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7 Technology

In any industry, output depends not only on the quantity (and quality) of land, labor, and capital, but also on the techniques used to arrange and integrate factors in the production process—that is, the technology available to and chosen by the entrepreneur. A whaling agent had little control over stocks of whales, but he could choose the number and skills of the men who hunted them and the types of capital they would use, and he could choose technical alternatives from a large and evolving menu.

Section 7.1 is a brief comparison of sailing and steam vessels. Section 7.2 describes sailing vessels at the beginning of the nineteenth century. Section 7.3 treats subsequent changes in sailing vessels—both improvements that affected ships in general and those specific to whalers—including innovations in hull design, sails, rigging, and machinery and other equipment. Sections 7.4 and 7.5 describe improvements in construction techniques and in ocean cartography and hydrography. Section 7.6 describes improvements in the boats and weapons used to hunt and kill whales. Section 7.7 describes the nature and consequences of institutional change.

7.1 Sail versus Steam

It is a popular belief, and one supported by casual empiricism, that the innovation of a technique leads quickly to the replacement of an old technology by a new one.[1] That may be true of the replacement of the mechanical calculator

1. Economists who study technical change note that *quickly* doesn't mean *instantaneously.* Schumpeter ([1934] 1961) hypothesizes that it takes some time for the herd of businessmen to recognize the profit potential of the entrepreneur's innovation and copy it; this delay is at the heart of his analysis of business cycles. Conversely, Knick Harley (1973) has shown that, in the case of the North American shipbuilding industry, a competitive model characterized by some short-term barriers to exit can be used to explain the slow displacement of traditional shipbuilding techniques.

by the electronic calculator or the fountain pen by the ballpoint pen; it is not always true. Often the pressure introduced by firms that adopt a new way of doing things leads to improvements in the traditional technology that keep the old way competitive for a substantial period of time. Such was the case for sailing vessels. Far from being driven from the seas by the advent of steam, the sailing vessel reached its apogee—in technological development, numbers, and importance—more than fifty years after oceangoing steamships began to arrive regularly at Continental ports.

Robert Fulton's *Clermont,* a river steamboat, was launched in 1807. By the 1820s steam-powered vessels were crossing the English Channel and the Irish Sea. A decade later regular service was established between England and Egypt, in 1835 between England and India, and within another decade between England and the United States. In the middle of the 1840s a steamship (the British naval sloop *Driver*), after a five-year passage, succeeded in circumnavigating the globe (Taylor 1951, 58; Greenhill 1980, 17).

In these early years steamships posed no commercial threat to sailing ships. The variance in their time of passage was less, but steamers were slower and much more expensive to operate. For passengers and mail the new technology was superior; but it was not until the screw had replaced the paddle wheel, the price of iron had fallen enough to make iron vessels competitive in price with wooden ones, and, most important, the prime mover had evolved to a point where the space needed to store coal did not preempt most of the cargo capacity, that the steamship became the most effective technology among merchant vessels. The last development was particularly long-delayed. It depended both on the gradual improvement of the engine—from the one-cylinder model of the paddle wheelers, through the two-cylinder compound engines of the mid-1850s, to the three-cylinder designs of the 1880s—and on the development of relatively cheap iron or steel boilers that could withstand pressures up to sixty pounds per square inch (Greenhill 1980, 30–32).

Even then the sailing ship did not surrender easily. One chronicler asserts that "[by] 1865 the steamship was at last developed to a point at which it could successfully compete with sailing vessels . . . [and] the demise of the sailing vessel was certain," but he recognizes that "[w]hat was uncertain was how long it would take her to die" (Greenhill 1980, 30). The 1890s and 1900s saw the introduction of four- and five-masted full-rigged ships that were more than competitive on long hauls of bulk cargo—wheat from Australia, nitrate from Chile—until the opening of the Panama Canal in 1914 gave steamships an insurmountable advantage on interocean voyages.[2] The most technologically advanced sailing ship of all time—the German-built *Preussen*—was a product

2. "[A] huge, Finnish-built, four-masted barque called the *Moshulu* that—I was astonished to learn—was still hauling grain under sail from Australia to Great Britain as the Second World War approached. Apparently the invention of machines to raise and lower sails meant that vast sailing ships could be operated by a tiny crew, and that a proprietor who had . . . an 'obsessional interest in reducing running costs' could operate commercial transport vessels under sail long after the

of the twentieth century. Launched in 1902, she was steel-hulled, five-masted, more than 430 feet long, over eleven thousand tons, powered by the wind pushing sixty thousand square feet of canvas shaped into forty-seven sails, and capable of sustained speeds of nine to eleven knots. There are people who believe that vessels such as the *Preussen* would have "founded a new sailing dynasty" and sail would have remained a technology of choice for at least another half century, if shipbuilders had been willing to take some risks (Villiers 1953, 2–21; Landström 1961, 200–201).

Steam power became important to American whalemen late in the nineteenth century. Through most of its history, however, the whaling fleet consisted chiefly of sailing vessels.

7.2 The Sailing Vessel in 1800

Douglass North, noting that the last major advance in shipping technology had been the invention about 1600 of the Dutch *fluyt* (also called the flyboat), argues that the shipping productivity gains he observes in the eighteenth and nineteenth centuries must have derived from shifts in institutional technology. That is, more efficient navies meant that merchant ships did not have to be armed to ward off pirate attacks, and shipowners were at last free to innovate the more productive Dutch technology (North 1958, 537–55; 1968, 953–70). C. Knick Harley (1988, 851–76) says there were no significant productivity gains until the widespread innovation of the iron steamship in the fourth and fifth decades of the nineteenth century. The traditional technological literature casts doubt on both arguments.

The fact that the British continued to build merchantmen in the warship tradition until the middle of the eighteenth century, despite their reduced carrying capacity, supports North's hypothesis (Goldenberg 1976, 4, 80). The body of traditional evidence leads to a quite different conclusion. In his seminal study of the British shipbuilding industry, Ralph Davis (1962, 71) finds a more than 50 percent increase in average tonnage per crewman on merchant ships entering London between 1686 and 1766. He concludes that this increase in efficiency occurred because of a major, but unknown, development in merchant ship design. For Alan McGowan (1980, 24, 30–31), "[I]t is inconceivable that any such development could have occurred without its having left a single trace" in the historical record—apart, that is, from its effect on productivity.

McGowan (1980, 24) offers an alternative set of explanations. With North he recognizes that for bulk cargoes the amount of accessible hold storage is crucial, concluding, "[T]he fine lines which gave warships the necessary handiness and weatherly qualities, produced awkward spaces which not only made stowage difficult but also reduced the volume of space available." He does

sort of activities popularly associated with sailing were afternoon outings in the harbor or charters in the Caribbean" (Trillin 1994, 71–72).

not believe that the improvements in productivity observed by Davis were due importantly to better hull design. Either naval architects continued to use warship hulls during this period, or the impact of the shift to more effective hulls was less significant than North had supposed. Hull *size* was a factor in productivity improvement, however, according to McGowan. The average size of merchantmen increased between 1685 and 1766, and labor productivity rose markedly with hull size.

Finally, McGowan (1980, 31, 33–34) believes there were two major technical advances in the eighteenth century that significantly improved per-man productivity: the replacement of the relieving tackles and the whipstaff by the steering wheel, and the substitution of fore-and-aft jib sails for the square spritsail and the spritsail topsail. Square sails produced immense power and imparted considerable leverage on the bow, but they could not be fine tuned, and they required more manpower than did the jibs. In the case of the wheel, not only were fewer men required to steer, but also the helmsman could steer within much narrower limits. Both innovations reduced the total labor requirement and, taken together, permitted the vessel to sail much closer to the wind. One result was more speed; perhaps more important was a reduction in the size of the crew, or an increase in the size of the vessel that could be handled by a crew of a given size.

Sail plans dominated by fore-and-aft rigging had been known since at least the seventeenth century, and builders recognized that they had three significant advantages over square sails: (1) they could propel the vessel even when the wind was a few degrees forward of the beam; (2) they could be set without sending men aloft, which meant that, as long as it was small, the fore-and-aft vessel required fewer and less skilled hands; and (3) they were "much more effective . . . in light winds unless the wind was right astern. The chief advantage gained by the increasing of fore-and-aft sails in combination with square sails therefore, was the ability to sail closer to the wind" (McGowan 1980, 36). There may have been some minor savings in labor as well.

In 1800 there were still at least two disadvantages to the new rigging style: (1) in heavy wind and sea the vessel could be overturned by the weight of the boom and sails; (2) raising the large lateen sail called for extra labor. For a vessel of more than one hundred tons, the potential gains from not having to go aloft and from the labor savings of increased hull size were more than negated by the additional number of men needed to raise and furl the heavy sail. The widespread innovation of fore-and-aft rigs in large oceangoing vessels had to await improvements in hand-operated winches and, for very large vessels, the development of the donkey engine to provide mechanical power (McGowan 1980, 36).

Yet another factor contributed to the level of "standard" as opposed to "best practice" technology at the beginning of the nineteenth century: the definition of a *register ton.* In 1773 the British government adopted a uniform measure of cargo capacity on which to base all tonnage taxes, pilotage fees, light duties, port tariffs, and other vessel-related charges (13 Geo. III c. 74). A similar rule was adopted in U.S. legislation of 1789, 1790, and 1799 (see chapter 3). If the measure had actually reflected the carrying capacity of a vessel, it is unlikely that it would have had an effect on ship design or performance; but it did not. For some reason, perhaps simplicity—the measurements could be taken and the calculations made by people with little education—the index chosen by Parliament assumed that the depth of a vessel could be proxied by one-half its breadth. The law encouraged builders to ignore established principles of design and to construct ships that were "deep, sluggish, flat-bottomed, flat-sided . . . [and] 'built by the mile and served out by the yard'" (Graham 1956, 78). In the words of the shipbuilder Lauchlan McKay, the author of the first American textbook on naval architecture, "according to our present law, like that of the English, you can build a double-decked vessel a mile high, and she will not measure one ton more than though she were but 20 feet."[3]

Not surprisingly, the law produced generations of "rule-cheaters" (Goldenberg 1976, 4). That a technical bias was incorporated in the capital stock is clear from the designs of warships. Not subject to taxes and pilotage fees, they were free of the design faults that plagued merchant vessels.[4] "[C]ommercial competition forced owners to order unwholesome [but, in one sense, cost-effective] designs" (Hutchins 1941, 217).

Sailing vessels that entered the American whaling fleet at the end of the War of 1812 were products both of existing technical conditions and of legal constraints. They required constant attention. Because they leaked, they had to be pumped regularly. To slow the leakage, the oakum caulking had to be continuously renewed. Decks had to be regularly soaked in seawater, to prevent the planks from drying out; otherwise, fresh water could leak into the vessel during rains and promote rot.

"All the ropes in the running rigging had to be tended, their ends had to be kept from fraying out . . . splices . . . had to be renewed, whole ropes had to be replaced. Blocks had to be oiled . . . . Spars had to be watched for shakes and for rot . . . . The ironwork itself had to be chipped and painted, and in particular the bolts which held it to the spars had to be watched for corrosion and for rot in the adjoining wood" (Greenhill 1980, 8–9). Since even a small vessel could have three to four hundred blocks, several miles of rope, and more than a mile of caulking, the work was not trivial. Maintenance routines dictated that masts and spars be unshipped and lowered to the deck, and that entire sections of masts be unrigged.

Given the demands on them in open seas and calm weather, to say nothing of those in foul weather and heavy seas, it was necessary that the crew be well trained. Some crewman had to be able to repair and forge new ironwork, make

3. As quoted in Hutchins 1941, 217. Lauchlan McKay was the brother of Donald McKay, a well-known ship designer; his textbook was *The Practical Ship-builder* (1839). See Chapelle 1967, 7.

4. That is, warships were well designed for their purposes, but warship designs did not make good merchant vessels. See North 1968; Goldenberg 1976, 80.

sails, manufacture new masts and spars from the timber carried on board. Even the lowliest seamen had to be able to work aloft in weather both fair and foul—handling the sails in normal conditions, and clearing away and replacing damaged spars and rigging during storms (Greenhill 1980, 8–9).

