
# 6 WARSHIPS, CARGO SHIPS AND CANNON: 1550-1600

The second half of the sixteenth century was marked by revolts within many established states of western Europe, in the Netherlands, Spain and France. Other states tried to exploit that internal instability. The conflict which resulted was international. The addition of a religious dimension to that of civil conflict and to international political competition made the fighting more bitter, if that were possible. The conditions offered freebooters more opportunites to pursue their own interests in the name of some higher authority. Political connections extended to the eastern Mediterranean and the Ottoman Turks participated in the international struggles. The defeat handed the Turks at Lepanto (1571) by a combination of Spanish, Venetian, Genoese and Papal forces at least temporarily neutralised them as a naval force. By the end of the sixteenth century, through military and naval success and more often through attrition and exhaustion, a certain political stability had been reintroduced. By a series of truces the major powers at least allowed a breathing space in the protracted wars, which meant also a breathing space for commerce. Trade, even during truces, did not escape its proper function as a weapon of state policy. The monarchs of

Illustration above: A four-masted warship carrying two lateen mizzens and heavy guns in the waist, seal of Michael Stanhope, Vice-Admiral of Suffolk, 1540.

Europe and their advisers were devoted to political success, an integral part of which was the enrichment of the state. Given the way politicians perceived their function, political and economic conflict with other states was inevitable.

The evolution in the design of ships in the second half of the sixteenth century followed the pattern laid down over the previous hundred years. The potential of the full-rigged ship was regularly tested. Innovation continued at all levels, from the rig on the smallest of inland vessels to the hull design of the largest of seagoing ships. The variety of types and designs continued to grow throughout Europe and for all sizes of craft. The most significant improvements came from specialised design. For the largest ships, major steps were taken in distinguishing ships for violence from ships for trade. The Dutch fluyt, first built in the last decade of the sixteenth century, was designed as a cargo ship. Meanwhile, the galleon, developed originally in Venice but later used extensively by states on Europe's Atlantic seaboard, became in the course of the sixteenth century the prototype for the ships-of-the-line of later navies. By 1600, cargo ships were easily distinguished from warships. The division between the two types over the seventeenth and eighteenth centuries led to great savings for the world economy. While the basis for that distinction was laid in the half-century after 1550, it was a part of the more general trend of specialisation and elaboration of earlier inventions. Small ships and boats went through much the same process and perhaps show equally graphically the pressures on sixteenth-century shipbuilders and how they reacted to those pressures.

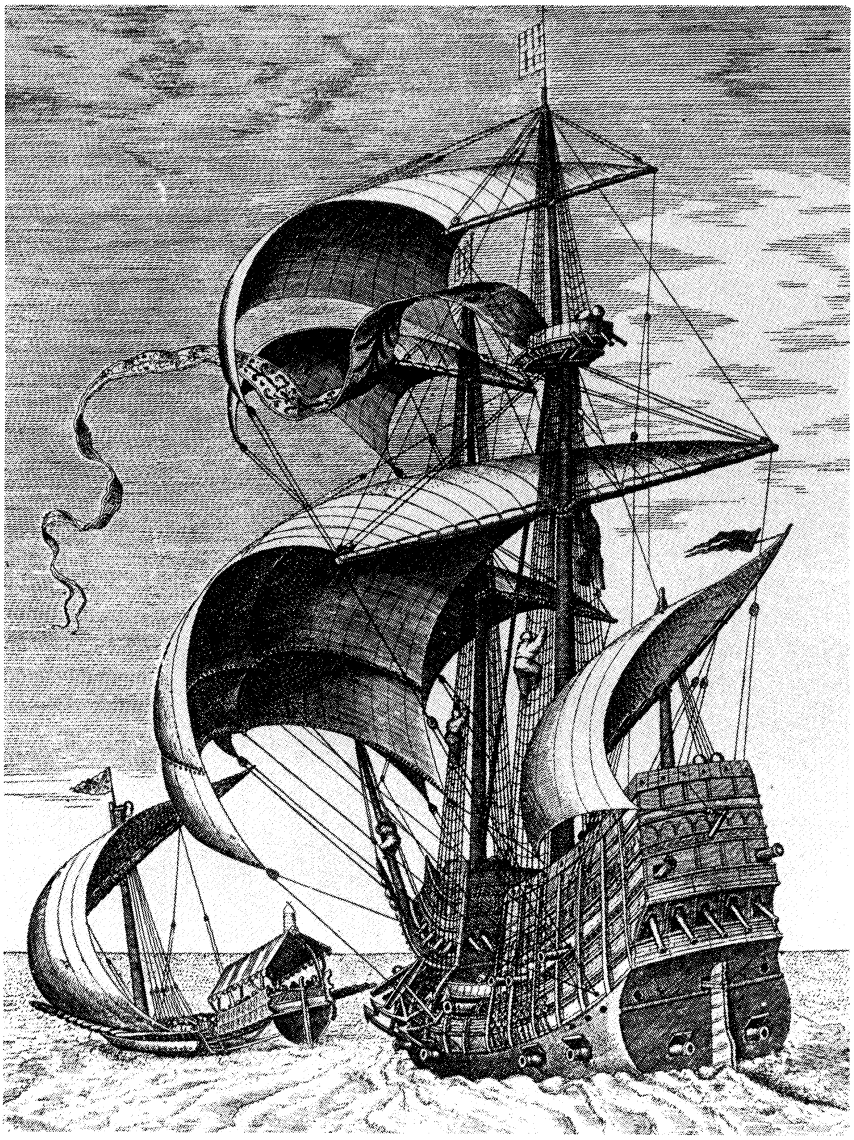
The increase in specialisation and variety among smaller ships and boats applied also to those intended for fighting. In the Netherlands, for example, various types were adopted or developed for engagements and patrol work along the rivers and lakes by both sides in the revolt which began there in 1568. Galleys similar to those of the Mediterranean were built in many coastal and river towns. Dutch builders also produced sailing gunboats, crompsters. Based on the flat-bottomed inland boat with a sharply turned-up prow, this boat made a stable gun platform. The fore-and-aft rig made it manoeuvrable. It still had shallow draught, despite the heavy artillery on board. Though they were not large ships, crompsters could carry 100 men or more. They offered exactly the advantages of galleys – good ships for coastal patrol and defence, well suited to amphibious operations.[1] There were also small seagoing ships. For carrying cargo, two-masted vessels of from 50 to 100 tons became more common in European waters. They were designed to fill the gap between the full-rigged ship and the single-masted coastal

and inland vessel. These two-masters with two, three or four square sails were also capable of making transatlantic voyages. For smaller vessels, for those usually used on inland waters, Dutch builders added another new feature, leeboards. An oval plank on each side of an almost flat or flat-bottomed sailing ship could be lowered to keep the boat from going to leeward. These leeboards acted like the later centre-board or took the place of a keel for many types which had to be built with shallow draught.[a] The European version was probably based on the Chinese use of a similar device.[2] Leeboards gave even more manoeuvrability and reliability to inland craft. They also allowed shipbuilders further to differentiate such vessels by function, even to the point of adjusting the length-to-width ratio of the leeboards.

Dutch shipbuilding is only the most extreme example of the increase in design specialisation. Shipwrights throughout Europe perfected many types as they and the users of ships clarified their goals and needs. As a result of the use of galleys for fighting, Venice had long been required to produce two kinds of ships, one for war and the other for trade. There were also differences between cargo and warships in the Viking era. In the second half of the sixteenth century, the same distinction between the two types came to apply to all sailing ships. The principal type of vessel in use for long-distance trade, the full-rigged ship, was subjected to that same drive by builders to make the design fit the job. This is not to say that cargo ships could not or did not become involved in fighting or that fighting ships could not or did not carry cargo, but the substitution of the two types, still common in the fifteenth century, no longer prevailed. By 1600, shipwrights were building warships for government and cargo ships for merchants who had no other goal than to carry goods at the lowest possible cost. The evolution of the sailing warship and its success led to changes in the oldest of European warships, the galley.

The increase in the size of galleys and the rise in weight because of the use of increasingly heavy guns led to a change in the rowing arrangement, to get more pull on the oars. Around 1550, earlier for some states and later for others, the trio of oars for each bench, with one man pulling on each oar, was replaced by a single oar, the three men all pulling together on it. All the rowers were at the same level, so each handled the oar at a different angle. The rowers on one thwart had to co-ordinate among themselves as well as with all the other groups of oarsmen. The oars were very heavy, more than 50 kilograms including the iron counterweight sunk into the handle. The oars had to pivot on the outrigger, which itself was very strong, taking the weight of the oars

25: Galley Rowed *a scaloccio* and a Mediterranean Warship of the Mid-Sixteenth century, from an Engraving by Pieter Breugel the Elder



and also gangways for fighting marines. It was impossible for the man furthest inboard to row seated. Rowers since the thirteenth century, and before, rose and then pushed themselves back to throw all of the strength of their thighs and torsos into the stroke, thus giving a short and choppy stroke which caused the ship almost to leap through the water. The action was accentuated even more when builders experimented first with four and later with five men to a bench. The original purpose of the change to rowing *a scaloccio* was, after all, to put more men on the oars. The rowers at the extremes added little to the pull of the oar, the one very cramped and the other almost running to keep up with the motion of the oar.

