Ships and shipping technology

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Ships of the world

In 1400, different ship types and maritime technologies dominated the oceans in different parts of the world. The western Pacific and China Seas were the domain of junks from China. Among the far-flung islands in the central and southern Pacific, log rafts maintained connections over great distances. In the Indian Ocean, it was vessels with designs based on practices in what is now the Indonesian archipelago. In the waters of the western hemisphere, paddled boats were the vessels of choice. The only place to find ships of European design was in European waters. Over the following 400 years, the world’s ships went through dramatic changes. The quality of European vessels improved markedly from the fourteenth century on, providing unparalleled tools to accomplish a broad range of tasks, some never previously imagined. By 1800, vessels of European design dominated the world’s oceans in numbers, size, variety, and range. There were European builders everywhere practising their trade and passing on their technical skills and knowledge to non-Europeans. The vessels from other design traditions borrowed from European practice. Local shipwrights even built imitations of European ships, accepting the superiority of those designs. Europeans also borrowed from some practices in other parts of the world. It was the superiority in ship design and building techniques that gave the people from western Europe an insurmountable advantage in commerce and in violence in any contact around the world.

Because of the improvements and growth in nautical archaeology in recent decades, much more is now known about the evolution in ships from 1400 to 1800. The development of effective SCUBA gear after the Second World War revolutionized underwater archaeology. Certain major projects brought attention to the burgeoning field. Greater experience and technical advances, such as the use of hyperbaric chambers for decompression, made work at greater depths possible. Sidescan SONAR made surveying sites much easier. Advances in photography made accurate recording of finds faster and more accurate. The many digs, including investigations of ships and harbours, in all parts of the world over the years have supplied and continue to supply a range of information about varied aspects of many types of vessels.
The melding of a number of European shipbuilding traditions around 1400 into the full-rigged ship led to a long period of development, modification, improvement, and refining of the design of sea-going ships of all types. Design advances in smaller vessels used on coastal and inland routes contributed to qualitative changes in relatively large ones. That was part of a long-term process of interchange, of borrowing from different building practices in Europe and, later, as European ships ventured further afield, from Asia and the New World. In the thirteenth century, different building traditions prevailed in different parts of Europe. In the north the cog, a tubby clinker-built vessel with a single mast and single square sail, had emerged as the principal carrier of bulk goods on any kind of scale because of its relatively small crews and large carrying capacity. It also served as an effective warship. There was competition for the cog from vessels of designs descended from the rowing barges that Vikings used so effectively in raids in the early Middle Ages. A variant of the ship used for violence, the _knarr_, was tubbier and suited for carrying cargo. The high and late medieval keels which evolved from that type were cargo ships capable of inland and coastal work as well as crossing the North Sea. There were also flat-bottomed vessels of Celtic design that found work in shallow waters and another type with a banana-shaped hull that found use on rivers and in estuaries. Almost invariably all types relied on a single square sail for power. None of the designs was static. Cogs grew out of the flat-bottomed Celtic design and were made more seaworthy by the addition of a keel around 1200. After that the cog grew in size. The hull shape meant it was best to mount a rudder on the sternpost with a helmsman to handle the tiller. By the fifteenth century, northern ships like the cog could be very large. The _Grace Dieu_, the failed warship of King Henry V of England built between 1416 and 1418, may have reached 1,400 tons. The planking was heavy and the limited uses of a ship of its size and design, despite an advanced rig, suggested that alternative designs were needed.

**The design breakthrough in Renaissance Europe**

In the south, two general ship types, the galley and the round ship, inherited from the classical world, remained the preferred choices of Mediterranean mariners. Galleys were low, narrow vessels powered by both oars and sails, the sails being triangular lateen ones that had been in use in the region for centuries. By 1300, the smaller versions of the galley were almost exclusively warships, their arrangements of rowers leaving little room for cargo. A big or great galley developed around 1300 proved useful on certain routes but the large crews needed to pull the oars meant use of the type declined over time. It disappeared by the end of the sixteenth century. One thing the great galleys could do was to get out through the Straits of Gibraltar and so make return trips to northern Europe. On those trips, the galleys carried a second set of sails which were square, an exception to standard practice for galleys and a sign of things to come. The use of small galleys also declined. In the sixteenth century, they were already restricted to patrol and amphibious work. Their low freeboard meant they could not survive in the open Atlantic. Navy after navy in the Mediterranean abandoned galleys, among the last being that of the Kingdom of Sardinia in the late eighteenth century. The scope of galleys was increasingly circumscribed by the
success of pure sailing ships for all seafaring purposes as a result of the dramatic design changes in the years around 1400.

