue LXVIII of Ancona requiring the port captain to remove the rudder of a foreign ship as security of payment of fees, dated A.D. 1397, in Pardessus, 1839: v.V, 174)

34 Et nihilominus teneantur uenientes ad portum Pisauri, eadem die uel sequenti qua ingressi fuerint cum eorum nauigiis, temones de eorum nauigiis et extrahere et extractos tenere de temonalis; et secundum loca praedicta eis assignata teneantur dicti uenientes dicta eorum nauigia tenere. (Pesaro statue CXVIII concerning the removal of rudders from a ship in port. The statue is dated A.D. 1532, but unlike the others it is written in Latin, and it is probably a transcription from a much earlier law. Pardessus, 1839: v.V, 114)

TABLE I
MEDIEVAL RUDDER DIMENSIONS AND ESTIMATED WEIGHTS

	Length (goas)	Circ. (cubitus)	Length (meters)	Diam. (meters)	Weight (m. tons)
Contract 2	24.00	9.50	17.93	0.75	11.15
Contract 3	22.00	9.00	16.43	0.71	9.05
Contract 4		7.00		0.55	
Contract 7	21.00	8.00	15.69	0.63	7.04
Contract 8		8.00		0.63	
Contract 9		9.00		0.71	
Contract 10		8.00		0.63	
Contract 12		7.00		0.55	
Contract 13		7.00		0.55	

The above table of medieval rudder dimensions and estimated weights is based on the contracts found in Appendix III. The contract lengths are given as *goas* or *cubitus*, which were approximately 0.747 meters. The diameters are given as the circumference of the rudder shaft, and are listed in *palmi*, which were 0.252 meters. The above values are for Marseilles and Genoa (Pryor, 1987: VII, 174). *Goas* and *palmi* could vary depending on the location. In Barcelona, a *goa* was 0.777 meters, and a *pam* was 0.259 (García Sanz, 1977: 50). In both cities, a naval *goa* or *cubitus* was composed of three *palmi*, while the normal terrestrial *goa* was only two *palmi*.

The calculation of rudder weight is based on the instructions in *Fabrica di galere* for a *nave latina* (Jal, 1840: v.II, 27, 92; Pryor, 1987: VII, 282). The blade was assumed to be triangular, with the width being one fifth the length of the shaft and the height equal to one half the shaft length. The blade thickness was assumed to be one half the shaft diameter, and a wood density of 0.8 was used. The weights given above should be considered the **minimum** weight for that rudder.

APPENDIX IV
CORRESPONDENCE AND LETTERS OF PERMISSION

Correspondence from Mr. John Coates (Page 1 of 2)

SABINAL · LUCKLANDS ROAD · BATH · AVON BA1 4AU ENGLAND
Tel. (0225) 23696

8 January 1990

Dear Mr Mott,

Thank you for your letter and please excuse this very delayed reply.

I assume that you have seen the report (BAR International Series 486) of the trials of OLYMPIAS in 1987. It contains about 1½ pages on turning. The 1988 trials have also been written up, but not yet published. In 1988 we achieved circles of 2 ship-lengths dia (Water line length) in diameter.

On resistance, the difficulty is to reconcile strength of rudder stock with resistance of a stock of the necessary diameter. It is the stock which generates most of the resistance, not the rudder blade. In OLYMPIAS there is no fairing of stock with rudder — perhaps there should be and we are having experiments made on this. Fairing might say halve the resistance.

However it is much easier just to have only as much rudder as is needed for course-keeping normally

Correspondence from Mr. John Coates (Page 2 of 2)

in the water! So far we get the impression that that is about half of one rudder, when the added resistance is relatively modest because there is almost no stock in the water, and what there is, is quite thin (as it tapers towards its lower end, forked over the blade). Our experience suggests strongly that the ancients used no more quarter-rudder area in the water than was needed in the prevailing circumstances: half of one rudder immersed in normal cruising, and even less if passage-making in a hurry under oar, while in battle or manoeuvring in harbour, both rudders would be fully immersed. In the thick of battle there would have been little opportunity for speed, but manoeuvring would obviously have been most important.

As steering devices, quarter-rudders are clearly very effective, mainly I think because they work in water clear of the ships wake (and that of the oars). Maybe, after more experience, we may reduce the diameter of OLYMPIAS's rudder stocks (180 mm). So far they are the only quarter rudder stocks not to have broken!