Galleys became bigger, rising to 170 tons with over-all lengths of some 45 metres and a width of seven metres. The number of benches remained the same, about 25 to a side. If there were only three rowers to an oar, then the crew size remained the same, but a rise to five rowers on each oar meant a 67 per cent rise in the total. The complement of 75 to 100 sailors and marines grew during the period. Under oars these galleys could do seven knots for brief periods, say in the middle of a battle. For longer pulls of some two hours the speed would have been little over four knots. These galleys were used as fighting ships in the Caribbean and off the coast of the Netherlands in the sixteenth century but their principal theatre of operations was, as always, the Mediterranean. There were variations in design from state to state, depending on the availability of rowers and guns and the type of war the states expected to fight. The rise in crew sizes increased manning problems. Fortunately, the change in the rowing arrangement did alleviate one problem. Only one of the rowers, the man furthest inboard on each oar, had to be skilled. He had to know how to row and was responsible for co-ordinating the effort of the men on his oar with the pulling of the rest of the crew. As to the other men, their function was just to supply muscle power and literally any man, even unwilling and weak, could do that. There was a high correlation between the use of slaves and the new rowing arrangement. In fact, the shortage of qualified oarsmen may have been the cause for the mid-sixteenth-century change in rowing. One critical result was a rise in costs because of the increasingly large crew; this, combined with the rising costs of food to feed the men on board, led to galleys being used increasingly for defensive purposes and much closer to home. Even before the change in rowing, Mediterranean states had difficulty paying the cost of maintaining galley fleets. For some states, by 1600, the cost was almost prohibitive.[3]

Galeasses, the design intended to combine the best of the sailing ship

and the galley, were the heavy units of Mediterranean fleets. They too suffered a change in the rowing arrangement which made for even larger crews. The northern European version largely disappeared in the second half of the sixteenth century, while its Mediterranean counterpart showed some different design features. Venetian galeasses were, like the merchant galleys from which they derived, capable sailing ships. They were bigger than the standard war galleys, rising to 55 metres in length and 12 metres in width. They had 25 or 26 banks of oars to a side, with perhaps six rowers to each oar.[b] In the last two decades of the sixteenth century, the galeass, like the galley, was superseded in the Mediterranean by sailing warships, vessels which by that time could deploy more firepower, more effectively, than could oared ships.

The development of the full-rigged warship began early in the sixteenth century. The introduction of heavy artillery, combined with the widespread use of full rig, dictated the need for a novel design. Pressed by this imbalance in technologies, shipbuilders turned to the combination of features from known types to get an efficient warship. The development of the galleon produced the warship that governments demanded. First built in the Venetian Arsenal, the great galleon was really a full-rigged sailing ship, and there lay its success. The name is confusing since it was also used for ships very similar to the galeass. By the middle of the century the galleon was about as long as a great galley but was wider, giving it a length-to-breadth ratio of under 4:1. It was, then, much narrower than other full-rigged ships. It was lower than the carrack, with a beak-head which showed its galley ancestry, and which served to break the waves before they reached the small forecastle. It was also a solid base for the bowsprit. The aftercastle was still sizeable and fully built into the hull. It included the half-deck which ran up to the mainmast. Because of the narrow build of the hull and the lack of extensive superstructure, the galleon did not have the deep draught of the carrack but it did not ride high in the water. It was much easier to handle than the carrack. Range was not sacrificed, since there was still a sizeable space in the hold for food for the crew. The sides tended to be straight. As fighting strength came from the guns, there was a good deal of internal strengthening and displacement was increased fore and aft to support the weight of the guns there. There were two or three decks and guns were arranged in one or two tiers on the decks. The ship was propelled by the standard complement of sails, with four masts on the larger galleons. Topgallants, square sails on the main- and foremasts above the topsails, were often added. There might in some rare cases be royals above the topgallants, thus giving even

greater divisibility of sails. The sails served to give much of the control, since the sternpost rudder was hard to handle and ineffective in heavy weather. By 1550, the type had spread to other parts of Europe, and Spanish, French and English shipwrights built galleons of the same design. There were variations and continuing experiments with the type. French galleons, for example, stayed small – about 100 tons – and were often used for work close to shore. Broadside armament, speed, greater handling qualities and her strength from internal ribs and external wales made contemporaries look on the galleon as a warship.[c] Tonnage did not reach the figure for the carrack, but galleons of 500 to 800 tons were not uncommon,[4] and very large crews could be carried – one man for each ton of capacity or slightly more. The men were there to fight but they also served as a pool of labour to handle the increased number of sails.

It was the galleon in its various modifications which drove the galley from its position as the most important fighting ship in the Mediterranean. Naval battles with sailing ships, long a feature of the Atlantic and northern European waters, also became typical in the Mediterranean after the introduction of the galleon and, more important, of more and cheaper guns. The quality of guns and gunpowder and of naval gunnery in general was still far from ideal but guns improved during the sixteenth century, thus increasing the effectiveness of the broadside fire of the galleons.

Reliable iron guns cost much less to make and were much easier to handle than their bronze predecessors. Gunners lost their privileged position, their higher status and incomes, as it became possible to train most sailors to fire the new weapons. With increased firepower and the improved handling qualities of sailing ships, tactics changed, at least for the weaker opponent, from boarding to standing off and firing cannon. In the 1580s, there was a large influx into the Mediterranean of English and Dutch sailing ships equipped with more guns. Their vessels proved highly effective for piracy, at which oared ships had previously excelled. It was in precisely these last years of the sixteenth century that heavily armed sailing warships drove oared vessels from their dominance of Mediterranean naval forces. Mediterranean navies had tried using broadside armament before, around 1500, but it proved ineffective because of the small numbers of guns and slow rates of fire.[5] It was the northern Europeans who solved those problems and so it was they who came, over time, to dominate the dangerous trades in the Mediterranean and long-distance trades outside Europe.

The campaign of the Spanish Armada in 1588 demonstrated that, at

sea, fighting was to be between fleets of ships firing guns. The plan of King Philip II of Spain to land troops in England failed for a number of reasons, including the weather, but certainly a principal cause of the English success in preventing any landing, or for that matter any co-ordination of Spanish efforts, was the manoeuvrability of their ships. Their galleons were smaller, faster, easier to handle than the Spanish and Portuguese warships and so the English were able to deploy their guns more effectively.[d] It was clear from 1588 that seapower would depend on that ability to use guns, making the low, narrow galleon of 500 tons or slightly more the best option for European navies.[6] The massive carracks, like those built for the kings of Europe in the first half of the sixteenth century, had lost their value. The massive fighting ships were expensive and had a bad tendency to sink easily. The English warship *Mary Rose* went down in the middle of the century because inexperience with using guns led her to heel over and water rushed in through the gunports which no one had thought to close. The *Gustavas Vasa* sank in Stockholm harbour on her maiden voyage in 1628 when there was a sudden strong wind.[e] She was unstable when built and the addition of heavy guns increased the problem. The *Vasa* was not a massive carrack but the loss did show the great liability of warships even in the seventeenth century. Since with heavy guns large ships could be sunk by almost any properly handled warship, the logical response of naval shipbuilders was to design for handling qualities, internal strength with thicker timbers and maximum firepower. The galleon supplied those requirements and, though large galleons could be built – 1,000 tons and more – such concentration of investment was rare. The galleon was not the only warship built in the second half of the sixteenth century. Heavily armed four-masted ships, really large carracks, still participated in sea battles. With or without guns, they were also used for commerce.[f] The engravings and paintings by Pieter Breugel the Elder of ships and battles from the 1550s are accurate reproductions of the large warships of the Mediterranean and the Low Countries. His representations of galleys are equally trustworthy.[g] The sailing warships of many of Breugel's works show the tendency towards longer vessels, straighter sides and greater reliance on internal rather than external support. Coming at the middle of the century, the prints include some transitional carracks which already had galleon features. At the same time, the works show the degree of diffusion of certain northern and southern rigging techniques.[7]

Galleons also made good cargo ships. They were costly to operate because of the size of the crew and the expensive guns. On the other

hand, they were highly defensible. Thus galleons were limited to use on dangerous trade routes where the value of goods per unit volume was high enough to cover the costs. On short voyages they might face competition from galleys but even there, by the end of the sixteenth century, the galleon could effectively compete, with its larger carrying capacity and therefore presumably lower cost for each ton shipped. For dangerous long-distance trades there was no question about the superiority of this type of sailing ship. The galleon found a place in traffic to the New World from Seville in Spain since the back cargo was silver. As silver production rose in the New World and as other states sent naval forces to try and capture the silver shipments, the number of galleons in the New World fleets rose. The increase in the average tonnage of ships going to the New World throughout the sixteenth century indicated not only a rising volume of trade but also greater opportunities for the use of the galleon. The design yielded greater advantages in the range of about 500 tons than in smaller versions. This is not to say that smaller sailing ships were not designed in imitation of the galleon. The New World trade was not the only trade where galleons found a place. Exchange of luxuries, including the carriage of silver, between Iberia and the Low Countries brought galleons to northern European ports. Northern Europeans, on their first trading ventures to the East Indies, used ships very like the Spanish galleons which sailed to the Americas.[8] The similarity in goods and in the expected dangers suggested the use of the same ship type.