In the high Middle Ages, Mediterranean vessels powered exclusively by the wind had rounded hulls, were steered with side rudders, and carried lateen sails. The sail plan meant the crews were sizeable, perhaps with tons-served-per-man ratios of around 7:1. The hulls were built in a way different from northern practice. There is no question that there was a change in ship construction in the Mediterranean in the early Middle Ages which had unpredictable and massive long-run implications, but describing the construction methods has proven difficult. Terminology is not invariably precise. In addition, there were always variants and hybrids in ways of constructing ships and boats. In the north, the usual form was plank-first building where the shipwright made decisions by eye, based on his personal experience and inherited wisdom, possibly along with some rules of thumb. What emerged in the medieval Mediterranean was frame-first construction where the hull planks were nailed on to a pre-designed and built framework. It was possible to set up the lower framing first, add hull planks, and then build a next level of framing which, in turn, was closed in and so on until the hull was complete. The more common method in the medieval Mediterranean and ultimately the standard one throughout Europe, though, was to build the whole frame first and then tack on the planks. Northern ships had overlapping or clinker planking which supplied both strength and water tightness. The planks on Mediterranean ships were flush, creating a smooth hull and in fifteenth- and sixteenth-century Europe, that flat hull was called carvel. Between plank-first (clinker) and frame-first (carvel) building there were great differences in how a ship was conceived, built, the costs involved, the weight of the finished vessel, the extent of maintenance needed, the ease of doing repairs, the organization of work on the shipbuilding wharf, and, above all, in the capabilities of the ship. Frame-first building expanded the possibilities for builders and produced ships that were typically lighter, more flexible, possibly required less wood, were easier to repair but more difficult to maintain and possibly less durable. Between 1400 and 1800, the method spread from the Mediterranean to northern Europe and from there around the world.

In general, the thirteenth century was a period of contact and technical exchange between the naval traditions of the western and eastern Mediterranean, while the fourteenth century was a time of contact and technical exchange between Mediterranean and Atlantic naval traditions. The diffusion of frame-first construction was set in motion by the appearance of northern cogs in the Mediterranean as early as the thirteenth century. Once shipwrights in the south saw the efficient bulk carrier they tried to imitate it by planking the hull like a Mediterranean ship. It was the beginning of a melding of the two building traditions. The next development was to work out a sail plan for the new type. Mediterranean shipwrights added a second mast, not unusual in those waters, and put a triangular lateen sail on it. The latter increased manoeuvrability, a problem with a tubby vessel like the cog. By the end of the fourteenth century, they added another mast, at the bow, with a square sail to balance the lateen near the stern, creating the full-rigged ship. With a combination rig the crew could handle each of the three sails separately so the numbers of men on board could be kept under control and less cargo space was needed for crew supplies. That increased the range of
the vessel. The type could be scaled up or down with no loss of advantageous characteristics. It gained acceptance through the fifteenth century for a variety of chores, especially for high seas voyages, among them voyages of exploration.14

Medieval ship types with well-established credentials held on in specific trades or tasks where they excelled. The two-masted or single-masted lateen-rigged caravel with origins in a Mediterranean fishing boat proved valuable for trips by Portuguese traders to uncharted waters along the coast of Africa. Built low, it could deal effectively with contrary winds. Larger versions carrying four masts, three of which had lateen sails, would ultimately find a home in trade from Iberia to the Atlantic islands and Brazil.15 Keels held on in coasting trades and lightering as in, for example, carrying coal in England.16 Coastal fisheries throughout Europe retained proven small boats of various types.17

Full-rigged ships in various forms took on an ever-larger share of the carrying trades in the fifteenth century. The emergence of this type and its long-term success proved that experimentation with designs and building practices along with cross-fertilization could yield great dividends. Shipwrights worked on small changes, gradual advances which, over time, could yield major cumulative gains in efficiency. The sail plan of full-rigged ships is a good example. Over time it became more balanced as, instead of one very large mainsail, designers put first two and then three square sails on the fore- and mainmasts. The total canvas area increased, the size of the individual sails decreased so each was easier to handle. Captains got much greater flexibility in deploying sail. A fourth mast at the stern seemed to make sense. With a lateen sail it would also serve to balance the foremast and also improve manoeuvrability. Popular for a while, by the mid-seventeenth century the bonaventure mizzen mast and sail were abandoned as unnecessary. More and smaller sails on each of the other three masts over time produced better results.18

