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Voyaging Canoes and the Settlement of Polynesia

Sailing trials with reconstructed double canoes show that intentional settlement of Polynesia was possible.

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The development of the sailing vessel was one of the most important inventions in human history, and as a result people were able to tap unprecedented amounts of energy for a relatively minor investment in building and manning sail-powered craft (1). While the role of this innovation in the development of world communication and commerce is well recognized, I draw attention in this article to the part played by sailing vessels—large voyaging canoes—in the opening to human settlement of a huge area of the Pacific—the triangular region bounded by Hawaii in the north, Easter Island in the southeast, and New Zealand in the southwest—known as Polynesia (Fig. 1).

The voyaging canoe was perhaps the one artifact most basic to Polynesian culture, for without it there would have been no Polynesians as we know them today. According to recent archeological interpretations (2; 3, p. 226), Polynesian culture developed not in any Asian or American homeland, but in Polynesia itself. Seafarers ancestral to the Polynesians moved from eastern Melanesia to the uninhabited islands of Tonga and Samoa between 1500 and 1000 B.C. They settled there, and over the centuries the basic Polynesian cultural pattern developed. Starting about the time of Christ, seafarers, full-fledged Polynesians now, moved from these western Polynesia centers to the east to settle first probably the Marquesas Islands and then the Society Islands (the most important of which is Tahiti). From these eastern Polynesia centers adjacent islands were settled, and colonists sailed southeast to Easter Island, north to Hawaii, and southwest to New Zealand to complete the settlement of the Polynesian triangle by at least A.D. 1200. The movement out of Melanesia, the colonization of Polynesia, and indeed the opportunity to develop a unique culture in the isolation of the Pacific, would not have been possible without watercraft capable of sailing hundreds, and in the case of distant archipelagoes like Hawaii and New Zealand, thousands of kilometers across the open ocean, carrying heavy loads of migrants, food and water supplies, and the domesticated plants and animals needed to found a new colony. The craft in question were almost certainly large double canoes. Polynesians apparently favored these twin-hulled canoes for long-range voyaging over single-hull outrigger canoes because of their greater stability and carrying capacity.

Problem

But we are not sure to what degree Polynesians controlled their migration. Was the migration primarily intentional, involving planned voyages of exploration and colonization, as long assumed by leading Polynesia scholars such as Buck and Emory (4)? Or, was it accidental, involving drift and exile voyages, as proposed by Sharp (5), whose views have gained wide acceptance since their publication in 1956? According to the view that the migration was intentional, Polynesians deliberately set out on voyages to find and settle new lands, and in some cases they were able to return home to spread news of their discoveries and initiate full-scale colonization efforts. According to the view that migration was accidental, the settlement of Polynesia came about through a long series of fortuitous landfalls made by canoes that were drifting before wind and current, after having been driven off course on some short coastal or interisland passage, and by canoes whose occupants were exiled by force or choice from their homeland and were randomly seeking a new land. Although the two views overlap in that one-way voyages in which return to the homeland is either impossible or not contemplated is a feature of both of them, on the whole the views differ radically in the degree of control they assign to Polynesians in the discovery and settlement process.

Discussion between adherents of these opposing views has in large part focused on the performance characteristics of Polynesian canoes, particularly on the capacity of the canoes to sail to windward, for it would not have been possible for the Polynesians to have exerted much control over their movements unless their craft could sail against the wind (5, p. 39; 6). Doubts about the windward sailing capacity of Polynesian canoes have arisen primarily because these canoes are shallow draft vessels that lack the keels, centerboards, or leeboards that are used in many other types of sailing vessels to resist leeway. Yet, it seems likely that Polynesian canoes could sail to windward. The main path of Polynesian settlement has been from west to east, against the direction of the prevailing easterly trade winds and equatorial currents. A recent computer simulation by Levison, Ward, and Webb indicates that accidental drift voyages probably could not have accounted for the initial movement from western to eastern Polynesia, and that drifting ca-

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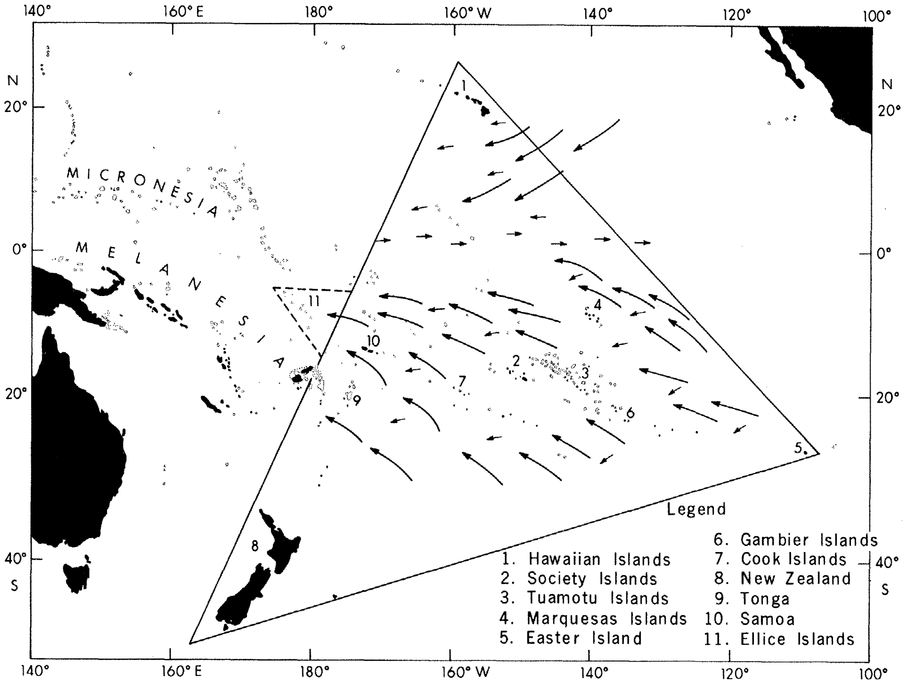


Fig. 1. The Polynesian triangle, which contains the major Polynesian islands. Some Polynesian settlements are located on small islands called "Polynesian outliers" in Melanesia and Micronesia. Long arrows indicate general direction of trade winds. Short arrows indicate general direction of dominant surface currents.

noes ". . . had no chance of reaching Hawaii, Easter Island, and New Zealand from other parts of Polynesia" (*7*, p. 42). But, as early European observers failed to systematically or precisely measure and record voyaging canoe performance, and as these craft have long since disappeared from Polynesian waters, we have no exact data on their windward ability. Recent sailing trials reported here with two reconstructed canoes provide our first firm indication of the windward capacity of Polynesian craft and allow us to understand better the probable nature of the settlement process. These trials included instrumented sails in Hawaiian waters with both canoes and a round-trip voyage of approximately 10,370 kilometers between Hawaii and Tahiti with one of them.