The change to smaller and more manoeuvrable warships was a lesson not lost on pirates. Piracy was always a problem for European commerce. In the latter middle ages and throughout the sixteenth century, piracy usually rose out of political conflict, since privateering and piracy were hard to distinguish. Piracy was more profitable if there was a state to support the robbers, to offer them sanction, a base of operations and a market for captured ships and goods. There was apparently some constraint on these men which kept them from unrestrained piracy, from acting indiscriminately without some excuse granted them by a belligerent power. Since there was usually a number of belligerent powers at any one time, they generally chose to act as privateers with some legal sanction. Government efforts to suppress piracy always proved unsuccessful – that is, except in a few rare instances where all parties agreed to join together in stopping the practice. In many cases governments used piracy as a method of carrying on undeclared war. The pirate fleets served as a source of trained men and warships in times of war, a source which could then be used as an official navy. Their

ships had manning ratios of three tons for each man, or less, while cargo ships would operate generally at ten tons per man, or more. With their ships built narrow and light and with some light guns on board, pirates could pursue, catch and take most cargo ships.[9] The addition of the guns, even if light, made the pirate ship much more productive. Crews still had to be large and so labour costs did not fall, but success in seizing cargo ships increased. If only by intimidating the commercial vessel with firepower, the pirate ship could better its chances. After all, pirates were not interested in sinking ships but only in capturing them for the goods on board. The increased power of pirate ships was combined with a general rise in the total volume of commerce and therefore a rise in the potential quantity of goods for the pirates to steal. More profitable piracy drew more investment and more sailors.

The threat from pirates meant that cargo ships had to better their defences. There was an increase in piracy in the Mediterranean in the sixteenth century, not just because of the operations of corsairs from Algiers. Northern Europeans and Turks were equally willing to exploit the new opportunities, thus giving even greater impetus to Mediterranean shippers to adopt ships like the galleon. English merchants trading to the Levant ordered heavy, well-armed highly defensible merchantmen from English shipbuilding yards so that they could make the long voyage through the Mediterranean unhindered. Not incidentally, the use of such types also gave them the possibility of becoming privateers or pirates if the opportunity presented itself. The cargoes of the Levant trade were valuable enough to support the higher cost of freight in these defensible ships and the charges were high since manning ratios were 5 to 4.5 tons for each crewman. Piracy, or rather privateering, was a business highly organised by a small group of investors exploiting the potential created by shipbuilders.[10] Once ship design made that kind of privateering venture possible, piracy spread to the New World where similar trade patterns and geography and the importation of European political conflicts combined to generate circumstances much like those in the Mediterranean. Whether for privateering or for navies, galleons became the fighting ships of Europe.

The specialised cargo ship was the product of a series of design changes throughout the sixteenth century. The progression was most obvious in Holland where shipbuilders first tested the extremes of design for a purely cargo-carrying vessel. Dutch trade was principally with the Baltic where ships went for grain to bring to the storehouses of Amsterdam for redistribution to western and southern Europe. For that traffic and for shorter voyages in the North Sea, Dutch builders

26: Boyer (left) and Netherlands Cargo Ship Showing Many Features of the Later Fluyt, from a Mid-sixteenth-century Engraving by Pieter Breugel the Elder

produced a series of low-cost carriers. The first to emerge was the boyer which gained widespread popularity in those trades in the 1560s and 1570s. Like its successors, it sacrificed speed and a large crew for cargo space. The boyer started as a flat-bottomed low vessel of shallow draught in the fifteenth century or earlier. In the sixteenth century it was made into a seagoing vessel. Sides were built up, it became larger and the rig was expanded. Though there were variations, the usual arrangement seems to have been two masts, the mizzen having a lateen and the mainmast carrying two square sails and a spritsail. Another sail was often hung from the forestay,[h] giving a combination of both square and fore-and-aft rig which made the ship highly manoeuvrable. Moreover, it took only a few men to handle the rig. The length-to-breadth ratio was better than 3:1, with lengths reaching 20 metres and more. There was a deck to protect cargo. Boyers of about 100 tons were most common, though they could be as small as 50 and as large as 130 tons. Boyers were capable of long voyages but they were most popular for short runs in the North and Baltic Seas. The manning ratio was among the best of any cargo ship, rising to 20 tons for each man.[11] The *vlieboot* tended to replace the boyer after the 1570s because it was even better designed for bulk carriage. It was also two-masted with one mast carrying a spritsail, but in this case each mast carried two square sails. It had a square built-up stern, broad beam and very shallow draught. These boats were small, rarely exceeding 100 tons. With its sizeable cargo space from the hull design and its combination of sails, it was the leading medium and small bulk carrier of the last years of the sixteenth century. It was superseded by a ship of even more efficient design.

The *fluit* grew out of the experience of builders with other bulk carriers. A date of 1595 has been given for the invention of the fluyt by a Dutch ship carpenter at the town of Hoorn, north of Amsterdam. This new ship may have been a marked improvement over its predecessors, but cargo ships with many features of the fluyt were certainly built before that date. Pieter Breugel, in one of his engravings, shows a cargo ship alongside a boyer which looks much like the fluyt of the seventeenth century.[i] Obviously, builders were making incremental progress towards the final fluyt design, not established until the second decade of the seventeenth century. The English called fluyts flyboats, which suggests that the fluyt and *vlieboot* were closely related. The unique features of the fluyt included a high length-to-breadth ratio – 4:1 in 1595 and higher in the following years, rising to 5:1 and even 6:1 – shallow draught, light upperworks aft and none forward, and a low centre of gravity. The bottom was nearly flat, the hold large and

almost square. The posts were close to vertical to give an even more box-like spacious hold. Bows were bluff and almost bulging. Usually there was a full deck. Given the form of the hull, it was a good sailer even to windward. The rig had a square sail on the foremast, two square sails on the mainmast and a lateen mizzen with a square mizzen topsail along with a spritsail under the bowsprit. The arrangement was common on full-rigged ships. The fluyt rarely added more canvas and in fact often dropped the topsails. Pole-masts were also used on some versions so that the work of handling the sails could be done from the deck. Most sailing ships of the second half of the sixteenth century had detachable topmasts so that the topsail and all its spars could be taken in in bad weather, thus saving valuable masts, creating greater flexibility and making for greater potential sail area. For the fluyt, however, sail area was far from maximised. It had shorter masts and spars and smaller sails than, for example, on galleons of comparable size. The fluyt was slower as a result, but builders did not design the fluyt for speed. The goal was to minimise costs. Pulleys and tackles were also extensively used for control of the sails, thus also keeping down the size of the crew. The stern was rounded, a return to the tradition of the sailing ships of the Low Countries before 1450. There was extensive tumble-home which gave the wing transom a taper, with the upper decks, if there were any, much narrower than the main deck. This design cut wind resistance and, along with the round stern, improved handling. It must have been difficult to bend the large planks to fit the great curves of the stern. Builders used as much pine as possible in construction, since it was easier to work and also made the fluyt even lighter.[12] The final result was a slow, light ship, with good handling qualities which could be and were traded off for smaller crews. It was specifically designed for the Dutch trades in salt, herring and grain and offered the lowest cost transport available for those goods, thus keeping delivered prices down and increasing the size of the market. Since the Dutch could move these goods in fluyts for less than could their competitors, the result was more trade in Dutch ships. The available data on Baltic trade in the late sixteenth and seventeenth centuries confirm the success of the fluyt.[13]

The fluyt rarely carried guns and, when it did, the armament was small. Given its slowness and light build, it was not worth much in a fight. It was primarily for use in the Baltic where piracy was at a minimum. Fluyts could in some cases be defensible. On rare occasions they were even used for piracy. The Baltic was not always a peaceful sea and fluyts found employment along the Atlantic seaboard and even in the