I hope this helps.

Yours sincerely John Coates

A transcription of the letter by Mr. John Coates.

8 January 1990

Dear Mr. Mott,

Thank you for your letter and please excuse this very delayed reply.

I assume that you have seen the report (BAR International Series 486) of the trials of the OLYMPIAS in 1987. It contains about 1½ pages on turning. The 1988 trials have also been written up, but not yet published. In 1988 we achieved circles of 2 ship-lengths (waterline length) in diameter.

On resistance, the difficulty is to reconcile strength of the rudder stock with resistance of a stock of the necessary diameter. It is the stock which generates most of the resistance, not the rudder blade. In OLYMPIAS there is no fairing of the stock with rudder - prehaps there should be and we are having experiments made on this. Fairing might say halve the resistance.

However it is much easier just to have only as much rudder as is needed for course-keeping normally in the water! So far we get the impression that that is about half of one rudder, where the added resistance is relatively modest because there is almost no stock in the water, and what there is, is quite thin (as it tapers towards its lower end, forked over the blade). Our experience suggests strongly that the ancients used no more quarter-rudder area in the water than was needed in the prevailing circumstances: half of one rudder immersed in normal cruising, and even less if passage-making in a hurry under oar, while in battle or maneuvering in harbour, both rudders would be fully immersed. In the thick of battle there would have been little opportunity for speed, but manoeuvering would obviously have been most important.

As steering devices, quarter-rudders are clearly very effective, mainly I think because they work in water clear of the ship's wake (and that of the oars). Maybe, after more experience, we may reduce the diameter of OLYMPIAS's rudder stock (180mm). So far they are the only quarter-rudder stocks not to have broken!

I hope this helps.

Yours sincerely,

John Coates

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August 16, 1990

Lawrence V. Mott
Nautical Archaeology Program
Dept. of Anthropology
Texas A & M University
College Station, Texas 77843-4352

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College Station, Texas 77843-4352

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D. LAWRENCE V. MOTT
NAUTICAL ARCHALOGY PROGRAM
DEPARTMENT OF ANTHROPOLOGY
Texas A y M UNIVERSITY
College Station,
TEXAS (U.S.A.)

Palacio Real, 25 de Junio de 1989.

VITA

Lawrence V. Mott was born June 20, 1952 to Lawrence D. Mott and Frances G. Mott in San Mateo, California. He grew up in Altadena, California.

Education:

University of California at Santa Barbara; Bachelor of Arts degree in geology (1976).

University of Wyoming, Laramie, Wyoming; Master of Science degree in geology (1978).

Positions Held:

Quartermaster 3rd Class, U.S. Coast Guard Reserve; January, 1972 to May, 1978.

Graduate Research Assistant, Department of Geological Sciences, University of Wyoming, Laramie, Wyoming; September, 1976 to June, 1977.

Graduate Teaching Assistant, Department of Geological Sciences, University of Wyoming, Laramie, Wyoming; September, 1977 to June, 1978.

Geologist, Atlantic Richfield Company, Denver, Colorado; August, 1978 to December, 1981.

Chief Geologist for the Sheep Mountain Project, Atlantic Richfield Company, Denver, Colorado; December, 1981 to November, 1984. (Resigned from ARCO November 20, 1984 to pursue nautical archaeology.)

Field Experience:

Dive Team Leader, Port Royal Excavations, Jamaica, June-August 1985. Underwater excavation at the site of a sunken colonial city which was inundated by an earthquake in 1692.

Principle Investigator, Spanish Medieval Ship Iconography Survey, Spain, July-October 1986, and February-June 1988. Location and documentation of medieval ship representations in Spain and Portugal.

Intern for 3 months at the RockPort Apprentice Shop in Maine learning wooden boat and ship construction techniques. Built a 15 foot skiff and a Norweign pram. Took the lines off an old sloop for the archives before she was scrapped.

Publications & Presentations:

Mott, L. and Drever, J., "Origin of the Uriniferous Phosphatic Zones of the Wilkins Peak Member, Green River Formation, Wyoming". *American Assoc. of Petroleum Geologists* (1983) **67**: p.70-82.

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Mott, L., "Ships of the 13th Century Catalan Navy". *International Journal of Nautical Archaeology* (1990) Vol. **19.2**: 101-112.

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