7.3 Nineteenth-Century Changes in Vessels

Maritime historians long believed that there was little improvement in the design of sailing vessels over the nineteenth century in general, and in the years before 1850 in particular. More recent work has shown that there were significant improvements before that date and major ones thereafter (Chapelle 1967, 279). American sailing ships benefitted from advances in the theory of vessel design, from the contributions of a number of extraordinary shipbuilders—such as Donald McKay, William Webb, John W. Griffiths, and Samuel Hartt Pook—and from the removal of legal constraints that had perverted vessel designs.

The legal change came first in England. In 1836 the government, in an attempt to reduce tax evasion and increase revenues, directed that a new formula be employed to calculate register tonnage (5 and 6 Wm. IV c. 56; Graham 1956, 78). The law did not require that existing ships be remeasured, and as a result, although vessel lengths increased somewhat, major changes were delayed. Until a much more stringent admeasurement law came into effect in 1855, it paid to buy an old vessel rather than to build a new one.[5] Even then it took time before newly constructed, rather than newly remeasured, vessels made up the bulk of the merchant fleet.

In the United States the legal change came even later. The fiscal stringency engendered by the Civil War led to the passage of a law, similar to the British law of 1855, which came into effect in 1865 (see chapter 3). Greenhill (1980, 12, 19, 22) argues that Americans were willing to build well-designed, fast vessels even before the U.S. admeasurement law was modernized. Their willingness may have been a consequence of experience. The Americans had a tradition of fast sailing hulls, a tradition formed during the disputes with England of the late eighteenth and early nineteenth centuries. Merchantmen were built to elude British men-of-war. In contrast, during the Napoleonic wars, the British had become accustomed to the slow speed of navy convoys. The difference in behavior also reflected the different types of trade in which the two fleets were engaged.

In Great Britain the most important component of ocean commerce was the transport of bulk commodities over short hauls, an activity in which there was no premium on speed. In America a small but profitable proportion of ocean commerce was directed toward long-distance trade with the West Coast and

5. The 1855 law (17 and 18 Vict. c. 104) required that registered tonnage be based "on the actual and rigorously investigated cubic capacity of the hull" (Graham 1956, 79).

the Orient (Greenhill 1980, 22). "In long-distant [*sic*] trades like tea, where speed was the prime consideration, inept tonnage laws did not necessarily destroy the profit-making capacities of the streamlined vessel with her fine entrance, shallower hull and long, clean run. In the California and China trades time meant money, and in the 1850s the great new American clippers made astonishing records for speed" (Graham 1956, 79). In fact, during that decade "the great urge for speed caused builders to ignore completely consideration of the admeasurement rule," at least on some occasions (Hutchins 1941, 295). Both the fastest twenty-four-hour run (465 miles on 12 December 1854) and the highest speed ever recorded by a sailing ship (twenty-one knots on 18 June 1856) occurred during the 1850s (Cutler 1951, 12, 17). Still, the typical American merchant ship of the 1830s and 1840s was long, narrow, and deep. The midships section was rectangular, the ends were short and full, and the ship did not sail well. The last remaining example of this "congressionally" designed model is the whaler *Charles W. Morgan,* resting in the whaling museum in Mystic, Connecticut.[6]

In the late seventeenth century, British and American shipbuilders began to use models in designing and constructing vessels. These models represented one-half of the hull (as though a complete model were split from the center of the bow to the center of the stern). Initially they were carved from solid blocks of wood. At the end of the eighteenth century the *lift* model came into use; the hull was carved from layers of wood, which were then held together by dowels. Such a model could be disassembled in order to measure the crucial relationships among the various parts of the hull in construction.[7] The technique was still atheoretical, but it was a substantial improvement over earlier methods, and the lift model remained a design tool through the 1840s.

In the next decade, following the lead of John W. Griffiths, designers began to work with plans based on mathematical analysis of the important features of the vessel. As early as 1844 Griffiths stressed the mathematical underpinnings of design, and by 1852 he recognized the value of sets of plans. His magazine became the industry's single most important technical reference manual.[8]

The development of the design of sailing ships involved three principal elements: cargo capacity, a function of both shape and size; speed, "a function of . . . length on the waterline"; and operating costs, a function of crew size—again in part a function of vessel size (Greenhill 1980, 20; McGowan 1980,

6. Greenhill 1980, 19. Bad design or not, the *Charles W. Morgan*—which was built expressly for whaling, not for mercantile activities—served eighty exceptionally successful years in the whale fleet and retired (in 1921) only when American whaling had effectively come to a close.

7. La Grange 1936, 332. "Plane up as many pieces as you have water lines as long and wide as the draft requires. These should be of different colored wood, as they will show the lines more distinctly" (Boole 1858, 12).

8. Griffiths 1844, 6; Chapelle 1967, 364. Griffiths's magazine was first called the *U.S. Nautical Magazine and Naval Journal* (1853–55) and then the *Monthly Nautical Magazine and Quarterly Review* (1855–57).

24). Designers of vessels for specific trades often sacrificed one or two of these characteristics in order to achieve outstanding performance on the remaining (as in the case of the China clipper—speedy, but with poor cargo capacity and high operating costs), but they took account of all three, equally, when they designed unspecialized vessels. Square riggers met these requirements in the 1850s and 1860s (Greenhill 1980, 22). By the late 1840s American shipbuilders were regarded as world leaders in the design and construction of general-duty wooden sailing vessels (Hutchins 1941, 302). It may not be true that the object of American designers "was to build a ship that should sail every other craft off the seas and so obtain the maximum of trade-carrying," but their innovations placed British builders under severe competitive pressure; "between the years 1841 and 1847, no fewer than forty shipbuilders went bankrupt in Sunderland alone (Chatterton 1909, 266).

Vessels became longer relative to their breadth and depth. The design of the stern was modified so that, instead of "squatting and holding the dead water, the ship slid through it cleanly with a minimum of resistance" (Chatterton 1909, 266). Cargo ships were built with "flat floors and hard bilges . . . . They also had fairly sharp, though convex, bowlines instead of the bulging, rounded sections which were formerly common. Considerable length was given to the full-bodied portion of the vessel amidships." The new vessel not only had a streamlined rather than a dumpy appearance but was a better sailer.[9]

Of all the nineteenth-century innovations the clipper ship has received by far the most publicity, even though its importance in the evolution of vessel design is debatable. Some maritime historians, such as Chatterton (1909, 266), believe that "the part played by the American clippers . . . is one of vast importance to the development of the sailing ship of any size." Others, including Howard Chapelle ([1935] 1982, 286), think that "[t]he importance of the clipper-ship model was small, as far as later ship-design was concerned." The number of clippers was always small relative to the total merchant fleet. An assessment of its long-run importance rests on its contributions to the design of the *medium* (or California or Australian) clipper—a vessel that was important in both the merchant marine and the whaling fleet. Few historians question the conclusion that the most significant innovation in sailing-ship design during the first seventy years of the nineteenth century was the medium clipper.[10]

9. Hutchins 1941, 292–93. The bilge is the part of the underwater body of a vessel lying between the flat of the bottom and the straight vertical topsides. Specifically it is the point of greatest curvature. The term *hard* refers to the angle of that point: the sharper the angle the harder the bilge. Thus a hard-bilged vessel has a relatively flat bottom.

10. Donald McKay's maritime biographer goes so far as to call McKay "the originator of the 'Medium' clipper model, afterwards universally used by American shipbuilders" (McKay 1928, 293). Even Chapelle ([1935] 1982, 286–87), although arguing that the medium clippers were merely larger and better built "revivals of the last and sharpest of the packet-ship models," recognizes that many of their fittings both "on deck and aloft had been developed in the clippers."

From the point of view of this survey, the origins of the vessel are irrelevant. Nor does it matter whether the medium clipper was the product of a gradual evolution or of a sudden revolution in naval architecture. Only the design is important. McKay's *Commodore Perry* and *Japan,* buoyant, steady, and with shallow draft, epitomized the small clippers of the mid-1850s. They were elongated, pointed in the bow, narrow in the stern, very fast, and capable in heavy seas (McKay 1928, 293; Hutchins 1941, 295). The virtues of the design were not immediately understood on all hands:

> You are aware that she [the *Lightning*] was so sharp and concave forward that one of her stupid captains who did not comprehend the principle upon which she was built, persuaded the owners to fill in the hollows of her bows. They did so, and according to their British bluff notions, she was not only better for the addition, but would sail faster, and wrote me to that effect. Well, the next passage to Melbourne, Australia, she washed the encumbrance away on one side, and when she returned to Liverpool, the other side was also cleared away. Since then she has been running as I modelled her. (Donald McKay, quoted in McKay 1928, 266–67)

Designers of general merchant vessels did not copy the clipper in every detail, but they did move in McKay's general direction (Greenhill 1980, 26).

By the late 1860s the grain trade between Pacific coast ports and Europe by way of Cape Horn had become important, and by the 1870s the center of American shipbuilding had shifted from Connecticut and Massachusetts to Maine. The product of the resulting interaction between the demand for an efficient carrier of bulk commodities over long distances and a new set of ship designers was the *down-easter,* a vessel that represented "the highest development of the sailing-ship; combining speed, handiness, cargo-capacity and low operating costs to a degree never obtained in any earlier square-rigger." Down-easters had medium sharp lines. They had fewer spars, and carried less canvas, than clippers, but they still "had enough sail area to drive them at great speed" (Chapelle [1935] 1982, 287; Hutchins 1941, 373–83; and see Lubbock 1929).

The whaling fleet was initially affected by these design changes indirectly. Many whalers were simply refitted merchantmen, so changes in the merchant fleet eventually led to changes in the whaling fleet (Morison 1961, 318). Of the 680 ships and barks in the New Bedford fleet whose origins are known, 419—more than 60 percent—transferred from the merchant service (see table 6.6), leaving about 40 percent built for whaling. Improvements in the design of these vessels—most built late in the period of American whaling—influenced the fleet directly. In an earlier era, when the industry was expanding rapidly, almost any vessel could be shifted from the merchant marine to the whaling fleet, and its owners could expect handsome (if highly variable) profits. By the early 1860s, circumstances had changed. As the writer of the annual review of the whale fishery noted in his survey of the year 1862 (*WSL* 13 January 1863),

> Other grounds for congratulation are these; viz: the greater number of suitable vessels that have this last year been fitted for the fishery, compared with those that have been fitted during the last few years; the growing determination in the minds of merchants not to introduce into service any more such expensive vessels as new clippers, and bulky ships that were never meant for whalers, but introduce vessels of proper size, and only such as may be built expressly for the business, and that can sail at a comparatively low figure.

The new additions were concentrated in the 1850s and 1870s. In the 1850s almost one-half the vessels that entered the New Bedford whaling fleet were built to order, in the 1870s exactly one-half. In the 1880s, with New Bedford whaling contracting, only sixteen vessels joined the fleet; twelve were built for whaling. New whalers were designed along the lines of the medium clipper, "with somewhat less beam and finer underwater lines than vessels intended for the merchant service generally .... [They] were built with raking stems and even sharper lines than the usual whalers" (Bathe 1967, 205). Unlike the clippers a significant proportion—and after 1855 the majority—of these new vessels were bark rigged. They were "sharp-floored and easy-bilged to make them roll down when 'cutting-out' a whale" (Chapelle [1935] 1982, 288).

In 1851 the New Bedford trade paper, *The Whalemen's Shipping List and Merchants' Transcript* (9 December), first reported the launching of a clipper ship, the *Jireh Perry*, that was specifically designed (by Currier and Townsend) for the sperm-whale fishery. By the next fall, "clipper" or "medium clipper" had become common in the paper's descriptions of new entrants (5 October 1852). In August alone the *WSL* (3, 24, 31 August) noted the addition of the *Gay Head* (389 tons, designed by Wilson Barstow with "fine proportions, and general adaptation for the whaling business"), the *Polar Star* (a medium clipper of 465 tons, with "ends . . . finely formed, being neither a clipper nor a full ship, but midway between the two"), the *Rainbow* (475 tons, designed by Reuben Fish; "[h]er ends are long and very sharp," and "[she is] modelled with particular reference to speed"), and J. and Z. Hillman's 400-ton *James Arnold* ("designed, modeled, and built . . . to combine the qualities of an easy sea-boat with those of a good carrier and fast sailer"). These vessels all were speedier than traditional whalers; equally important, all were designed to carry between three thousand and thirty-five hundred barrels of oil.