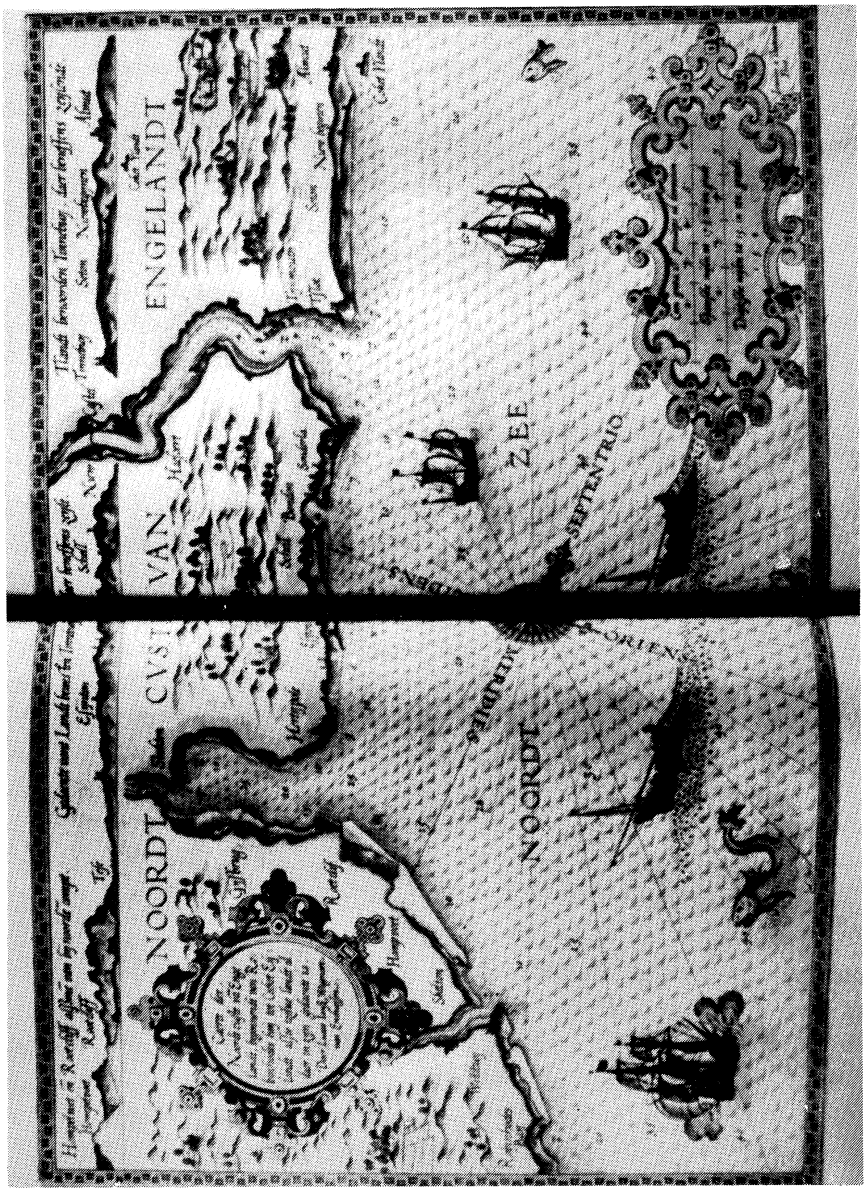
West Indies, both areas well known for danger from freebooters. For these voyages and for trips to the Mediterranean, shippers chose modified and better-armed fluyts. More important in those trades was the protection offered by convoys. In the fifteenth and sixteenth centuries, as shipbuilders produced specialised cargo ships, governments began to organise the convoys arming ships to sail with and protect the relatively defenceless vessels. In the Low Countries the process began with the herring busses, built as fishing boats with no consideration for defence. As shipyards produced more efficient cargo ships, the need for protecting them, especially in time of war, became a pressing problem. By 1600, northern European governments had accepted the responsibility for defending shipping. Fishermen and shippers had to pay for the service, usually by a levy based on the duration of the voyage and the tonnage of the ship. It was the government admiralties, though, which built the warships and organised the convoys. The pinnass, square-sterned, full-rigged and heavily armed, was a standard ship for that work. The term was used rather loosely in the sixteenth century but, by 1600, it typically meant a vessel of over 50 tons, fast and intended for defence. Smaller versions were rowed and the sleekness of the sailing warships may have earned them the name. Since ships had been made more efficient by the design changes, the cost of state-organised convoys could be more easily sustained. Governments were glad to offer protection to valuable shipping and at the same time find a way to cover the cost of operating their warships. The increased vigour of governments in organising convoys and supplying protection served to push back even more the constraints on shipbuilders. They could go further in building specialised low-cost bulk carriers – that is, except for ships trading in difficult waters such as the Mediterranean and the West Indies, but even here the convoy system kept some slower, lighter, less well-armed ships in service.

Convoys worked to decrease the flexibility of seaborne commerce, tying skippers to specific routes and sailing dates. Convoys could only move as fast as the slowest ship. But technical changes more than compensated for the loss in flexibility. Southern methods of navigation were slowly introduced in the North. Improvements in aids to navigation in northern Europe attest to the rise in long-distance trade between North and South. Moreover, there were advances in the equipment used. A ship's position could be more easily and more accurately determined, thanks to improvements in the compass and the quadrant. Better projections made it possible to navigate a great circle course with contemporary charts. The appearance of trigonometry tables for use by

sailors made it easier to resolve courses. Moreover, by the end of the sixteenth century, along with printed rutters of an increasing variety, navigators in the Atlantic and the North Sea had charts available to them as good as any for the Mediterranean. They were less expensive too, thanks to low-cost copper engraving developed in the Netherlands.[14]

More important to over-all efficiency than improvements in navigation were the decisions by builders and shipowners to use ships of less than maximum size. While wooden cargo ships could be built up to 2,000 tons, it was found that the optimal size was significantly less, somewhere between 300 and 500 tons. Especially with the fluyt, this kept down crew size and meant shippers could offer more varied services for the fluctuating demand for transport. Small vessels, those of under about 100 tons, tended to disappear from long-distance trade, as did the giants. The great ships had always presented problems, with their long turnaround times. The advantage had been in the lower cost for each ton shipped, implied by the great carrying capacity. The improvements in the fluyt, by cutting the manpower needs, had erased any of that saving. There were no advantages to be gained from the larger scale implied by big carracks. With shorter turnaround time and easy handling, the fluyt of 300 to 500 tons could also compete favourably with small ships, taking away at least part of their advantage in being able to make more trips each year. By decreasing labour costs and increasing the return on investment, the fluyt established an optimal size for a specialised cargo ship. In the process it brought more diversity to trade routes and to trade goods.

By the end of the sixteenth century, ship design had reached something of a plateau. Until the late eighteenth century, there was little change in the design of warships or of larger cargo carriers. The galleon emerged as the ship-of-the-line, while the rig and hull design were modified to give greater speed and reliability without increasing crew size. Much more significant advances were made with small craft, now increasingly limited to short hauls along coasts and on inland waters. What savings were made in the cost of shipping goods by sea over the seventeenth and eighteenth centuries came not from design changes but rather from changes in political and economic conditions which allowed shippers to exploit the design improvements of the fifteenth and sixteenth centuries.[15] The division between cargo ship and warship among sailing vessels was certainly made by 1600. The economic bulk carrier needed for the expansion of European commerce had been created in the fluyt. The greater ability to move bulk goods was reflected in the invasion of the Mediterranean by northern European ships in the last




27: Herring Busses Fishing off the English North Sea Coast, from the *Spiegel der zeevaerdt* of Lucas Jansz. Waghenaer, 1584-85.

decade of the sixteenth century. Crop failures led to a famine in the Mediterranean and Dutch, along with German and English, traders exploited the opportunity by carrying grain to southern ports in sharply increased quantities. The bulk carriers provided valuable services both to and within the Mediterranean. English shippers with large and defensible cargo ships, more effective than small local ships, had already made a place for northern shippers, and for that matter pirates, in the Mediterranean. The great volume of trade between the North and the South, however, was in the bulk goods exported from northern Europe in Dutch fluyts, demonstrating to all Europeans the superior qualities of Dutch bulk carriers. Recognising this fact, shippers from throughout Europe bought ships from Dutch yards.[16] The success of Dutch shipbuilders reflected not only their own skill at designing ships for a specific purpose but also the general rise in the volume of trade in bulk goods. The situation of the fourteenth century was reversed. The South still ran a balance of payments surplus with the North, exports being of higher total value than imports. But now the Mediterranean was importing a larger volume of goods than it exported. Mediterranean producers were faced with the problem of finding a bulk cargo to fill the holds of those slow cargo ships from northern Europe for their return voyage. Almost any back cargo would do in order to cut the cost of the total trip. It even proved worth while to carry Italian marble back to the North. But then Dutch ships, rather than go in ballast, carried bricks to the Baltic and even to the East Indies. Carrying cargoes of such low value was possible, under the right circumstances, because of the efficiency embodied in the specialised fluyt.

Shipbuilders in the second half of the sixteenth century faced the same general and pervasive pressure to lower the price of their finished product while maintaining, or preferably increasing, its quality. Builders certainly became better able, over time, to deal with designs and design features. That kind of learning was combined with the fuller exploitation of previously developed improvements, such as the more divided sail plan, to increase the security of ships. Perhaps the better sail arrangement and their own confidence with skeleton-building allowed shipwrights to cut down on the massive amount of wood used in hulls and ribs, thus creating a saving in capital as well as in the labour used in construction. The design of the fluyt also demonstrated the advantage of keeping the ship light, at least where cargo vessels were concerned. It was not, of course, possible with warships.

