5 THE GREAT INVENTION: 1400-1550

In 1453 Constantinople and the Byzantine Empire fell to the Ottoman Turks. By that late date the event was a minor one, both politically and economically. Turkish naval forces already presented a threat to Italian and especially Venetian commercial shipping. To hold and to improve their political position the Turks had found that they needed a powerful navy. By 1500 their holding of all the continental naval bases in the eastern Mediterranean had revolutionised sea power. In the sixteenth century the Turks challenged the power of Italian trading towns and of Spain in a series of naval battles. The Mediterranean was effectively divided into two spheres, with the eastern half patrolled by Turkish warships and the western half, along with the Adriatic, reserved largely for the warships of Christian states. In Italy itself the consolidation of certain states had led to the emergence by the mid-fifteenth century of a balance of strength among them, which changed, however, in 1494 with an invasion by French troops. After this invasion the Italian states were dragged into another general conflict but, instead of Christians and Turks, the contestants were the Habsburg and Valois dynasties.

By a series of marriages and convenient successions the house of

Illustration above: A three-masted ship but with square sails on each of the masts, seal of Louis de Bourbon, Admiral of France, 1463-86.

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Habsburg had gathered together enough titles and states to make it the most powerful in Europe. In the person of the Holy Roman Emperor, Charles V, all the different states were united. Charles saw his job as the unification of Christendom. The kings of the House of Valois in France contested this bid for European hegemony, at the same time advancing their own dynastic interests, thus leading to almost continuous wars between France, on the one hand, and Spain, the Low Countries and the other states under Hapsburg rulers, on the other. England was a makeweight in these contests, as were the smaller states in Germany. The diminished position of the English crown was in part the result of the defeat suffered in the Hundred Years' War with France. By 1453 and the end of the war, the king of England had to surrender almost all his continental possessions. Despite a more aggressive naval and commercial policy from the late fifteenth century, England remained a state of secondary importance to the balance of political and naval power.

The Hanseatic League, meanwhile, because of internal strife and external pressure, faced the slow erosion of both political and economic power from the early fifteenth century. The counties of Holland and Zeeland were added to the lands of the Dukes of Burgundy in the fifteenth century, uniting them, among others, with the wealthy county of Flanders. Merchants throughout the Low Countries, then, could expect greater and more effective political support. That possibility was enhanced when the region became part of the massive holdings of the House of Hapsburg at the end of the century. Dutch traders, from Holland and Zeeland, were able to supply similar shipping services for less than their Hanse competitors. Dutch merchants also enjoyed close connections with monarchs in Scandinavia, who were able slowly to reassert their political power, supplanting the aristocracy and at the same time challenging the dominant position of German merchants by inviting Dutch traders to compete against them. The internal troubles of, and the fighting among, the principalities of the North, however, were peripheral to the struggle in central and western Europe.

The Protestant Reformation complicated the politics of Europe. Starting in Germany as a theological debate on questions basic to Christianity, it soon brought into question the entire character of relations between church and state. Pressures increased on all parties to take a side in the controversy. The Papacy, having declared the opinions of Protestants anathema, urged secular authorities to suppress the heresy. In doing so the church created a new network of allegiances which in some cases did and in other cases did not overcome other bases for political and military affiliation among states. Merchants were

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not totally immune from the pressures of the new religious controversy. At times states prohibited certain merchants from trading because of their religion. The importance of religion to both politics and commerce increased in the course of the sixteenth century, as both Catholics and Protestants mobilised forces for what both sides saw as a necessary struggle. These battles were far enough removed from the daily operation of most trade, and especially small-scale trade, however, that shipbuilders continued to function as they had for centuries, subject to the pressures of the economics of shipping and the sporadic and unique demands of government.

By the end of the fifteenth century, the pattern of design development had become general throughout Europe. Not only did contact among the various regions increase but also shipbuilders turned themselves to the construction of similar types in most of the major ports of the Continent. The fact that shipping had taken on a general European dimension was already evident in the late fourteenth century. The structure of demand for ships thus became increasingly similar for all builders. At the same time the invention and technical innovations of the fifteenth century made certain designs significantly superior to earlier ones and made the new forms acceptable for many jobs in many different places. This is not to say that regional and local variations were eradicated: quite the opposite. There was still a difference between types built in northern and those built in southern Europe. The climate, the nature of the winds and tides and the generally different sailing conditions in the Baltic, in the North Sea, along the Atlantic coast and in the Mediterranean still guaranteed variation in the way local builders executed designs. But shipbuilders, by borrowing and copying design features, did create a range of highly versatile vessels, vessels which, with minor adjustments, could be used anywhere in the world.

One of the major features of fifteenth- and sixteenth-century shipbuilding was the greater differentiation and specialisation in the design of smaller vessels – that is, ships and boats under about 50 tons. The introduction of certain new types of rig, including the transfer of lateen rig to northern Europe, made possible that greater differentiation. The smaller ships and boats were solid and reliable. They usually had higher manning ratios than had larger vessels, but the implied higher cost was often fully offset by faster turnaround time. Skippers used these vessels as coasters, tramping from port to port. In the tenth and eleventh centuries tramping had been a job reserved for the largest cargo ships, those of 200 tons and often more. By 1450, small vessels heavily

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outnumbered large ships; this was true when comparing all seagoing ships of over and under 100 tons. The large number of small ships gave shipwrights many more chances to experiment with improvements to those vessels, though typically the improvements were minor ones. Moreover, in the second half of the fifteenth and in the sixteenth century, the absolute and relative number of these smaller vessels rose. The general growth in the economy and the relatively faster expansion of commerce created more opportunities for using smaller vessels than for using the largest of seagoing ships. The coasters could carry anything. In periods of growth they could supplement large carriers on major routes, while opening and serving new and shorter routes.[1] Shipbuilders responded to the trade revival by building more ships and by building vessels better suited to the opportunites at hand.

The names given to these smaller craft are in many cases hard to match with a design. Still, there is an unmistakable impression that the variety of ship types grew in the fifteenth and sixteenth centuries. The variety is unfortunately bewildering but the repetition of certain names in many of the records suggests that certain types of smaller craft did enjoy a widespread popularity among shipbuilders. Crayers and balingers appeared alongside various barks, barges and snikkers in German and English records. There were also other local types. The balinger, for example, was a popular type. It may have started as a whaling boat used along the coast of Brittany and the Bay of Biscay. In the fifteenth century it changed from a small oared fishing boat to a sailing vessel with two square sails on two masts. A sailing balinger carried from 20 to 50 tons but there were larger balingers of up to 100 tons and in one case of 500 tons. A balinger was capable of sailing from the Low Countries to the eastern Mediterranean. The change to a sailing ship lowered the manning ratio and made the type economic for trade along the coast and for use between France and England and between Spain and England. The development of the barge in the fifteenth and sixteenth centuries is not as clear. Certainly, barges were used for ceremonial transport on rivers but they also acted as troop transports and cargo ships, going from 25 tons up to 240 tons. They too may have combined oars and sails for propulsion. The use of the name for northern European seagoing cargo carriers decreased in the fifteenth century, probably because of improvements in other ships which became more efficient and could replace the barge. Spinaces, later pinnaces, of around 20 tons appeared in English customs records, along with picards and many other types, including keels. How much the last owed to the Scandinavian cargo ship of the eighth century is not known but, by the

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fifteenth century, there were at least three different forms of keel, each with a single mast and single square sail.[2] Many of these types were used as lighters in harbours or for short-distance coastal voyages. That meant that they rarely exceeded 20 tons. Of course, they enjoyed the advantage shared by all these small types of being able to get in and out of almost any port.

In Normandy shipbuilders constructed all kinds of ships, from galleys of Mediterranean design to the biggest sailing vessels, but the large majority of their ships were small ones able to visit the ports among the coastal cliffs and travel up the Seine to Rouen. There were clinker-built barges similar to those in England. Balingers also came from Norman yards, as did crayers, galiots, brigantines, frigates and many others. There was also a number of fishing boats. These, like many of the other types, grew in size throughout the fifteenth and sixteenth centuries, so they could be used efficiently on the high seas. The opening of the Newfoundland cod fishery in the sixteenth century contributed to the growth of those ships. Vessels of 50 tons could make the trip to the New World and back but the average ship was closer to 80 tons and ships of 200 tons were not uncommon. As much of the work of preparing the fish was done on board, the manning ratios were high.[3] Growth in size did not change the basic and simple design of these different types. The pattern was apparently similar along the Atlantic coast of France.

In the Mediterranean the successors of lateen-rigged round ships carried the goods of local and regional commerce going by sea. The felucca was a small boat with two masts, each with a lateen sail. It was built in Portugal as well as in the Mediterranean. There were barks of various types, along with small galleys, presumably made broader and more like sailing ships in order to be economic cargo carriers.[a] Certain designs were imported from Iberia. Shallops, which started as whaleboats in the Bay of Biscay, and Portuguese barks with two square sails, one on each mast, easily found a place in the Mediterranean coasting ports.[4] But even the largest ports had their share of various smaller types to maintain contact with nearby coastal villages and towns.

If the variety of small types is confusing for fifteenth-century Germany, England, France and the Mediterranean, it is staggering for the Low Countries. Dutch shipbuilders, even more than their counterparts in the rest of Europe, were able to generate specialised designs. One reason was the poor and constantly changing conditions of the many harbours and inland waterways used by most ships in the Low Countries. Another reason was the increase in a broad range of maritime

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activities by Netherlanders. The fishery expanded rapidly as North Sea herring replaced Scania herring in European markets. Low Countries fishermen used a larger net and improved curing methods, with salting and packing of the fish done on board – thus necessitating a bigger fishing boat designed specifically to exploit the new techniques. Dutch builders supplied the herring buss. By 1500 it carried three masts, all detachable so that they could be taken down when fishing. There was a square sail on each and sometimes a square topsail above the main on the mainmast. The posts were sharply curved, giving bluff bows. The stern was flat. There was often a bowsprit, usually pointing down to give better control over the net when it was cast over the bow. Larger busses had a full deck with a large hatch to take the casks filled with fish. There was little resemblance to the thirteenth-century Scandinavian cargo carrier but presumably the two types with the same name at least had a common ancestor in the Viking cargo ship. Other deep-sea fishing vessels came from Dutch yards, such as the dogger and the hoeker, both for the cod fishery. The hoeker, like the buss, offered a specialised type for certain fishermen. Hoekers had flat sterns and two and sometimes three masts, each with a square sail. The hull was often pierced with many small holes to create a bath of sea water in the middle of the ship for the catch. Fish could be stored there and delivered fresh. Doggers, on the other hand, were typically used for producing salted cod though salting was also done on board hoekers.[b] Added to these types were the pinks, *schuiten* and *slabberts* of the coast fishery. The *schuit* was a small flat-bottomed boat with a sail. It could be and was used on inland waterways and indeed throughout the Low Countries. The design may have been typically the same as the second-century riverboats excavated at Zwammerdam. Another inland cargo and passenger carrier was the poon. It, like the pink, was short with a rounded bow and sharp sternpost. The bottom was flat, at least for part of the hull, and it could be beached anywhere. There were corvers, smacks and plats, which turned up in the fishery and also in the rapidly expanding cargo trade to ports in eastern England.[5] All these vessels were sturdy and designed to take the rough waters of the great rivers of the Low Countries and of the North Sea.

The fishing boats were unemployed for a sizeable part of the year because of the limited fishing season. Since they could weather North Sea storms they were well suited for cargo carriage. Skippers in the off-season went in search of cargoes for their busses and hoekers. Voyages as far as the Mediterranean were possible. The buss began as a small vessel of 30 or 40 tons but by 1550 was usually well over 100 tons and

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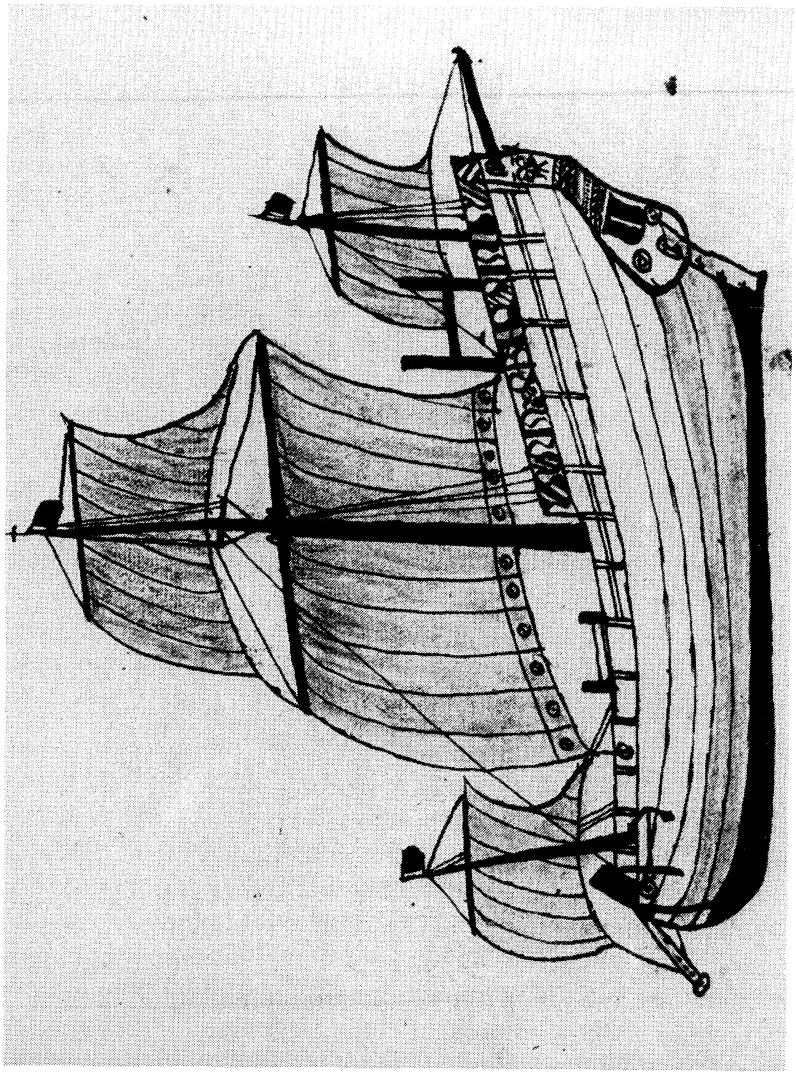

19: Dutch Herring Buss, Sixteenth Century

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20 metres or more long. Crew size fell, by as much as 50 per cent, making it more efficient in fishing and an even better candidate for carrying cargo. By the mid-sixteenth century, Dutch yards produced vessels of buss design but destined exclusively for taking cargoes. There were other cargo ships, exclusively designed for short-distance carriage, such as the *heude*.[6] These were vessels, like the buss, of about 100 tons or less, and able to negotiate the estuaries, rivers and shoals of the south coast of the North Sea and the Channel. A small version of the cog was also popular on Dutch inland waters. The design still served, as it had in the seventh century, on the sandbanks and shoals of the Low Countries. The cog, like most of the other smaller cargo and fishing boats of the Netherlands, was derived from earlier designs. Dutch ship carpenters were familiar with these types and continued to build them, constantly adjusting them to changing demand. It was a matter of exploiting what was known.