Method

When faced with lack of knowledge of the function or efficiency of some ancient artifact, archeologists sometimes turn to experimentation by reconstructing and testing the artifact in question (*8*). However, as artifacts are difficult to reproduce exactly, and as it is not usually possible to control all factors involved in the use of an artifact, results of archeological experiments are seldom conclusive. But they are usually suggestive, and when combined with other forms of evidence can often yield firmer bases for hypotheses about the past than if experimental possibilities are ignored.

The windward sailing capacity of ancient craft can be investigated experimentally by reconstructing and testing such craft, although I have found no report of a systematic effort to do so. For example, Needham (*9*, p. 608; *10*) reviews the inconclusive evidence of the period in which Europeans developed this capacity and calls for the use of experimentation to elucidate the problem, but can cite no relevant experiments with fully reconstructed craft. There have been a number of spectacular efforts to reconstruct and sail non-European craft over some putative ancient migration route, such as Heyerdahl's raft voyage from South America to Polynesia and a recent, but unsuccessful, attempt to sail an ancient-style junk from Taiwan to North America (*11*); but these have all been undertaken over routes with predominantly following winds, and no systematic efforts were made to measure windward performance. Bechtol (*12*), in his experiments with model canoes, found evidence that canoe models with hull shapes characteristic of various Pacific island craft could sail to windward and, on the basis of these experiments, called for the testing of full-sized canoes. In Hawaii we experimentally approached the windward sailing problem by building two Polynesian double canoes: (i) Nalehia, a 12.9-meter-long replica of a single-masted Hawaiian sailing canoe (Fig. 2); (ii) Hōkūle'a, a 19-meter-long reconstruction of a two-masted early Polynesian voyaging canoe (Fig. 3), and by sailing them in realistic ocean conditions.

The design of Nalehia, which was built in 1966, presented no problem, as it was meant to duplicate a late 18th- or early 19th-century traditional Hawaiian craft for which we had drawings, one full plan, and even fragments of old canoes to follow. But the design of Hōkūle'a, which was built between 1974 and 1975, was more difficult because it was meant to reproduce a voyaging canoe of the type that would have been in use some 600 to 1000 years ago during the voyaging era. There are no rock engravings or other depictions of ancient canoes to follow, and we could not copy designs of canoes from Hawaii or any other islands, as these would incorporate features suitable for local conditions or features recently introduced. Instead, we followed the strategy used by Haddon and Hornell (*13*) in their analysis of Pacific island canoes and selected design features general to Polynesian voyaging canoes, avoiding local adaptations and recent introductions. For example, of the two features most crucial to windward performance: (i) the Polynesian sprit sail, a triangular sail mounted apex downward, was chosen in preference to the Oceanic lateen sail because, whereas the lateen is apparently a relatively recent introduction limited in its distribution in Polynesia, the sprit sail is found throughout Polynesia and therefore probably represents the basic Polynesian sail; (ii) the semi-V-shaped hull was chosen in preference to the other common Polynesian hull shape, the rounded-U shape such as that of Nalehia, and in preference to the deep-V shape common in Micronesia but apparently not used in Polynesia. The semi-V shape, which is characteristic of Polynesian voyaging canoes such as the Tahitian *pahi* and the Tongan *tongiaki* (*14*), may be a shape especially adapted to Polynesian voyaging requirements. Its wedge-shaped bottom apparently gives it some resistance to leeway, and its bulging sides give it considerable carrying capacity, perhaps an ideal combination of features for a voyaging canoe that must make long ocean passages to windward carrying large loads of migrants, food and water, and domestic plants and animals.

Because of the lack of traditional materials and construction skills in Hawaii, both Nalehia and Hōkūle'a were built largely of modern materials and hence can provide no data on the strength and durability of traditionally built canoes.

However, I believe that both canoes perform approximately in the same manner as ancient craft because they are heavy craft (displacing approximately 2,300 and 11,400 kilograms, respectively, when fully loaded) that follow basic Polynesian designs in hull form, in spacing and lashing together of the hulls, in sail plan and rigging, and in other features.

Nalehia was first sailed in 1966, and again between 1974 and 1976. Hōkūle'a underwent sailing trials between 1975 and 1976. Formal trials reported in Hawaii took place between 1975 and 1976 and were planned for two phases: (i) short sails with both canoes in Hawaiian waters in which instruments would be used to measure sailing performance, and (ii) a voyage of Hōkūle'a from Hawaii to Tahiti and return for a realistic test of sailing performance over a route for which there is some evidence of intentional voyaging (*15*, p. 139).

Sea Trials in Hawaiian Waters

Initial sea trials with Nalehia and Hōkūle'a taught us the basic sailing characteristics of Polynesian double canoes. They are extremely sea-kindly craft, in the sense that their slim hulls cut through rough seas with a minimum of pitching and rolling. They sail well, running before the wind, reaching with a beam wind (sailing approximately 90° off the wind), and can beat to windward