In the 1870s again there was an increase in the number of newly built vessels joining the whaling fleet. Echoing its comments of more than a decade earlier, the *WSL* reported in 1876 (11 January), "Some vessels may possibly be added to the fleet from the merchant service; but as such ventures are attended with so heavy an outlay for repairs, alterations and whaling inventories, it is not probable that many such additions will be made." The next year (16 January 1877), it again noted the economic attractiveness of the new designs: "The building of ships for the whaling service marks a new era in the business, and is an encouraging feature." In 1878 (15 January) the effects can be seen even more clearly: "Ship-building has revived, and twelve whalers were built during the year, it being now apparent that at the present prices new vessels can be built cheaper than merchantmen can be altered into whaleships." It should be noted that the new vessels were added at a time when, because of increased competition from iron and steam, the price of used wooden sailing vessels was falling, and when the size of the whaling fleet was rapidly contracting, as many of its vessels were converted into merchantmen.

One change (it is not clear whether it should be called a design or a rigging change) affected the whaling fleet far more than it did the merchant marine. That technical breakthrough was the innovation of the bark—square rigged on the fore- and mainmasts and fore-and-aft rigged on the mizzenmast. Improved winches and lighter canvas had made it possible to handle the lateen sail on vessels of more than one hundred tons, but it still could not be handled easily. In the merchant marine, where vessels in the twelve-hundred- to two-thousand-ton range were common, economy absolutely dictated that the widespread introduction of the massive sails await the innovation of the steam-driven donkey engine to provide power to raise and lower them.

Whalers were not exempt from this manpower constraint; barks continued to require more men than ships of similar capacity. In the decade 1866–75, for example, the average burden of a New Bedford whaling ship was 11.9 tons per man and that of a bark 10.4—a difference of 14 percent. For whalers, however, the constraint was not a noose. They were in the three- to four-hundred-ton range, and the demands of whaling always required that they carry more men than merchantmen of similar size, regardless of rig. The extra costs associated with the mixed-rig plan, although not trivial, were not so high that the configuration could not be employed when the design had compensating advantages. The bark did.

First, it could move nimbly among the ice floes of the Arctic, and escape when the ocean froze at the end of the hunting season. (Twice the Arctic fleet was caught and crushed because the ocean froze so rapidly.) Second, the bark was more easily handled by the few men left aboard when the whaleboats were manned and most of the crew had joined the hunt. Since the mizzen was normally already raised, the shipkeepers did not have to raise it while the hunt was on. Third, and least important, the rig structure gave more clearance for the operation of the two boats near the stern. Thus, while barks joining the fleet in the 1840s were less than one-fifth as numerous as ships, technical changes in winches and canvas combined with the opening of the Arctic ground to make them dominant by the 1860s. At the end of the century, the shift to the new technology was complete; no whaling ship entered the New Bedford fleet after 1877. (See table 6.6.)

Between the 1820s and the early 1870s there was a nearly total technical transformation aloft. Screw- and lever-operated rod rigging and turnbuckles, iron-strapped blocks, and ironwork for masts and spars were introduced in the 1820s and 1830s (Chapelle 1967, 279). During the 1840s the sails themselves changed both in material and in design. Largely because New England had become its most efficient producer, Americans began to substitute light, pure-cotton canvas for flax and hemp in sails (Chatterton 1909, 266). The canvas was durable, but sails made from it had to be very well cut and set to operate efficiently. It was gradually recognized that sails "set like large white bags, big-bellied, flapping tent-like things . . . were altogether crude and inefficient." In order to allow the vessel to work close to the wind, sails were kept as flat as possible (Villiers 1953, 14). As McKay showed in the *Daniel Webster,* a diamond packet built in 1850, vessels with flat-set cotton canvas and new bracing on their yards could "head a point higher than other ships" (McKay 1928, 93).

In the 1820s the typical ship had four sails on each of its three masts—from bottom to top, first, a foresail, mainsail, or mizzen (depending on the mast), then a topsail, then a topgallant, and finally a royal. A bark had a similar configuration on its fore- and mainmasts. Dealing with single topsails and topgallants had always required substantial amounts of skilled labor. As vessels grew larger, so did these sails; as they became larger, they became more difficult to set and take in, and work aloft became more dangerous. Double sails, each smaller than an unwieldy single sail, were introduced to solve this problem (Greenhill 1980, 28). "A ship rigged with this rig was more seaworthy, because she was always considered as under close-reefed topsails, and could be worked by fewer men than a vessel of the same size, having the old rig." Since split sails did not require buntlines, reef tackles, or clew lines, the canvas was not chafed, and lasted much longer (McKay 1928, 250–51, 284–85). The innovation proved cost-effective and spread quickly. Donald McKay, for example, first used the double topsail rigging within months of its invention, and from then on employed it on every vessel he designed.

Because of the adverse effects of the tariff—particularly after the rate increases of 1861 and 1864—American builders lagged behind the British in replacing hemp with iron. Still, as the price of iron fell, chain cables and iron (later steel) wire came into more general use for standing rigging and for some running rigging. Iron rods were used to connect the topmast rigging to the lower mast, iron trusses, to attach the yardarms to the masts. The new fittings required much less maintenance; taken together with the quality of the shore-based riggers' craftsmanship, this meant there was less work (and much less skilled work) to be done aloft. Moreover, the vessel handled more easily, particularly in sailing to windward.[11]

In an attempt to eke out the last fraction of a knot in light winds, designers of clippers added studding sails and kites.[12] The former, rigged from temporary

11. Hutchins 1941, 298, 382–83; McKay 1928, 214–15; Chapelle [1935] 1982, 290. The duties on the ironwork for a one-thousand-ton vessel rose from 2 percent of its total cost in the 1850s to 10 to 12 percent in the next decade. Running rigging is used primarily in setting, furling, and otherwise handling sails, and it usually runs through blocks and pulleys. Standing rigging is permanent (stays and shrouds, for example) and is used to secure masts and fixed spars.

12. Kites were the lightest and usually the loftiest sails (skysails and spinnakers, for example) and were ordinarily set only in very light breezes. They were sometimes called flying kites.

booms attached to the yards, were lateral extensions of the topsails and topgallants. They provided some additional speed, but the benefits were not worth the maintenance costs, except where speed was of overwhelming importance. Kites were the skysails and moonrakers set above the royal. They may have been "a delight to the more bombastic masters and a source of wonder to the passengers"; they were a "curse to the crews." Their contribution to speed in light winds was marginal at best, and there were substantial extra costs even in furling and setting them, not to mention those of maintenance. Both studding sails and kites disappeared in the 1860s (Hutchins 1941, 381–82; Villiers 1953, 110–13).

Technical changes in the machinery and equipment used on sailing vessels were also substantial. Between 1820 and the mid-1840s a number of new deck machines were developed. They included "geared windlasses, crabs and capstans, steering gear, improved pumps, cargo and rigging winches, ventilators, patented rigs, improved blocks, cranes, jeers, and other mast and spar ironwork, such as turnbuckles, or 'rigging screws.'"[13] Below deck, life was improved by new marine stoves and water closets. McKay's 1850-built *Staghound* had a cylindrical cast-iron tank that could hold forty-five hundred gallons of fresh water (Chapelle 1967, 419; McKay 1928, 124–25). Iron chain replaced hemp in the ground tackle that linked the vessel with its anchor.

No invention was more important than the modernized windlass. Before the 1850s the windlass was turned by the main force of men, pushing on handspikes. The handspikes afforded little leverage, and raising the anchor was extremely difficult. In the 1850s a new windlass, much more powerful and easily managed, was introduced. Men were still the source of power, but now they had efficient leverage. "It was no child's play, in old times, to handle a ship's ground tackling. To 'overhaul a range of cable' in cold weather, was a forenoon's job; now it is done in a few minutes. To heave it in of a cold day; and stow it away in the cable tier, was positively the very worst work a crew could do. Now, a few minutes at the new-fashioned windlass and the anchor is apeak, and the cable let run into the chain boxes without delay" (McKay 1928, 213). The new windlass was used on small vessels until the ultimate demise of wind-driven ocean transport; on large vessels it was replaced in the 1880s by the steam-driven donkey engine (McKay 1928, 214; Greenhill 1980, 28). The same technology could be, and was, used to raise, set, and furl the sails, which made the bark rig economically feasible.

The more complicated and effective gearing mechanisms also were applied to the steering apparatus; patents were issued to cover a variety of new designs. For example, in reporting the addition of new clippers to the whaling fleet in 1852, the *WSL* (5 October 1852) noted, "All of them, except the James Arnold, are supplied with Reed's patent Ship Steerer, which is considered by our mer-

13. Chapelle 1967, 364–65. See also Greenhill 1980, 28. Jeers are combinations of tackles used for hoisting or lowering the lower yards.

chants and builders the best of the various substitutes for the wheel and tiller." One man could steer a vessel and keep it within a point or two of its course (McKay 1928, 215).

In the 1850s new pumps also reduced the number of men needed to handle a sailing ship. Almost every vessel more than a year or two old had to be pumped several times a day, at a cost of many man-hours. The new copper pumps were still hand-powered but, utilizing both winches and flywheels, they were faster, operated with fewer men, and could serve other purposes as well. In 1852 the *WSL* (16 November) reported on the advantages of one of the more recent inventions, the Flanders' Patent Suction and Forcing Pump: "[F]or whale ships the Forcing Pump must be invaluable. The wetting of the hold for the purpose of preventing the leakage of oil will be accomplished by this pump with the utmost facility. Its introduction into our whalers would certainly promote this practice of wetting hold. With slight power Flander's [*sic*] pump may be used to throw water to a great height, thereby acting as an efficient fire engine."

The introduction of the steam engine was the last of the major nineteenth-century advances in machinery and equipment, but it had little impact on the whaling fleet. McKay's *Great Republic* (1853) employed a fifteen-horsepower steam engine in a multiple capacity. It was used to hoist the anchor, raise the sails, and pump the ship; but the "Steam Tar" could also be offloaded into a small boat and used as an engine to drive the boat and to tow the clipper in periods of calm (McKay 1928, 233–34). It was not until the late 1870s that donkey engines were employed more than occasionally, and then it was the four-masters that were the major beneficiaries (Greenhill 1980, 39).

Techniques for removing and processing blubber and bone changed little. When a whale was killed, it was either marked by a waif buoy for later recovery or towed straightaway to the vessel. There it was brought to the starboard side and secured, tail forward.[14] A *cutting stage* was rigged at the level of the deck. Initially this was simply a narrow board, swung out on ropes on the seaward side of the whale. A mate stood on this pitching platform and, using various slicing implements (spades) attached to twenty-foot handles, dismembered the whale. The process varied from one type of whale to another, but in each case either the head was taken off—to obtain the head oil (from sperm whales)—or the upper jaw was detached for the whalebone (in the case of baleens), and the blubber was then removed. The mate needed excellent sea legs if he was not to be pitched into the sea and the teeth of the sharks that normally swarmed around the whale.[15] The job also took great skill. The cutter-in wanted to detach

14. Hohman 1928, 167. Except where otherwise indicated, the following material is drawn from Lytle 1984, 136–65.

15. In *Moby-Dick* Tashtego falls into the decapitated head of a sperm whale: "Whether it was that Tashtego, that wild Indian, was so heedless and reckless as to let go for a moment his one-handed hold on the great cabled tackles suspending the head; or whether the place where he stood was so treacherous and oozy; or whether the Evil One himself would have it to fall out so, without

all of the blubber, so that no oil would be lost, but he also wanted to minimize the amount of flesh taken. Flesh in the trypot meant a lower quality of oil. The only change in technique was that the cutting stage was eventually made more secure. It became "an eighteen inch wide plank about twenty feet long braced out from the side of the vessel by boards about ten feet long, either tied or bolted to the ends of the stage" (Lytle 1984, 136–37).