Another long-term trend in European shipbuilding also emerged in the course of the fifteenth and sixteenth centuries with full-rigged ships. There were signs of specialization in design. The most obvious case was caused by the introduction of gunpowder weapons on board. At first carrying largely light firearms, by the end of the fifteenth century ships were fitted with heavy cannon. On galleys, the guns went in the bows and had to be balanced. The shallow draught of the type meant a heavy cannon even tilting to one side could capsize the vessel. For galleys there was no marked change in construction other than reinforcement in the bow to carry the ordnance and keep it in place. Sailing ships had heavy guns placed in the waist amidships. Through the sixteenth century, guns became more reliable and builders got better at fitting them for effective use. The larger the complement of guns, the more powerful the fighting ship, but also the smaller the payload. The distinction between warships and cargo ships was still in train in the early seventeenth century with vessels intended to carry cargo often still carrying guns, especially those visiting dangerous waters. A trend of differentiation, though, was obvious and intensifying.19

Large carracks were the common type of full-rigged ship in the fifteenth century. They had deep waists and high castles both fore and aft. The goal was often to increase carrying capacity, the extreme case being the giant version that Portuguese yards produced for trade to India and on to East Asia. The ships were of 1,600 tons and more,
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among the largest wooden ships ever built. Often subject to problems of being built too quickly, or with improperly seasoned wood, gradually they and the East Indiamen from other countries in Europe became more reliable. The shape of the hull presented some problems for carracks, for example in crosswinds. To combat those difficulties, builders, first in Venice and then throughout Europe, experimented with borrowing hull features from galleys to make a better fighting ship out of the carrack. The end result was a different type of full-rigged ship. The galleon, as it came to be called, proved effective as a long-distance cargo carrier in the Atlantic and beyond, as well as a serviceable warship when heavily armed.20

The impressive voyages made by carracks and galleons in the sixteenth century overshadow the success of smaller types such as the boyer and the buss which builders improved as well. In the Baltic and North Seas, the two-masted boyer proved highly versatile in regional trades. It carried a number of different sails of different types: a lateen on a mizzenmast, and on the mainmast two square sails along with a sprit sail, the last in the same plane as the keel of the ship with the square piece of canvas held up by a large boom or sprit fixed to that mainmast. This was the start of increasing use of such fore-and-aft sails and not just in the north. They were already known in small boats with a crew of just one, used in rivers and waterways near the coast. The sail would make its way onto sea-going ships over time. In the fifteenth century, Low Countries shipwrights also developed new types for the fisheries. The most prominent example was the herring buss. Improved through the sixteenth century, it was made to pull long drift nets and to carry supplies of salt for preliminary treatment of the herring when brought on board. The rising scale of investment made in ships and shipping made it possible to deploy more purpose-built types for specific tasks.21

Seventeenth- and eighteenth-century innovations in European shipbuilding

Specialization in design, under way in the sixteenth century, became ever more obvious in the seventeenth century. The most prominent advance was in the development of the Dutch fluyt. It was a full-rigged ship developed in the late sixteenth century with features that made it the workhorse of bulk trades in the Baltic and North Seas and even beyond. Among other things, it had a relatively high length-to-breadth ratio. Early full-rigged ships, carracks of the fifteenth century, were 2.5 times as long as they were wide. The first fluyts went up to 4:1 and over time got even longer, possibly helped by having an extended curve to the stempost which lengthened the bow. Small vessels might have high length-to-breadth ratios but the fluyt was a sea-going cargo carrier able to handle sizeable payloads. The rigging was kept extremely simple with ropes in place so that much of the work of handling the sails could be done on deck. Crews were small relative to carrying capacity, up to around 15 tons per man.22

The width at the waterline was considerably greater than at the deck, giving the sides marked tumblehome. Originally, probably for tax reasons since toll collectors would measure the width of the ship at the deck, that hull shape proved to be an advantage in sailing and so became common on seventeenth-century vessels. The design gave a pear-shaped appearance to the stern. The basic design could be, and often was,
modified for specific trades. In the north, fluyts were lightly armed or not armed at all. For voyages to Spain and the Mediterranean they carried cannon.23