Dutch builders did make a major change in many of the designs. The typical square rig of northern Europe was dropped and replaced by a sprit-rig. This form of fore-and-aft sail, known in the Roman Empire, had apparently fallen out of use, replaced by the lateen sail in the fifth and sixth centuries. Sprit-rig may have been used throughout the middle ages and just not have appeared in records or in illustrations. More likely it was simply forgotten. It is apparently one of the few cases where knowledge of a design feature was lost. In the fourteenth century, sprit-rig came back into Europe, first in the form of a sail on two poles with a common base – an arrangement common in southeast Asia. In any event, by the early sixteenth century, Dutch small craft carried fore-and-aft sails, either spritsails or gaffsails. The gaffsail was, like the spritsail, rectangular or trapezoidal but it was hung down from a yard, extending back from the mast and pivoting on it. The gaffsail in general could not be made as large as the spritsail. Both, however, had the advantage of having the leading edge of the sail stretched to the mast; as a result, they were better for going against the wind and especially good in a crosswind, something that Dutch small craft typically had to face. The spritsail could also carry a bonnet at the bottom so that size could be increased in fair weather.[7] A second sail was often added, hanging from the forestay. A triangular staysail had many of the same properties and thus further improved handling qualities. Dutch small boats typically carried this rig but it was also used on larger ships of up to 100 tons.[c] The rig increased manoeuvrability, cut down time wasted waiting for a fair breeze, and also required less manpower to operate than any competing rig. The result was a highly versatile craft well

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suited to short-distance carriage across the open sea and along the coast. For single-masted vessels it was markedly superior to lateen rig. It gave Dutch shippers an advantage in regional and local transport, and thus in the distribution of goods, which in turn drew more long-distance trade to ports in the Low Countries. The improved rig was adopted about 1400, and may have been taken on in response to the troubled state of the Holland economy in the late fourteenth century. While escaping the worst immediate economic effects of the Black Death, the Dutch economy suffered in the years just before and after 1400. The revival and expansion after the middle of the century served to increase opportunities for experiment and the adaptation of fore-and-aft rig to Dutch ships.

As to the improvements in fishing boats, the changes in productivity wrought by the Black Death led to greater consumption per person of protein foods, of meat, cheese and also fish. The pressure on producers to increase output, combined with the improvements in related technology, in the catching and preserving of fish, created an imbalance which brought ship carpenters to concentrate their efforts on finding the right combination of design features to make fishing vessels more productive. Since the size of the market had grown relatively and there was upward pressure on prices, it was possible to build a ship of specialised design. If it could be used to carry cargo in the off-season, that was a lucrative but not a necessary benefit. As the absolute size of the market for fish grew throughout the fifteenth and sixteenth centuries, shipbuilders took the opportunity to improve the design and to make it even more specialised. In the process they also made the ship more efficient. The Dutch example is only the most extreme and the most impressive in the development of specialised smaller craft. The greater variety of these vessels and their greater efficiency constituted a valuable addition to total shipping services in Europe. Since Dutch shipbuilders went to the greatest extremes of specialisation, it was Dutch shippers who reaped the greatest advantages.

Galleys were still used. They survived as warships until the nineteenth century but by 1400 they were already different from their twelfth-century predecessors because of the change to three oarsmen to each bench. Galleys were usually under 40 metres in length but they could exceed 50 metres. The width was usually one-eighth of the length. The rise in the number of rowers had made it possible to build the galley longer, broader and heavier. There were typically about 24 benches to a side, giving a total of 144 oarsmen. There was generally a single mast with a lateen sail, though larger galleys, especially those for

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the transport of troops, still carried multiple masts. The war galley was not a ship for the open ocean but it did dominate the Mediterranean. There were galleys in northern Europe, copies of Mediterranean galleys, but they remained exclusively warships for fighting on the rivers and along the coast. They were used as far north as Finland, and the Spaniards deployed a squadron in the Caribbean where conditions both of weather and of piracy were similar enough to those in the Mediterranean to make them effective.[8]

The greatest change in the galley came from the introduction of artillery on board. The guns replaced older ballistic devices and took their place at the bow. Guns were already used at sea in the wars between Venice and Genoa in the fourteenth century. Only as guns became more reliable were they put on the majority of galleys. By 1500, a single large gun set along the centre line at the bow was the principal offensive weapon of the galley.[d] These guns were heavy bronze cannon, like those used in sieges on land; they were very expensive and the galley provided the most versatile platform for them. Small guns, as many as six, flanked the large piece. Superstructure disappeared since crews were no longer worried about being higher than the enemy. There was still a small fighting platform above the gun for marines. The addition of heavy guns forward made the ship even more unstable. Artillery changed the value and character of galleys. Large round ships, manoeuvrable and equipped with guns, were almost invulnerable to these light ships. In the early sixteenth century, navies used galleys equipped with cannon to cover landings, to shell fortresses and in general to support amphibious operations. As sailing ships gained more armament, that use declined in importance but not until after 1550. Galleys remained in the fleets of all Mediterranean naval powers to deal with opponents' galleys. Boarding was the usual tactic for victory at sea. Galleys were best suited to the job of making contact with an enemy ship at a lightly defended point and staying long enough to give a boarding party a chance to take the other vessel. With oars for propulsion, galleys could always avoid sailing ships, so only other galleys could effectively neutralise them in naval battles. Galleys were also effective in supplementing the defence of fortified coastal positions. They proved highly effective in the incessant piratical war of attrition fought largely between Christian and Muslim states.[9] So long as the number of guns remained small and galleys had an overwhelming superiority in manoeuvrability over sailing ships, they remained a critical part of Mediterranean naval forces.

Great galleys were driven out of commercial service as improvements

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in the design of sailing ships made them as efficient in carrying goods. Regular state-sponsored galley service from Venice and from Florence continued throughout the fifteenth century but by the beginning of the sixteenth century these voyages had been sharply curtailed and by mid-century they had disappeared entirely. In the fifteenth century, great galleys carried three lateen sails. Oars were still handled by individual oarsmen. A length of 45 metres was typical. The measurements and design remained much the same as long as great galleys were built at the Venetian Arsenal. They survived longest in voyages from Venice to the eastern Mediterranean. At the end of the fifteenth century, they were still the best carrier for pilgrims going to the Holy Land. So that they could compete with sailing vessels, great galleys were built bigger. By 1500, they had reached capacities of 250 to 300 tons which, given the amount of hold space and methods of measure, probably gave them a payload equivalent to that of a sailing ship of 600 tons.[e] Crews of 200 men or more made them highly defensible but also raised operating costs relative to sailing ships.[10] In part because of government support, in part because of the unique nature of Venetian transport needs in the eastern Mediterranean and in part because of the ability of shipbuilders to expand the capacity of great galleys, this type continued in use well into the sixteenth century; but the success in designing sailing ships in time drove the great galley out of more and more trades. Shipbuilders then turned their attention to building a sailing ship which could retain at least some of the advantageous features of the galley.

The galeass of the first half of the sixteenth century was a large sailing warship, but with oars and with a length-to-breadth ratio like that of a great galley, about 5:1. Because of its larger size it could handle more guns than a galley but retained much of its manoeuvrability. The compromise did not work because the galeass was little more than a big, well-armed but much slower galley. The galeass was clumsy and still had trouble dealing with a warship powered exclusively by sails. Finding crews to man the heavy oars was a constant problem. As sailing ships on the open Atlantic, galeasses left a great deal to be desired. Galeasses could reach 450 tons, making them quite large warships. There were three masts, sometimes four, with lateen sails in the Mediterranean and square sails in the North. Rowers worked on a deck below the full top deck. The latter was reserved for the marines, the cannon and the other missile launchers. The crews were massive, one galeass 47 metres long having a total of 700 men on board. Navies used galeasses in most of the major naval battles of the sixteenth century. King Henry VIII of England considered galeasses a necessary part of his naval armament

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and had some 15 of them. Of course, the king of France had to have a fleet of galeasses to meet them.[11] For much of the sixteenth century the design of galeasses in northern Europe was little different from that in southern Europe.[f] The type was developed purely because of the demand of governments for a specific kind of warship; based on experience with great galleys and with contemporary sailing ships, builders generated the combined design. The migration of ship carpenters, especially from Italy to northern Europe to work for government shipyards there, guaranteed a consistency of design. Begun in the late thirteenth century, the transfer of shipbuilders at least made the design of certain kinds of warships the same throughout much of Europe. Shipbuilders failed to make the galeass into a viable warship. By the late sixteenth century, sailing ships were better for fighting than were galeasses, just as they were better at carrying cargo than were the similar great galleys.

The history of the caravel, another type originally developed in southern Europe, is rather confusing. The name was first attached to a fishing boat and probably has an Arabic origin, but the exact form of that mid-thirteenth-century fishing boat is unknown. The name may have been used to indicate the type of planking and there is little question that the caravel was, from the first, carvel-built. The Portuguese government, committed by Prince Henry the Navigator to a policy of expansion by sea, needed a ship which would serve for the exploration of the African coast. Explorers used barks of about 25 tons, which had a single mast and may have been very much like earlier Scandinavian and English cargo ships. Explorers also used the *barinel* which was longer and larger than the bark. Neither of these was adequate for the increasingly longer voyages so, by 1440, the caravel joined the squadrons travelling south into the Atlantic from Portugal. From 20 to 30 metres long and 4 to 5 metres wide, they were vessels of 50 tons and more. They carried two masts with lateen sails. Draught was shallow. The caravel was highly manoeuvrable and was able to sail back to Portugal from West Africa despite contrary winds and currents. There was no forecastle on these ships and the small aftercastle was only there to make handling the sails easier. The low sides, sharp ends and lateen rig all created a vessel which could sail closer to the wind than other contemporary European vessels.[g] Carrying capacity was small on the caravel and indeed on all ships used for exploration, so small that they could carry little food for the crews. Such ships had to be able to stay at sea for long periods and could not count on being supplied from ports along the way. The quantity of supplies required was about double that needed for voyages inside Europe. Crews were larger on voyages of

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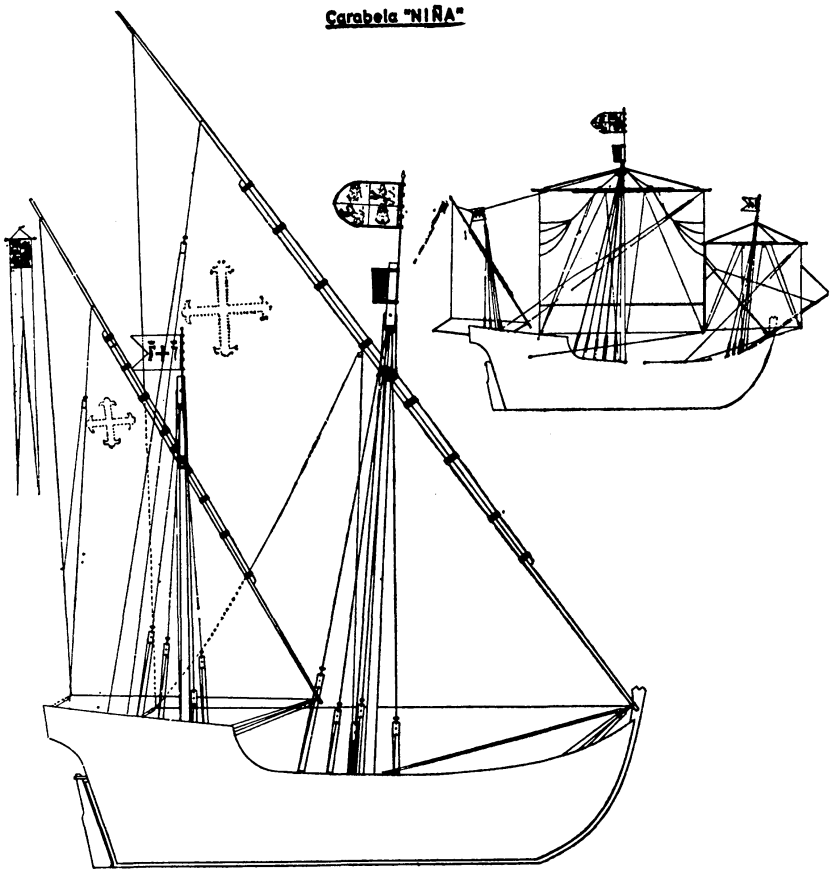
20: Sail Plan of Christopher Columbus's *Nina* as a Lateen Caravel, and Transformation into a Square Caravel in a Reconstruction by J.M. Martinez-Hidalgo



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exploration, at least double those on regular trips. Ships of 30 tons, which could carry a payload of more than 22 tons trading in Europe, did not have enough room for the food required for a voyage of exploration.[12] The lack of cargo space in caravels, then, sharply decreased the range of the explorers, but this price had to be paid in order to get the superior handling qualities of the caravel.