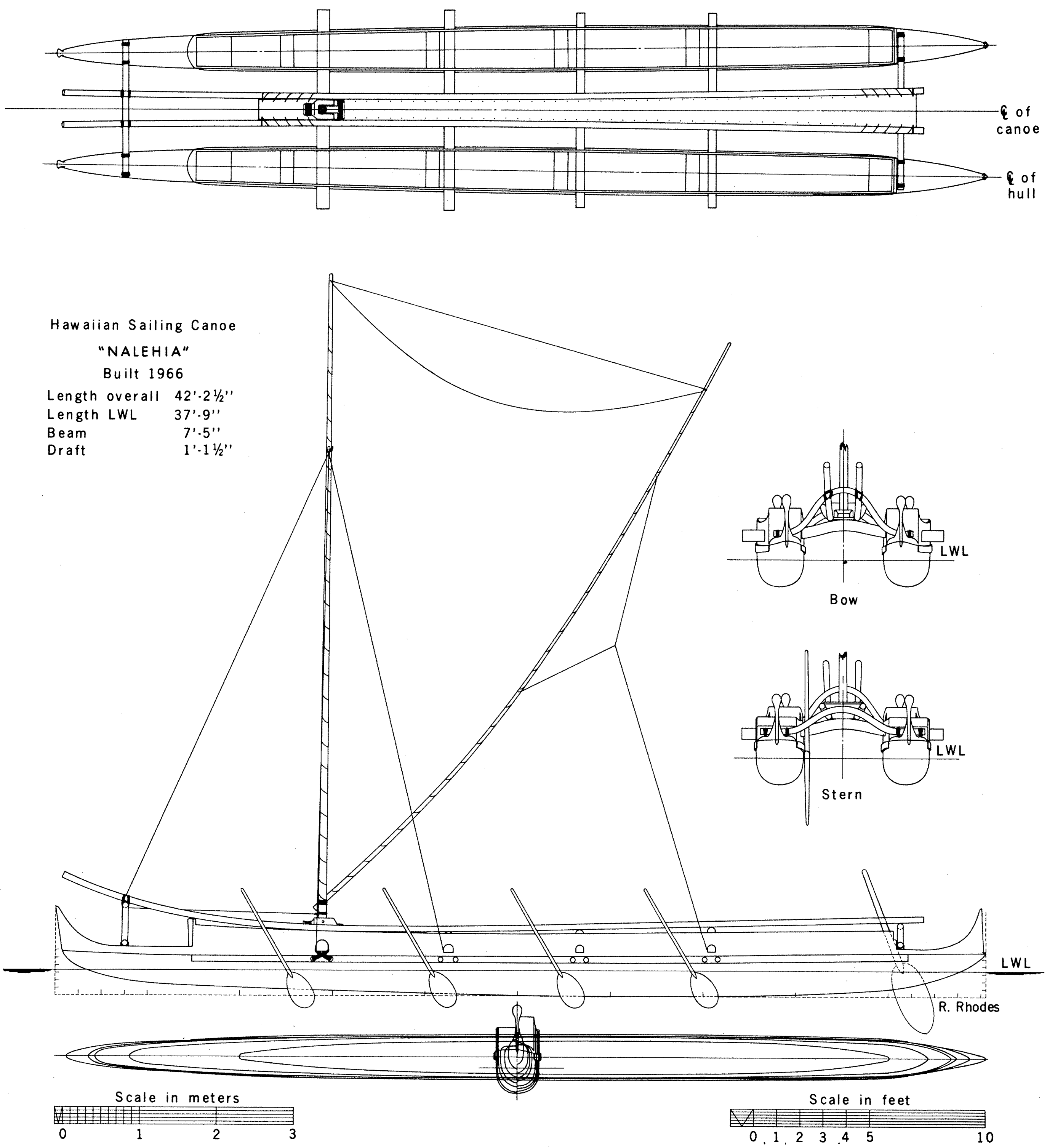


Fig. 2. Sail and deck plans, end views, and lines of Nalehia. End views omit third through fifth crosspieces.

(sailing less than 90° off the wind) to a limited though significant extent. They do not sail, however, as fast as modern catamarans, which are double-hull craft inspired largely by the Polynesian double-canoe concept and which incorporate innovations that allow them to reach speeds in excess of 35 kilometers per hour. Neither Nalehia (whose top speed is approximately 16 km per hour) nor Hōkūle'a (whose top speed is approximately 18.5 km per hour) can approach the speed potential of modern catamarans, primarily because their hulls are much more narrowly spaced than those of their modern descendants. The ratios of the hull beam (measured between the center lines of the hulls) to the water line length of Nalehia and Hōkūle'a are 0.15 and 0.21, respectively, whereas those of modern catamarans of comparable size would be at least twice that. The limited strength of wooden crosspieces and coconut-fiber lashings that joined the crosspieces to the hulls of traditional double canoes, and the consequent danger of breaking apart if hulls were too widely spaced, apparently dictated the narrow spacing of the hulls of Polynesian double canoes. This spacing reduces the speed potential of the canoes primarily because it permits only a modest sail area to be carried without danger of capsizing. Whereas Nalehia carries approximately 19.5 m^2 of sail and Hōkūle'a carries approximately 50 m^2, modern catamarans of comparable lengths carry at least 2 to 2.5 times as much sail (and much more when genoa jibs and spinnakers are added to their regular sail plans). Drag caused by bow wave interference between the narrowly spaced hulls also probably acts to reduce the speed potential of traditional double canoes (*16*).