Dutch shipbuilding of the seventeenth century was a case of the incomplete adoption of a new technology. The highly successful shipwrights in the Low Countries adapted frame-first construction, disseminated from the Mediterranean, to local conditions and their own experience. They developed a unique way of building, a composite or compromise merging the old and the new. They started the lower part of the hull with plank-first construction, placing the planks end-to-end, and then extended the rest of the hull using frame-first methods. This decreased the amount of forward planning required, and allowed them to make adjustments as work went along. In the course of the seventeenth century, Dutch shipwrights went over to setting up all the frames and then adding the hull planking, following the full, long-established Mediterranean practice. In the late seventeenth century, two books appeared in the Dutch Republic describing the trade of shipbuilding. The first book, Nicolas Witsen’s of 1671, described the hybrid method of starting with the first strakes put in place before the frames, while the second, Cornelis van Yk’s of 1697, talked about putting the frames up first.24 The appearance of written works on the technology was both a sign of changes in work on wharves and of efforts to systematize the process of construction. The transition from traditional northern building to partial adoption in some kind of hybrid, and then to the full imitation of frame-first construction, might well have prevailed in other parts of Europe. Older ways of building were probably most durable with smaller boats. It was apparently true with forming planks. In the early Middle Ages, boat builders in Scandinavia split trees into eight or 16 parts and then dressed the pieces to make hull planks. In the Mediterranean, sawing was the norm for making planks as it was better suited to frame-first construction. In Scandinavia, with abundant supplies of wood, split planks, and even naturally curved pieces of wood specially selected to fit in where needed, remained common in small boats for some time.25

In the eighteenth century, the trends toward specialization in ships and systematic thinking about design increased. Advances in other vessel types reduced the scope for full-rigged ships though it still was by far the dominant type for ocean-going trades. The sailing packet became the workhorse of international commerce. Generally well below the maximum potential size of such vessels, they were typically less than 600 tons and often about half that size in, for example, transatlantic trades. Ships sailing round the Cape of Good Hope were typically larger full-rigged ships, the East Indians of the increasing number of state-supported companies in Europe arming their heavily built ships generously.26 Decoration, on the other hand, became less elaborate. While in the seventeenth century ships carried extensive carved additions on virtually all parts of the vessels, in the eighteenth prudence and cost-saving prevailed. All sorts of animals and the coats-of-arms that festooned warships were largely gone from the rising number of ever-larger and more heavily armed vessels of European navies.27 The distinction between warship and cargo ship, already clear by the late seventeenth century, led to the expansion of navies and to administrative and financial challenges for European governments. The development of reliable iron guns around 1600 meant lighter weight and lower cost of armament.28 The number of cannon
on warships increased and through the eighteenth century the battleships leading fleets into engagements relentlessly grew in size. Navies replaced the lateen sail on the mizzen mast with a fore-and-aft gaffsail, trapezoidal in shape and hanging from a relatively short yard or gaff. This change made the sail easier to handle and allowed a topsail to be put on the mast. Warships themselves became more specialized. For protection of commerce, European navies deployed relatively more, faster frigates, leaving the fighting of set-piece naval battles to bigger ships with more guns.29

Specialization in cargo ships became more pronounced in the eighteenth century. Smaller ships are generally under-represented in depictions of vessels and that is true for the late Middle Ages and on into the nineteenth century. It is harder to describe their development since less visual evidence about them survives. Better designs of various kinds of two-masters gained them an increasing role in trade in the North and Baltic Seas. They had varying types of rigs, often incorporating fore-and-aft sails which were easier to handle and so kept crew size down. Brigs were two-masted, each with a gaffsail. Snows were relatively large two-masted vessels with square sails on each mast and a small mast just behind the mainmast which carried a spritsail which, like a gaffsail, was trapezoidal and fixed to a yard in the same plane as the keel. With ketches, instead of a mainmast and foremast as with a brig, the smaller mast was fixed toward the stern of the vessel and served as a mizzenmast. Kofschepen were Dutch two-masters fitted with a mainmast rigged with squaresails and a spritsail, and a mizzenmast behind the mainmast carrying a fore-and-aft spritsail. The various types had some success on the Atlantic as well in northern European waters.30 The single-masted sloop with two fore-and-aft sails, one in front and the other behind the mast, proved fast and easy to handle. The type made considerable inroads in coastal trades in North America and, by the end of the eighteenth century, armed versions appeared in navies. In the Mediterranean, variations on two-masted vessels had long found many uses. The felucca even had a third mast added in some cases to power larger versions though, no matter the size, freeboard was low and the hull relatively long. The sails were lateens as with the xebec which also started as a two-master but, by the eighteenth century, might well have had a third mast to carry another lateen. It could have oars as well, indicating its connections to earlier variants of the galley. The polacca, a seventeenth-century design, had a third mast, fitted with square sails, and placed between two latten-rigged masts. The seemingly odd rig does indicate a flexibility and willingness to experiment among shipbuilders. Toward the end of the eighteenth century, larger vessels in the eastern Mediterranean like the polacca took on square sails, latten rig being retained on smaller vessels. The shift was in response to a sudden and rapid expansion of Greek shipping in the Ottoman Empire.31 There were various kinds of fishing boats throughout Europe, built with the specific conditions and the target species in mind, a further sign of the maturing of shipbuilding technology.