In the second half of the fifteenth century, the caravel became larger and also more beamy in order to increase the carrying capacity for each metre of length. Ship carpenters made little sacrifice in manoeuvrability as they modified the design. By 1480, caravels were from 150 to 200 tons. Length-to-breadth ratios also fell, probably into the range of 4:1 and 3:1. The lateen rig was also changed. Yards were made shorter so that they were easier to handle. The yard was set perpendicular to the ship and was held closer to the mast. All these modifications made it possible to come about without having to carry the yard over the masthead. Manpower was not saved, since ships on voyages of discovery always carried big crews, but manoeuvrability was increased. There was a loss in sail area, so a third mast was added to fit a third lateen sail. The new larger version of the caravel, with minor modifications, could be an effective warship. In this new form caravels were also capable of long and profitable voyages on the high seas. They were used in trade from Spain to England and later to the Americas, and they also found a place carrying luxury goods in the eastern Mediterranean. They were faster than earlier sailing ships and there was a major saving in manpower, compared to galleys. In smaller versions, of around 100 tons, caravels were popular also as coasters. Their greatest success, however, came in trade to the Atlantic islands and to West Africa from Iberia.[13] Originally designed for those waters, caravels could efficiently move the growing exports of wine and cane sugar to Europe where demand for those goods rose throughout the fifteenth century.

Despite the fact that Portuguese builders knew about sprit-rig, they retained lateen sails for their caravels. The sprit-rig was more efficient but, after the improvements made in lateen rig in the fifteenth century, the difference had been narrowed. The tradition of using lateen sails was probably not as important a consideration in retaining that rig as the need for larger and heavier masts when any alternative rig was used. For a large spritsail, the long sprit put a strain on any mast. To get enough sail area for an exploring ship, very large masts were needed and masts were already expensive. It was not uncommon to take the masts and spars from a wreck and use them again, since they were so valuable. Moreover, the greatest advantage of the sprit-rig was that it saved man-

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power. Since crews had to be large anyway for most voyages by caravels, there was no gain from changing to sprit-rig. Though the caravel became an effective cargo carrier, the original inspiration for developing the design came from the orders of the Portuguese government which was striving to promote domestic shipbuilding and design improvement in order to pursue the possibilities of expansion by sea.

The exploration and indeed the entire programme of the Portuguese government was made possible by improvements in a related technology, in navigation. Prince Henry the Navigator fully appreciated the interdependence of ship design and navigation and gave extensive support to research in the latter. The result was the development and dissemination of the method of sailing by *altura*. The latitude of the ship was determined by examining the height of the sun at midday. Earlier sailors had used the Pole Star as their guide but Portuguese navigators lost sight of that star as they went south along the African coast and so had to use another approach. By the end of the fifteenth century, the *altura* method was made easier by the use of more reliable instruments and declination tables relating height of the sun to degrees of latitude. Used along with the navigation techniques of the fourteenth century, which had also been improved, the combination gave a practical system of broad capability, certainly superior to that in contemporary use in the Indian Ocean. By 1500, a Portuguese navigator could take his ship to the latitude of his destination and then run along that latitude until he got to the port he wanted, a valuable help in navigating by dead reckoning. To do this, however, he had to have a grasp of the theory of astronomical observations for finding positions and he had to be able to do some mathematics.[14] Arab and Chinese pilots of the Indian Ocean knew how to take the position of the sun or stars to derive their own position and they used that information to run down latitudes. Indeed, they had developed a form of quantitative navigation well before the Portuguese in the fifteenth century. But western Europeans enjoyed the advantage of a tradition of making charts and using them on board ship which was not shared in the East. Thus they were in a better position to visualise and measure their progress as movement from one cross on a map where latitude and longitude met to another.[h] By the early sixteenth century knowledge of navigation was well enough organised to allow for the publication of many guides and tables for pilots. New books of sailing directions, rutters, were printed, covering European waters. Though Iberian governments tried to monopolise the new technology, the information diffused rather quickly throughout Europe. As a result, some navigators were in a position to choose among

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a collection of routes, the decision dependent on where they would expect to find the most favourable wind or currents. In combination with vessels like the caravel, long-distance voyages through unknown waters could be made and, more important, repeated with a high level of accuracy. It was possible to learn how to make such voyages in some way other than by experience. Most navigators for voyages within Europe still relied on only a few aids: the compass in a binnacle-like box, lead and line and a sandglass to measure time. Few sailors had the skills or equipment to use the new navigational methods.[15] Even so, by creating new possibilities, the combination of improvements in technology meant that sailors were in a much better position to exploit natural forces. Once the first voyages of discovery had been made, Europeans could travel along the new routes and establish regular travel. For that task, as for many others inside Europe, they used another type of sailing ship, the type with the greatest versatility.

The full-rigged ship was the great invention of European ship designers in the middle ages. The development of this type marked a major improvement in ships and established the basis for the design of seagoing ships to the nineteenth century and the introduction first of the clipper ship and then of steam power. The full-rigged ship has been called the Atlantic type because it may have been developed by Basque shipbuilders somewhere along the coast of the Bay of Biscay. It is not possible to say who first hit on the idea of building this type but it is true that shipbuilders and shippers from the Atlantic coast of Europe were the ones who adopted it most quickly and who first demonstrated its potential. The full-rigged ship could survive the difficult journeys along that coast and was well suited for making voyages between northern and southern Europe. By the sixteenth century the versatility of the type had made it popular with all European shippers, who used it for all kinds of voyages throughout the world.

For such an important invention, the full-rigged ship on first examination seems quite simple. It was a combination of design features from the cog, as modified by Mediterranean builders, with other features from southern and northern types. The hull planks were placed edge to edge and, like the modified cog it was of full skeleton construction. It had a length-to-breadth ratio a little higher than the cog though, about 3:1 to 3.5:1. Of course, the figure varied. There were through-beams piercing the hull; they supported the two and sometimes three decks. There was a large and high aftercastle running from the stern to the mainmast and a smaller, usually triangular, but still high, forecastle. In fact the forecastle was higher than the aftercastle, the opposite of earlier

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southern design. To carry the forecastle the forepost was swept up. The sternpost, on the other hand, was straight and at a slight angle to the keel. The ribs were heavy. The bottom may have retained the same kind of flat section around the middle of the ship that appeared on the Bremen cog. The hull tended to be broad at the bow. There was a keelson which also supported the mast. The keel itself was straight. On the sides there were skids as well as wales for protection. On larger ships there was sizeable tumble-home – that is, the breadth of the ship at the deck was significantly less than its breadth at the waterline. The decks could thus carry more weight but the upper parts of the sides were weaker than normal, thus making reinforcing skids all the more necessary.

Control came from a sternpost rudder. There might be a small amount of space between the rudder and the point where the sternpost met the keel, and this was filled with deadwood. With the stern built up there was a hole for the tiller to pass inside to the whipstaff, a common arrangement for all large ships by the sixteenth century. The entire stern was rarely flat. Usually there was a wing transom, a flat section on the upper part of the hull at the top of the rudder. The full square stern, which became more common in the sixteenth century, especially on vessels in southern Europe, did not help control but it did improve carrying capacity.[i] The greatest improvement in handling came from the change in the rig.

Full rig typically included three masts, the fore- and mainmast carrying square sails and the mizzenmast having a lateen. The change to multiple masts was not illogical. There were apparently many experiments with two-masted ships around 1400 but these types were quickly replaced by three-masted vessels. The second mast could be and was stepped either forward or aft of the mainmast. Illustrations survive of both types.[j] Such masts were added to both small and large vessels. But if surviving illustrations and records are a guide, there were surprisingly few two-masted vessels used in Europe in the fifteenth and sixteenth centuries.[16] The addition of one small sail made it necessary to balance that sail with another. So, rather than change the position of the mainmast or redesign the hull, builders simply added a third sail to match the second. It was not necessary that the after- or mizzenmast carry a lateen sail. As late as 1466, a three-masted ship carried all square sails.[k]

By the end of the fifteenth century, yet another sail had been added, slung on a yard hanging below the bowsprit. The bowsprit had been on ships for 150 years before the spritsail was introduced. It acted as a headsail, like the foresail, giving some pull against the rudder. With a spritsail, the foremast could be moved back from the bow and the fore-

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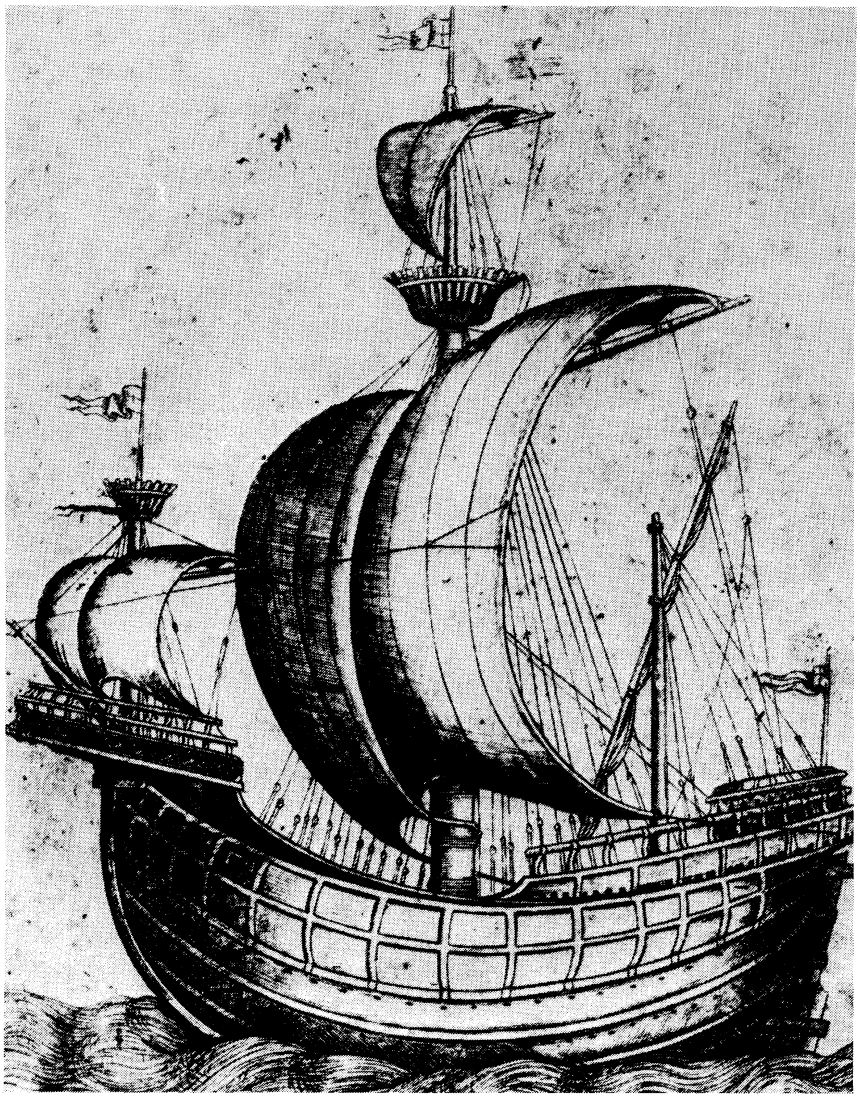
21: Italian Full-rigged Ship, 1470-80



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sail could be increased in size without losing control. The spritsail in fact may have been used rarely, only in conditions where manoeuvrability was crucial. The mainmast might be composite – that is, made up of a number of pieces of wood lashed together to get the necessary height and strength. In the South shrouds were still set up with tackles, so there were no ratlines and a ladder just behind the mast was the only way to the top of the mast. Also fore- and mainyards were often two spars fished together. In the sixteenth century those features disappeared, making the southern version even more like its northern counterpart.[17] Lifts were often used for the yards, another sign of the Mediterranean contribution to full rig. In many cases a topsail was added above the mainsail on the mainmast but it was small and made little contribution to the total sail area. The result was the common full rig of the sixteenth century with a spritsail, one square sail on the foremast, two square sails on the mainmast and a lateen mizzen.[1]

The combination rig gave the advantages of both square sails and lateen rig. Though the mainsail was still the principal driving sail in 1500, it was possible to divide square sails, something that could not be done with lateens. Captains could shorten sail or take down some sails in bad weather without having to take down sail and yard. Divisibility, a major advantage with square sails, was increasingly exploited over time. While the mainsail got a little smaller, the other square sails got much bigger. The process was a slow one and had only just got under way by 1550. One method of obtaining some measure of divisibility with lateen sails was to add another on a fourth mast, a bonaventure mizzen aft of the mizzenmast. That extra mast appeared as early as the second quarter of the fifteenth century and as far north as Denmark. By 1500, it was not uncommon both in the Mediterranean and in northern Europe.[m] The sail was usually sheeted to an outlicker, a spar extending from the squared-off top section of the stern,[18] thus making it possible to put the mast close to the stern and give more space to work the sails. It and the other mizzen were often set off centre to give more room to handle the rudder. With the lateen sail, whether one or two, the full-rigged ship was not only more manoeuvrable but also could sail closer to the wind, as little as 80° off the direction of the wind. It could, though to a lesser degree, emulate the Portuguese caravel in being able to get off a lee shore. The square sails, too, were easier to handle, thanks to improvements made in the fourteenth century in the ropes controlling them. With full rig, both propulsion and especially control were markedly better. The full-rigged ship could do more than any of its predecessors and could do so with considerably less risk.

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Ship carpenters were building full-rigged ships in the second decade of the fifteenth century but they may have started before then. Dates are based on illustrations which are notoriously late in showing design changes. What the illustrations do show, however, is the rapid change-over in the fifteenth century to the new form of rig. Iberian shipbuilders may have been the leaders in the change. The new type was known by a number of names, the most common of which was carrack, a word of Arabic origin meaning cargo ship; northern Europeans gave most southern vessels that name well into the sixteenth century. Carracks were not essentially different in design from northern full-rigged ships except that they were higher. Less severe winds in the Mediterranean made it possible to increase the upperworks. Southern Europeans called northern full-rigged ships bretons, and also hulks. All the names may well have referred to minor variations in the designs made to deal with certain local or regional needs. Some northern ships were called carvels, and this name certainly referred to the type of hull planking but did not imply any resemblance to the Portuguese caravel.[19] The widespread and rapid adoption, in both southern and northern Europe, of the generic term ship for the full-rigged type, however, reflected its popularity, its versatility and the composite nature of the design.