The question of capital costs became more pressing in the sixteenth century, as, for the first time, European shipbuilders had some serious

problems with supplies of raw materials. While in the late fourteenth and fifteenth centuries wood prices probably remained firm, in the sixteenth century wood prices rose sharply. In some cases, builders could not get the right type of wood at all. The big pieces of oak for keels, ribs and knees and the tall pine for masts had to be of just the right size and shape. Shipbuilders in the Low Countries always had to import their wood. As the sixteenth century progressed, they had to look further afield. Supplies were harder to find in England and in France, so builders there had to import more of their wood, both as timber and as cut and prepared lumber. The wood came principally from the Baltic and from Norway. Shipbuilders could not just walk into the forest to select what they needed. They had to rely on a long chain of merchants and shippers to get them the right kind of wood. Wood was not the only raw material that had to be imported. For example, hemp for rope, tar and pitch all had to be brought into western Europe, and the principal sources were in the North, in Scandinavia and in lands bordering the Baltic. This created an expanding trade in such materials and, with it, a greater demand for ships. But the increase in the total production of ships was much less important to builders than obtaining the quantity and the kind of wood they needed at a price that would keep them competitive. As the wood had to travel great distances, first by road or river and then by sea, the possibility of interruption of supply and of price increases was greater. In the fifteenth and even more in the sixteenth century, as farmers cleared land in Poland and Russia to raise grain, they generated timber for export. The process of colonisation meant short-term abundance of supplies but also meant a long-term migration of sources eastward and northward.[17] Merchants, especially those from Holland, by organising the trade and by finding efficient ships, were able to contain increases in the delivered price of wood and to a great degree maintain security of supplies to western Europe.

In southern Europe, in Iberia and along the northern shores of the Mediterranean, the situation was much more critical. The change in ship design towards higher ratios of length-to-breadth increased the demand for wood – especially hardwood for planking – for each ton of carrying capacity built. With the fluyt, the rise to a ratio of 6:1 meant a sharp rise in the amount of wood needed, and southern European builders were handicapped in imitating the design because of shortages of wood. Importing wood from the Baltic and Scandinavia was expensive. German shippers from Gdansk and Königsberg still found a lively and growing market for their wood in Spain and Portugal in the fifteenth and sixteenth centuries. The rising price served to keep transport costs

down as a percentage of delivered cost. Despite this fact and improvements in ships, it was apparently never economically advisable to carry wood for shipbuilding into the Mediterranean in large quantities. Supplies of wood there were shrinking. Indiscriminate cutting had, over time, led to soil erosion on islands in the Adriatic and on the mainland. Forests did not replace themselves. All the easily accessible wood had been used and so the cost of bringing trees from the hills and mountains drove up the price of timber. Recognising the problem, governments, and especially the Venetian government, embarked on programmes of forest management to protect limited and decreasing supplies. Their principal goal, however, was to assure themselves of sufficient wood to build warships. Venice made officers of the Arsenal responsible for overseeing the cutting and use of trees. By effectively depriving private shipbuilding yards of wood, the government doomed them to collapse. The process of importing shipbuilding wood in finished form was thus accelerated. Completed ships from northern Europe were brought in, not only because of their superior design but also because northern builders had access to wood, at prices below those faced by their Mediterranean counterparts. States in southern Europe were driven to find alternative sources of ships. The Portuguese government considered having all its ships for trade to the Indies and the New World built in Gdansk. Both Spain and Portugal developed shipbuilding yards in their colonies. The growing local market, the availability of labour but, most important, the abundant supplies of timber recommended the decision. The Portuguese found that carracks for the trade to India built in Goa of local teak were better and more reliable than those built in Lisbon.[18] Over time, Indian-built ships constituted a larger share of the Portuguese merchant marine. Colonial yards in the Americas and the Philippines made similar inroads in Spanish shipping.

Technical change in ship design in the sixteenth century worked against builders short of wood. Shipwrights in the South could not follow the Dutch in building their vessels lighter. Pirates and the continuing war of attrition made trading in the Mediterranean dangerous, so ships had to be heavy and strong. In the case of these designers, it proved impossible to develop a technology which could overcome the loss of the shipbuilders' principal raw material, wood. The generally rising price of wood created pressure for design improvement throughout Europe. The price increases created a threshold of technical change which was needed to continue building ships. The threshold was low enough in northern Europe and especially in Holland for builders to overcome the problem. They were rewarded with the largest share of

the European market for bulk-carrying cargo ships. In the Mediterranean, existing technologies and political conditions combined to make the price threshold too high and builders withdrew to work on smaller craft or on warships on which governments by fiat removed price constraints. As with Muslims in tenth-century Egypt, the lack of wood in adequate quantities and at a less than prohibitive price led to the decline of shipbuilding in Italy and Iberia. No technical change was made to counter the decline and the decline itself decreased the chances for innovation. The downturn was self-reinforcing.

Since northern European ships came to spend more time in warm waters in the sixteenth century, shipbuilders were pressed to find a solution to attacks on hulls by the shipworm. It was an old problem in the Mediterranean. The Roman practice of covering the hull with paint and wax may well have continued throughout the middle ages. The waters of the Caribbean were as bad or worse than those of the Mediterranean and sixteenth-century Spanish builders tried methods such as the long-abandoned Roman one of covering the hull with a layer of lead sheathing. The covering was later changed to copper, perhaps to decrease the weight, but, as it also increased the price, the method was rarely used. In any case, such additions had to damage the handling qualities of the ship. In the North, the typical solution was to add another hull, a sheathing of thin planks over the true hull with a layer of tar and oakum or horsehair between the two. If the shipworm attacked the outer layer, at least those boards could be replaced with less danger and less cost. No solution was foolproof. Shipbuilders had the same type of problem with dry rot, a fungus which attacked the wood and spread through the timbers of the hull unless caught in time.[19] For neither of the two problems was there anything like a systematic study of the causes or the potential cures. Obviously, with all solutions there was a trade-off and most of those suggested or tried by ship carpenters were discarded simply because they cost too much – that is, unless governments insisted on the solution as, for example, with the use of copper sheathing. The failure to find an answer to attacks either of the shipworm or of dry rot gave ship carpenters more repair work. Bad planks were torn out and replaced if the trouble was discovered in time. The failure to deal effectively with those problems kept up capital costs throughout the middle ages. In the sixteenth century, the situation became more critical because of the rising price of wood. The penalty was greatest for southern European shippers, since they traded in regions at home and in the East and West Indies where the shipworm thrived. In this case also, southern shipbuilders failed to overcome an immediate

and obvious problem, thus creating another advantage for northern Europeans.

Shipbuilders in the second half of the sixteenth century faced increased pressure to expand their range of knowledge. The appearance of the first treatises on shipbuilding in the fifteenth century indicated that ship design had to some degree changed character. With the introduction of full-scale skeleton construction on all large ships, builders had to approach the job of designing and setting up the vessel in a different way. The effect was greatest in northern Europe where shell construction had protected builders from the problem into the fifteenth century. The compromise of southern European shipwrights, by which one or three ribs were set up and connected by wales and the remaining ribs cut to fit, retained some of the uncertainty, as well as difficulties in handling the ribs common to shell construction. By the late sixteenth century, ship designers were drawing all the ribs and lines of the entire ship before they laid down the keel. Not only did they have a better idea of what they would end up with, but they also cut out all the internal framing in place and then simply added the hull planking. This method was faster and easier, especially for large vessels, but it meant that ships had to have plans and builders had to use not only simple mathematics but also compass and ruler to make the scale drawing of the vessel. At least that was the approach in one case. Mathew Baker, the master shipwright to Queen Elizabeth I of England, in a short and confusing treatise on shipbuilding, showed how drawings could and should be used.[j] His drawings gave the shape of the section amidships and, for that matter, throughout much of the vessel. Shape was defined by a series of arcs and circles and proportional relationships.[20] The same type of information could be obtained from models of ships. In the late sixteenth century, buyers of ships, especially governments, began to insist on scale models before agreeing to buy the vessel. The model could in fact be a drawing on paper as well as a replica in wood. The replica had the advantage of giving the shape of the rib. Builders took the shape by pressing a flexible lead rod against the outside of the model. By no means did all shipwrights approach their job in this way, but builders of larger ships, and especially builders of warships, increasingly relied on some kind of systematically developed, preconceived and fixed design executed before the keel was laid down. Shipwrights still imitated past success – a common approach – but at least, in the course of the sixteenth century, the ability to imitate previous experiment had improved and a basis was laid for the evolution of systematic and transferable techniques. Treatises contained more

vulgarised mathematics and borrowings from writers who dealt with questions of buoyancy in a more abstract way. Such works were more easily available. The first book on shipbuilding was published at Mexico City in 1587. Included were plans, a model of a ship and illustrations and directions for a number of other jobs associated with shipbuilding, such as making sails.[21]

None of these changes made shipbuilding a formal or systematic science. Certainly, the improvements in approach and in diffusion of information helped shipwrights to deal with technical changes already made. They allowed more builders to use the new techniques and increased the opportunities for further improvements as more men tried their hand at using models in designing and building. But shipbuilders still could not predict the major attributes of the ship before launching. It was not until late in the seventeenth century that anyone could say beforehand with any accuracy what the draught of a ship would be. Shake-down cruises were still a necessity because the hull often had to be filled out in certain places to make the ship seaworthy. The experience with the *Vasa* showed the degree of inaccuracy in ship design. Builders retained a notion that the hull should be something like a mackerel or some other relatively long fish on the simple understanding that if the fish moved well through the water then a ship of similar design logically would do so too. Despite such thinking, it is clear that, by the late sixteenth century, some European shipbuilders were applying more sophisticated techniques to the whole problem of designing ships. Shipwrights like Mathew Baker found themselves employed by governments on a permanent or semi-permanent basis for the production of warships. The situation of the Venetian Arsenal in the fourteenth century became widespread. Shipwrights working for governments had a greater incentive to develop systematic approaches to design. Since much of the pressure came from the governments, the change in approach was most noticeable and the need to learn much greater for the builders of warships. Only slowly did learning encroach on the handicraft tradition of the building of cargo ships.