The mate began by cutting a strip in the skin and blubber of the whale. He then opened a hole at the beginning of the strip and inserted a hook on a chain attached to the winch. The winch was turned, the vessel heeled over, the strip (called a *blanket strip*) disengaged from the whale, and the carcass turned slowly in the sea. Periodically the winch was stopped and a new hole was cut in the blanket and secured by a hook. Another mate, wielding a double-edged sword called a *boarding knife*, then cut across the strip above the new hole, and the severed blanket was brought aboard and lowered into the blubber room. There the blanket strip was divided into *horse pieces*, roughly eighteen inches long and six inches wide (Scammon [1874] 1968, 238). Whatever flesh remained was removed by seamen using long *leaning knives*. The horse pieces were *minced*—that is, many parallel cuts were made in the blubber, but not in the skin—to facilitate trying out. Mincing called for a long, two-handled knife. Efforts to mechanize the process began in the 1820s; despite a number of inventions, no cost-effective machine was produced. Hand mincing continued to the end of American whaling.

The minced horse pieces were thrown onto the deck and thence, by seamen using long-handled forks called *blubber hooks*, into the try-pot. The try-pot, a large, cast-iron pot set in a brick tryworks, was fueled by whaleskin and other scraps left over from the trying-out process. The boiling oil was periodically skimmed for scraps, which were thrown into the fire. The oil itself was taken from the pot by means of a long-handled iron or copper bailer and placed in a copper cooling tank, from which it was removed to a holding tank. Oil casks were filled from this tank and stored in the hold.

The head oil from sperm whales could be bailed directly into casks. No processing was required. The heads of baleens were brought to the deck, where men with spades cut off the blubber and men with spades and axes removed the baleen.

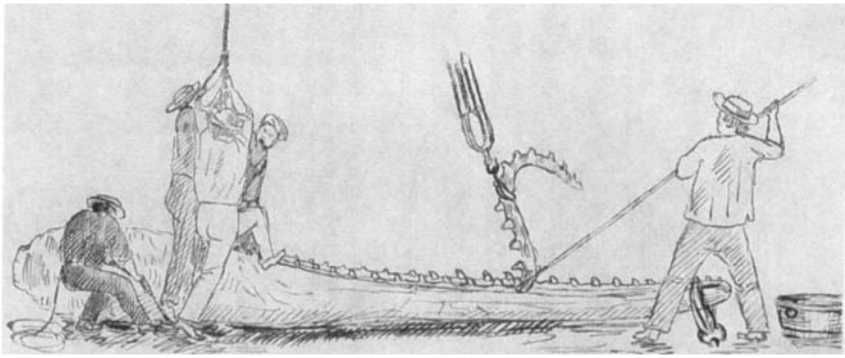
It will be obvious that the tasks of cutting in a whale and trying out the blubber were arduous, dangerous, and time-consuming. Efforts were made to shorten the process, lessen the required labor, and improve safety; but no important innovations resulted. Lytle (1984, 149) devotes more than a page to Hunter's slicing machine, ending with the sentence: "There is no record of

stating his particular reasons; how it was exactly, there is no telling now; but, on a sudden, as the eightieth or ninetieth bucket came suckingly up—my God! poor Tashtego—like the twin reciprocating bucket in a veritable well, dropped head-foremost down into this great Tun of Heidelburgh, and with a horrible oily gurgling, went clean out of sight!" Queequeg delivers him by cesarean section, conducted with a boarding-sword. (Melville [1851] 1983, 351–52).

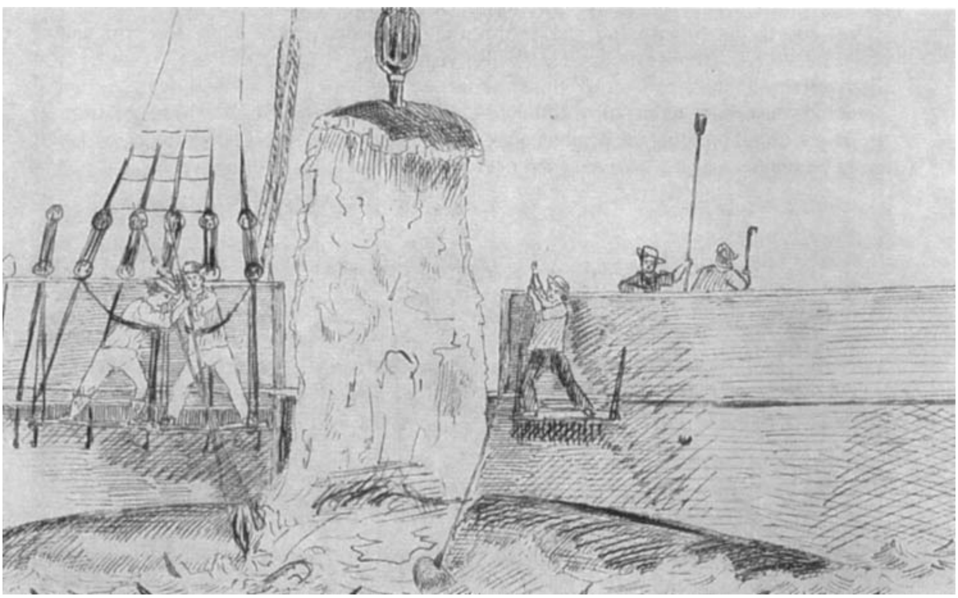
Bailing the case. This drawing and the next four come from the journal of an anonymous crewman aboard the whaling bark *Clara Bell* of Mattapoisett, Massachusetts, in the 1850s. They were first reproduced to illustrate Haley 1948.

The *case* is the upper part of the head of the sperm whale; case oil is very pure and could be stored without processing. It's also very slippery, as one of these crewmen is discovering: "[T]he clear, snow-white spermaceti [is] bailed or scooped out; the men plunging waist-deep in the pulpy, cellular ooze" (Church 1938, 36). Oil was bailed from the case without bringing the head on deck when the whale was very large; the crewman stood on the head as it was suspended over the sea from the side of the vessel.

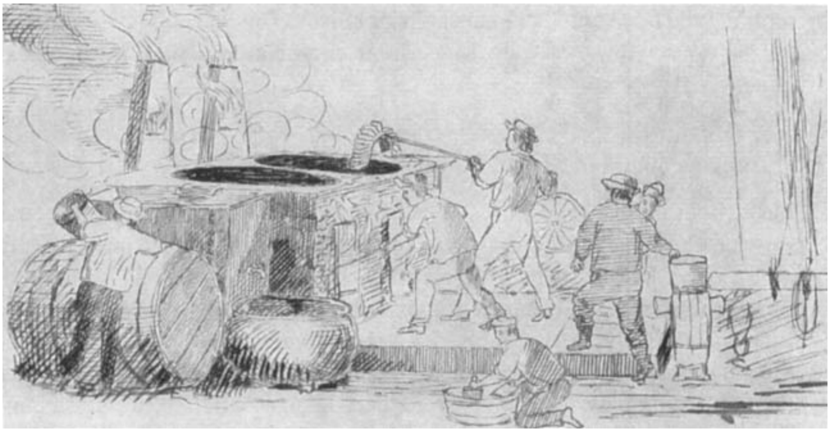
Cutting up the junk. The *junk* is the central section of the head of the sperm whale. The oil it contains had to be extracted by trying out. These men are cutting the junk into pieces small enough to fit in the try-pots, using *spades*.



Stripping ivory. The *ivory* is the sperm whale's teeth, which will be used by these fellows and their shipmates for scrimshaw, "perhaps the only indigenous Yankee handicraft." Scrimshaw includes a variety of carved articles, ranging from pictures engraved on the teeth to implements for use in the kitchen, such as pie wheels (Murphy 1967, 16).



Hoisting the blanket strip. Note the men balanced somewhat precariously on the *cutting stage,* and the sharks swimming around the carcass.



Trying out the horse pieces. The man at the far side of the tryworks is using a blubber hook to add a minced horse piece to the try-pot (minced horse pieces were also called *bible leaves*). His companion is stoking the fire.

Hunter's blubber-cutting machine ever having been used." Another page and a half on Ricketson's mincing machine end, "Ricketson's machine was not practical and it is doubtful that it was ever used" (152). Finally, there is Hunter's tryworks; two pages describing its advantages end, "There is no record of a whaleship using Hunter's mechanical tryworks" (165). Innovations in vessel design made whalers more productive, but the processes of cutting in and trying out did not change significantly from the beginning to the end of New Bedford whaling.

The only major innovation in bone production was the introduction of improved winches to move the baleen. (This account is taken from Bockstoce 1986, 79–85.) The baleen operation began when a boatsteerer—usually the one who had first harpooned the whale—dropped down onto the carcass, lashed to the side of the vessel, and began removing the whale's lip. Holes were cut in the lip to accommodate hooks attached to lines carried inboard, cuts were made at the base of the lip, and the lip was hauled aboard.

The boatsteerer—in this capacity known as the *monkey*—now began to cut the whalebone free of the upper jaw, using a spade. The position of the whale was periodically shifted, by putting pressure on the blanket piece, to permit the monkey to cut away the baleen across the entire upper jaw. When the baleen, an enormous structure weighing as much as two thousand pounds, had been cut free, it was winched aboard.

Then the baleen was split into sections, the first step in a series that divided the clumps of baleen. The remaining steps—cleaning and drying—were carried out over an extended period following the removal and trying out of the blubber. The principal activity involved removing a white, gumlike substance by scraping the bone with coconut shells or knives. This job and the drying out had to be done with great care, since improper handling could mean a loss of value.

7.4 Improvements in Shipbuilding Methods

Throughout the first two-thirds of the nineteenth century, Americans could buy vessels from the world's most efficient shipbuilding industry. In 1776 fully one-third of all British-owned vessels were American-built (McGowan 1980, 27), and the economic advantage that underlay that degree of market penetration increased for the next seventy-five years. Some of the advantage was, of course, due to the low price of timber, but it also rested on a more efficient production technology. "Working in a small, almost barren yard with a constantly changing labor force . . . the energetic colonial builder could produce two ships a year, in comparison with the one launched by the English counterpart" (Goldenberg 1976, 71). Despite the increasing size and complexity of vessels, American builders held to that schedule throughout most of the nineteenth century. Even after 1870 when the American advantage in wooden shipbuilding was beginning to be undercut, it usually took only four or five months to complete the hull of a typical ship or bark, and six months for the hull of even the largest. The keel of the 3,401-ton schooner *Eleanor A. Percy*, for example, was laid in March 1900 and the vessel launched in October (Hutchins 1941, 396).

Between the 1820s and midcentury, American builders gradually introduced new construction techniques. Steam-driven saws meant frames could be cut and beveled—the most difficult single task—with one-sixth less labor, but diffusion was slow outside the most progressive yards. While most Maine shipbuilders were using steam saws by the early 1870s, the first such plant to open in Bath (the state's shipbuilding center) used equipment imported from McKay's Boston yard after his 1869 bankruptcy. McKay had been using a steam-driven tilting saw for twenty years (Bathe 1967, 207). Planking was also cut, tapered, and beveled in steam-driven mills. Power-driven lathes were developed to cut the treenails (wooden pins) that fastened the timbers of the hull together; the yards' blacksmith shops developed metalworking techniques and by the 1840s were importing machine tools from Europe. At that time, steam winches had generally replaced horses as the source of stationary power (Hutchins 1941, 330–31).

"In most yards . . . large sheds, open on one side, were provided for hewing and fashioning in bad weather" (Hutchins 1941, 395). The most prosperous firms constructed ship houses for building vessels indoors. Before 1850 only two navy yards were so endowed (Chapelle 1967, 279). By the Civil War, large, progressive builders had adopted most of these improvements, but there were still small establishments that built in the open and used hand techniques.