The state of the market for shipping services made it possible to use the new full-rigged ship very effectively. Even before the Black Death there was something approaching regular trade between northern and southern Europe. As a result of changes in consumption patterns and also access to supplies of alum in the late fourteenth century, Genoese shippers established regular sailings from the Mediterranean to the Low Countries and England. They carried bulk goods. The Venetians and Florentines, using great galleys, exploited the possibilities for selling light and expensive southern and eastern goods in the North. Genoese trade, on the other hand, needed ships which were cheaper to operate for each ton of payload. With fixed and known cargoes and dates of sailings – that is, within a relatively narrow range – the ships for the trade to northern Europe could be built larger. Big Genoese ships, carracks, were well known in the English Channel in the first and second decades of the fifteenth century. As warships, they joined the naval forces of the king of France in fighting the English. By the second half of the fifteenth century Florentine and Venetian shippers also used carracks. Yet for Venice the round ships did not form the overwhelming part of the merchant fleet, as they did at Genoa. The carracks were only marginally less tubby than the cogs which preceded them. If nothing else, they were big, and thus harder to handle and cut down on

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turnaround time since it took so long to load and unload them. Full rig only partially compensated for these disadvantages. At Venice, by the 1490s, the majority of carracks built for the government were of 1,200 tons. Average tonnage rose throughout the fifteenth century, and in the sixteenth there were many ships of 600 tons in the Venetian merchant fleet – a great change from the Venetian cogs of the fourteenth century which were of 250 to, at most, 400 tons. The Genoese built big carracks much earlier than the Venetians. In the middle of the fifteenth century, Genoese carracks of 500 tons, with an over-all length of almost 40 metres and a breadth of slightly over ten metres, were making direct voyages from the eastern Mediterranean to northern ports. There were larger carracks too, reaching 1,000 and even 1,400 tons. The big carracks were made stronger and were more extensively reinforced. The bows became even more bluff than before and the stern was typically made completely square.[n] The unique size of Genoese ships grew out of their carriage of alum to cloth makers in northern Europe. When the Genoese lost control of supplies of alum, their trade changed to lighter goods and the shipbuilders turned to smaller vessels.[20]

The Genoese chose carvel-built cogs, in the fourteenth century, to move their large cargoes of alum. These cogs were popular because the carrying capacity could be easily augmented, but then a new problem was created. The maximum feasible size for a square sail is 500 square metres. In order to move the biggest ships more sail area was a valuable, if not necessary, addition. Multiple masts and sails provided a simple solution. The full rig allowed carracks to be bigger than cogs. At the same time there was a gain rather than a loss in manoeuvrability. Since trade per person had fallen, or at least was not rising, during the 100 years after the Black Death, cutting shipping costs through increasing ship size was all the more desirable. The goods carried on the big Genoese carracks had higher prices per unit volume than many of the bulk commodities shipped by sea and so they were better able to sustain any increase in charges, thus making it easier to experiment along the Atlantic route, and also increasing the returns to successful experiments. The use of the full-rigged ship made it possible to maintain or increase the volume of trade and at the same time raise profits. The conditions of the first half of the fifteenth century created a low threshold for the adoption of the full-rigged carrack, just as conditions in the fourteenth century had created opportunities for using the cog between southern and northern Europe. Once the full-rigged ship came into general use on that one route, the diffusion of the design throughout the rest of Europe presented few problems.

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Spanish shipbuilders built full-rigged ships from the early years of the fifteenth century. Their example, along with that of Italian shipwrights, their reputation for high-quality work and their export of full-rigged ships to northern Europe, contributed to the general adoption of the design there by the end of the fifteenth century. Of course, the simpler single-masted hulk was still used,° but the growth in the absolute volume of commerce after about 1450 increased the output of northern shipyards and made the change to full-rigged ships even more rapid. The new design was suited to smaller vessels, down to 100 tons or less, so the increase in the number of those ships did not slow down the adoption of the new type.[21] The pay-off was greater, of course, in larger vessels. Iberian carracks had no projecting beam-ends and these were later also abandoned in the Mediterranean. It was probably the Iberian form of the carrack that was most commonly seen in the North in the second half of the fifteenth century, and it was on that form that northerners modelled their own full-rigged ships.

In the ports of the German Hanse the full-rigged ship was often called a hulk. It may be that the essential shape was retained from the type developed in the last years of the fourteenth century. But there was a major change in the hull. It was now carvel-built. Apparently, builders in the Low Countries and in Germany were not able to construct carvel hulls immediately. It took them some time to become familiar with the approach. Placing planks edge to edge could not have presented a problem since they already used this design on the hulls of cogs. The source of the trouble may have been a change from a modified version of shell-building long in use in the North to the almost complete skeleton construction typical of the new ships. Shipwrights had to be imported from France to the Low Countries to build the first carvels. Any resistance to the new design in the Baltic was broken down by the unique career of the *Peter of La Rochelle*, a full-rigged French ship of about 700 tons which arrived in Gdansk in 1462 and then remained there because it was deserted by the captain after a controversy over repairs and ownership. Gdansk shippers and the government found uses for the vessel and Gdansk shipbuilders took the opportunity to learn about the type. The first carvel-built three-masted ship was begun at Gdansk in 1473 and large versions were built there after 1488. By the late fifteenth century, then, ship carpenters in the Baltic could and did build the latest type of full-rigged ship, comparable to those from Venice or Genoa in everything but size. There were, of course, minor differences, for example in the fitting of the yards to the masts, in the number and size of wales, in the absence of a through-deck and in other

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minor features.[22] The ship was, however, in all basic respects the same as its southern counterparts.[p] It relied on internal heavy ribs for strength, and hull planks with edges pushed tightly together and caulking forced in between them for watertightness.

The interest of Gdansk builders and shippers was fed by their need for an economic bulk carrier. Their position was different from the Genoese in that they were handling salt and grain where faster delivery meant little. One voyage a year from the eastern Baltic to the Biscay coast of France or Spain and back was about all that was possible before winter weather prevented sailing. Once such voyages were possible marginal gains in speed meant at best marginal gains in productivity. But Hanse shippers did share with the Genoese a need for bigger ships. The volume of the salt carried east from the Bay of Bourgneuf grew rapidly in the early fifteenth century as the price of Bay salt became competitive with that of locally produced salt in the Low Countries and especially in Germany. The Hanse towns in Prussia were in the best position to exploit the advantages of new larger hulks. Ports to the west soon followed in using the new type. Lübeck, for example, found an immediate use for full-rigged ships in trade to Bergen in Norway. The exchange on that route of grain for fish was a trade well suited to the new type. The largest hulks were still found in towns like Gdansk and Riga, where they reached 300 tons and more. Despite wars and piracy, throughout the fifteenth century that trade continued and expanded. But slowly the nationality of the carriers changed, as Dutch ships replaced those of the Hanse.[23] In part, the success of the Dutch came from their ability to build and effectively to use vessels of the new design.

The goods of Dutch trade were the same as those of Hanse trade. Dutch shippers carried cloth and salt to the Baltic and brought back grain, especially rye. To their exports they added cargoes of herring, caught and packed aboard busses in the North Sea. Bay salt was used to preserve the herring, which created another market for imported salt and gave another reason for the development of an entrepôt trade in salt in the Low Countries. The redistribution gave employment to smaller Dutch ships and fishing boats in the off-season. One problem for Hanse ships was that they had grown too large to visit many harbours in the West, especially in the Low Countries. Dutch builders avoided that difficulty. Their ships tended to be more manoeuvrable and smaller than German hulks. Dutch full-rigged ships did reach 300 tons and more, but the average was probably under 200 tons. The traditional date for the construction of the first skeleton-built ship in the Low

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Countries is 1460, though some vessels of the new type may have been built before that date. Local ship carpenters adapted the design to suit local conditions. Dutch ships were known for their ability to sail in any weather, something which could not be said, for example, for Spanish full-rigged ships. By the mid-sixteenth century, the size of the Dutch merchant marine compared favourably with that of any competitors in northern Europe.[24] German Hansards, among others, tried to undermine the competitive advantage of Dutch shippers but failed to do so. Acts of protection generally hurt them more than the Dutch. The Hanseatic League repeatedly prohibited the sale of domestically built ships to foreigners, in an effort to deprive Dutch shippers of hulks. Not all towns observed the embargo and so the policy failed. Moreover, this policy served to promote the expansion of the Dutch shipbuilding industry. A number of German ports at times refused to allow Dutch ships to enter and trade there. Dutch shippers merely changed to smaller ports or did business directly with the growers of grain and the harvesters of wood along the shores of the rivers and inlets of the Baltic.[25] This was feasible because their ships were designed to sail in shallows and estuaries. These Dutch ships were highly versatile and gave Dutch shippers the opportunity to exploit possibilities created by the growth in the volume of commerce in the late fifteenth and the sixteenth century.

Dutch shipbuilders, according to one chronicler, first learned about full-rigged ships from Bretons. Indeed, Breton shipwrights appear to have been responsible, along with Spanish builders, for the interest in this type in western and northern Europe, by producing and using them in relatively large numbers. The Bretons had a ready use for the type in carrying salt to the Low Countries from Brittany. The number of Breton ships in the salt trade rose throughout the fifteenth century. The actions of other governments and the lack of sophisticated business skills in Brittany prevented that growth from continuing in the sixteenth, however. The conditions of harbours and the need for larger ships allowed Bretons to use the new design and incorporate it in smaller ships as well. Around 1500, the average tonnage of the Breton fleet was probably about a hundred; this included coasters of 30 to 35 tons, caravels like those of Portugal of 80 to 110 tons, and full-rigged ships of over 200 tons. The early acceptance of the full-rigged design and its use in a broad range of vessels presumably explains the fact that, by 1500, the Breton merchant fleet boasted a total tonnage four or five times that of Normandy.[26] In each case, in Genoa, in towns of the German Hanse, in Holland and Zeeland and in Brittany, specific trading circumstances made the adoption of full rig advisable and profitable at some

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point in the course of the fifteenth century. As important as solving the specific transport problems, though, were the general savings which accrued to any shipper using the new type.

Skeleton-building in fifteenth-century northern Europe meant a saving in wood. Since planks did not overlap, as with clinker-building, but were placed edge to edge, less wood was needed for the shell of the ship. The savings which Italian builders found before the eleventh century were still to be had in fifteenth-century northern Europe, and more than compensated for the marginal increase in wood required because the length-to-breadth ratio of full-rigged ships, especially those built in the Low Countries, tended to be higher than for cogs or hulks of the same tonnage. Also, a large skeleton-built ship, above about 300 or 400 tons, was stronger and more reliable than a clinker-built ship of the same size. If strength was to come from internal ribbing, then ribs had to be heavy. By the fourteenth century, clinker-built ships already had an extensive system of heavy oak internal supports along with bulkheads to separate cargo holds. Over time, builders had put the ribs closer and closer together, almost creating another wall inside the wall of hull planking.[27] So conversion to skeleton-building made no appreciable difference in the quantity of wood needed for internal planking. There may have been a marginal increase in the amount of time builders spent in selecting wood for the frames and ribs, but this, like the building of the edge-to-edge hull itself, was a logical use of the skilled labour which was relatively expensive. The high cost of wood sealed the decision to go over to skeleton-building. The extensive clearing of forests to create arable throughout the thirteenth century had limited supplies of timber. The abandonment by farmers of marginal agricultural land after the Black Death did not lead to a quick recovery in timber supplies from that land. In some places, because of soil erosion, trees could not grow. More important, the replacement rate for trees is slow, especially for the large oak-trees needed for the internal ribs of the now larger ships. So, despite the fall in demand for timber after the Black Death, the price did not collapse because the supply was highly inelastic. Thus any saving in wood was even more attractive for shipbuilders; in northern Europe this meant accepting the southern method of hull construction which lowered timber costs and therefore lowered capital costs to shipping.

This is not to say that clinker-building was totally abandoned or that shipwrights could not build large vessels with overlapping planking; but to build ships the size of Genoese carracks meant extending shell construction rather far, perhaps approaching its technical limits. In the

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second decade of the fifteenth century, the English navy had to have big ships, in part to transport troops to Normandy for the campaigns of King Henry V and in part to contest control of the Channel with those Genoese carracks in the service of France. A great deal of wood was used, as the example of the English ship *Gracedieu* shows. She was built at Southampton in 1418 by local ship carpenters. The hull had triple clinkering – that is, there were always two layers of hull planking. The keel was more than 38 metres long, the over-all length perhaps as much as 60 metres and the tonnage over 1,400.[q] She probably had two masts, the second being much smaller than the mainmast. Though the ship was apparently capable of sailing, she must have been hard to handle. The need for transport to carry troops to France disappeared with the English victories in Normandy, so the *Gracedieu* was laid up, never fully fitted out and left to sit tied up along the river.[28] There was seemingly no other possible use for a ship of that design. The *Gracedieu* represented a massive capital expenditure. If nothing else, that ship proved that investment per ton had to fall and the versatility of large ships had to increase. The combination of a change to full skeleton-building and the adoption of full rig met precisely those requirements.

A full-rigged ship needed less labour than its predecessor both in construction and at sea. On the wharf, northern Europeans got the same savings that southern Europeans had earlier come to enjoy. There was a decrease in original work but an increase in repair and caulking, thus lowering the level of skill required – a valuable improvement in the first half of the fifteenth century. As the supply of skilled craftsmen, thanks to the training system, caught up with demand after the middle of the century, ship carpenters' real wages tended to fall. So any increase in the work, caulking and repair that had to be done with the new type of hull was even less crucial. The productivity of ship carpenters increased with the introduction of the brace. That tool made it easier and faster to drill all the holes for nails and treenails. If the brace was too small for large holes, it could be used to make guide holes for bit augers. The brace saved time, since its motion is always positive with no stopping or going back.[29] It raised the productivity of the lowest-paid workers on the wharf and so tended to generate greater equality among shipbuilders.