The voyages of exploration and the trade routes that followed created new problems for shipbuilders. Some, most notably the slave trade, placed a great premium on speed. That meant regular cleaning of hulls to minimize fouling. Conditions in tropical waters resulted in a threat from shipworm. Actually a mollusc, the animal bores into wood and is abundant in warmer waters in Asia and the West Indies. A
way to address both problems of speed and shipworm was to cover hulls with some
form of sheathing. It was common in the seventeenth century to add an extra set
of hull planking under the waterline and put tarred hair in between the two layers
of wood. In the early decades of the century, the Dutch East India Company even
tried a layer of lead sheathing. Problems with electrolysis, the weight of the lead, and
the cost involved caused the Company to abandon the practice by the 1620s. Both
archaeological finds and the works of writers on shipbuilding confirm that at least stem- and sternposts were still sheathed in copper in the eighteenth century. Those
valuable and heavy timbers were seen to be more vulnerable. A solution to the danger
of shipworm came in the last decades of the eighteenth century when the Dutch
and English East India Companies, and the navies of the two countries, went over to
copper sheathing of the hull below the waterline. Among the results, apparently, were
decreases in the time it took for ships to travel between Europe and ports in India
and East Asia.32

In the eighteenth century, established trends continued. Sail plans became more
divided, fore-and-aft sails came into ever wider use and studding sails, small pieces of
canvas on temporary yards fixed at the end of existing yards, appeared on ships where
speed was important. The steering wheel slowly replaced the whipstaff, a vertical
lever in use since the fifteenth century to control the tiller. There was resistance to
the steering wheel, which found acceptance for warships and large cargo carriers but
only slowly spread to smaller vessels.33 The literature on shipbuilding expanded as
more writers with credentials as scientists took up questions of best design practice. There were some rare full-scale experiments and some, very few, efforts to establish
a system of formal education for men in the profession. The use of builders’ mod-
els became common and mathematical formulae began to intrude into shipbuilders’
practice.34 While in trading companies and navies there might have been some inter-
est in putting ship design on a more scientific basis, for builders on most wharves
traditional methods sufficed.

The success of European ships led to their imitation in other parts of the world
and exposure of Europeans to designs elsewhere led builders to consider modifying
what they were doing. Though there were independent traditions which builders
followed, they were by no means cut off from what was going on elsewhere. The
dissemination of information was easy because ships travelled widely and offered
examples of options. The adoption of newly learned forms of building was slowed by
the high cost of error but, even so, shipbuilders were apparently interested in what
others did and tried out new variants based on what they learned from examining the
products of other shipyards. Between 1400 and 1800, shipping on the high seas over
long distances expanded in volume and the variety of destinations. Dominated for a
considerable time by countries along the Atlantic front, from the fifteenth century the
situation changed. In the eighteenth century, the maritime states of Britain and the
Dutch Republic still had very large merchant marines while France and the Iberian
kingdoms also continued to have considerable tonnage involved in trade. However,
new European regions joined the field. People from the Scandinavian states of Swe-
den and Denmark–Norway and, more important for the long term, Greeks, began
to supplant more established rivals. They adopted ships built in the same style and
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design, easily and comfortably borrowing from their predecessors in order to compete effectively with them.35

Warship design was subject to more varied influences than cargo ships. The competition of other naval powers created pressure on builders to imitate the success of their opponents. The geography of ports created constraints: countries with easy access to bases could build heavier, more stable, and faster ships with narrower hulls and deeper draught. Governments were buyers different to ship owners whose commercial interests shaped all decisions. Everyone, though, wanted to cut costs. Governments typically built ships in their own yards, hired the ship designers and builders and set standards, hoping to gain some level of interchangeability. Navies had establishments with fixed dimensions and armament for vessels of each class or rate. It proved extremely difficult to achieve standardization though regulations to achieve that goal did tend to stifle innovation in warships. It also proved difficult to control costs since naval procurement became so large and navies were prone, like other government departments, to corruption.36