Progress was also made in providing better-quality vessels. For example, before the 1840s the life of a vessel was often cut short by rot in the keelsons—the beams (usually three) that run lengthwise above the keel to provide a ship's structural foundation. Captain R. B. Forbes solved this problem by hollowing tunnels in the keelson timbers and filling them with salt pickle. Connecting pipes permitted the pickle to be replaced when the timbers had absorbed the current supply (McKay 1928, 45–46).

Not all problems were solved. As the virgin forests were cut, builders of wooden ships faced a shortage of curved timbers to use for frames. What was needed was a machine that could bend timbers to shape. Despite numerous experiments with clamps and steam boxes, and some partial success (the *Ocean Bird* [1853], the *Pawnee* [1858], and the 1,147-ton *New Era* [1870]), the process remained too costly to be profitable (Hutchins 1941, 395).

The existence of small yards attests to the fact that, as late as midcentury, there were few economies of scale to be captured. Despite the emergence of Maine as the major shipbuilding center and concentrations of activity in Massachusetts, Connecticut, the Hudson River valley, and the Chesapeake, ships were built in small yards up and down the Atlantic coast (Morris 1979, 164). By the 1870s, however, the new technology began to show evidence of increasing returns. The number of American yards declined. Donald McKay was among those who failed, but the decline was concentrated among the smaller yards. Remaining firms grew larger. They expanded their facilities to incorporate the latest technology, and managed to capture the available scale economies (198), but in wooden-ship construction these were never comparable to the economies available to builders of iron or steel hulls.

7.5 Improvements in Oceanography and Cartography

A summary of the developments that increased productivity in ocean shipping in general, and in whaling in particular, must include innovations in oceanography and cartography, as well as the explorations on which more precise maps and charts were based. There was nothing new about exploring virgin waters and mapping their navigational hazards; sailors had always made charts. What was different was the extent of the area that was sailed for the first time between the late eighteenth century and 1900, and the degree to which governments professionalized what had been a largely amateur enterprise. Moreover, "[i]n the life of sail, storms were less to be feared than calms, and unlike the steamship which could . . . travel the shortest distance between two points, the sailing ship route varied greatly according to seasonal winds and currents. Until the middle of the nineteenth century, there was no systematic research on ocean currents, winds and weather (Graham 1956, 81).

The British navy had been involved in both cartographic and hydrographic endeavors since at least the time of James Cook's voyages to the Pacific in the

1770s. The history of American government efforts is intimately associated with the evolution of the U.S. Navy's Depot of Charts and Instruments (later the U.S. Hydrographic Office) and two of its early directors, Charles Wilkes and Matthew Fontaine Maury.[16]

Beginning in the early 1830s Congress enacted a series of laws calling for naval surveys of areas of particular maritime concern. In 1836 an act was passed calling for the exploration and survey of the Pacific coast and the South Seas, in order "to determine the existence of doubtful dangers reported in the track of the United States trade, to make astronomical observations for locating shoals, islands, reefs, etc.; observations of terrestrial magnetism, variation of the compass, etc."[17]

Two years later the government sent out the U.S. Exploring Expedition, with Wilkes in command.[18] In 1837 the depot published four charts resulting from surveys made by American naval officers; over the next five years it published eighty-seven more, nearly all products of Wilkes's expedition. Upon his return in 1842, Congress approved the publication of an account of his discoveries; between 1844 and 1874 eleven atlases and twenty-four volumes, including Wilkes's famous volume 23, *Hydrography,* were produced. Both the charts and the Wilkes volumes were made available to shipowners and sea captains.[19]

Although Wilkes's expedition was by far the most famous, it was not the last of those government-funded scientific enterprises. On 3 August 1852, for example, the *WSL* reported that the Senate was considering "a bill 'to authorize an exploration and reconnoisance [*sic*] of the courses of navigation used by whalers' in the regions of Behring's Straits; also such parts of the China Seas, Straits of Gaspar, and Java sea as lie directly in the route of vessels proceeding to and from China." The editor applauded the measure because "the number of whale ships now cruising in those seas is about 250, and it is generally admitted that nearly all the charts of that remote portion of the globe are very imperfect." Late in August Congress approved, and within a year the North Pacific Exploring and Surveying Expedition, which was to last six years, was launched (*Stats. at Large of USA* 10:104). It was first commanded by Cadwalader Ringgold, who had been a member of Wilkes's expedition fifteen years before,

16. Wilkes is one of four candidates for discoverer of Antarctica. The others are a French naval lieutenant and two American sealers. The story of one of the sealers—Nathaniel B. Palmer of the sloop *Hero*—is told in Colby 1990, 57–61.

17. In 1832, for example, Congress appropriated $20,000 to carry out the coastal survey authorized in 1807 (An Act to Carry into Effect the Act to Provide for a Survey of the Coast of the United States, 1832, *Stats. at Large of USA* 4:570–71). The 1836 act was An Act Making Appropriations for the Naval Service, for the Year 1836 (*Stats. at Large of USA* 5:27–29). The quotation is from the 1924 *Annual Report of the Hydrographic Office* as quoted by Weber 1926, 12. See also U.S. Navy 1952, 204.

18. For a thorough and beautifully illustrated account of the expedition, see Viola and Margolis 1985.

19. Weber 1926, 13. The act of Congress was An Act to Provide for Publishing an Account of the Discoveries Made by the Exploring Expedition, under the Command of Lieutenant Wilkes, of the United States Navy, 1842, *Stats. at Large of USA* 5:534. Although it directed the publication of only one hundred copies, subsequent acts provided for reprints and their distribution.

and then by John Rodgers.[20] Between 1853 and 1859 the expedition produced enough information to enable the government "to publish detailed coasting charts of the entire coast of Japan, the coasts and islands of the Bering Sea, and of a portion of the Arctic Ocean (Weber 1926, 19).

Wilkes became famous for his expeditions; Matthew Fontaine Maury seldom left Washington between 1 October 1844, when he took over the command of the depot, and 1861, when he joined the Confederate Navy. Wilkes's contributions lay in the accuracy of the notes and measurements that he made personally, Maury's, in his ability to collect and synthesize the notes and measurements of others. Wilkes provided the basis for a generation of maps and charts, Maury, for the scientific study of hydrography and for most sailing directions for the rest of the century.

Maury was not the first hydrographer, but his work stands out because of its breadth and attention to detail (Villiers 1953, 78–79). He made no attempt to do all of the work himself. Instead, he tried to recruit the help of all the nation's sea captains, and managed to recruit a substantial number. Each cooperating captain was furnished with a set of forms on which he was asked to report—on a day-by-day basis—his ship's destination and location, the mileage sailed, the ocean currents encountered, wind speed, air pressure and temperature, water temperature, and any other marine and meteorological phenomena he thought pertinent (McKay 1928, 115–16; Weber 1926, 17). Maury collected, synthesized, and analyzed these reports. He plotted on a single chart the tracks of several hundred ships traveling from one specific port to another but traveling in different years and in different seasons—noting along each track the winds and currents encountered each day.

The statistics gathered in these working charts—charts based on the combined experience of a sizable fraction of the nation's navy and merchant captains—gave Maury the evidence he needed to generalize about ocean conditions (Graham 1956, 82). He established the best routes for sailing ships at various times of year on all the standard voyages. He did not claim that "there was one sailing route, and only one: but at each season of the year, there was very definitely a *best* way" from one port to another. Certainly there were variations in the weather, but Maury's routes were best for average conditions in any given month, or even week (Villiers 1953, 79). His charts included information on winds and currents, ocean temperatures, and even magnetic influences on a

20. John Rodgers came of a distinguished naval family. His father, John, "fired . . . the first shot in the war" of 1812 and at the conclusion of the war was offered the position of secretary of the navy, which he turned down. The son surveyed the coast of Florida in 1840–43 and 1849–52 and took part in the expedition to chart the North Pacific in 1852–55. In 1855, in command of the *Vincennes,* he explored the Arctic Ocean. From then until 1861, when he began his service in the Civil War, he participated in writing the report of the explorations in which he had taken part. After the war Rodgers was the commandant of the Boston Navy Yard, commanded the Asiatic fleet, and ended his career as superintendent of the U.S. Naval Observatory in Washington, DC, where "under his administration Prof. Asaph Hall discovered the moons of Mars" (*Appletons' Cyclopaedia of American Biography* 1888, 5:297).

vessel's compass (Graham 1956, 82). As Maury said, "[T]hus the young mariner . . . would here find at once that he had already the experience of a thousand navigators to guide him on his voyage."[21]

The results of Maury's work were published in a series that came to be known as Wind and Current Charts and in his ten-volume *Sailing Directions*. There were six series of Wind and Current Charts: Track Charts, Trade-Wind Charts, Pilot Charts, Whale Charts, Thermal Charts, and Storm and Rain Charts. Together they covered such diverse topics as the "prevailing winds and currents, their limits and general characteristics, and, in general, all the physical features of the ocean, including its meteorology, the limits of icebergs, the feeding ground of whales, and all the facts of interest and value to the maritime community."[22] Maury oversaw eight editions of *Sailing Directions*. The first three track charts were issued in 1848. The rest, as well as the "other series of Wind and Current Charts were issued from time to time, as they were succesively completed, and their coverage was gradually extended to include every navigatable sea" (Weber 1926, 18).

The impact of Maury's work on the lengths of voyages was dramatic. By the early 1850s, for example, the average passage from an East Coast port to the Equator had been reduced from forty-one to thirty-one days. One Baltimore captain even made the run in twenty-four. The average passage from England to Australia via the Cape of Good Hope—eleven thousand miles—had taken 125 days. With the new charts it was reduced to 92 (Graham 1956, 82).

It is not surprising that Maury's work was rapidly diffused. During his tenure the depot issued and distributed free, "to merchant vessels alone, twenty thousand copies of Sailing Directions, and two hundred thousand copies of Wind and Current Charts." During the same time, the depot engraved, published, and oversaw the distribution of an additional forty-four general sailing charts that depended both on Maury's work and on the explorations of Rodgers and Commodore Perry (Weber 1926, 18).

In the fifteen years after 1850, whaling and merchant captains benefitted also from a worldwide expansion of the network of lighthouses and from the introduction of other aids to navigation, such as channel buoys, in restricted waters. In 1861 the east and west coasts of the United States were joined by the electric telegraph, and New Bedford agents could communicate with whalers reprovisioning in San Francisco. The Civil War hastened the expansion of the domestic telegraph net; news of markets and prices now diffused quickly, and

21. Quoted in Graham 1956, 82. Maury's work was beneficial chiefly to merchant ships sailing from port to port on predetermined schedules, but whalers gained as well. Not only were captains able to choose the best routes on their outbound voyages to the Indian, Pacific, and Western Arctic Oceans and on the return trip to New Bedford, but they were able to choose the best tracks to take as they shifted operations from the Arctic to the New Zealand grounds or from the Sea of Okhotsk to the northwest coast of the United States. And, of course, whalers alone reaped the benefits of Maury's whaling charts.

22. Commander Bartlett to the National Academy of Sciences, letter about Maury's activities, quoted in Report of the Joint Commission 1886, 26–27.

the performance of markets improved. The Atlantic cable—linking the United States, through Great Britain and the Channel cable, with the now very fully articulated Continental system—was opened in 1866; it proved a great boon for oil merchants in need of market information. In the 1870s the European systems spread to take in Scandinavia, Russia, the Middle East, India, Australia, and New Zealand.

For whaling agents this meant contact with more reprovisioning and shipping points, and easier control of ventures. The rapid expansion of the Latin American systems in the 1870s and their connection with the U.S. system further augmented the information network. Whalemen lost a potential extension of the communications net when the Western Union Telegraph Company gave up plans to run a line through Canada and Alaska, across the Bering Strait, and through Russia to China and Japan. The company had not believed that the Atlantic cable was possible; once the impossible was accomplished, the Orient was accessible via Europe. The company wound things up: "[T]he iron wires were sold to the Indians to be used for suspension bridges and fishing tackle, while the green-glass insulators supplied the Indians with drinking glasses for years" (Ahvenainen 1981, 30; see also Bright 1911; Tribolet [1929] 1972).