On board, the adoption of full rig did not increase the manpower requirements. The divisibility of the square sails meant that the same number of men could work more canvas, turning their attention first to one sail and then to another. The newly added lateen sail took more skill to handle but, at least at first, was so small that sailors probably

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had no trouble with it. The lateen could become rather large before it took more manpower to handle than was needed to raise the mainsail. In fact that threshold was probably never reached. The gain was a more manoeuvrable ship. The result in increased safety, involving a saving in capital reflected by lower insurance rates where insurance was in use, would alone have made the adoption of full rig worth while. But the increase in manoeuvrability also decreased the time spent waiting for the right wind. Big carracks had to spend more time in harbours, loading and unloading, but they spent less time waiting to get in and out of those harbours. Since sailors were paid and fed while on board, the decrease in waiting time meant lower labour costs. The level of piracy was still a primary consideration in the manning ratio of ships. The danger of loss from attack could prevent shippers from fully exploiting the potential labour saving, but the introduction of full rig at least removed the technical constraint on the number of men for each ton shipped. Sources are neither plentiful nor continuous but there is every indication that manning ratios fell throughout the fifteenth and sixteenth centuries. Warships created a special case. The French navy insisted on having one man for each ton of the ship. Small boats and fishing boats could handle only three or four tons of cargo for each crew member. The same ratio held for Genoese carracks in the mid-fifteenth century. In the Baltic, crew sizes were in general relatively small. Defence made a great difference in the size of the crew but, when the Hanse set a minimum manning requirement at about the same time, it still allowed for ten tons per man. For Mediterranean full-rigged ships of the mid-sixteenth century the figure was up to thirteen tons for each man, and that for the largest of cargo ships.[30]

The long-term fall in both capital costs and operating costs was also promoted by the greater flexibility European shipwrights built into full-rigged ships. These men at the same time developed modifications and variations for the new regions where the type was used. The most common modifications came in sail plan. The obvious example was the addition of a second lateen sail on a fourth mast. Though the bonaventure mizzen was especially popular with warships, it was equally common on large merchantmen. The addition of a fourth mast was part of the more general trend of the late fifteenth and the entire sixteenth century towards greater division in the sail plan. The first carracks had sails supplementing the mainsail to help control the ship, and those sails gradually grew in size relative to the mainsail and in the process took on more of the task of propulsion. The foremast became taller, the foresail got bigger and a topsail was added on that mast. The main-topsail

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became larger relative to the mainsail. Other sails were added on some ships but most of them were later abandoned because they were too small and could be used only irregularly. Those extra bits of canvas were not as important as the development of balance in the rig. The typical result was a square spritsail, two square sails on the fore- and two on the mainmast, and one or two lateen mizzens. There was greater balance in the rig, with the load shared more equally among all sails – a trend started with the introduction of multiple masts.[31] The change in sail plan saved labour only if the absolute size of the mainsail fell. Since the size of ships was increasing, even though the other sails grew relative to the mainsail, its absolute size may not have decreased. Increasing divisibility of sail area continued through a period of rising population when presumably finding sailors was not a pressing problem. Saving labour, then, was not as crucial as was the case previously. But, as always, shippers were interested in lowering costs, and also in keeping up the size of their ships. The recovery of population led to a recovery in grain prices, so more grain found its way into the holds of European ships. With more goods to be moved, shippers were in a better position to exploit larger vessels, and that meant a need for more sail area. If the improved balance of the rig also led to a fall in crew size, the payload could rise without increasing the size of the ship; if this was not enough, then the increase in security made the change worth making. The cost of more equal size of sails was, after all, minimal.

Once Europeans adopted the full-rigged ship, they quickly turned it to a number of different tasks. Of course, it held its place in the bulk trades inside Europe and also in long-distance carriage in Europe. Its success suggested it as the type for the all-water route to the Indies. By the last years of the fifteenth century, the Portuguese had found that the caravel could not carry enough goods for their longer voyages of exploration along the African coast. They started using full-rigged ships and, when the explorer Vasco da Gama opened direct trade from Portugal to India, the carrack quickly became the ship for that trade. Most important, it had the advantage of being big. By the end of the sixteenth century, Portuguese shipwrights were producing the largest wooden ships ever built, exceeding 2,000 tons in some cases. The great distance and the fixed dates of sailing placed intense pressure on carrying capacity. Space on board was for the spices and other luxuries brought back from the East and for the silver carried out there, but also for the people, their food and personal effects, and for the small quantities of trade goods that each sailor was allowed to take. In the sixteenth century, on average 2,400 people left Portugal for the East on the seven

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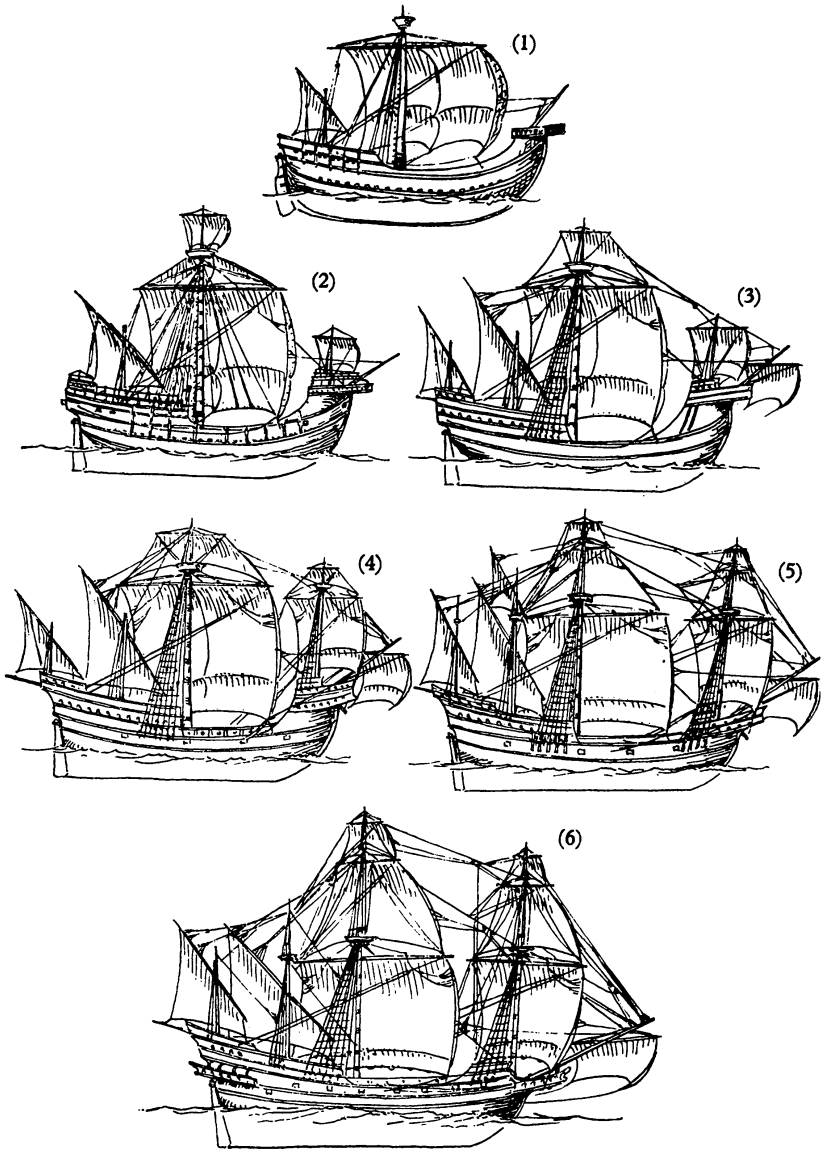
22: Increasing Divisibility of Sail Plan, 1430-1600: (1) c. 1430, (2) c. 1450, (3) c. 1500, (4) c. 1530, (5) c. 1560, (6) c. 1600



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to fourteen ships that sailed out there each year. The port of Lisbon presented no problem. There was no constraint on the draught of the carracks. An English squadron, with a great deal of difficulty, captured one of these giant carracks in the late sixteenth century. The ship impressed the English not only because it was 50 metres long and of 1,600 tons but also because of the great value of the cargo. These ships were highly built up, with aftercastles rising in a series of decks above the three or four full decks, so there was a great deal of space for passengers. They were so high in the water and so big that they were virtually impregnable.[r] Voyages were not pleasant and the death rate among sailors and passengers attests to the crowded conditions and poor hygiene. These Portuguese carracks had the same design as carracks used in Europe, only bigger and with a broader beam and a stempost so sharply curved that it turned back into the ship. Despite the full rig, it was still hard to handle these monsters. The mainsail was massive, carrying two bonnets whenever possible. The Portuguese government tried to limit the size of the ships, finding that carracks of about 600 tons were safer. Finding the right wood for big carracks must increasingly have been a problem. Still, builders and captains continued to opt for the biggest ships. The high value of cargo made the smallest increase in carrying capacity a source of a sharp increase in revenue. Overloading added to the risk. Just a small amount of sloppy caulking could in these circumstances lead to a massive loss. Even so, in 1582, one commentator said it was safer to go by ship from Goa to Lisbon than from Genoa to Barcelona. These ships, 1,000 tons by the mid-sixteenth century, even at that date could not visit most northern European ports on account of their deep draught. There was some question whether such a ship could get through the Sound.[32] The full-rigged design made trade with the East Indies by sea viable and profitable. The situation was similar for other emerging long-distance trades outside Europe. Not incidentally, the use of the carrack on voyages to India increased the use of full-rigged ships within Europe. For example, Portugal had to import copper from northern Europe for trade to west Africa. Portuguese merchants also needed to market their spices in the North. For that carriage along the Atlantic coast of Europe they used carracks, though not as large as those going to the Indies.

The full-rigged ship could also be used for exploration. In fact, most early voyages, in uncharted and often dangerous waters over long distances, were made in ships built for the common trades of western Europe. Virtually none of the ships was designed for exploration and in fact they were often poor examples of European cargo ships. The

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most famous example is Columbus' *Santa Maria*, used on his first voyage to the New World. The greater potential capacity meant that larger crews might be carried. More important, though, was the fact that smaller versions of full-rigged ships, like the *Santa Maria*, with higher length-to-breadth ratios than the carracks and relatively larger lateen sails, were capable sailing ships. They could not match caravels in manoeuvrability and that type was still popular on such voyages. Columbus used two of them in 1492.[s] Full-rigged ships used for exploration were small, rarely exceeding 100 tons. They carried castles but those were small too. The type was also used in the first tentative trading voyages to the New World. Once trading relationships had been established, size increased.[33]

The caravel also changed in the course of its use on voyages of exploration. The *caravela redonda* had a length-to-breadth ratio of just over 3:1, compared to 7:1 for earlier caravels. The change increased capacity, but the heavier hull needed more sail area to move it. For long reaches, like that made by Columbus across the Atlantic, captains rerigged their caravels, putting a square sail on the mainmast, thus leading to a type with something very similar to full rig, square sails on the fore- and mainmasts and a lateen mizzen. The lack of castles, the gentle small curve of the stempost and the cut of the hull still made it a caravel.[t] It was in that form that the caravel came to be known and copied in northern Europe. In the sixteenth century, the Portuguese caravel took on its classic form. There was a foremast raked slightly forward with one and often two square sails and then two or three other masts, each with a lateen sail. It could never achieve the size of the carrack but it was better going to windward and faster. The manning ratio was about the same, since manpower was needed to handle the lateen sails. Though used in the Mediterranean and along the Atlantic coast, that style of caravel was popular only in Portugal,[34] probably because it made an effective cargo ship for trading to the coast of Africa and the Atlantic islands, more economical than its smaller predecessor which was completely lateen-rigged. It could also be used as a warship but for that job full-rigged ships were much preferred.

Another technical change external to shipbuilding promoted the adoption of the full-rigged ship. Guns had been in use on land and sea for some time before 1400 but it was not until the late fifteenth and sixteenth centuries that they were made large enough, accurate enough and reliable enough to assume an important place on ships. The change affected the design and use of galleys but it affected sailing ships much more. Galleys with guns were effective warships, as they had been

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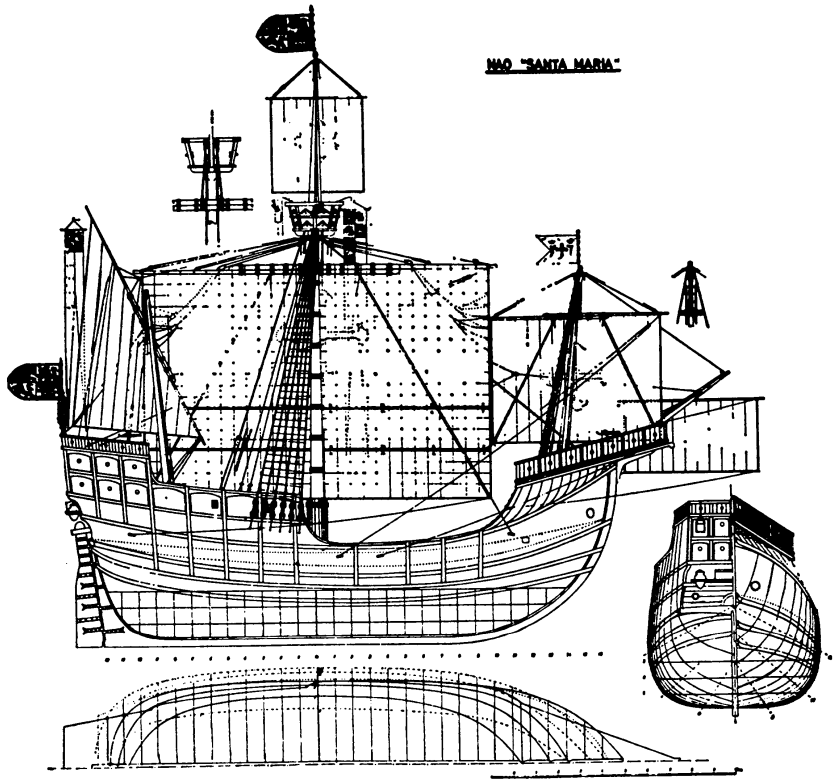
23: The *Nao Santa Maria* of Columbus: Hull Lines and Sail Plan in a Reconstruction by J.M. Martinez-Hidalgo