Though there were problems with obtaining and maintaining supplies of wood for shipbuilding, labour appears to have been relatively abundant. The continued growth of population in the second half of the sixteenth century, despite some checks here and there, supplied the necessary pool of unskilled workers for the industry. Migration to the cities brought even more potential workers close to the sites of shipbuilding yards. The need for unskilled workers had increased relatively because ships were bigger. More muscle power was needed to raise those

large frames. For skilled labour the ship carpenters' guilds, to be found in most major ports by the second half of the sixteenth century, continued to train new men. These would-be ship carpenters were drawn by the expectation of rising incomes, rising if not because of higher wage rates at least because of more regular work with the greater demand for ships and therefore for shipbuilders' services. Guilds of ship carpenters did not attack the problem of formal training to teach men to deal with the new methods in the trade, to make models and understand written works on shipbuilding.

The results of design change in the second half of the sixteenth century formed a microcosm of the effects of technical improvements in the design and building of ships over the years from 600 to 1600. The same sectors of the economy enjoyed the advantages of lower transport costs, and similar economic opportunities were pursued in those sectors. As was to be expected, European governments found the pressures on them and the opportunities for them similar to those created by earlier design changes. After all, design change followed a similar pattern over the 1,000 years. Builders were devoted to lowering the cost of shipping goods, no matter what or who those goods might be. At the same time, the structure of demand had changed at various times so that shipwrights, in response to those demand changes, had attacked one aspect of the general problem and then another. Throughout, however, the greatest demand they faced and their greatest success was with the movement of bulk goods. It was here that waterborne transport enjoyed a competitive advantage which land transport could overcome only with great difficulty and only in certain highly specific circumstances. By no means did builders ever abandon building ships for carrying luxuries. Indeed, in many cases, competition from land transport created yet another pressure on shipbuilders to refine and improve the designs of such carriers. But with moving bulk goods, the opportunity to supply a ready market almost invariably existed. By retaining many designs, by borrowing from designs of smaller or different types of vessels as occasions arose and by supplying ships in the quantity and type to fulfil the needs – both immediately perceived and less obvious – of shippers, shipbuilders, over time, generated the potential for lower-cost bulk transport. The potential was embodied in the design of their ships. The cheaper shipping services made possible world-wide economic connections, on a continuing basis. The lower-cost bulk carrier also opened the door to regular reliance on distant suppliers for all kinds of goods, including luxuries, since over great distances that type of ship proved efficient in handling them too.

Falling transport costs could and did lead to specialisation in production by region. Commercial agriculture was practised ever more widely. Farmers did not produce necessities for their own consumption but rather relied on ships to bring them those goods to exchange for their own output. This led logically to the more intensive exploitation of land in agricultural districts far removed from centres of consumption. It also led to the problems inherent in the complete reliance on one product. While agriculture became more specialised by region, industry became less tied to a specific location. As shipping costs became a smaller portion of the delivered price of raw materials, industries could move those supplies over greater distances to the point of manufacture, with no increase in costs. In general the potential fall in the cost of moving goods, and especially bulk goods, allowed for a greater distribution of productive activities and of population. Moreover, that possibility was enhanced by the greater flexibility of transport by sea.

With improvements in ships and in the ways of building them, shipwrights enjoyed the higher status and buoyant incomes which reflected the better quality of their work. Shipbuilders were now technologists and, though they were not exactly the equivalent of engineers, they could still expect to receive something of the same kind of recognition. Shipbuilders not employed by governments still had to combine a large number of skills. They were not only designers but also skilled artisans working on the ships and businessmen with all the problems of raising capital and finding and paying workers. The capital requirements of builders increased, if slowly, throughout the sixteenth century. Owners of shipbuilding wharves, in 1600, were still typically shipwrights – that is, with the exception of government shipyards. If those men wanted to build larger ships, they had to have slipways, which meant investment in floor planking, capstans, chains and other apparatus. Owners also had to supply more tools and a shed for the tools, along with sheds to protect some of their wood. Shipbuilders had to become even more skilled to continue to design ships. All these forces combined to generate a greater distinction and a more unequal income distribution among builders. The differentiation was not sharp nor was it extreme – that took some time to emerge – but the rising capital requirements of shipbuilding, both physical and human, established a basis for setting certain builders apart from other ship carpenters. This situation was less true among merchants. The boom in commerce of the sixteenth century served to make more merchants wealthy. On the other hand, on board ship the distinction between the captain, now himself more of an employee than an employer and shipowner, and the seamen who worked

under him continued to grow.

The expansion of trade, and the establishment of new trading relationships made possible by the lower shipping costs, brought greater diffusion of business methods. The most obvious example is the use of marine insurance which, throughout the fifteenth and sixteenth centuries, spread from Italy to Iberia, France and northern Europe. Southern European merchants living in the North set up markets in insurance and after some delay northern Europeans took up the practice themselves. Partnership arrangements to build and operate ships effectively spread risks in the North, as elsewhere, and worked to retard the diffusion of marine insurance. But the increasing volume of trade, the size of ships and their greater reliability which brought down insurance premiums made the practice common by the late sixteenth century.[22] At the same time in northern Europe merchants increasingly used factors, agents and correspondents. The methods of the Mediterranean of the twelfth and thirteenth centuries were widely imitated by 1600. The establishment of trading posts by Europeans in the New World, in south and southeast Asia also served to spread those Italian techniques. In northern Europe the bulk character of trade had slowed the diffusion of those business methods for many years but the development of bulk carriers of optimum size, which in turn meant a greater flexibility of transport, served to create something more like the commercial conditions of the twelfth- and thirteenth-century Mediterranean which made it worthwhile to imitate the already well-established Italian practices.

The specialisation of cargo ships and warships placed certain constraints on European governments. Power, the ability of the state and the dynasty to impose its will on other states, depended on guns, including guns on board ships, if effectively deployed. In order to pay for the guns, states needed the kind of money which, in the sixteenth century, could only be obtained from trade. Government administration continued to expand in order to maintain naval forces and to deal with the growing regulations of trade. Among those duties was the collection of taxes. The promotion of trade and its control by government was intended to enhance state power. The growing volume of trade, increased by the lower cost of waterborne transport, created an even larger stream of income for the state to tap. The organisation, control and direction of trade to the East Indies and the New World by Spain and Portugal was only the extreme example of a pattern repeated in the rest of Europe. In principle, governments, with rare exceptions, looked on commerce with the same eye. The apparatus of government legislation, which was later to be called the mercantile system, was set

up to take advantage of the potential created by, among other things, improvements in ship design.

Of course, not all social change was a result of the technical improvements in transportation and especially of improvements in shipping. From 600 to 1600, trade was always a small proportion of total economic activity. The origins of social change are multiple, technical change being only one source. Ship design changed slowly, much too slowly to be at the base of the complex mass of adjustments made in European society over the 1,000 years. Yet the temptation still exists to credit design improvements in ships with making a significant contribution to many of the social changes in that period. This temptation comes from the pervasive nature of the effects of changes in the cost and nature of shipping services. The results of design improvements unquestionably reached a broad spectrum of society. Shipbuilders provided capital goods to the most productive sector of the European economy. The effectiveness of shipbuilders in improving their products, therefore, was crucial to what economic growth there was.

The catalogue of design changes is lengthy. It is easy to see the changes as an unbroken line of incessant and relentless improvement, leading to the galleon and the fluyt of the late sixteenth century. Of course this is a gross exaggeration. The impression is created by foreshortening the developments of a millennium, by concentrating on the most significant changes, especially those in larger ships, and by generally ignoring any loss of technology. The major changes are the ones most easily documented and those subjected in the past to the most extensive study. But small improvements, the obscure and almost arcane minor adjustments, could be and were the source of significant productivity changes, generating, in the long run, over-all savings of sizeable proportions. In the absence of extensive quantitative material on the cost of shipping goods, however, the economic contribution of design changes will never be known to a high degree of accuracy. Still, it is possible to estimate, within a relatively narrow range, the potential increases in productivity of both labour and capital for many design improvements.

The ability of economic circumstances to induce technical innovation is an open question, and will undoubtedly remain so for some time. There is the same problem with the relationship between the economy, and more specifically factor costs, and improvements in ship design in the middle ages. Evidence from marine archaeology has increased sharply our knowledge of the boats and ships built in classical and medieval Europe. Marine ethnology, the study of ship design as

evidence about local and indigenous culture, has shown the survival until very recently in many parts of Europe of designs from centuries past. The impression from study in both fields suggests strongly that, at any time between 600 and 1600, shipbuilders throughout Europe had at their disposal a broad range of designs. In small boats especially, ship carpenters apparently knew about and were familiar with many very distinct possibilities of how to go about their job. While in larger craft, at any point in time, the variety was much more restricted, the potential existed of scaling up and modifying any of the designs of smaller ships. While shipwrights could try new ways of building ships, it was always much simpler to do what they had been doing all along. They had to have reasons and very good ones to take on a new design.