The telegraph system was not extended to Honolulu in time to do whalemen much good. To do so was feasible at a fairly early date, but for some reason—perhaps the limited returns expected—the line was not built until much later.

7.6 Whalecraft Innovations

In 1874 Charles M. Scammon (1968, 216) published the statement, "There has been as great a revolution in the mode of killing whales during the past twenty years, as there has been in the art of naval warfare; were it not for this, but few whalers would now be afloat." This section describes whalecraft innovations of the nineteenth century, investigates the speed with which they were adopted, and tests Scammon's belief that the important innovations were produced and diffused within a short time.[23]

In American-style whaling the attack was made from small, light but strong, double-ended, open boats—twenty-eight to thirty feet long, six feet wide, and shallow. The craft had to be light because the whaling routine called for them to be lowered and then brought back aboard the vessel many times on a voyage. Lightness, shallow draft, and the design of hulls and oars made them relatively easy to row, an important characteristic, since the pursuit of the whale often meant rowing for hours at a time. They had to be strong, to resist the "racking strains of being towed by the whale or being lowered and raised in the davits." To achieve this end, they were "*clinker built* . . . i.e. the thin boards that cover

23. Much of the information on inventions comes from Lytle 1984. This excellent book is concerned chiefly with invention, per se, rather than innovation and diffusion. See also Scammon [1874] 1968.

the ribs overlap one another, thus giving strength to the boat and enabling it to be made much lighter." Finally, they had to be seaworthy, since whalemen worked in all weathers, and over considerable distances: two boats of the *Essex,* after that vessel was sunk by a whale, sailed more than two thousand miles before they were picked up.[24]

The equipment in the boat and the method of attack depended somewhat on the type of whale and the location of the chase. Gray whales and humpbacks were typically taken in bays, where the water was shallow enough for equipment that would be useless in the rougher and deeper waters outside. For example, since a humpback sinks when it dies, hunters carried buoys to mark the location of the carcass until it rose again to the surface, but the technique worked only in shallow water. Anchors had uses in bay hunting, but none in the open sea. The Greener swivel harpoon gun was effective in bays, and it kept hunters a safer distance from the ferocious gray whale than did the standard harpoon, but the Greener was rarely used by American open-sea whalemen because it was ineffective unless the seas were perfectly calm—an unusual event on the ocean grounds.[25] Whalemen were reluctant to employ explosive devices against sperm whales. These animals travel in pods of fifteen to twenty, which would scatter at the sound of an explosion. Explosives were used in hunting right whales, since they travel alone or in very small groups. Bowheads posed peculiar problems. They could—and did—seek escape from hunters under the Arctic ice. In the bowhead fishery there was a premium on implements that could stop the whale in its tracks; there, explosive devices were quickly adopted.

Despite these variations the American system had some characteristics observable in all the fisheries. We will take, first, the case of a vessel hunting sperm whales in the Pacific, and then examine the differences in other fisheries and other grounds.

Slung from davits above the deck were four or five whaleboats; two or three spares were stored on skids above the poop. Men were in the crosstrees on watch. When whales were sighted and the vessel had been maneuvered to within about a mile of the pod, the boats were lowered to give chase. Each boat carried six men—five oarsmen (three starboard, two port) and a steersman (*boatheader*). The latter was normally a mate, although it was not uncommon for the captain, and occasionally for an extra-skilled seaman, to serve as

24. Ansel 1978, 2, 3; Olmsted [1841] 1969, 19. The description of "clinker built" is from Olmsted. In the eighteenth and early nineteenth centuries, boats were typically smaller than those described here and carried five men. See Macy [1835] 1970, 142.

25. Lytle 1984, chaps. 4, 6. The *Florida* was outfitted with a Greener and twenty irons in 1858. See Williams 1964, 209. Part of this book is the diary of Eliza Azelia Williams, who went whaling with her husband and raised a family at sea. She describes the first mate's shooting at fin whales from the deck of the vessel, probably with the Greener (47, 51). She does not report that he hit any finners with it, but once he shot (but lost) a humpback, while the gun was mounted in his whaleboat (139).

boatheader. With all the boats on the sea, two to five men were left aboard the ship to sail it, keep lookout, and signal the movements of the whales.

A whaleboat was sailed when there was a wind and a good distance to go, but the sail was taken down and the oars unshipped as the boat neared the whales. If there was danger that the sounds of rowing would frighten them, paddles were used instead.

A whaleboat was crowded with gear: a mast and a spritsail or lag sail, a long steering oar, five rowing oars, and paddles. In the center, between the rows of oarsmen, were two tubs filled with line. The line in one tub was run to the stern, around the loggerhead (an upright post), and then forward, where it passed through a metal groove in the bow and was attached to the harpoons. The second tub contained spare line, spliced to the primary line and ready for use should the whale dive deep enough to require it. The boat also carried, among other things, harpoons, lances, perhaps whale guns (more likely in right whaling), and cutting implements called spades. All told, Scammon says, something like eighty-two items of gear were stored aboard the typical whaleboat.[26]

When a whale had been approached and the boat virtually driven onto its back, the boatheader told the forward starboard oarsman—called the *harpooner* or *boatsteerer*—to rise and cast his harpoons. The harpooner tried to place two harpoons; if there wasn't time to cast the second, it was stored in the bottom of the boat, or, if already attached to the line, it was thrown over the side to prevent injury to men and craft.

With the whale securely held by the harpoons and the oars removed from the water, boatheader and harpooner changed places, harpooner now becoming boatsteerer.[27] Consider the character of this maneuver. Once the whale felt the harpoons, it usually swam off at a rapid clip; sperm whales have been known to move at a rate of twenty-five miles per hour. The line attached to the harpoons—it ran down the center of the boat, from stern to stem—paid out so

26. "The equipment belonging to a modern whale-boat consists of one mast and yard, or sprit, one to three sails (but usually a jib and mainsail), five pulling-oars, one steering-oar, five paddles, five rowlocks, five harpoons, one or two line-tubs (into which the line is coiled), three hand-lances, three short-warps, one boat-spade, three lance-warps, one boat-warp, one boat-hatchet, two boat-knives, one boat-waif, one boat-compass, one boat-hook, one drag, one grapnel, one boat-anchor, one sweeping-line, lead, buoy, etc., one boat-keg, one boat-bucket, one piggin, one lantern-keg (containing flint, steel, box of tinder, lantern, candles, bread, tobacco, and pipes), one boat-crotch, one tub-oar crotch, half a dozen chock-pins, a roll of canvas, a paper of tacks, two nippers, to which may be added a bomb-gun and four bomb-lances; in all, forty-eight articles, and at least eighty-two pieces" (Scammon [1874] 1968, 224–25).

Scammon notes that "[t]he full equipment as here enumerated, is modified to suit the particular branch of whaling pursued, as for instance, in deep-sea whaling there is no use for the anchor, and in sperm whaling the sweeping-line, buoy, etc., are not required; while in California Gray whaling in the bays or lagoons, the anchor is indispensable, and the grapnel, sweeping-line, lead, and buoy, are of much service. But many other articles are left out or supplied to a limited extent, so that the boat may be as light as possible, and work easily and quickly in shallow water."

27. The oar handles were set in cleats, to keep the blades out of the water.

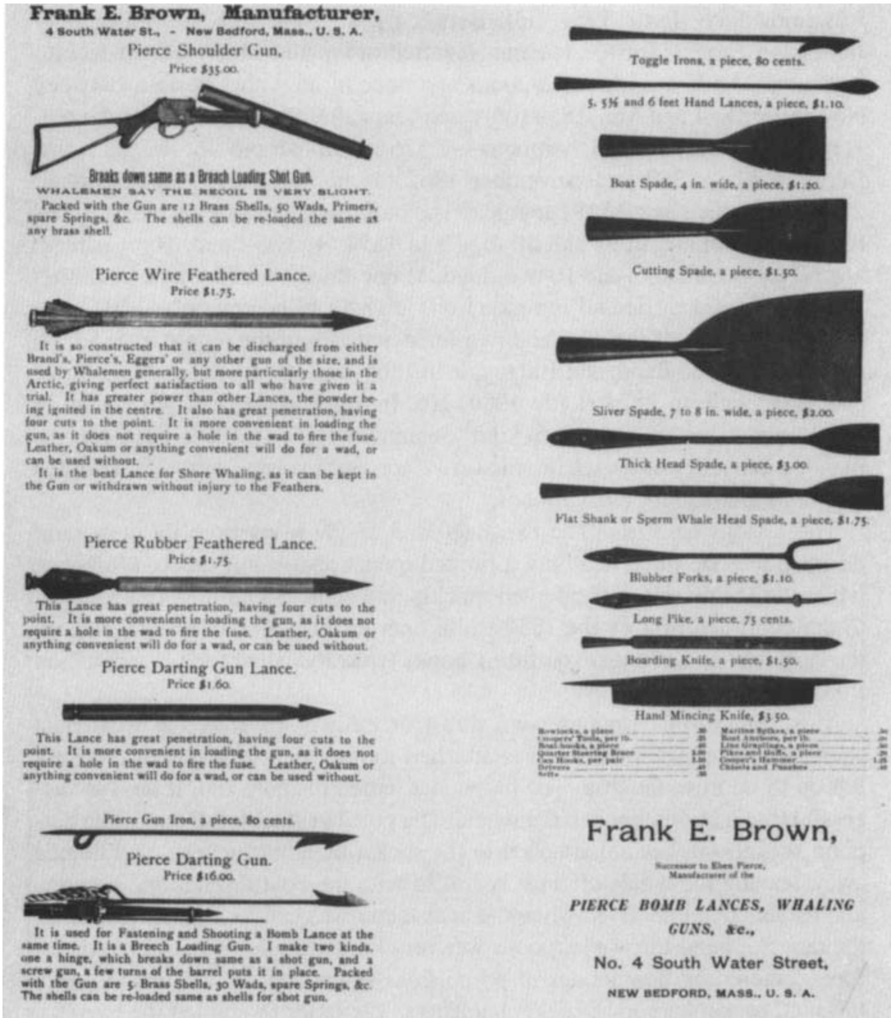
fast that it could remove the arm or leg of a man unlucky enough to be caught in one of its loops. The boat was small and narrow, and it was packed with gear. These were the circumstances in which the boatheader ran from stern to bow, passing the harpooner, who was moving back from bow to stern. If all went well, the maneuver ended with the harpooner (now the boatsteerer) taking over the steering oar, and the boatheader standing in the bow with a spade or lance in his hand. If he had moved forward quickly enough, before the whale sounded, he slashed at it with his spade in an attempt to sever the tendons in its flukes (tail) and cripple it. Unless they were perfectly executed, the exchange of positions and the second physical assault on the whale could produce disaster for boat and men. In fact, the attempt to cut the tendons was so dangerous that it was eventually abandoned by most whalemen.

The purpose of most harpoons was to hook the whale and attach it to the whaleboat. The injury rendered by the harpoon coupled with the weight of the line and boat were intended to tire the whale and permit it to be approached again. Frequently the second approach took place only after many miles had been covered and many hours had passed. The actual killing was left to the boatheader, who stabbed the whale with a lance—a long, handheld, spearlike implement.

The hunting technique remained essentially unchanged, but over time the implements were improved significantly. The principal innovations were introduced between the late 1840s and the mid-1860s, and they were widely diffused during the period of the American fleet's decline.

From the American point of view the most important innovations in harpoons (called irons by whalemen) involved their design and the means by which they were propelled from boat to whale. Both sets of improvements were intended to increase the probability that, once launched, the harpoon would fasten securely to the whale rather than missing completely or pulling loose.