Non-European shipbuilding, 1400–1800

Across the world, ship designs borrowed features and characteristics from the most successful of European vessels. In New World waters, European technology completely dominated. The collapse of indigenous populations, thanks to epidemic diseases brought by Europeans, and with that the collapse of social organization, left the field open for Europeans to import their maritime technology and make it the norm. On inland waterways, canoes in various forms held their own, built by local people or by immigrants from across the ocean. Relatively long boats, powered by paddles wielded by the relatively large crews, were found along rivers and in short-distance coastal voyages. For any substantial coastal carriage, naval operations, and oceanic travel, ships of European design quickly took over from traditional craft. The same was largely true in the Pacific from the eighteenth century, when European ships became more common visitors. The islanders’ rafts, which had much smaller payloads, faded in importance. Vessels built in the traditional style of the Indonesian archipelago were related to Pacific rafts and they suffered the same fate. While traditional Malaysian craft in the Indian Ocean had an extensive history of long-distance shipping, a new heavier and larger variant appeared in the course of the thirteenth and fourteenth centuries. Built of teak and equipped with two side rudders, the type still had no iron nails as was standard practice in the Indian Ocean. The hull form was sharp, the planking heavy, as much as four layers thick. Despite its size and heavy planking, European ships largely replaced the type in ocean-going trades in the seventeenth and eighteenth centuries.37 Smaller versions of Malay design remained in use in the Dutch East Indies with some cross-fertilization; Dutch shipbuilding practices it appears influencing traditional designs. If trade through Makassar on the island of Sulawesi is a reliable indicator, both local and European traders employed by the Dutch East India Company used ships of European design and of traditional Malaysian design side-by-side. There were indications that there was borrowing across sets of practices. Local designs continued to evolve with new types appearing through the eighteenth and
into the nineteenth century. The Dutch East India Company used larger vessels for trade to the island, including vessels consistent with the design of the ships that sailed from the Netherlands to the southeast Asian colony. There, local shipwrights found they could produce European-style traders as was the case in shipyards in Vietnam, India, and other parts of Asia. Over time, on Sulawesi, types with roots in Malay building traditions were supplanted. By the late eighteenth century ships were more commonly Chinese or European. Even the local type, the chialoup, which was based on a European design as the name suggests, was pushed aside by larger vessels most notably in long-distance trades. The presence of a colonial government with power to hand down rules on ship movement did have some impact on the types in use. Still, the apparent long-term success of, especially, vessels of European design throughout Asia suggests that they had certain commercial advantages in the context of prevailing circumstances.38

By the eighteenth century, builders in India were producing the pal which had all the features of contemporary European vessels and found use as both a warship and a cargo ship. Alongside those larger craft were smaller, narrower ghurābs which had low freeboard and carried a sail much like a lateen. It was a traditional Arab-Indian boat so the hybrids that borrowed from western practice did not completely eradicate existing types. Often, though, even vessels of traditional design acquired European characteristics. The dhow, probably developed in the fifteenth century, was the one- or two-masted double-ended sailing ship of the Arabian Sea. Based on Malaysian design, hulls were held together by stitching with no iron used in construction. Baghlas, the largest of dhows, had square sterns, a sternpost rudder and, in many cases, the sterns had ornamentation similar to that on Portuguese ships. By the eighteenth century in India, shipwrights often used iron nails to fasten hull planking, a change from sewn-planking which was traditional standard practice, and a sign of European influence.39 Though the Portuguese were very impressed by what they saw of ships in the Indian Ocean when they first arrived, there is little evidence that they copied characteristics of local vessels. The borrowing went more strongly in the other direction, with influence greater in the design of larger ships because in those Europeans apparently enjoyed an advantage.40

One type that withstood European design influence was the Chinese junk. The type, which dated from the early Middle Ages and had proven an efficient cargo carrier capable of operating over an extensive range, remained in use alongside full-rigged Dutch and English vessels into the twentieth century. Even European traders used junks for the South China Sea trade in the eighteenth century since the type was more than competitive. Junks proved highly versatile, effective as small river boats or high seas traders going from China to Southeast Asia, or even Africa. They could be as large as 2,000 tons with motive power coming from batten lug sails, up to seven of them on separate masts on the largest ones. The junk lacked a keel, the bow was squared, and the bottom flat. There was an axial rudder and heavy bulkheads dividing the hold into watertight sections. Methods of building junks appear to have changed little after the arrival of European ships in the sixteenth century, a fact that led to their being superseded over time.41 On inland waterways traditional narrow, relatively long vessels with flat bottoms, powered by sails or oars, continued to predominate. While
Chinese builders did little to change their junks, Europeans appear to have borrowed from the design. Leeboards were prominent on many Dutch inland craft by the late sixteenth century. The heavy pieces of lozenge-shaped wood could be lowered to simulate deeper draught and so reduce drift. With leeboards raised, the boats could still navigate shallow rivers and canals. They were probably inspired by a removable keel-like extension on Chinese ships.42