Forces external to shipbuilding from 600 to 1600 were often such as to give shipbuilders a reason for trying something new. Usually those forces were apparently economic. In the fifth and sixth centuries, it seems that the high level of skill typical of Roman shipwrights was lost and many sophisticated techniques had to be abandoned. That retrogression, the opposite of technological advance, also seems to have been the result of economic forces. The shipbuilders of the early middle ages lost Roman techniques but in another sense they chose a different way to build their ships, a simpler and less expensive way to move the smaller volume of goods in trade. So even apparent decline in skill was a result of conscious choice based on economic circumstances. Builders borrowed or adapted designs over the years when faced with specific difficulties. Always they were confined by past practice but always they did respond in some way to external pressure. Their efforts were not always successful and the continuing problem of what to do about wood supplies was often dealt with but never completely solved.

If there was one single effect of all the changes, great and small, in the design of European ships over the millennium to 1600 it was greater specialisation. It was true of the ships and the shipbuilders as well. By no means was the process complete by the end of the period nor for that matter were there no specialised ship types in the early middle ages. But in 1600 there were more full-time shipbuilders than ever before, men whose entire efforts were devoted to a single profession. There were more ships relegated to specific duties and able to earn more because they had design features specific to those duties. Ships on the average became bigger over the millennium and were of more specialised design, even though they were larger.

Demand conditions and factor prices were the two pressures between which shipbuilders found themselves. Intermittently, they also

had to deal with the dictates of political authorities. Those were the forces which shaped their decisions on design change. The greater professionalisation of shipbuilders, the increasing volume of work and thus growing opportunities for experiment made them better able, over time, to solve the problems of buyers. The pace of technical advance did quicken, especially in the fifteenth and sixteenth centuries. At the same time, though, that pace could slow if the economic conditions acted to deter innovation. In each century, in each decade, shipbuilders had to deal, above all, with the costs of materials and labour and with the immediate needs of shippers. The unique set of circumstances, economic and political, which prevailed in Europe from the seventh to the seventeenth century, led shipbuilders to make a series of technical advances which, over time, yielded greater efficiency in moving goods. The process was not a simple one nor was it entirely in one direction. It did lead to conditions in which the shipbuilding industry could and did respond more directly and fully to demands. It did lead to a reliance on innovation or variation in design to deal with changing circumstances. The process ultimately became self-reinforcing, as success led to greater experiment. Over the entire 1,000 years, though, it is often hard to see any trend in the great variety of products which came from European shipyards. Finally, however, there emerged the most versatile, durable and efficient warships and cargo ships produced anywhere in the world. Ship carpenters proved themselves, over the long term, above all capable of responding to the external forces which pressed on them. It was precisely that technical responsiveness which formed the base of the long-term economic success of European shipbuilders and the men who used their products.

## NOTES

1. L. Th. Lehmann, 'Use and construction of galleys in the Netherlands', *Mededelingen van de Nederlandse Vereniging voor Zeegeschiedenis*, XXXVI (1978), pp. 11-23. G. C. E. Crone, *Onze Schepen in de Gouden Eeuw*, pp. 98-104, 149-50. R. H. Boulind, 'The Crompster in Literature and Pictures', *MM*, LIV (1968), pp. 3-17.

2. William A. Baker, 'Gosnold's *Concord* and Her Shallop', *AN*, XXXIV (1974), pp. 236-40. Edward Bowness, 'Some Drawings of Old Ships', *MM*, XLII (1956), pp. 323-7. Edwin Doran, Jr, 'The Origins of Leeboards', *MM*, LIII (1967), pp. 39-51. Alan Moore, 'Rig in Northern Europe,' pp. 14-15.

3. William L. Rodgers, *Naval Warfare under Oars, 4th to 16th Centuries* (United States Naval Institute, Annapolis, 1939), pp. 230-6. Randal Gray, 'Spinola's Galleys in the Narrow Seas, 1599-1603', *MM*, LXIV (1978), pp. 71-83; the defence preparations made by the English and Dutch in the face of the threat

from Spinola's galley flotilla show that contemporaries still thought them effective warships even in northern waters. John F. Guilmartin, *Gunpowder and Galleys*, pp. 69-72, 108-11, 196-232. Lionel Casson, *Illustrated History of Ships and Boats*, pp. 118-19. F. C. Lane, *Venice*, pp. 373-4. In the seventeenth century, on the largest Venetian flagships there were eight men to each oar, an extreme case.

4. William A. Baker, 'The Arrangement and Construction of Early Seventeenth-Century Ships', *AN*, XV (1955), p. 265. Tom Glasgow, Jr, 'The Shape of the Ships that Defeated the Spanish Armada', *MM*, L (1964), pp. 177-8. F. C. Lane, *Navires et Constructeurs à Venise*, pp. 47-8, and 'Venetian Naval Architecture about 1550', pp. 27, 39. Charles De La Roncière, *Histoire de la Marine Française*, vol. II, pp. 471-2. Josip Luetić, 'Dubrovački Galijun Druge Polovini XVI. Stoljeća [The Galleon of Dubrovnik in the Second Half of the sixteenth century], *Anali Historijskog Instituta Jugoslavenske, Akademije Znanosti I Umjetnosti U Dubrovniku*, VI-VII (1959), pp. 129-41. G. P. B. Naish, 'Ships and Shipbuilding', pp. 480-4.

5. Peter Padfield, *Guns at Sea*, pp. 37-45. John F. Guilmartin, *Gunpowder and Galleys*, pp. 35-9, 83-93, 272-3. James A. Williamson, *The Age of Drake* (A. and C. Black, London, 1938), pp. 253-4, 261-80. J. E. G. Bennell, 'English Oared Vessels of the Sixteenth Century', *MM*, LX (1974), pp. 9-26, 169-71.

6. Literature on the campaign of the Spanish Armada is extensive. The best summary is Garrett Mattingly, *The Defeat of the Spanish Armada* (Jonathan Cape, London, 1959). D. W. Waters, *The Elizabethan Navy and the Armada of Spain*, National Maritime Museum, Greenwich, Monographs and Reprints, 17 (1975). C. H. Haring, *Trade and Navigation between Spain and the Indies*, pp. 226, 275-6.

7. O. Buyssens, 'De Schepen bij Pieter Breugel de Oude Proeve van Identificatien', *MAB*, VIII (1954), pp. 159-91. H. Arthur Klein (ed.), *Graphic Worlds of Peter Bruegel the Elder* (Dover Publications, Inc., New York, 1963), pp. 51-5. G. La Roërie, 'More About the Ship of the Renaissance', pp. 186-8; Breugel's works were based on the paintings of a Portuguese artist of the first half of the sixteenth century so the date of 1556-60 for the ship studies may be misleading. I am indebted to T. Iain Gunn-Graham of the University of Alberta for pointing out many of the features of these ships.

8. Huguette and Pierre Chaunu, *Séville et l'Atlantique (1504-1650)*, vol. VI, part 1, table 12E. C. H. Haring, *Trade and Navigation between Spain and the Indies*, pp. 263-5. *HSUA*, pp. 256-7.

9. Fernand Braudel, *The Mediterranean and the Mediterranean World in the Age of Philip II*, pp. 129-30, 866-80. J. Craeybeckx, 'De Organisatie en de Konvooiering van de Koopvaardijvloot op het Einde van de Regering van Karel V', *Bijdragen voor de Geschiedenis der Nederlanden*, III (1949), pp. 194-5. C. L'Estrange Ewen, 'Organized Piracy Round England in the Sixteenth Century', *MM*, XXXV (1949), pp. 29-33. *HSUA*, p. 256.

10. Kenneth R. Andrews, *Elizabethan Privateering During the Spanish War, 1585-1603* (Cambridge University Press, Cambridge, 1964), pp. 102, 217-31. Fernand Braudel, *The Mediterranean and the Mediterranean World in the Age of Philip II*, pp. 288, 305, 886-7. Ralph Davis, 'England and the Mediterranean, 1570-1670', in F. J. Fisher (ed.), *Essays in the Economic and Social History of Tudor and Stuart England* (Cambridge University Press, Cambridge, 1961), pp. 117-37. Alberto Tenenti, *Piracy and The Decline of Venice 1580-1615* (University of California Press, Berkeley, 1967), pp. 3-86.

11. J. van Beylen, *Schepen van de Nederlanden*, pp. 123-5. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 82-92. Alan Moore, 'Rig in Northern Europe', pp. 13-14. G. V. Scammell, 'Manning the English Merchant Service in the 16th Century', *MM*, LVI (1970), p. 132. R. E. J. Weber, 'Note: The

Hollanse Hulck', *MM*, LIX (1973), p. 298.