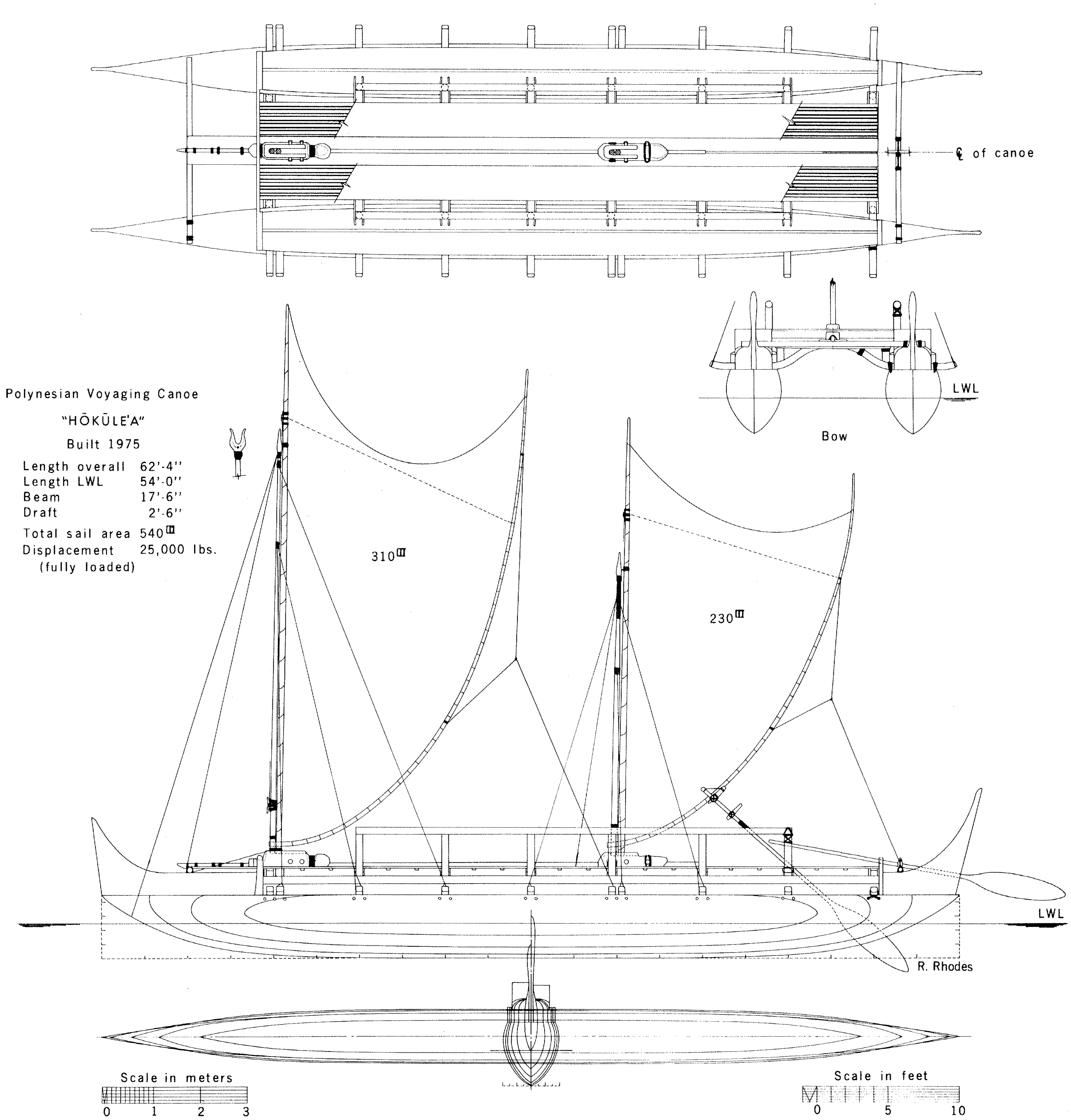


Fig. 3. Sail and deck plans, end views, and lines of Hōkūle'a. Sleeping shelters, animal cages, and stern rails are not shown.

Although generally seaworthy, the traditional double-hull design appears to be vulnerable to breaking apart and swamping in heavy seas. Swamping may have been a particular danger for a double canoe, as opposed to a single-hull outrigger canoe. Once a double canoe is swamped in the open ocean it is extremely difficult to bail out because, when one hull is emptied of water, its buoyancy depresses the other hull farther into the water.

In 1966, I estimated Nalehia's maximum practical windward performance as 75° off the wind by using a protractor to measure the angle between the canoe's longitudinal axis and the direction of the true wind (as indicated by local surface waves) at the point at which Nalehia was sailing well to windward without greatly losing speed and by subtracting leeway (estimated by using a protractor to measure the angle between the canoe's axis and its wake) from this. In 1975, E. Doran, D. Scelsa, and I were able to estimate more precisely Nalehia's performance by using instruments to measure relative wind speed, canoe speed, heading in relation to relative wind, and leeway [following the procedure adapted by Doran (*17*) to measure outrigger canoe performance], from which true wind speed (Vt), course made good to the true wind (γ), and maximum speed made good directly to windward (Vmg) were calculated. The 1975 measurements indicated that, under ideal conditions of moderate-to-strong trade winds (approximately 22 to 46 km per hour), expert sail trimming and steering, and a smooth sea, Nalehia could make good a course of up to approximately 55° off the true wind. They also indicated, however, that when winds were light, when the canoe was not properly sailed, or when rough seas were encountered, windward performance fell off significantly.

Figure 4 illustrates the effect of sea conditions on Nalehia's performance. The figure is based on data gathered off Oahu Island in the smooth waters of Ke'ehi Lagoon (K), in the partially protected waters off Waikiki (W), and in the open sea south of Diamond Head buoy (D), on 20 August 1976, a day of moderate trade winds (mean Vt was 28 km per hour). Nalehia's performance in each sea condition is indicated by curves K, W, and D. They represent Nalehia's speed at various angles (γ) off the true wind in terms of the ratio of the canoe speed to true wind speed (Vb/Vt), which is shown radially by circles of increasing intervals. Curve K represents the best observed windward performance. In the smooth waters of Ke'ehi Lagoon, Nalehia reached her maximum speed to windward (Vmg, which is represented by the tangent to the curve) at approximately 53° and her maximum speed at approximately 80°. Curve W shows that, when even small swells and surface waves are encountered, performance begins to fall off, and curve D indicates how even mild open ocean conditions cause a considerable decline in windward performance. In regular trade-wind seas of approximately 0.4 to 1.3 m in height, Nalehia reached her maximum Vmg at approximately 63° and her maximum speed at approximately 110°. Although I do not have precise data on Nalehia's performance in heavier seas, my experience in sailing Nalehia over a 3-year period indicates that Nalehia's windward performance falls off even further when seas become rougher and higher and that when the canoe is heavily loaded, as she would be for a long voyage, she is even more sensitive to sea conditions. High seas, particularly breaking seas coming at close intervals, appear to reduce windward performance both by slowing the craft and increasing her leeway.

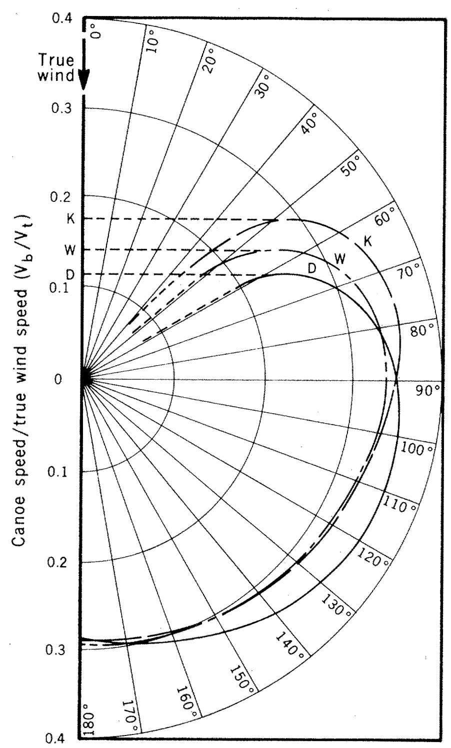


Fig. 4. Sailing performance of Nalehia in terms of course made good off the true wind (γ) and the ratio of the canoe speed to the true wind speed (Vb/Vt) based on 160 nearly simultaneous observations of canoe speed, apparent wind speed, heading of canoe in relation to apparent wind, and leeway made on the port tack on 20 August 1976 off Oahu Island. The mean observed true wind speed was 28 km per hour. Separate curves represent performance in the smooth waters of Ke'ehi Lagoon (K), in the light seas off Waikiki (W), and in the medium trade-wind seas south of Diamond Head buoy (D). Points of maximum speed directly to windward (Vmg) are represented by tangents to the curves.