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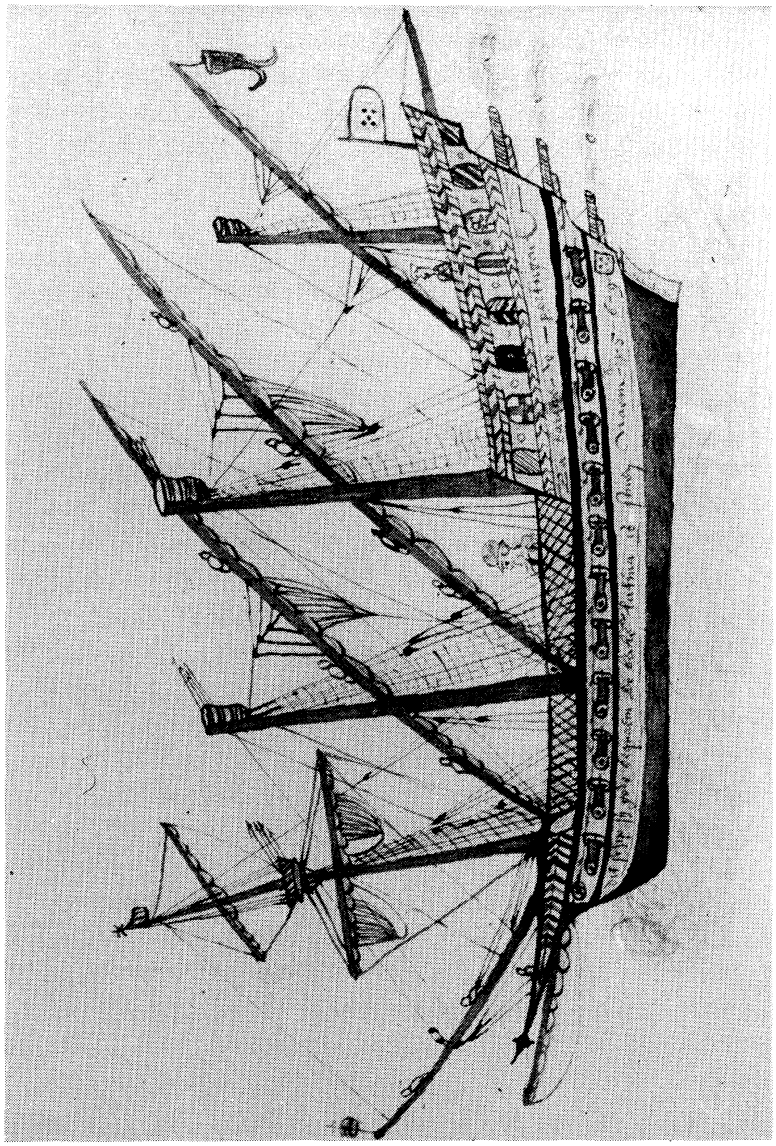

24: *Caravela Redonda* fitted as a Warship, from a Sixteenth-century Dutch Illustration

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previously. Sailing ships with enough guns and handled properly could be effective warships against all opponents, and this was new. The first guns were small and used as anti-personnel weapons, therefore, like all other projectile launchers, gaining an advantage from height above the water. They were light enough to be fitted in the castles. The carrack's over-all size, high freeboard and very high castles recommended it as a warship. Moreover, it was well suited to this use of light guns. The major step was the introduction on board of heavy artillery of cast bronze, the type used for sieges on land. So they would not make the ship unstable, the guns were placed in the middle of the ship, in the waist. Ports, like those used for handling cargo, were cut in the top wale, thereafter called the gunwale. The square stern was also a likely place to put some of the lighter guns. On larger ships, by the 1530s, guns were placed on the lower deck, keeping down the centre of gravity, and the hull was pierced with rows of gunports. These heavy pieces were as much to scare the enemy as to pierce his hull. Rates of fire were very low and guns and gunners were inaccurate. In the first half of the sixteenth century, it was still expected that fighting would come down to boarding, so small guns were retained to clear the decks of enemy ships. As early as 1513, however, a ship was sunk by enemy gunfire. The Portuguese fought the first sea battles which were decided by guns and not by boarding in the Indian Ocean in the early years of the sixteenth century. Heavy guns implied some changes in the design of ships. The tumble-home of the sides was increased to take the weight of the cannon. The greatest change was the more rapid adoption of carvel-building. With that type of construction it was easier and less dangerous to pierce the hull with gunports.[35] The ship was also less vulnerable to gunfire since the source of strength was internal rather than external. Moreover, the interior system of ribs was better able to support the heavy artillery. In 1550, there was still no strict division between warships and cargo ships but, because of the improvements in guns, shipbuilders were already moving in that direction.

The use of guns on board led governments to promote the change to skeleton-building and the adoption of the carrack design. It also led governments to exploit the limits of the new type. In the first three decades of the sixteenth century, there was almost a craze for the construction of the largest possible warships for the kings of northern Europe. Even the Portuguese did not escape, despite the fact that they already had cargo ships of unprecedented size. The possession of a great ship became a matter of prestige for kings, more important to them than the fighting qualities of the ship. They typically demanded massive

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ships with high castles and extensive armament. To move these vessels more and more canvas was added. Four masts were necessary. Three square sails on each of the two forward masts were typical and in some cases a fourth and even a fifth sail were added on the mainmast.[u] The mizzenmasts carried topsails on the largest French ship, which also had a fifth mast. There was a tennis court on board too. Rated at 1,500 tons, that ship demonstrated all the problems with such vessels. The crew was massive, at least 500 men just to sail her and then another 1,300 to 1,500 soldiers. She was not highly seaworthy and after one voyage was caught in a storm and blown over on her side. It proved impossible to right her and she was broken up. As warships, in general, these ships were not highly serviceable but, with their ever-increasing size, reaching 74 metres and more in length, they were built in response to the actions of other rulers rather than out of a desire to have an effective warship. The city of Lübeck built such a ship too, merely because the king of Sweden had one. Except for rare appearances in battle and in ceremonies, these ships stayed, well guarded, in harbour.[36] Even if these ships could sail, there was little for them to do and the massive investment was unproductive. If the kings, in their demand for ever more impressive ships, proved anything, it was that sail area could be divided effectively. The only limit was the amount of manpower available to handle the sails. The royal ships also showed the technical and economic disadvantages of the overextension of the carrack design.

The changes in warships from 1400 to 1500 had more direct and obvious effects on European governments and society than did the introduction of full rig on cargo ships. Unfree men worked the oars of European galleys for the first time. When men refused to accept the heavier work at a price the state could afford, governments began by putting petty criminals on board; thus they divested the job of any status it may have had, no volunteers could be found at any price and rowers became exclusively men who had not chosen the task.[37] Uninhibited by concern for the humanity of subjects, governments freely impressed rowers for the galleys, using it also as punishment for political and religious opponents or as a place for prisoners of war. The labour problems of the fifteenth century, the lack of interest in pulling the big oars already obvious on pilgrim galleys in the fifteenth century, the increasing power of the European states and the pressing need to maintain fleets of war galleys in the Mediterranean, made impressment a necessity. Though it may have been undertaken with reluctance in some cases, the use of forced labour under miserable conditions as punishment reflected and contributed to the new relationship between the

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state and its subjects.

There was a change at the same time in the kind of men needed on board sailing ships. The general tendency towards the production of specialised warships – for example, the development of the galeass and the conversion to carracks with guns on board – meant that sailors had to be able to handle ships and also to handle guns in battle. Thus not only the quality but also the range of skills required of sailors on those warships was increased. Training sailors to use the light artillery and hand guns of the fifteenth and sixteenth centuries was relatively simple. Indeed, it was much simpler than training archers. Handling the heavy guns in the waist required a great deal more skill. Guns were unreliable because of the quality of contemporary casting techniques. The unpredictability of cannon made gunners into artists rather than technicians knowing how to get the most out of their own guns. Their skill and their bravery – guns often exploded when fired – gave gunners a unique status, far above that of sailors and marines, and higher incomes. Gunners were part of a specialised and privileged profession, which eroded as guns became more reliable and more predictable after the mid-sixteenth century.

For governments it was no longer possible just to convert cargo ships to warships. Throughout much of the fifteenth century, as in the fourteenth century, obtaining warships merely meant hiring cargo ships and putting soldiers on board with, at most, minor modifications to the superstructure. The change in ships forced a change in the form of naval administration. All governments had to develop permanent yards for the construction and maintenance of warships. The prototype naval yard, the Arsenal at Venice, itself had to expand buildings and workforce. Governments had to have facilities to support a permanent force of warships, though that force could be small. They had to have facilities for the impressment or hiring of crews and the modification and supply of merchant ships used for war. Governments, therefore, had to develop methods of oversight of all these operations and of the increased budgets of the navies. The office of admiral had appeared in the twelfth century. Originally a financial officer, by 1200 the title was associated with a naval commander. The office was usually temporary and, when it was more permanent in the fourteenth and fifteenth centuries, admirals had been responsible only for handling legal problems associated with shipping. From the sixteenth century, however, the admiral's occasional task of calling out the fleet changed to a permanent function, which in turn created a need for a stable and continuing staff of officers. Navies had to have a bureaucracy and, by the second half of the sixteenth

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century, many European admiralties were exactly that. If nothing else, these people were needed to deal with the work generated by larger naval forces. The sailors of the king even got something like uniforms, thus creating more work for the new bureaucrats. The position and the responsibilities of these men were increasingly subject to strict regulation.[38] Many states had war fleets before the sixteenth century but, from then on, like Venice, and the Byzantine Empire before it, all states had to have a navy, with all the continuing apparatus that went with it.

Governments in the fifteenth and early sixteenth centuries became involved even more in shipbuilding and in more phases of the whole process of designing, selling and building ships. Improvements in ship design had fed, and continued to feed, the rising absolute and relative income of states, thus giving governments the ability to mobilise the capital needed for projects which were beyond the scope of individuals. The building of giant warships was not as economically important in this as the launching and promotion of certain trades. Venice and Florence subsidised the galley trade to Flanders. Iberian states followed similar practice in the organisation and development of trade to the New World and to India. Both the Portuguese and the Spanish governments accepted the job of training pilots for the voyages. They also supplied ships, men, ship repair facilities, protection for traders and many other services to make the trade profitable and successful. In northern Europe the kings of Sweden, among others, invested in the building and operation of ships to promote trading activity by native merchants.[39] The result of such promotions, in the long run, was generally to raise state incomes. The increasing volume of trade and the way it was directed, promoted and supported by governments, all placed at the disposal of monarchs more ready money. The process, which became clear in the second half of the fourteenth century, became more obvious and more pronounced over the fifteenth and sixteenth. Certainly, monarchs recognised this fact and so turned themselves more vigorously to the promotion of shipping and shipbuilding.

In general, the drift towards government involvement in shipping became a rush by the sixteenth century. With the introduction of full-rigged ships and guns on board those full-rigged ships, the importance of sea power was even more appreciated as a source for political power and for economic power, which amounted to the same thing. Governments became more conscious of economic policy in general and increased the mass of legislation on trade, and especially trade at sea. For example, the Iberian governments at various times set manning

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ratios and maximum and minimum tonnages for ships in their trades to the East and West Indies. In some cases legislation was passed to guarantee defensibility, in some cases to guarantee access to certain ports. The result of legislation and of regulation of the shipbuilders themselves, was to limit what they could do. In fact, those rules could in extreme cases cause changes in the rules of construction.[40] Certainly, the minute regulation of manning, armament and so on forced minor adjustments. Having contributed to the development of more effective governments interested in shipbuilding, the shipbuilding industry became a subject for direction by those governments, whose promotion of change in ship design took a number of different forms. There were direct subsidies in the form of rebates on customs duties or cash payments to men who built and used the kinds of ships the government wanted. The Venetian state needed big ships to fight the Turks in the fifteenth century but the capital requirement was too high and the returns too low for any citizen or group of citizens. So the government gave cash subsidies to anyone undertaking the building of such ships. The policy cost less than if the government itself built the ships. The private owners used them in commerce but, since they were Venetian, the government could seize them and use them as warships when necessary. The simplest solution to the problem of having cargo ships large enough and with enough superstructure to be effective warships was to offer a bounty for ships over a certain size.[41] That device stretched both the finances and the administrative skills of most governments. Shipbuilding also received an indirect subsidy from governments in the general promotion of shipping. Rules which required that ships on certain routes had to be of native construction might hurt the trade but gave domestic shipbuilders a protected market for a certain type of ship. Governments could and did make such rules, not only because they had the power but also because shipbuilders had shown throughout the fifteenth century an increasing ability to design craft suited to specific jobs. Thus the economic losses from such protection decreased. It may well be that governments, by their regulation and protection of shipbuilding, slowed the response on the part of designers to the economic needs of shippers but, in the process, governments introduced their own limitations, pressures and direction on the development of ship design.

For smaller vessels the most prominent change in the fifteenth and sixteenth centuries was the diversification and specialisation in design, which led directly to the greater specialisation of workers in shipping. Specialisation was by no means complete but at least it was possible in some cases, for example, for a fisherman to be exclusively a fisherman.