**Navigation**

The ability of European ships to make longer voyages created a need for better methods of navigation. At the same time, advances in navigation made possible different kinds of trips and so created a need for improvements in ships. Wayfinding on the water in 1400 borrowed from Greek and Roman practice and also from Chinese methods, most notably in the use of the compass, which was either developed independently in Europe or borrowed from East Asia. Knowing direction sailed and approximate measures of distance travelled, it was possible by the thirteenth century for Europeans to compile books of sailing directions. Those lists, produced in the Mediterranean, reported how to get from one port to another. Even before 1300, cartographers made graphic summaries of such data in the form of portolan charts. People on land then had visual representations of shipping routes, while sailors could literally chart a course at sea on a map. How extensively navigators used charts is not certain but in the long term they proved a valuable asset. Making portolan charts required some knowledge of mathematics, part of a general long-term trend of the infusion of science into what had been a traditional craft, learned by experience and based on simple visual observation of coastal landmarks.43 As Portuguese ships went further south along the African coast in the fifteenth century, they found that prevailing winds and currents made it easier to return home if they stood out to sea, out of sight of land, and going north until they reached the latitude of Lisbon. So navigators needed ways of measuring north–south position to know when to change course for the Portuguese capital. The height of the sun at midday was the easiest option for establishing latitude, but then sailors needed to know how the angle of the sun to the horizon changed through the year. By the late fifteenth century, longer open-ocean voyages led to consultation among scholars and the production of tables which reported relevant data about changes in the height of the sun with the seasons and over time.44 Armed with a well-made mariner’s astrolabe, a navigator could get reasonable readings and sufficient accuracy for his purposes. Charts in use had errors but with more observations they got better, as did the instruments on board.45 By the eighteenth century, sextants and octants, in use on naval and some cargo ships, provided better readings. Celestial navigation became another tool available to captains and while its use was exceptional in the late Middle Ages, it much improved over time, became common, and was even required of sailors by 1800.

For that transition, knowledge of methods needed to be disseminated and practitioners had to be trained in needed skills. From around 1500, books of sailing instructions called rutter, which gave not only compass directions but other details of how to navigate, increased in number and extent. The development of printing made easier
the production and distribution of such books, which could also include tables for establishing latitude. Trying to measure longitude remained problematic. Some of the best scientific minds of the era attacked the problem. It was an English clockmaker, John Harrison, who solved it. He made a chronometer, successfully tested at sea in 1736, that retained accuracy on board ship and so could consistently show the time at a specific location. Comparing high noon, established by finding the zenith of the sun, with what the chronometer said would produce the distance between the ship and a meridian which passed through the specific location. Until the device became standard equipment on board ships, sailors had to guess their longitude, a matter that became more pressing by the end of the fifteenth century when European ships began venturing further and further afield. The greater availability of books that taught celestial navigation was matched by a growth in the number of schools, often run by retired sailors, teaching navigation. As employers increasingly demanded sailors understood celestial navigation techniques for any career advancement, such schools became a feature of port towns in Europe. Even with better ways to establish position using sightings of heavenly bodies, many sailors continued to rely on traditional methods of simple observation of birds and seaweed and landmarks along the coast.

Cargo handling and port facilities

Also important for the increased scope of the use of sailing ships were improvements in cargo handling. Northern European ports saw the introduction of cranes in the high Middle Ages. They advanced over time from simple devices to, in some ports, large ones with complex pulley systems and power sources. Cranes were a small part of investment in harbour facilities. Places for ships to tie up increased in size. Ports moved downstream to accommodate bigger ships, to give easier access to open waters, and to take advantage of underutilized land. At many sites, wooden docks gave way to more permanent stone quays, warehouses on the docks grew in number and size, and access to the docks through streets, increasingly paved, improved. The first one-way street scheme, introduced in 1617, was to help carters negotiate their way to and from the London docks on the left bank of the Thames. Work in harbours was better organized by civic authorities often through the mediating institution of a guild or guilds of stevedores. These specialists relieved ships’ crews from having to handle cargo. Better ways of packing cargo, a result of learning by doing over time, in barrels, bales, bags, or even loose in the holds of ships, made the vessels more efficient and also eased the work of longshoremen on the docks with the task of shifting cargo.