Unfortunately, a swamping incident with Hōkūle'a in late 1975 and a subsequent long period needed for repairs and refitting for the Tahiti voyage prevented collection of enough instrumented sailing data to fully reveal Hōkūle'a's performance potential. However, judging from incomplete data, the following comparison of the performance potentials of Nalehia and Hōkūle'a appears to hold. Hōkūle'a is capable of sailing somewhat faster than Nalehia and of making good a course slightly closer off the wind than Nalehia. Nonetheless, like Nalehia, Hōkūle'a's performance is sensitive to heavy seas and light winds, particularly when heavily loaded, and suffers from improper sail handling and steering. It was observed by a number of us with sailing experience on other Pacific island canoes and on modern catamarans that, although Hōkūle'a could be sailed fairly close to the wind, better overall windward performance was attained if Hōkūle'a was sailed full and by, a position a little farther off the wind than the closest angle possible, at which good speed could be maintained, while still pointing fairly well to windward. Sailing full and by in moderate-to-strong trade winds, Hōkūle'a made good a speed of at least approximately 10 to 11 km per hour and a course of from 70° to 75° off the true wind.

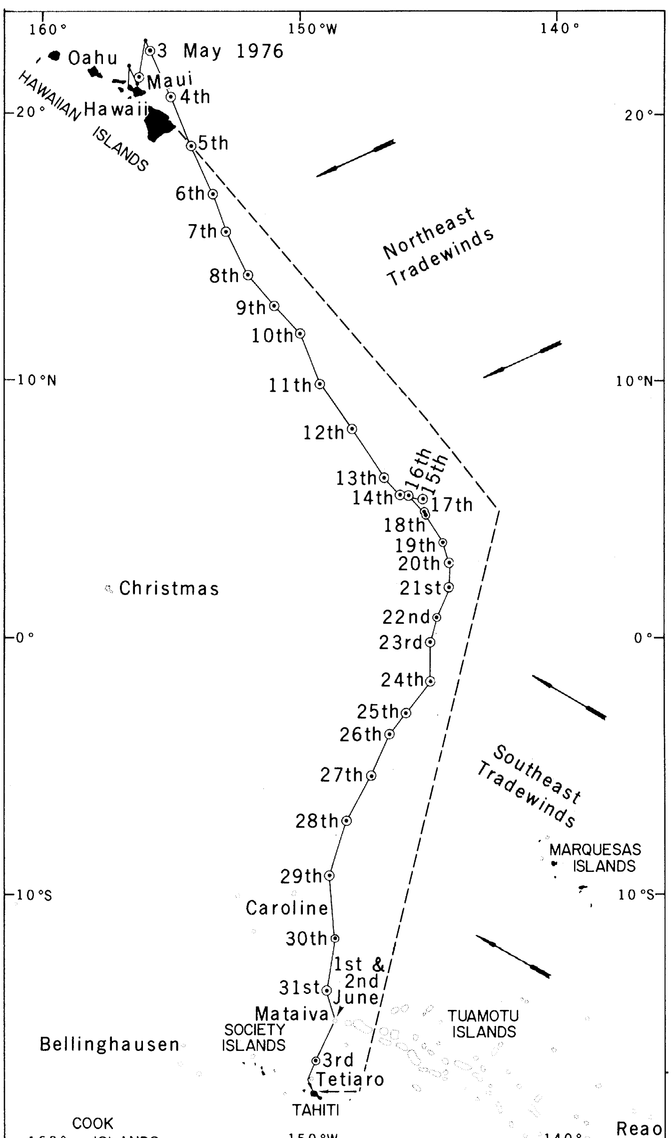
Hawaii to Tahiti Voyage

Hawaiian legends tell of return voyages from Hawaii to the cultural center of Tahiti, long voyages that must have tested the capacity of the double canoe to sustain windward sailing, for Hawaii lies well to the leeward of Tahiti. Hōkūle'a's voyage, which was undertaken with a crew of 17 between 1 May 1976 and 4 June 1976, followed a route and sailing strategy that I proposed in 1967 by plotting a wind course of 75° to estimated wind and current (Fig. 5). At that time I hypothesized that a canoe could make sufficient easting (progress to the east) against the prevailing northeast and southeast trade winds and the equatorial currents, which sometimes can move vessels 75 km or more a day to the west, to reach Tahiti by following a strategy of sailing as close as practical to the wind at all times. The projected course, which was boomerang-shaped, had three main segments: (i) the northeast trade-wind zone where a canoe would sail southeast against trade winds and equatorial current; (ii) the doldrums of the intertropical convergence zone, a shifting band of calms and light variable winds usually located just north of the equator between the northeast and southeast trade-wind systems, where southward progress would be slowed but where the strong equatorial countercurrent flowing eastward would push the canoe farther to the east; (iii) the southeast trade-wind zone where the canoe would be forced by wind and current onto a course slightly west of south. If sufficient easting could be gained in segments (i) and (ii) and loss of easting minimized in segment (iii), a canoe should make a landfall somewhere in the Tuamotu Archipelago to the northeast of Tahiti, and from there it would be able to sail easily to Tahiti.

Because we sailed Hōkūle'a to Tahiti in the Polynesian manner without compass, sextant, or other instruments, primarily by holding as close to the wind as possible and by estimating course and position through dead reckoning and observation of the horizon and the polar and zenith stars, we could not precisely measure windward performance as we had done in the previous instrumented trials. However, estimates of wind and course taken without instruments on board the canoe, plus position fixes made daily by a yacht following the canoe, allow analysis of Hōkūle'a's progress and thus performance along the route (Fig. 5).

Hōkūle'a generally followed the projected route, although somewhat to the western, leeward, side of it. Hōkūle'a made significant easting in the northeast trade winds but not as much as projected because, apparently: (i) the trade winds were farther east than expected (blowing from an estimated mean of 65° true instead of the projected 57°); (ii) speed and windward efficiency were reduced as the heavily loaded canoe (made heavier by the accumulation of seawater in the bows not discovered and removed until after passing 10°N) encountered sometimes heavy and confused head seas; and (iii) the heaviness of the bows, combined with crew inexperience, led to steering difficulties. Hōkūle'a averaged 196 km a day in the northeast trade winds, and the longest day's run was 241 km on 11 to 12 May.