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Greater concentration of effort in a specific job was an obvious source of increased output from workers. Probably more significantly, at the same time there was an increase in the specialisation of ports. Certain harbours became centres for a certain type of ship or for certain types of shipping. The resources of the area and the location of industry also contributed to the specialisation of ports. If only by cutting turnaround time, a saving was made. The improved design of smaller vessels also led to a significant growth in short-haul shipping throughout Europe. As a result, more ports and more regions could count on economic water-borne transport service and on greater frequency of that service. As population grew, settlement spread out and was not as concentrated in certain cities or districts as otherwise would have been the case. The better service made possible the survival and indeed the prosperity of a large number of towns of the second and even third rank. Large ports and cities did emerge as centres of long-distance commerce served by the new bigger full-rigged ships. But at the same time there were, around those cities, many coastal towns and villages which acted to supply them and formed a market for goods off-loaded at the large ports. The growth in the total volume of trade and the use of specialised coasters generated an expansion in those smaller ports. Using fore-and-aft rig, those vessels could approach the labour productivity of big carracks. By making more frequent voyages, they might also approach the capital productivity. They opened a wider range of trading possibilities, since in some cases and on some routes it was not economically feasible to use vessels of full-rig design, even if they were scaled down to 100 tons. In any case, the smaller size meant a fall in the required initial investment. Entry by new shippers was made much easier. This was most noticeable in northern Europe. The tendency from the mid-fifteenth century on, then, was back to a broad base of investment and of participation in the ownership of vessels. It was obscured by the success of large ships and certain very wealthy merchants who exploited monopolistic privileges. But in all likelihood there were more shippers, both absolutely and relatively, in the sixteenth century than in the fourteenth.

The adoption of the full-rigged ship, along with other design improvements in larger vessels, made possible the voyages of discovery. In many cases they were not actually discoveries, since Europeans already knew about and had travelled to the places. Scandinavians had visited North America and Italian merchants, in the thirteenth century, had kept up an active overland trade with China and India. What was novel in the fifteenth and sixteenth centuries was the discovery of new routes which

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by that time could be exploited commercially. Ships were seaworthy enough to make voyages along the trade routes and to make them consistently. Not incidentally, shipbuilders thus had a reason to keep on building the new types of ships. The success of Europeans in Asia and America had complex origins and was by no means based solely on the quality of the vehicle they used. The commitment of governments to exploration and exploitation of the discoveries for political and religious reasons and the ability of Europeans effectively to coerce resident populations with guns certainly made trade with these areas safer and more profitable for the Europeans. However, expansion was based on commerce and exploiting the potential for commerce. It was the profit from trade which was responsible for the existence of the European colonies or rather trading posts, for the continued interest of European merchants, shippers and shipbuilders and for the continued interest and support of the ventures by European states. It is easy to overestimate the short-term economic and cultural effects of the discoveries on Europe, but it is much easier to underestimate the long-term effects. Similarly, it is easy to underestimate the effects of the opening of viable commercial connections on Asia and the Americas. The full-rigged ship did not create the discoveries but it did make them feasible and did allow for the first steps to be made in integrating the trading relationships of large regions of the world.

By 1550, significant steps had already been taken towards the integration of the diverse local and regional economies within Europe. From the mid-fifteenth to the mid-sixteenth century, sailing ships from the Atlantic and northern Europe expanded their activities in the Mediterranean. Along the Atlantic coast, direct voyages were being made from Portuguese salt ports to the eastern Baltic. Dutch shippers travelled to Reval and Gdansk in the East and to Iberia in the South. The lower cost of transport implicit in the carrack and related types allowed long-distance intra-European trade to increase in volume and in value. The greater over-all efficiency in the economy and the growth it implied also meant a greater interdependence of the economies of all parts of Europe. The extensive expansion of European trade, typified by the discoveries, also made possible, and indeed created pressure for, an intensive expansion of commerce within Europe.

The increase in trade brought with it a rise in the absolute number of merchants. There was also an increase in their relative number. As a larger percentage of the total population, the group became more important politically. That position was positively enhanced by their access to the technology of the most productive sector of the economy.

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Within the kingdoms of western and northern Europe, merchants, shippers and shipowners took on more of the attributes and the political position which had for some time been enjoyed by their counterparts in the Italian merchant republics. Economic growth and the character of investment in shipping worked to decrease the differences in income among merchants. There were still some merchants who were much richer than the great majority. The differences that remained illustrate a certain division of labour among merchants, with men specialising in a certain type of trade or along certain routes. That division was even more acute on board ship. On larger vessels, given the size of the crews, differentiation of task and greater regimentation were necessary. A hierarchy of status became typical. The lowest men in that hierarchy sold their strength for a fixed wage. There was increasing hostility between the sailors and the skippers, their bosses. For example, legal sanctions were established against the collective action of sailors to raise wages.[42] The rise in the number of smaller vessels, however, prevented such sharp distinctions within crews from becoming commonplace.

The success of shipbuilders in the fifteenth and sixteenth centuries enhanced their social and economic position, but the change was most noticeable for men who had the skill to design the newest types of vessels. There was the beginning of a distinction between the designer and the builder, a division not complete even in the twentieth century. By the sixteenth century, however, the designer was a man who could do something more than form wood. It was an advantage for him to know how to read and write and even to have some simple mathematical skills. The success of experiments with ships led to further experimentation, which, combined with improvements in navigation, led to a much wider interest in practical knowledge. Scholars and humanists turned their attention to shipbuilding, admittedly only rarely, as a worthy topic of investigation. The actions of governments, their interest in standardisation and the improvements in the skill and literacy of ship designers, generated the first efforts by those men to give some order to their knowledge. They wrote the first treatises on shipbuilding, but only for a limited audience. The major goal was to reduce at least some of their knowledge to mathematical formulae so that other skilled craftsmen could imitate their work. It is clear from the treatises that these men did not, and perhaps simply could not, transform their acquired knowledge to an easily transferable body of information.[43] Treatises could not be used as effective tools of learning. That is why northerners, to imitate superior Italian skill, simply imported Italian shipwrights.

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At the same time, though. Europeans established institutions for the teaching of shipbuilding and ship design. Most men still learned by observation and imitation of a master, without the intermediary of the written word. That handicraft tradition was institutionalised in guilds of ship carpenters. The fifteenth century saw a rapid expansion of guilds for all types of trades in a response to the need to train new men. Shipbuilding did not escape but ship carpenters' guilds were different from industrial guilds. Instead of acting to suppress competition, they rather directed competition towards improvements in the design of the product. By giving certificates on completion of a training period and completion of a masterpiece, in some cases they also made ship carpenters more mobile, thus aiding the diffusion of techniques as the skilled craftsmen could travel more freely from place to place. The success of guilds as promoters of technical change and of education varied from town to town and from region to region,[44] but the effect, especially in northern Europe, was on the whole positive, as the development of new designs for smaller ships, the diffusion of those designs and the more rapid pace of technical change in the second half of the sixteenth century, bear witness.

NOTES

1. Dorothy Burwash, *English Merchant Shipping, 1460-1540* (University of Toronto Press, Toronto, 1947), p. 142. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', *TCHM*, V, pp. 139-40. G. V. Scammell, 'English Merchant Shipping at the End of the Middle Ages: Some East Coast Evidence', *Economic History Review*, second series, XIII (1960-61), pp. 332-4.

2. G. Asaert, *Westeuropese scheepvaart in de middeleeuwen*, pp. 101-3. Jacques Bernard, *Navires et Gens de Mer à Bordeaux (vers 1400–vers 1550)* (SEVPEN, Paris, 1968), pp. 237-41. Dorothy Burwash, *English Merchant Shipping, 1460-1540*, pp. 103-17, 124-7, 140. Walther Vogel, *Geschichte der deutschen Seeschiffahrt*, pp. 498-507. Wendy R. Childs, *Anglo-Castilian Trade in the Later Middle Ages* (Manchester University Press, Manchester, 1977), pp. 158-9.

3. A. Anthiaume, *Cartes marines, constructions navales, voyages de découverte chez les Normands 1500-1650* (Ernest Dumont, Paris, 1916), vol. II, pp. 280-8, 292-6, and *Le Navire Sa construction en France et principalement chez les Normands* (Ernest Dumont, Paris, 1922), pp. 160-4, 204-9. Jehan Banse, 'Les Corporations des Constructions Navales dans Le Port de Fécamp', in *Le Corporatisme Ancien de Construction Navale en France* (Académie de Marine, Paris, 1939), pp. 155-7. Harold A. Innis, *The Cod Fisheries, The History of an International Economy* (University of Toronto Press, Toronto, 1954), pp. 16-21, 40-2.

4. R. C. Anderson, 'Jal's "Memoire No. 5" and the Manuscript "Fabbrica di Galere" ', *MM*, XXXI (1945), p. 165. William A. Baker, *Sloops and Shallops* (Barre Publishing Co., Barre, 1966), pp. 14-24. Fernand Braudel and Ruggiero Romano, *Navires et Marchandises à l'entrée du Port de Livourne (1547-1611)* (Librairie Armand Colin, Paris, 1951), pp. 39, 109. Jacques Heers, 'Types de

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Navires et Spécialisation des Trafics en Méditerranée à la Fin du Moyen Age', pp. 107-8. Marco Bonino, 'Lateen-rigged medieval ships', pp. 18-21.

5. J. van Beylen, *Schepen van de Nederlanden Van de late middeleeuwen tot het einde van de 17e eeuw* (P.N. van Kampen en Zoon N.V., Amsterdam, 1970), pp. 127-9, 134-9, 141-6, 175-81. Dorothy Burwash, *English Merchant Shipping, 1460-1540*, pp. 127-8, 136-40. G. C. E. Crone, *Onze Schepen in de Gouden Eeuw* (P. N. van Kampen en Zoon N. V., Amsterdam, 1943), pp. 156-63. H. A. H. Boelmans Kranenburg, 'Zeescheepvaart in Zuid-Holland 1400-1550', *Zuid-Hollandse Studiën* XI (1965), pp. 225-35. Alan Moore and R. Morton Nance, 'Round-Sterned Ships', *MM*, I (1911), pp. 105-9, 293. Both the hoeker and the buss were given round sterns at the end of the sixteenth century.

6. J. van Beylen, *Schepen van de Nederlanden*, pp. 121-4. O. Buyssens, 'Antverpia Mercatorvm Emporivm Actvm 1515(?)', *MAB*, VI (1952), pp. 190-1. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 92-6.

7. J. van Beylen, *Schepen van de Nederlanden*, pp. 11-12, 183-5. Richard Lebaron Bowen, Jr, 'The origins of fore-and-aft rigs', pp. 160-2. Joseph Needham, *Science and Civilisation in China*, vol IV, part III, pp. 588-9, 606, 614-15.

8. M. Garnier, 'Galères et Galéasses à la fin du Moyen Age', *TCHM*, II, pp. 38-42. G. P. B. Naish, 'Ships and Shipbuilding', in Charles Singer *et al.* (eds), *A History of Technology*, vol. III (Oxford University Press, London, 1957), pp. 471-2. Alberto Tenenti, *Cristoforo Da Canal La Marine Vénitienne avant Lépante* (SEVPEN, Paris, 1962), pp. 29-30. *HSUA*, pp. 208-10.

9. J. van Beylen, *Schepen van de Nederlanden*, pp. 4-5. The use of guns on ships came much slower in northern Europe. The first instance in Flanders was in 1365. Guns were first used in the northern Low Countries in 1396. Also see John F. Guilmartin, 'The Early Provision of Artillery Armament on Mediterranean War Galleys', *MM*, LIX (1973), pp. 258-80, and *Gunpowder and Galleys Changing Technology and Mediterranean Warfare at Sea in the Sixteenth Century* (Cambridge University Press, Cambridge, 1974), pp. 37-41, 59-62, 74-83.

10. R. C. Anderson, 'Italian Naval Architecture about 1445', *MM*, XI (1925), p. 144. F. C. Lane, *Navires et Constructeurs à Venise*, pp. 13-21, 25-9, 129-32, 222-3, 'Venetian Naval Architecture about 1550', p. 144, and *Venice*, pp. 337-53. Michael E. Mallett, *The Florentine Galleys in the Fifteenth Century*, pp. 40-63, 144-51. Jules Scottas, *Messageries Maritimes de Venise XIV^e et XV^e siècles*, pp. 70-83, 137-83, 209-32. E. G. R. Taylor, *The Haven-Finding Art*, pp. 143-5. Alberto Sacerdoti, 'Note Sulle Galere Da Mercato Veneziane Nel XV Secolo', *Studi Veneziani* (1962), pp. 80-6.

11. Romola and R. C. Anderson, *The Sailing-Ship*, pp. 131-3. A. Anthiaume, *Cartes marines, constructions navales, voyages de découverte chez les Normands 1500-1650*, pp. 280-2. M.Garnier, 'Galères et Galéasses à la fin du Moyen Age', pp. 43-4. *HSUA*, pp. 211-12. R. C. Anderson, 'Henry VIII's "Great Galley" ', *MM*, VI (1920), pp. 274-81.

12. G. Asaert, *Westeuropese scheepvaart in de middeleeuwen*, pp. 105-7. J. Ferreira David, 'Aperçu Historique des Types de Navires à Travers les Siècles et l'Influence des Navires Ibériques sur la Construction Naval Européenne', *TCHM*, V, pp. 153-5. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', pp. 142-4. Quirino da Fonseca, *A Caravela Portuguesa e a prioridade téchnica da Navegacoes Heniquinas* (Imprensa da Universidade, Coimbra, 1934), pp. 597-9, 619. Edgar Prestage, *The Portuguese Pioneers* (A. and C. Black, London, 1933), pp. 331-2.

13. Wendy R. Childs, *Anglo-Castilian Trade in the Later Middle Ages*, p. 159. Huguette and Pierre Chaunu, *Séville et l'Atlantique (1504-1650)* (Librairie Armand Colin, Paris, 1955), vol. VI, part 1, table 12E. R. Morton Nance, 'Caravels', *MM*, III (1913), pp. 267-9. J. H. Parry, *The Establishment of the European*

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Hegemony, 1415-1715 (Harper and Row, New York, 1961), pp. 24-5.

14. L. Denoix, 'Les Problèmes de Navigation au Début des Grandes Découvertes', pp. 136-9. E. G. R. Taylor, *The Haven-Finding Art*, pp. 123-8, 154-83. D. W. Waters, 'Science and the Techniques of Navigation in the Renaissance', in Charles S. Singleton (ed.), *Art, Science, and History in the Renaissance* (The Johns Hopkins Press, Baltimore, 1967), pp. 201-8. See also D.W. Waters, *The Art of Navigation in England*, pp. 455-96. J.H. Parry, *Discovery of the Sea*, pp. 172-90.