Innovations in design were numerous, and some were widely and quickly adopted. Although the variations on each style were great, there were three basic types: the two-flued, the one-flued, and the toggle. The names are descriptive. The two-flued harpoon was shaped like an arrowhead, with sharp leading edges designed to enter the whale smoothly and dull following edges intended to lodge in the flesh and secure the whale. Nonetheless, all too often the two-flued harpoon pulled out. The one-flued harpoon—with only one following edge—was designed to minimize the chance that the whale would escape; it was widely thought to be superior to its predecessor, the two-flued. The point of the harpoon that entered the whale was narrow. When the whale pulled against it, the single barb—or flue—caught in its flesh, the soft neck of the iron bent, and the harpoon turned parallel to the body of the whale, thus firmly attaching the animal to the line and, in turn, to the boat. The toggle iron achieved the same result more effectively. It turned on a pivot. When the harpoon was thrown, it was held in a fixed position—sharp edges forward—by a



This advertisement in the *Whalemen's Shipping List and Merchants' Transcript* for a manufacturer of whalecraft shows a variety of implements available to the trade in the mid–nineteenth century.

Reproduced courtesy of the Old Dartmouth Historical Society–New Bedford Whaling Museum.

small, light piece of wood; when the harpoon entered the whale the wood broke, the head turned, and the whale was securely hooked.[28]

The toggle iron was first employed in 1848, and its effect on the industry

28. See, for example, the favorable reports of the toggle in the *WSL* 31 May, 19 July 1853. The first report (from the ship *Ohio*) asserts that twenty-two bowheads were hit and twenty-one cap-

was immediate (Lytle 1984, 33). Between May 1830 and November 1844 James and Thomas Durfee, leading New Bedford manufacturers of whalecraft, produced 22,133 two-flued harpoons and none of any other design. Between November 1844 and May 1850 (only two years after the innovation of the toggle) they produced 7,791 harpoons—7,526 two-flued and 265 toggle irons. Between May 1850 and November 1862 the numbers were almost equal: 20,462 two-flued and 20,191 toggle.[29] The outfitting books of the bark *Ospray* list 190 "common" irons and 50 toggle in 1854; 40 two-flued, 10 one-flued, and 60 toggle in 1866; and 10 two-flued, 11 one-flued, and 90 toggle in 1880.[30] The bark *Louisa* carried all common irons in 1850; 130 common and 50 toggle in 1853; 42 each of the one- and two-flued and 100 of the toggle in 1856; 36 two-flued, 20 one-flued, and 100 toggle in 1865; and 10 two-flued, 3 one-flued, and 120 toggle in 1874 (Lytle 1984, 16). In 1869 the bark *Globe* listed 36 toggle and none of any other kind. Scammon ([1874] 1968, 316) recommended that a first-class whale ship on a Cape Horn voyage carry 15 two-flued harpoons and 150 toggle harpoons.

The lessons are clear. The two-flued and toggle irons were the important designs; the one-flued had only a limited transitional significance. Moreover, while the toggle iron was adopted quickly and achieved an importance equal to the two-flued iron by the 1850s, it did not displace the older designs until the early 1870s. Even then, outfitting books typically called for a few common irons in addition to toggles.

Most American harpoons were thrust or thrown—*darted,* the whalemen said—by hand. The harpoon was attached to the trunk of a sapling, its bark left on to improve the grip. The harpooner darted his pole and, if he was successful, the harpoon hooked the whale. The pole eventually fell out of the harpoon socket—it was not attached to the socket by any fastener—and floated away, leaving the whale effectively linked with the boat through the harpoon and its attached line. Even when the boatsteerer was extraordinarily powerful, the range of hand-thrown harpoons was very limited. Innovative efforts, therefore, centered on new modes of propulsion—guns and, to deliver the newly invented rocket harpoons, rocket launchers. The latter resembled the bazooka of World War II. The swivel gun was invented in the early eighteenth century and figured in the Scotch and English fisheries, but never played a prominent role even there. It could not be accurately aimed in rough seas, and its kick often damaged the whaleboat. The latter consideration was of particular impor-

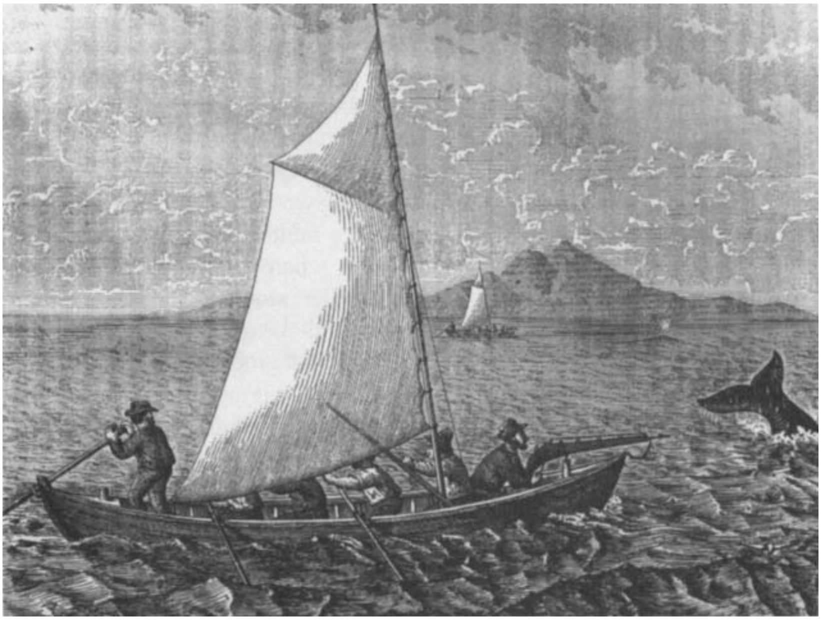
tured, with only eight toggle irons. The second tells of the capture of forty-one whales with thirty-five toggles, none of which failed.

29. Durfee Papers. Lytle (1984, 11, 172–74) traces the careers of the Durfees as blacksmiths, shipsmiths, and machinists.

30. *Ospray* 1854, 1866, 1880. We believe we have looked at every outfitting list and every record of a manufacturer of whalecraft housed in the Old Dartmouth Historical Society Whaling Museum, the Melville Room of the New Bedford Free Public Library, the libraries of Harvard University, and the G. W. Blunt White library at Mystic, Connecticut.

tance to the Americans, whose whaleboats were lightly made. Thus the early swivel gun made no impact at all on the American fishery.

In 1837 an English gunsmith, William Greener, produced an improved version of the swivel gun. At that time it was not well suited to the American fishery, and few were employed. Within two decades the discovery of new grounds made the Americans more receptive to its innovation. The Pacific gray whale migrates each autumn from the North Pacific to the Baja Peninsula, where its young are born and nurtured. Once these Lower California grounds were discovered, Arctic whalemen, driven out by advancing ice each fall, found gray whales to be ideal off-season prey. They were trapped while tending their young in the confined spaces of the shallow Baja bays. The waters were calm enough to permit the effective use of the Greener, and the ferocity of the mothers protecting their young (whalemen called the gray whale the devilfish) made hunters grateful for the distance the swivel gun allowed them to keep. By 1850 the Greener was advertised in the *WSL*, and it soon made its mark in California bay whaling (Lytle 1984, 80–81). It was not extensively employed in any other part of the American fishery.



A whaleboat under sail—probably off Baja California—approaches a gray whale. The man in the bow is prepared to fire his Greener gun as soon as the whale surfaces.

This drawing was published in Charles M. Scammon's *Marine Mammals* in 1874. It is reproduced here courtesy of the Old Dartmouth Historical Society–New Bedford Whaling Museum.

The rocket launcher would seem to have represented a more promising line of development. It was light and did not have the kick of a gun. Both American and British inventions were patented as early as the 1820s, and the British version was said to have killed a large number of whales during its initial trials. Neither invention was widely adopted, and therefore neither had any significant impact on the whaling industry. Contemporaries viewed both as inventions that might provide a foundation for their attempts to hunt the fast-swimming rorquals, which nineteenth-century whalers seldom managed to bring home. The blues, fins, seis, and minkes could not normally be approached and taken by conventional methods. Rocket launchers, advertised as capable of hitting a whale at a distance of forty yards or more, seemed to have solved this problem.

There was also initially a hope that the rocket-driven harpoon would overcome a second obstacle: rorquals tend to sink when they are killed. If they were to be successfully hunted, a method had to be developed to keep them afloat or to raise them from the deep. Among the rorquals, humpbacks frequented shallow coves. There they could be killed by conventional methods and their bodies marked by buoys, to picked up days later when the accumulating gases eventually forced carcasses to the surface. The blues and the fins—the largest and most numerous of the rorquals—could not be taken in this way. William Congreve, the inventor of the British rocket harpoon, believed his device would solve the problem. It included an explosive charge in the harpoon that could, he argued, both kill and physically alter the whale in a way that would keep the carcass afloat. In fact it did not. His harpoon killed a number of rorquals, but most sank and were lost (Tønnessen and Johnsen 1982, 18).

It is not clear why the rocket harpoon was not employed in the sperm- and right-whale fisheries, where losses from sinking were negligible. In the case of sperm whales, the explanation may lie in the hunters' recognition that they could, if they were careful, take three or four whales from a pod by conventional methods. One shot from a rocket launcher would scatter the pod, and the hunter would have to settle for at most a single whale (if, of course, he was lucky enough to hit one). It may also be true that the rocket represented only a modest gain for right and bowhead whalemen. With it they might kill an occasional whale that the boats were unable to approach, but the gains with respect to the rest may not have been seen to be very great.

Neither explanation is entirely satisfactory. After all, four to six sperm-whaling boats, each armed with a rocket launcher, could surely get off four to six shots, rather than one, before the pod scattered. Furthermore, given the fighting abilities of sperm whales, harpooning from a distance ought to have reduced the loss of boats, equipment, and men. In the case of the bowhead, the rocket launcher would also appear to have had real virtues: a dead whale cannot escape under the Arctic ice. Nonetheless, the rocket launcher was nearly confined to the rorqual fisheries, and Americans hunted few rorquals.

The two Americans who employed the rocket launcher most extensively were Thomas Welcome Roys, a whaling captain from Southampton, New

York, who opened the Western Arctic hunting grounds, and Gustavus A. Liliendahl, of New York City, an explosives expert. Roys patented rockets and their launchers in 1861, 1862, 1866 (with Liliendahl), and 1879 (the last patent was granted two years after his death). He joined with Liliendahl in an effort to use the rocket to hunt fins and blues off the coast of Iceland, a venture that was continued by Liliendahl after he and Roys parted company. The partners employed steamboats to tow whaleboats to the hunting ground. When whales were sighted, the whaleboats were released to launch the attack. The rocket was intended not only to kill the whale but also, like a conventional harpoon, to fasten it securely to the whaleboat. If the whale sank, the steamboat was standing by and could winch it up. Once secured, the whale was towed by the larger vessel to a shore station for processing. There was, however, a grave danger that the whale would be attached to the whaleboat while still alive. In that case the whaleboat and crew were likely to be taken on a ride at speeds much greater than were encountered on the sleigh rides of the conventional whale fishery.

The Roys-Liliendahl firm managed to kill some whales, but captured only about one-half of those destroyed—a much poorer record than that of the conventional industry. The firm also experienced severe financial difficulties, and in 1867, a year after the partnership broke up, it failed. The Roys technique continued to be used until the early 1870s, but only a few whales were captured. Altogether, in all years, Roys's innovation killed fewer than 150 rorquals. There is a strong suggestion that the method was not widely imitated because it was technically flawed, but it is possible that the problem lay at least in part with Roys's and Liliendahl's inadequate business sense and managerial skills.[31]

Conventional harpoons did not kill whales, but only hooked them. Whales were actually killed by a lance—a spearlike implement. Harpoons were made of iron, the shank of soft iron that allowed it to bend under pressure, reducing the likelihood that the head would pull out of the whale. Hand lances were stabbing instruments, not hooks. To permit the boatheader to strike again and again, they were designed to be easily thrust into the whale and easily withdrawn. The body of the lance was usually made of tough wrought iron mounted on a pole, but the head was frequently made of steel. Steel was preferred; it completely displaced wrought iron "after steel was produced in quantity in this country" (Lytle 1984, 133). The substitution was presumably associated with a decline in the relative price of steel, which fell particularly sharply after 1867. If the ratio of steel to wrought-iron prices in 1867 is taken as a base of one hundred, the relative price of steel fell to seventy-two in 1875 and to fifty-three in 1882 (Swank 1892, 514). Agent response was swift; outfitting lists immediately reflected the change: the lists for the *Emily Morgan* (1842) and

31. Tønnessen and Johnsen 1982, 18–20; Lytle 1984, chap. 6. Tønnessen and Johnsen cite business problems. Lytle (128) records the following words from the posthumous patent: "These last improvements made by Roys are intended to remedy the defects in the implement as formerly constructed, and which actually rendered it to a great extent impracticable."

the ships *Julius Caesar* (1837), *Magnolia* (1842), and *Francis Henrietta* (1843) mention no steel-headed lances, while those for the barks *Globe* (1869) and *Mary Frazier* (1876) mention no iron-headed lances. Scammon's best-practice list ([1874] 1968, 316) for the early 1870s also contains no hand lances with iron heads. The *Ospray* (1854, 1868) carried half common and half steel-headed lances in 1854, but its outfit changed to all steel-headed by 1868.