In the doldrums, which stretched from approximately 6° to 2°N, Hōkūle'a alternately was becalmed and sailed slowly in



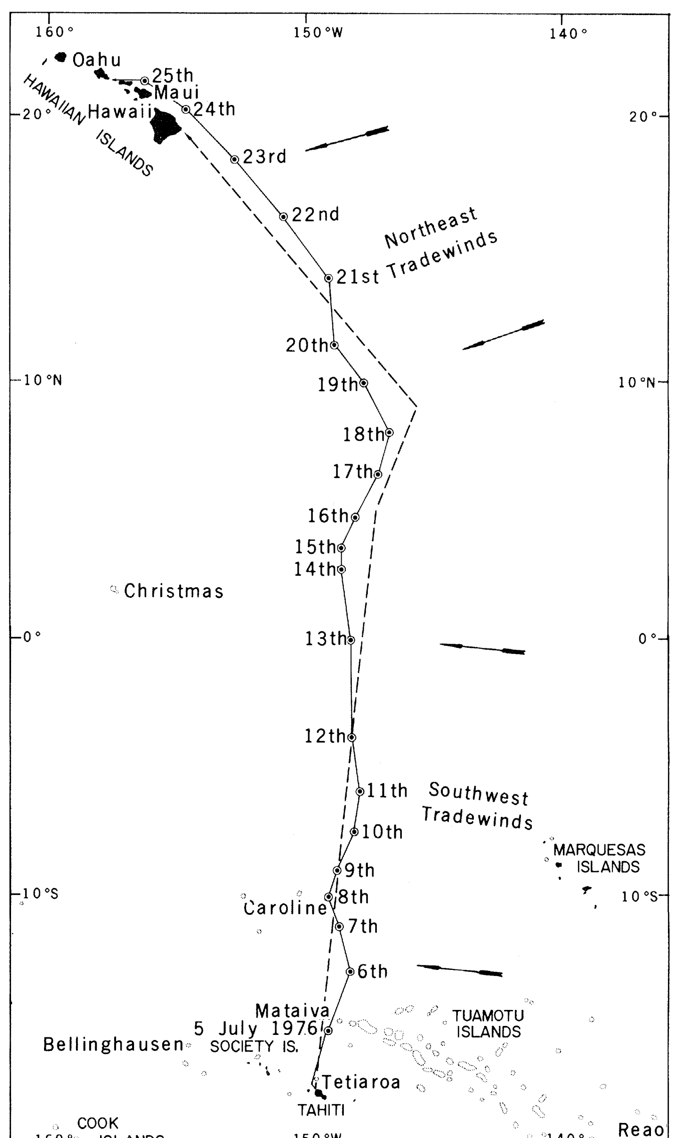


Fig. 5 (left). Projected (– – –) and actual (_____) course of Hōkūle'a from Honolula Bay, Maui, to Papeete, Tahiti, 1 May to 4 June 1976. Projected course is from Finney (*16*, p. 157). Actual course is based on noon positions (except for 2, 3, 4, and 14 May when dead-reckoning estimates are used) taken by navigator L. Burkhalter on the yacht Meotai, which closely followed Hōkūle'a. Fig. 6 (right). Projected (– – –) and actual (_____) course of Hōkūle'a from Papeete, Tahiti, to Honolulu, Oahu, 4 July to 26 July 1976. Projected course is from Finney (*16*, p. 154). Actual course is based on noon positions taken by navigators L. Puputauki and J. Lyman on board Hōkūle'a.

light variable winds for 7 days. Fortunately, as expected, the equatorial countercurrent pushed the canoe farther east to a point approximately 1375 km east of our starting point on Maui Island and to within approximately 160 km of the projected course line.

South of the doldrums, light winds reduced Hōkūle'a's windward efficiency and blew from a more southerly direction than was expected. At times Hōkūle'a was forced onto a southwesterly heading which, if held, would have taken her to the Cook Islands, well west of Tahiti. After 8°S the wind increased to approximately 37 to 46 km per hour and backed slightly to the east, allowing Hōkūle'a to sail a more southerly course directly to Tahiti. The better winds also allowed Hōkūle'a to sail faster and log the longest day's run of the voyage, of 267 km, on 29 to 30 May. At 14°S the wind backed farther to the east-northeast, putting Hōkūle'a, which was then trimmed to sail full and by automatically without the use of steering paddles or sweeps, on a south-southeast course. This heading led to a landfall on Mataiva Atoll in the Tuamotus and would have, had Hōkūle'a sailed past Mataiva, allowed the canoe to intersect the projected course line. After a 1½-day stay on Mataiva, Hōkūle'a sailed directly to Tahiti to complete the approximately 5370-km voyage in 32 sailing days (*15*, p. 148; *18*).

Tahiti to Hawaii Voyage

Linguistic and archeological research points to the Marquesas and Tahiti as the most likely sources for the population of Hawaii. While Hawaiian traditions do not preserve the origin of the first settlers, they do celebrate the arrival of Tahitian seafarers sometime after initial settlement. Sailing north with trade winds abeam in search of new lands, Tahitians probably could have reached Hawaii without great difficulty, as is indicated by a hypothetical course drawn in 1967 by plotting a wind course of 95° (Fig. 6). The return voyage of Hōkūle'a closely followed the hypothetical course, although modern navigational techniques were used, since the noninstrument navigators who guided Hōkūle'a to Tahiti were not available for the return voyage. The voyage, which was undertaken with a crew of 13, was completed in only 22 days, from 4 to 26 July 1976. Hōkūle'a averaged 236 km a day, with the longest day's run being 343 km on 12 to 13 July. The return passage was faster than the voyage to Tahiti, primarily because the winds were more favorable. Hōkūle'a was able to pass quickly through the doldrums region in 3 days, and, as Tahiti lies to windward of Hawaii, the canoe could be sailed on a reach much of the way, the most efficient sailing angle for a double canoe.

Windward Sailing and Intentional Voyaging

I conclude from the instrumented trials with Nalehia and Hōkūle'a, and the voyage of Hōkūle'a to Tahiti, that the earlier estimate based on the 1966 Nalehia trials that voyaging canoes could make good a course of about 75° off the true wind remains a valid estimate for sustained windward sailing over long open ocean passages. This is meant as a realistic, even conservative, estimate that takes into account the unpredictable behavior of wind, sea, and man. Although in ideal conditions both canoes can make good a course closer off the wind than 75°, it seems that on a long sea voyage light winds, heavy seas, human error, and possibly other factors could easily combine to limit effective windward performance to around 75°.