European shipping also benefited from scale economies as volumes, especially on certain routes with specific and consistent cargoes, rose over time. The increasing quantities of goods shipped meant that costs, both at sea and in harbours, could be spread more widely and reduce expense per unit. As specific trades between known locations developed, there were sufficient rewards to warrant designing, building, and using specialized vessels. This emerged as a long-term trend first within Europe, for example between the Baltic and the Low Countries, and then in extra-European trades such as those to Africa for slaves, or to East Asia and South America for tropical
goods. Copper sheathing for tropical waters was a case of technical change in light of growing commerce. The same was true of reinforcements in the bows of ships sent to the Arctic in search of whales. The biggest gain from rising trading volumes, though, came from reducing turnaround times. Vessels often spent long periods of time inactive, tied up in the winter because of fear of bad weather or sitting in port waiting to gather a large enough cargo to make travelling worthwhile. From the high Middle Ages, the sailing season lengthened, as navigational techniques improved and as ships became more reliable. As routes became more established, captains could more accurately predict when and where they would find paying cargoes waiting for them. The gathering of goods at one site, the concentration of long-distance trade in certain ports with smaller ones acting as sources, and smaller vessels serving to marshal the goods in one hub, served the same purpose. Improvements in coastal craft and, in some cases, taxing methods of governments which preferred to have goods directed to so-called headports where it was easier to levy duties, also contributed over time to ships spending relatively more time at sea with goods in their holds during the year, always an advantage to ship owners.51

Technically improved ships were an essential feature of maritime success. Vessels became more efficient. The number of tons served per sailor rose over time as sailing ships replaced oared ones, as convoys and naval protection translated into fewer guns and crew on board, and as designers improved the rigs and rigging of their products. The rise in manning ratios between the fourteenth and nineteenth centuries was more than threefold. While there was a sailor on board for every six tons in 1400, on average the figure was one for every 18 tons, more or less, by 1800. The growth in labour productivity was the result of technical advance, more efficient organization, and capital investment in shipping and related cargo handling. The smaller crew size per unit of cargo meant vessels could travel further without stopping to resupply with food and lower overall costs which could yield higher profits for the owners of vessels or, along competitive routes, lower freight rates. The greater efficiency contributed to the overall growth in trade which, in turn, contributed to an expansion of shipping.52

Conclusion

In around 1400, shipbuilders, probably along the Atlantic coast in Iberia or south-western France, created the platform for a ship type that was more efficient and reliable than others in the world by mixing the designs and construction methods represented in the vessels they saw. The superiority of the ship-rigged, frame-first built vessel was clear in the eighteenth century. The design, like all others, evolved and improved over time. Builders did not completely abandon old methods and designs but accommodated and adjusted what they knew and gradually improved the output of their shipyards. There was always a great variety of building techniques and ship types in use, to meet specific conditions and needs. While historians and even contemporaries may try to apply strict divisions and names, implying precise characteristics to the ships that builders produced, information strongly suggests that any taxonomy of ships in the period from 1400 to 1800 is overly simple. Builders did borrow ideas and practices, learning from other shipwrights and even those they never met and
from different parts of the world. The strength of European shipbuilding, its success in supplying effective vessels for shipping, came from major innovations but also from flexibility, a willingness to experiment, and the presence of a great variety of types with different attributes available to be borrowed and exploited.

The result of technical changes in ship design, shipbuilding, and navigation over the years from 1400 to 1800 was increasing efficiency in moving goods and people, especially when those advances were combined with improvements in harbour facilities, and the packing and organization of cargoes. It is all too easy to read back the remarkable success of European shipping in the nineteenth century into earlier years. The scale in the previous four centuries was not like it would be in the era of the Industrial Revolution. After 1800, shipping was transformed by the introduction of iron for internal supports for hulls and then for building entire hulls of iron and later steel, and the introduction of steam power, first for tugboats and then for regional and finally deep-sea trading vessels. The era from 1400 to 1800 was a pre-industrial one. It was also a pre-globalization era. The volume of trade was not great enough to join economies into mutual dependence and extensive specialization in production, a pattern that emerged in the wake of industrialization. However, in the earlier era the geographical range of shipping did become global.

Better shipping technology grew out of the unique economic and political developments of the late Middle Ages. Advance grew out of the multiple strands that went into fifteenth-century European maritime technology. It would be wrong to diminish the accomplishments of shipbuilders in the ports large and small from Greece to Finland from the late fourteenth to the early nineteenth century. Theirs was no modern industrial world with massive increases in production, population, output per person, and extensive imposition of imperial power, nor were there new processes and products becoming available to supplement or replace inferior older materials. The ships they built at least did create, in part because of their design improvements, international connections on a regular basis. They were a critical and necessary contributor to a shift to Europe as the centre of global trade and to the European domination of the high seas.

Notes


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12 Adams, A Maritime Archaeology of Ships, pp. 53–90, 175–91.


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printed for T. Cadell, 1769, for eighteenth-century English definitions which are in some cases limited in scope.


42 Unger, *Dutch Shipbuilding*, pp. 54–5.


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52 Lucassen and Unger, ‘Shipping, Productivity and Economic Growth’, pp. 8–17, 23–32.

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