The substitution of steel for iron was not the only potential improvement in the lance that inventors offered. At one time or another, they suggested heating, electrifying, and poisoning the lance.[32] None of these plans came to much. Not surprisingly, crewmen concluded that, if the poison killed the whale, it might also kill them when they handled the blubber.

The problems of making the lance explosive were more tractable. The devices developed—some intended to kill by driving a lance head deep into the whale, others, by the force of the explosion—were usually part of an innovation that also included a mechanism for delivering the lance. The first of these was handheld and was similar to a shotgun. Unfortunately, it had a kick so strong that the boatheader was often thrown to the bottom of the boat. Sometimes his collarbone was broken; sometimes the craft was capsized. Considerable inventive effort was directed toward dealing with these problems, and eventually the Allen gun—more frequently called the *Brand gun* because it was developed and promoted by C. C. Brand—achieved wide acceptance.[33] The progress of the shoulder gun is exhibited nicely in the outfitting lists of the bark *Ospray:* those for 1851 and 1854 show no whale guns; those for 1866 and 1868 show three (fewer than one per boat); the number rose to six at the beginning of the 1870s; it was still six (one per boat plus two spares) a decade later. The bark *Globe* carried four in 1869, and Scammon in the early 1870s (1968, 316) called for four on his Cape Horn whaler. The *Lottie Beard*, a resupply vessel, carried eight boxes of guns and lances in 1886 (*Lottie Beard* Ac-

32. Similar means were attempted to make harpoons deadly. Lytle's comment (1984, 134) on the prussic-acid lance probably can be applied to the rest as well: "It is doubtful that this type of lance was ever used in the American whale fishery." It was used in the English fishery at least once, with great success—that is, it killed the whale. However, the *WSL* (14 August 1860) reported that "the men were so appalled by the terrific effect of the poisoned harpoon that they declined to use any more of them." The electric harpoon was a German innovation that was reported to have been used in the Pacific by vessels sailing from Bremen, as well as by French vessels. The apparatus consisted of a 350-pound battery and a hand-cranked generator. The inventor claimed great success for it, but it seems not to have had much impact on the industry, certainly not on the American industry. See the stories in the *WSL* of 8 June, 5 July, 3 August 1852, and 12 April 1853.

33. The first report of a bomb lance in the *WSL* was on 17 August 1847: "The whole apparatus is certainly ingenious; whether or not it is really an improvement on the present mode of killing whales, is more than we are able to say." By 13 November 1855 the newspaper was able to assert, "Guns for driving the harpoon have, we believe, been pretty generally abandoned," but the bomb lance was being used "quite extensively." See also stories and advertisements on 14 December 1852 (reporting an accident with an exploding whale gun), 16 November 1852, 7 June 1853, 11 July 1854 (reporting that the problem of the kick had been solved in the new Brown gun), 25 December 1855, 26 May 1857, 8 June 1858, 14 September 1858, 5 October 1858, 13 December 1859, and 27 September 1864.

count Book). The order books of Frank E. Brown, a New Bedford seller of whaling implements, show the sale of 1,906 feathered lances (for shoulder guns) and 921 long or unspecified lances (presumably all handheld) in 1877 and 1878. In the fall of 1899 and the spring of 1900, Brown listed only feathered lances and lances for darting guns.[34]

Reports from the fleet indicate the effectiveness of the bomb lance. In 1850 the *Parker Cook* of Providence confronted a very large, angry sperm whale that had already "eaten up" two of her boats. The beast "made for the vessel, striking her in the bows, and knocking the cutwater aside, but without doing much more damage. The ferocious monster was then attacked from the bark, with the Patent Whaling Gun and Bomb Lance, and after receiving three lances was dispatched." The *WSL* (11 November 1851) commented: "In the case of the *Ann Alexander*, if Capt. Deblois had used the Bomb Lance it would no doubt have prevented the loss of his ship. . . . Most of the ships fitted this year, are supplied with this apparatus."

In 1855 (13 November) the newspaper reported:

> [T]he extent to which gunpowder is now being employed in the manufacture or rather in the capture of oil, is perhaps little suspected by the mass of our readers. Guns for driving the harpoon have, we believe, been pretty generally abandoned, but we are assured by a manufacturer of fuse, who has lately contracted for making a quality especially adapted to this sub-marine and blubbery location, that the bomb-lance is now being quite extensively employed by many vessels, and that some have sent home from the Sandwich Islands for further supplies.

The manufacturer's story was confirmed by the report from Honolulu of Captain Cleaveland of the ship *Julien*, who noted that he had on board eleven hundred barrels of oil and that he "had taken most of his whales with the bomb lance" (*WSL* 25 December 1855).

Three years later the paper (8 June 1858) sang the further praises of the new technology, and acknowledged its widespread innovation.

> The most ugly species of whale to take is said to be the "California greys." They are extremely shy, and when after a long chase, or by surprise, an iron is fastened in them they can run as fast as a locomotive, dive to the bottom of the ocean, or more frequently turn upon the boat and crush it to atoms with their flukes. . . . The Bomb Lance has, consequently, become an indispensable article in the outfit of these whalers—Some ships carry one gun for each boat, while others take only one or two. The guns cost from $40 to $50 each, and the bombs $3.50 a piece.

34. Order Book, Whaling Implements, 1877–1922, Brown Collection. Butler (1973, 42) points out that the bomb lances were particularly useful in the Arctic, to keep whales from escaping under the ice. "Since this was not a problem when hunting the sperm whale, and because the noise of the guns scattered the other whales in the school, sperm whalemen made less use of these weapons."

The last significant innovation in whalecraft combined characteristics of the harpoon and the whaling gun. The darting, or Pierce, gun was mounted on the staff of a harpoon. When the harpoon was darted into the whale, a lever was depressed, the gun fired, and an explosive lance was driven deep into the whale. The Pierce gun delivered the explosive lance much more accurately than a shoulder gun. The location of the gun—close to the whale when it went off—meant that the lance was sent into the whale with great power, but did not convey a recoil to the boat. Finally, the weapon usually stopped the whale, preventing the long struggles that were common when a standard harpoon was thrown. In the Arctic, with the danger that a harpooned whale would dive under the ice, this feature was particularly important.

The darting gun was probably the most effective single piece of whalecraft introduced into the American fishery in the nineteenth century; its development and diffusion, however, came late. It was invented in 1865 but not widely adopted until the 1870s. The outfitting books of the *Ospray,* for example, make no mention of darting guns in the late 1860s and early 1870s, but two of them plus thirty-one lances appear in 1880. In 1874 Scammon (1968, 316) called for four—one per boat—and fifty darting-gun bomb lances. Clearly Scammon saw important uses for the darting gun, but even he did not believe it would replace all its predecessors—his list also includes 35 steel-headed lances, 4 whaling guns other than the darting guns, and 150 shoulder gun bomb lances. The Frank E. Brown order books show a steady increase in the relative importance of the darting gun: the fraction of lances that fit it rose from 7 percent in 1877, to 9 percent in 1878, to 14 percent in 1879, to 41 percent in the fall of 1899. That Brown sold only eight Brand shoulder guns between the beginning of 1877 and the end of 1879, while disposing of eighty-one Pierce guns, is an even clearer indication of the change then under way.

In summary, the most significant innovations in whalecraft were made between 1848 and 1865, and they were widely diffused from the 1850s through the early 1880s. The order of invention and adoption ran about as follows: toggle iron (1848–70), steel-head lance (1855–70), shoulder gun (1855–70), darting gun (1865–80). From the date of the widespread diffusion of the toggle iron (mid-1850s) to the period of general adoption of the darting gun is an interval of about twenty-five years. During that quarter century, the markets for sperm and whale oil were contracting, and the industry was contracting along with them. Whalecraft innovations, like the improvements in rig and vessel design, enhanced productivity and slowed the industry's decline.

7.7 Institutional Innovation

As long as whaling voyages were restricted to the North Atlantic, they were relatively short. The vessel returned periodically to its home port, off-loaded oil and bone, reprovisioned, acquired new outfits, filled vacancies in the crew, and set off on its next voyage. As new hunting grounds were developed, voyage length increased. Just to reach the Indian Ocean, the Pacific Ocean, or the Western Arctic took months of sailing. A vessel that returned to New Bedford after a year or so at sea did not make a very efficient use of its capital.

Vessels began to remain away for three and four years. Supplies ran out. Crews were depleted by injury, death, and desertion. Accidents called for repairs; hulls had to be scraped, and worn-out gear had to be replaced. Oil and bone had to be shipped home.

The facilities of ports on the west coast of Panama, in California, in Hawaii, and on the west coast of Australia developed to meet these requirements. Vessels could put in to such towns, send injured crewmen ashore, and recruit replacements. Provisions were taken aboard, including fresh fruits and vegetables to fend off scurvy. Supply ships from New Bedford brought whalecraft to replace the harpoons, lances, bombs, and guns used up in the hunt; they also brought mail. By prearrangement, instructions from agents were picked up by whaling captains, and news of the hunt was sent back to New Bedford. Agents formed business connections in resupply ports that made it possible for captains to be supplied with cash. U.S. consuls provided help in dealing with local laws and customs.

By permitting longer voyages and by making vessels less dependent on their home ports, the rise of these towns changed the nature of the industry. The reprovisioning towns, indeed, took on the character of alternative home ports. Once the Western Arctic became a premier hunting ground and the transcontinental railroads were in place, the connections with New England were attenuated for many vessels, and San Francisco played a more important role in their activities than did New Bedford.

This institutional innovation affected not only the whaling fleets but also the resupply ports themselves. Perth became a whaling boom town, as did many other resupply ports, but the economic gains were not without costs. The costs were often due to the behavior of the rough seamen loosed on the port by visiting whalers—crewmen anxious to erase the memory of tedious days and nights afloat, many with diseases to be passed on to the residents of the town. Hawaiian culture suffered from the intrusion of western sailors; all the resupply towns were unusually violent places.[35]

Compared with the important changes in vessel design, rigging, and whalecraft, the innovation of transshipment points appeared relatively early in the nineteenth century. Demand developed as soon as vessels began to sail to the South Atlantic, and it became more pronounced once whalers had begun seriously to hunt the Indian and Pacific Oceans. The use of resupply and transshipment ports must be dated to the 1820s; they became important elements in the story by the 1830s.

35. The first American whaler to make port in the Hawaiian Islands was the *Balena*, registered in New Bedford, Edmund Gardner, master. She arrived in the fall of 1819 (Judd 1974, 17). See Morgan 1948, 82–85, for an account of the impact of the whaling industry on Hawaiian economy and culture.

Improvements in the design of the capital stock also date from the 1820s, but the most pronounced developments did not occur until the second half of the century. During the 1850s, 1860s, and 1870s the speed with which innovations in the design of hulls, rigging, and whalecraft took place accelerated. These developments were important because there were forces at work during these decades tending to drive productivity down. For example, the quality of crews was declining. The innovations were a countervailing force, pushing productivity upward. Which set of forces was the more powerful? The question is treated in the next chapter.