In comparative terms, this is a modest windward capacity, closer to that of a square-rigger than that of a racing yacht (*9*, p. 593). Nonetheless, I propose that this windward capacity is sufficient to have enabled Polynesians to intentionally explore and settle that vast region we now know as Polynesia. After Levison, Ward, and Webb (*7*, p. 60; *19*) found, in their computer simulation analysis of drift voyaging, that canoes probably could not have drifted from the western Polynesian homeland to the central islands of eastern Polynesia and then on to Easter Island, Hawaii, and New Zealand, they repeated some of their experiments, substituting sailing 90° off the wind for drifting before the wind. As their results indicate that possibly a small percentage of voyages, sailed 90° off the wind, could have made these crossings, a complete repetition of all their experiments, performed with the understanding that canoes could sail to within 75° off the wind, would probably show that a significant percentage of simulated voyages could have sailed along these major routes of Polynesian settlement. We, of course, cannot rule out the possibility that drift voyages played some role in Polynesian movement and settlement, as for example in the minor movement westwards from western Polynesia to the Polynesian islands outlying Melanesia and Micronesia (Polynesian outliers). Nonetheless, the basic data on winds, currents, and canoe performance serve to emphasize the probable intentional character of the overall Polynesian thrust into the Pacific. The Polynesians were sailors who had the craft and seamanship skills to move their frontier halfway across the Pacific against the direction of prevailing winds and currents.

But this does not mean that all voyages could have been made by sailing long slants as close to the wind as possible. For example, in normal trade-wind conditions Polynesian canoes probably could not have sailed close enough to the wind to have traveled directly, on one tack, from Tonga to the Marquesas or from the Tuamotus to Easter Island. Tacking back and forth to gain easting could perhaps have been tried, but this would have been an extremely arduous and lengthy procedure. Polynesian seamen probably waited in beginning their easterly explorations for the appearance of westerly winds which usually blow, in Polynesia south of the equator, several times every summer for periods of a few days to a week or so. Westerlies were used in historic times by Samoans, Tongans, Cook Islanders, and Tahitians for staging voyages to the east within their respective archipelagoes or to adjacent ones (*20*). Although westerlies probably would not have lasted long enough to take explorers directly to distant islands, they might have given voyagers enough of a boost to the east so that, when the trade winds resumed, a course held close to the wind would lead to a landfall. If, for example, Tongan voyagers had been able to run east for a week or so before a strong westerly, they might well have been in a position to have sailed east-northeast directly to the Marquesas once the trade winds resumed. A similar boost to the east might have led to a landfall on Easter Island. Or voyagers who happened to sail south of the trade-wind zone, where westerly winds are more common, might have been driven far enough east to have reached, once they sailed north back into the trade winds, this easternmost outpost of Polynesia. As the simulation study of Levison, Ward, and Webb includes probable wind patterns throughout the year, it reflects the effect of westerly winds but does so in a random manner and so ignores the use of them as part of a voyaging strategy. A realistic study of intentional voyaging, whether by computer simulation or other means, should take into account the Polynesian strategy of using periodic westerlies to gain easting.

An appreciation of possible climatic changes over the last 2 millennia may also be crucial to an understanding of Polynesian voyaging and settlement. Although some modern researchers have tended to discount traditional evidence, it should be noted that a century ago Fornander (*21*) analyzed Polynesian legends and concluded that, after a period of intense interarchipelago sailing, long-distance voyaging abruptly ceased at the end of the 14th century. Now some archeologists are puzzled by the fact that there is a general sameness of artifacts collected over much of eastern Polynesia and traceable to a seemingly brief settlement period, while in the succeeding period there is a marked differentiation among artifacts collected from the same area (*22*). This situation and the traditional testimony suggest a rapid dispersal of population throughout the region, followed by the isolation of the peripheral islands from the more central ones. If this did occur, the recent suggestion by climatologists that climatic fluctuations could have had an impact on Polynesian voyaging bears examination. Wilson and Hendy, and Bridgman (*23*) independently hypothesize that during the Little Climatic Optimum, a warm period beginning approximately in A.D. 450 and culminating in the period between A.D. 1100 and 1300, conditions favored voyaging. The mild trade winds, interrupted perhaps by more frequent and enduring westerly wind shifts than they are now, were ideal for long-range voyaging in their view. Moreover, they hypothesize that the coming of the Little Ice Age from A.D. 1400 to 1800 brought strong trade winds and an increased incidence of storms, which may have made long-range voyaging more hazardous and led to its decline. Although these postulated climatic changes may lack full confirmation, we cannot afford to ignore a possible relation between major weather shifts and voyaging patterns.

That many canoes were lost at sea in vain attempts to reach new islands cannot be doubted. But it does violence to Polynesian maritime history to argue, as Sharp (*5*) has done, that canoe expeditions setting out to seek land in unexplored waters were akin to accidental drift voyages because the outcome of any voyage was uncertain or because the discovery of a previously unknown island necessarily must have been fortuitous. Setting sail against the wind, or at least against the direction of the prevailing winds, requires intentional choice. While most studies of Polynesian settlement have emphasized the role of famine, overpopulation, war, chieftain rivalry, and the search for adventure in providing motivation to leave settled islands (*3*, p. 106; *24*), we should also consider the reasons voyagers may have had for setting out to windward. Polynesians would have explored to windward for at least two reasons. First, the accumulated voyaging experience of the Polynesians and of their immediate ancestors would have told them that, whereas the ocean to leeward was filled with populated islands with possibly hostile inhabitants, the ocean to windward was filled with inviting, uninhabited islands. Second, an exploring party that, after having vainly searched for land to windward or having found a new island to windward, wished to return home for more supplies or to spread the word of their discovery, would have had a good chance of returning home with a fair wind. A party that had sailed downwind, however, would have had much more difficulty returning home, particularly if supplies were low and the canoe were in disrepair, as would have been likely after a long exploring voyage (*25*).

We do not know what role was played in the settlement of Polynesia by two-way voyaging, such as might have occurred between a homeland and a newly founded colony until the colony had grown sufficiently in numbers of people, plants, and animals to be viable. Although two-way voyaging is mentioned in some Polynesian traditions (*26*), at the time of European contact Polynesians were not sailing back and forth between distant archipelagoes. The interarchipelago voyaging documented by Europeans was that between contiguous islands or groups such as Tahiti, the leeward Society Islands, and the Tuamotus in eastern Polynesia and Tonga, Samoa, and Fiji in western Polynesia. But this does not necessarily mean that there never was two-way voyaging over longer routes in Polynesia, for many factors, from climatic change to the desire to concentrate scarce personnel and resources on local development, could have discouraged the continuation of voyaging between distant outposts and the more central islands.