12. J. van Beylen, *Schepen van de Nederlanden*, pp. 42, 101-9. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 92-117. R. Morton Nance, 'The Ship of the Renaissance', pp. 294-7. Richard W. Unger, 'Dutch Ship Design in the Fifteenth and Sixteenth Centuries', *Viator*, IV (1973), pp. 387-411.

13. Aksel E. Christensen, *Dutch Trade to the Baltic About 1600* (Martinus Nijhoff, The Hague, 1941). Pierre Jeannin, 'Le Tonnage des Navires utilisés dans la Baltique de 1550 à 1640 d'après les sources Prussiennes', *TCHM*, III, pp. 45-63.

14. D. Gernez, 'Lucas Janszoon Wagenaer: A Chapter in the History of Guide-Books for Seamen', *MM*, XXIII (1937), pp. 190-7, and 'The Works of Lucas Janszoon Wagenaer', *MM*, XXIII (1937), pp. 332-50. D. W. Waters, 'Science and the Techniques of Navigation in the Renaissance', pp. 231-2, and *The Art of Navigation in England*, pp. 497-500. W. E. May, *A History of Marine Navigation*, pp. 14-19, 123-8. A. W. Lang, *Seekarten der südlichen Nord- und Ostsee* (Deutsches Hydrographisches Institute, Hamburg, 1968).

15. F. C. Lane, 'Progrès technologiques et productivité dans les transports maritimes de la fin du Moyen Age au début des Temps modernes', p. 302. Gary M. Walton, 'Sources of Productivity Change in American Colonial Shipping, 1675-1775', *Economic History Review*, second series, XX (1967), pp. 67-78.

16. Fernand Braudel, *The Mediterranean and the Mediterranean World in the Age of Philip II*, pp. 226, 621-36. Fernand Braudel and Ruggiero Romano, *Navires et Marchandises à l'entrée du Port de Livourne (1547-1611)*, pp. 49-56, 99. J. H. Kernkamp, 'Scheepvaart- en Handelsbetrekkingen met Italië Tijdens de Opkomst der Republiek', in *Economisch-Historische Herdrukken* (Martinus Nijhoff, The Hague, 1964), pp. 199-234. F. C. Lane, *Navires et Constructeurs à Venise*, p. 108. David Parker, 'The Social Foundation of French Absolutism 1610-1630', *Past and Present*, 53 (1971), p. 85. At La Rochelle he says that any ship over ten tons was imported from the Dutch Republic. A. P. Usher, 'Spanish Ships and Shipping in the Sixteenth and Seventeenth Centuries', in *Facts and Factors in Economic History* (Harvard University Press, Cambridge, 1932), pp. 193-5.

17. Marian Malowist, 'L'approvisionnement des ports de la Baltique en produits forestiers pour les constructions navales aux XV$^{e}$ et XVI$^{e}$ siècles', in *TCHM*, III, pp. 25-40. Otto Röhlk, *Hansisch-Norwegische Handelspolitik im 16. Jahrhundert* (Karl Wacholtz, Neumünster i. H., 1935), p. 30.

18. C. R. Boxer (ed.), *The Tragic History of the Sea, 1589-1622*, pp. 3-5. Gervasio de Artiñano Y de Galdácano, *La Arquitectura Naval Española*, pp. 128-9. Konrad Häbler, *Die Geschichte der Fugger'schen Handlung in Spanien* (Emil Feber, Weimar, 1897), pp. 35-7. F. C. Lane, *Navires et Constructeurs à Venise*, pp. 98-9, 107, 203-6, and 'Venetian Shipping during the Commercial Revolution', *American Historical Review*, XXXVIII (1933), pp. 234-7. Robert Mantran, 'L'écho de la bataille de Lépante a Constantinople', *Annales (ESC)*, XXVIII (1973), p. 402; the Ottoman Empire may have also had a system of forest management to guarantee supplies of wood for warships. Ernst Schäfer, 'Internationaler Schiffsverkehr in Sevilla (San lucar) auf Grund einer spanischen Schiffahrtsstatistik vom Ende des 16. Jahrhunderts', *Hansische Geschichtsblätter*, LIX (1934), pp. 172-3.

19. J. van Beylen, *Schepen van de Nederlanden*, pp. 42-3. Tom Glasgow, Jr, 'Sixteenth-Century English Seamen Meet a New Enemy The Shipworm', *AN*, XXVII (1967), pp. 177-84. C. H. Haring, *Trade and Navigation between Spain and the Indies*, pp. 277-8. F. Moll, 'The History of Wood-Preserving in Shipbuilding', *MM*, XII (1926), pp. 357-60.

20. Wescott Abell, *The Shipwright's Trade* (Cambridge University Press, Cambridge, 1948), pp. 28-36. Ernst Baasch, *Beiträge zur Geschichte des deutschen Seeschiffbaues und der Schiffbaupolitik*, pp. 34-9. Arne Emil Christensen,

'Lucien Basch: Ancient wrecks and the archaeology of ships A comment', p. 143. He does not agree about the development of the skeleton form of construction. G. P. B. Naish, 'Ships and Shipbuilding', p. 488.

21. J. van Beylen, *Schepen van de Nederlanden*, pp. 31-6. L. Denoix, 'Caractéristiques des Navires de l'Epoque des Grandes Découvertes', pp. 141-2. Olaf Hasslöf, 'Main Principles in the Technology of Ship-Building', in O. Hasslöf, H. Henningsen, A. E. Christensen (eds), *Ships and Shipyards, Sailors and Fishermen, Introduction to Maritime Ethnology* (Rosenkilde and Bagger, Copenhagen, 1972), pp. 59-68. Diego Garcia de Palacio, *Instruccion Nautica para Navegar*, Colleccion de Incunables Americanos, VIII (Ediciones Cultura Hispanica, Madrid, 1944). Vernon D. Tate, 'The Instruction Nauthica of 1587', *AN*, I (1941), pp. 191-5. Gerhard Timmerman, 'Das Eindringen der Naturwissenschaft in das Schiffbauhandwerk', pp. 15-16.

22. L. A. Boiteux, *La Fortune de Mer*, pp. 89-114. Jelle C. Riemersma, 'Trading and shipping associations in 16th century Holland', p. 332.

## NOTES TO ILLUSTRATIONS

a. H. H. Brindley and Alan Moore, 'Square-Rigged Vessels with Two Masts', *MM*, VII (1921), figures 1-5. Björn Landström, *The Ship*, nos. 396-7. Alan Moore, 'Rig in Northern Europe', p. 14.

b. *HSUA*, pp. 209, 246. Björn Landström, *The Ship*, nos. 324-6, 328, 330, 332, 333. Randal Gray, 'Spinola's Galleys', *MM*, LXIV (1978), p. 73. See also Chapter 5, d. and f.

c. Romola and R. C. Anderson, *The Sailing-Ship*, pp. 128-9, 138. R. C. Anderson, 'Ship-Paintings in the Alhambra', p. 3. Björn Landström, *The Ship*, nos. 286-8, 291, 292, 307, 310-12. R. Morton Nance, 'The Ship of the Renaissance', pp. 291, 296. G. La Roërie and J. Vivielle, *Navires et Marins*, vol. I, pp. 253, 274, 275.

d. Romola and R. C. Anderson, *The Sailing-Ship*, p. 136. Lionel Casson, *Illustrated History of Ships and Boats*, nos. 122-3. G. S. Laird Clowes, *Sailing Ships*, part I, plate X, part II, plate V. Björn Landström, *The Ship*, nos. 302, 304.

e. Björn Landström, *The Ship*, no. 357, and *Sailing Ships*, nos. 262-5. *HSUA*, pp. 233, 242-3, 248-9.

f. Romola and R. C. Anderson, *The Sailing-Ship*, pp. 126, 137. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, plate XXIV.

g. Romola and R. C. Anderson, *The Sailing-Ship*, p. 134. Lionel Casson, *Illustrated History of Ships and Boats*, nos. 119-20. Claude Farrère, *Histoire de la Marine Française*, p. 96. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, plate XXV. Björn Landström, *Sailing Ships*, nos. 228-9, and *The Ship*, nos. 196, 297. *HSUA*, p. 246. R. Morton Nance, 'The Ship of the Renaissance', p. 295. G. La Roërie and J. Vivielle, *Navires et Marins*, vol. I, pp. 97, 260-1, 263, plates XII, XIV.

h. J. van Beylen, 'Zelandiae Descriptio', p. 97. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 82, 84-5, 94-5.

i. Romola and R. C. Anderson, *The Sailing-Ship*, p. 135. O. Buyssens, 'De Schepen bij Pieter Breugel de Oude Proeve van Identificatien', *MAB*, VIII (1954), pp. 181-3. Bernhard Hagedorn, *Die Entwicklung der wichtigsten Schiffstypen*, pp. 74, 96. Björn Landström, *The Ship*, nos. 298, 362, 363. R. Morton Nance, 'The Ship of the Renaissance', p. 294.

j. G. S. Laird Clowes, *Sailing Ships*, part I, plate XII. Björn Landström, *The Ship*, nos. 299-301, 303. *HSUA*, p. 244. G.La Roërie and J. Vivielle, *Navires et Marins*, vol. I, pp. 265, 267.