15. Joseph Needham, 'Abstract of Material Presented to the International Maritime History Commission at Beirut', *TCHM*, VIII, pp. 143-6. M. A. Clos-Arceduc, 'La Genèse de la Projection de Mercator', *TCHM*, III, pp. 143-5. W. E. May, *A History of Marine Navigation*, pp. 119-25. D. W. Waters, *The Art of Navigation in England*, pp. 46-57, and *The Rutters of the Sea* (Yale University Press, New Haven, 1967). Samuel Eliot Morison, *The European Discovery of America The Southern Voyages A.D. 1492-1616* (Oxford University Press, New York, 1974), pp. 174-7.

16. H. H. Brindley, 'Note: Mediaeval Two-Masters', *MM*, X (1924), pp. 215-16. H. H. Brindley and Alan Moore, 'Square-Rigged Vessels with Two Masts', *MM*, VII (1921), pp. 194-8. Alan Moore, 'Accounts and Inventories of John Starlyng, Clerk of the King's Ships to Henry IV', *MM*, IV (1914), p. 173, and 'Rig in Northern Europe', *MM*, XLII (1956), pp. 9-11, 14-15. R. Morton Nance, 'The Ship of the Renaissance', pp. 189-90.

17. H. H. Brindley, 'Early Reefs', *MM*, IV (1920), pp. 77-85, and 'Mediaeval Ships', *MM*, II (1912), pp. 130-4, 172. The last illustration of reef-points is from 1528. They did not reappear until the late seventeenth century. T. C. Lethbridge, 'Shipbuilding', in Charles Singer *et al.* (eds), *A History of Technology*, vol. II (Oxford University Press, London, 1956), p. 587. José Maria Martinez-Hidalgo, *Columbus' Ships* (Barre Publishers, Barre, 1966), pp. 59-61.

18. R. C. Anderson, 'Note: Danish Drawings of Fifteenth-Century Ships', *MM*, XXIII (1937), p. 108. J. van Beylen, *Schepen van de Nederlanden*, p. 3. R. Morton Nance, 'Some Old-Time Ship Pictures VII A Batch of Carracks', *MM*, IV (1914), p. 281.

19. R. C. Anderson, ' "Carvel" and "caravel" ', *MM*, XXVIII (1932), p. 189. Jacques Bernard, *Navires et Gens de Mer à Bordeaux (vers 1400-vers 1550)*, pp. 359-68. O. Buyssens, 'Antverpia Mercatorvm Emporivm Actvm 1515(?)', p. 181. He wants to say that a carvel had a sharper bow than a carrack and a flat stern. This is probably correct for many uses of the word carvel in the Low Countries. J. van Beylen, *Schepen van de Nederlanden*, pp. 6-8. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 42-3, 74-5. *AB*, p. 292. English shipyard ledgers at the end of the fifteenth century include 'carvell nayles' for the first time to distinguish them from the old 'clinchnayl'.

20. R. C. Anderson, 'Italian Naval Architecture about 1445', pp. 149-50. A. Anthiaume, *Le Navire*, pp. 153-5. W. Brulez, 'The Balance of Trade of the Netherlands in the Middle of the 16th Century', *Acta Historiae Neerlandica*, IV (1970), p. 34, says that Antwerp in the mid-sixteenth century imported 16,000 tons of alum annually. The figure is misleading since volume had undoubtedly increased since the early fifteenth century and it does not represent total alum imports in northern Europe. Still, even if the Genoese were shipping half that amount north in 1425, it would have required about twelve carracks of over 600 tons. Jacques Heers, *Gênes au XV^e Siècle*, pp. 273-6, and 'Types de Navires et Spécialisation des Trafics en Méditerranée à la Fin du Moyen Age', pp. 111-14. R. Morton Nance, 'Some Old-Time Ship Pictures VI A Group of Florentines', *MM*, III (1913), pp. 238-44. F.C. Lane, *Navires et Constructeurs à Venise*, pp. 43-4, 94-102, 222-8.

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21. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', p. 14. R. Morton Nance, 'The Ship of the Renaissance', pp. 283-4, and 'Some French Carracks', *MM*, IX (1923), pp. 131-2. G. La Roërie, 'More About the Ship of the Renaissance', *MM*, XLIII (1954), pp. 181-4. Wendy R. Childs, *Anglo-Castilian Trade in the Later Middle Ages*, pp. 160-1. She found a rise in the average size of ships to the 1460s, and then a fall.

22. H. H. Brindley, 'A Ship of Hans Burgkmair', *MM*, III (1913), pp. 81-4. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 58-68; another potential source for the change to full-rigged design came from the orders from Italians for ships to be built in Gdansk – they chose that port presumably because of the availability of wood and of cargoes for the maiden voyage west and south. R. Morton Nance, 'A Hanseatic Bergentrader of 1489', *MM*, III (1913), pp. 161-7. Otto Lienau, 'Danziger Schiffahrt und Schiffbau in der zweiten Hälfte des 15. Jahrhunderts met 7 Bildtafeln', *Zeitschrift des Westpreussichen Geschichtvereins*, LXX (1930), pp. 77-9, 82. Dagmar Waskönig, 'Bildliche Darstellung des Holks im 15. und 16. Jahrhundert', pp. 143-61.

23. Arthur Agats, *Der Hansische Baienhandel*, pp. 35-6, 64-75, 94-105. E. Daenell, *Die Blütezeit der Deutschen Hanse* (Georg Reimer, Berlin, 1905), vol. I, pp. 433-5, vol. II, pp. 345-50. Niels-Knud Liebgott, 'A wooden Norwegian calendar of 1457 with ship graffiti Problems relating to the source value of primitive representations of ships', *IJNA*, II (1973), pp. 156-7. Presumably it was the Hansards who introduced the full-rigged ship to Scandinavia. Walther Vogel, *Geschichte der deutschen Seeschiffahrt*, pp. 356-9, 495. Konrad Fritze, *Am Wendepunkt der Hanse* (VEB Deutscher Verlag der Wissenschaften, Berlin, 1967), pp. 63-81.

24. G. C. E. Crone, *Onze Schepen in de Gouden Eeuw*, pp. 11-14. W. S. Unger, 'De Hollandsche Graanhandel en Graanhandelspolitiek in de Middeleeuwen', *De Economist* (1916), pp. 260, 339-48. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 56-8, 67-8. A. R. Bridbury, *England and the Salt Trade in the Later Middle Ages*, pp. 78-101, 118-27. W. Brulez, 'The Balance of Trade of the Netherlands in the Middle of the 16th Century', pp. 26-30. Grain imports from the Baltic by the 1560s had reached over 100,000 tons annually. This meant a sizeable demand for Dutch ships. The salt trade made similar demands on capacity.

25. Ernst Baasch, *Beiträge zur Geschichte des deutschen Seeschiffbaues und der Schiffbaupolitik*, pp. 2-8, 214-15, 268-71. F. L. Carsten, *The Origins of Prussia* (The Clarendon Press, Oxford, 1954), pp. 117-34. E. Daenell, *Die Blütezeit der Deutschen Hanse*, vol. I, pp. 265-75, vol. II, pp. 377-88, and 'Holland und die Hanse im 15. Jahrhundert', *Hansische Geschichtsblätter*, IX (1903), pp. 3-41.

26. Jacques Bernard, *Navires et Gens de Mer à Bordeaux (vers 1400–vers 1550)*, pp. 363-5, 519. Henri Touchard, *Le Commerce Maritime Breton à la fin du Moyen Age* (Les Belles Lettres, Paris, 1967), pp. 261-3, 319-25, 378-80.

27. G. D. van der Heide, 'Oudheidkundig Onderzoek in de Voormalige Zeebodem', *Mededelingen van de Nederlandse Vereniging voor Zeegeschiedenis*, XVII (1968), p. 25. Friedrich Jorberg, 'Beiträge zum Studium des Hanseschiffes', *Zeitschrift der Vereins für Lübeckische Geschichte und Altertumskunde*, XXXV (1955), pp. 65-6.

28. R. C. Anderson, 'The Bursledon Ship', *MM*, XX (1934), pp. 158-70. The ship has been the object of more than one archaeological excavation. It now lies in the mud of the Hamble River where it settled after burning in 1439. J. R. Claridge, 'Joinery of Medieval Hulls, c. 1450', *MM*, XLV (1959), pp. 78-9. Michael E. Mallett, *The Florentine Galleys in the Fifteenth Century*, p. 259. L. G. C. Laughton, 'The Great Ship of 1419', *MM*, IX (1923), pp. 83-7.

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M. W. Prynne, 'Henry V's Grace Dieu', pp. 122-6, and 'Note: The Dimensions of the *Grace Dieu* (1418)', *MM*, LXIII (1977), pp. 6-7. W. J. Carpenter Turner, 'The Building of the *Gracedieu*, *Valentine* and *Falconer* at Southampton, 1416-1420', *MM*, XL (1954), pp. 55-72, and 'The Building of the *Holy Ghost of the Tower*, 1414-1416, and her Subsequent History', *MM*, XL (1954), pp. 270-81.

29. W. L. Goodman, *The History of Woodworking Tools*, p. 175. Henry C. Mercer, *Ancient Carpenters' Tools*, p. 205. Lynn White, Jr, *Medieval Technology and Social Change* (Oxford University Press, Oxford, 1962), p. 112.

30. E. Daenell, *Die Blütezeit der Deutschen Hanse*, vol. II, p. 355. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', pp. 141-3. Jacques Heers, *Gênes au XV^e Siècle*, p. 301. Harold Innis, *The Cod Fisheries*, pp. 19-21, 47-8. Charles De La Roncière, *Histoire de la Marine Française*, vol. II, pp. 456-7. M. J. Tadić, 'Le Port de Raguse et sa flotte au XVI^e siècle', *TCHM*, II, pp. 15-16.

31. G. La Roërie, 'More about the Ship of the Renaissance', pp. 191-2. Alan Moore, 'Rig in Northern Europe', pp. 11-13.

32. E. W. Bovill, 'The *Madre De Dios*, the taking of a carrack', *MM*, LIV (1968), pp. 129-52. C. R. Boxer (ed.), *The Tragic History of the Sea, 1589-1622*, Hakluyt Society Publications, series II, CXII (Cambridge University Press, Cambridge, 1959), pp. 1-5, 17-25, 55, 115-16, and *The Portuguese Seaborne Empire* (Hutchinson, London, 1969), pp. 206-19. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', pp. 145-6. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 75-6. C. L. Kingsford, 'The Taking of the Madre De Dios. Anno 1592', in Naval Miscellany, vol. II, *Publications of the Navy Records Society*, XL (1912), pp. 85-121. Vitorino Magalhães Godinho, *L'Economie de L'Empire Portugais aux XV^e et XVI^e Siècles* (SEVPEN, Paris, 1969), pp. 665-77.

33. J. H. Parry, *The Age of Reconnaissance*, pp. 67-8. A. Anthiaume, *Le Navire*, pp. 213-18. C. H. Haring, *Trade and Navigation between Spain and the Indies in the Times of the Hapsburgs* (Harvard University Press, Cambridge, Mass., 1918), pp. 261-3. José Maria Martinez-Hidalgo, *Columbus' Ships*, pp. 8-9, 24-39, 51-61, 87-90.

34. R. C. Anderson, 'Ship-Paintings in the Alhambra', *MM*, LI (1965), pp. 1-6. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', pp. 144-5. Quirino da Fonseca, *A Caravela Portuguesa*, pp. 313-28, 606-9. José Maria Martinez-Hidalgo, *Columbus' Ships*, pp. 99-100. Alan Moore, 'Rig in Northern Europe', p. 15. R. Morton Nance, 'Caravels', pp. 267-71.

35. Romola and R. C. Anderson, *The Sailing-Ship*, pp. 121-2, 127-30. Guns firing from the waist certainly date from the 1480s in northern Europe and probably earlier. Arne Emil Christensen, 'Lucien Basch: Ancient wrecks and the archaeology of ships A comment', p. 141. John F. Guilmartin, *Gunpowder and Galleys*, pp. 157-75. L. G. C. Laughton, 'Hull Protection', *MM*, XXVI (1940), pp. 55-60. *HSUA*, pp. 227-30. R. Morton Nance, 'The Ship of the Renaissance', pp. 288-9. Peter Padfield, *Guns at Sea* (H. Evelyn, London, 1973), pp. 19-33.

36. A. Anthiaume, *Le Navire*, pp. 211-17. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 68-72. Michel Mollat, *Le Commerce Maritime Normand*, pp. 343-5, 464-5.

37. F. C. Lane, *Navires et Constructeurs à Venise*, p. 27. Venice, because of a long tradition, was the last state to give up free rowers on its galleys. See also F. C. Lane, *Venice*, pp. 366-9. Alberto Tenenti, *Cristoforo Da Canal* (SEVPEN, Paris, 1962).

38. C. S. L. Davies, 'The Administration of the Royal Navy under Henry VIII: the Origins of the Navy Board', *English Historical Review*, LXXX (1965), pp. 268-88. Henry Kitson, 'The Early History of Portsmouth Dockyard, 1496-1800',

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39. Fernand Braudel, *The Mediterranean and the Mediterranean World, in the Age of Philip II* (Collins, London, 1972) (first French edition, 1949), pp. 449-50. Carl Ekman, 'Skeppet Svanens resa till Holland år 1546', *Sjöhistorisk Årsbok* (1951-52), pp. 163-6. C. H. Haring, *Trade and Navigation between Spain and the Indies*, pp. 21-35. Archibald R. Lewis, 'The Medieval Background of American Atlantic Development', in Benjamin W. Labaree (ed.), *The Atlantic World of Robert G. Albion* (Wesleyan University Press, Middletown, Conn., 1975), pp. 37-8.

40. Lawrence A. Clayton, 'Ships and Empire: The Case of Spain', *MM*, LXII (1976), pp. 239-44. E. Daenell, *Die Blütezeit der Deutschen Hanse*, vol. II, pp. 342-5. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 53-4. C. H. Haring, *Trade and Navigation between Spain and the Indies*, pp. 262-76. M. J. Tadić, 'Le Port de Raguse et sa flotte au XVI^{e} siècle', p. 15. Iberian governments were not alone in fixing maximum tonnages for ships.

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