In addition to well-found craft, two-way voyaging requires a navigation system that enables voyagers to keep track of their course to an island and to be able to retrace that course on the return home. We know that Polynesians employed a navigation system that combined noninstrument celestial observations with dead reckoning and observations of wind, swell, birds, cloud patterns, and other phenomena. Although Sharp and Åkerblom (*5*, p. 32; *27*) have argued that because the methods used by the Polynesians lack the precision of those used by modern navigators they could not have been accurate enough to have enabled Polynesians to make round trips between distant islands, the weight of ethnographic and navigational evidence accumulated by Lewis (*28*) supports the opposite view. The recent revival of round-trip canoe voyages of over 2000 km between the Caroline and Marianas Islands of Micronesia, which are being navigated by methods similar to those once used in Polynesia (*29*), and the noninstrument navigation of Hōkūle'a from Hawaii to Tahiti (*30*) lend further support to the view that Polynesians were able to make two-way voyages over long distances. Because most Polynesian islands, with the exception of Easter Island and a few isolated atolls, are part of archipelagoes, the task of the early Polynesian navigator was made easier. The large block of islands of an archipelago, not the single small island, was the navigator's initial target. After making a landfall on any island in the group, he then could pilot his craft along the island chain to the particular island destination. On the voyage of Hōkūle'a to Tahiti, for example, the Tuamotu and Society Islands formed a screen of islands almost 2000 km wide through which it would have been difficult to pass without making a landfall on at least one island. We knew that once we sighted an island in the chain we would be able, upon identification of the island, to make our way to Tahiti, as proved to be the case.

Nonetheless, despite the apparent technical feasibility of two-way voyaging between distant islands, I do not believe that such voyaging was ever extensive. Even for Hawaii and Tahiti, which are the two distant island groups most favorably situated in reference to wind patterns for the two-way voyaging, we have no evidence that can be construed as indicating more than an occasional round trip (*31*). If two-way voyaging did occur between other distant islands, such as between Tonga and the Marquesas or Tahiti and New Zealand, where winds are less favorable for sailing back and forth, such voyages probably would have been few in number and would have been major accomplishments that tested Polynesian craft, navigational skills, and organizational ability. Two-way voyaging involving Easter Island would have been unlikely, given the extreme windward position of that lonely island and the lack of surrounding islands serving as a sizable navigational target. If, however, two-way voyaging was not an extensive feature of the Polynesian settlement experience, this does not necessarily make that settlement less intentional, as Sharp (*5*) maintains. The recent emigration of European peoples to the far corners of the world, a movement made possible by the development of modern sailing craft and navigational methods, may have included extensive back-and-forth movement between distantly separated home country and colony (*32*). But this movement was unique in world history and should not be used as a standard by which to judge whether a previous migration was intentional or not.

Summary

Sailing trials with two reconstructed Polynesian double canoes indicate that these craft can make good a course to windward up to approximately 75° off the wind on long ocean voyages. This windward performance would have enabled Polynesians to exert a degree of control over their movements that would have been denied them had they only been able to sail or drift before wind and current. Indeed, without this windward sailing capacity there probably never would have been a Polynesian people today, for in a sense they are a product of their maritime technology. Had there been no great voyaging canoes, the settlement of Polynesia might have had to await the relatively late entry into the Pacific of the European navigators. But the Pacific was the scene of early innovation in weatherly sailing canoes, and as the European navigators "discovered" island after island, they were surprised to find that neolithic seafarers had preceded them into this vast ocean realm.

References and Notes

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18. I do not think that Hōkūle'a's canvas sails and painted hulls made her sail significantly better than would a traditional craft with pandanus leaf mat sails and hulls coated with indigenous preparations. Although canvas sails are probably much more durable and easier to maintain than pandanus sails, opinions differ whether canvas sails are necessarily superior aerodynamically [T. Gladwin, *East Is a Big Bird* (Harvard Univ. Press, Cambridge, Mass., 1970), p. 96; (*15*, p. 148)]. Antifouling paint was removed from Hōkūle'a's hulls for the voyage to Tahiti, and hence they became fouled, which probably slightly slowed the canoe's speed, just as it must have slowed the speed of the traditional craft. However, because of an encounter with sharks while scraping barnacles off Hōkūle'a 3 weeks after leaving Hawaii, antifouling paint was reapplied in Tahiti. The hulls, therefore, stayed fairly clean on the return trip, and the canoe's speed was thus probably slightly enhanced.
19. Of the experiments that were rerun, the most relevant to this article indicated that on selected courses that: (i) from Samoa, 6.8 percent of simulated voyages reached the Marquesas; (ii) from the Marquesas, 8.5 percent reached Hawaii; (iii) from the Cook Islands, 61.7 percent reached New Zealand; and (iv) from the Gambiers, at the southeast end of the Tuamotu chain, a low, but unspecified percentage of voyages reached Easter Island.
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25. Canoes that sailed or drifted west to the Polynesian outliers of Melanesia and Micronesia would have been in this position [R. G. Ward, J. W. Webb, M. Levison, in *Pacific Navigation and Voyaging*, B. Finney, Ed. (Polynesian Society, Wellington, N.Z., 1976), pp. 57–70].
26. The value of legends, genealogies, and other oral accounts of voyaging has recently been questioned. D. R. Simmons [*N.Z. J. Hist.* **3**, 14 (1968)] argues that New Zealand Maori voyaging epics are, in part, late 19th-century creations, and D. Barrere [*Kumuhonua Legends* (Bishop Museum, Honolulu, 1969)] has shown that the Hawaii-loa legends of Hawaiian discovery were similarly fabricated. However, there remains a number of so far unchallenged traditions throughout Polynesia, such as those linking Hawaii and Tahiti, which, although they may not be literal records of past voyages, may reflect actual events of the voyaging era. For Hawaii, see B. Cartwright, *Bishop Museum Occasional Papers* **10** (No. 7) (1933); A. Fornander, *Collection of Hawaiian Antiquities and Folklore* (Bishop Museum Press, Honolulu, 1919), vol. 4, pp. 112–173; N. B. Emerson, *Papers of the Hawaiian Hist. Soc.* (No. 5) (1893).
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30. The noninstrument navigation of Hōkūle'a was flawed as an experiment by the unauthorized radio transmission of rough position fixes to some crew members.
31. Primarily, the legendary evidence for this is given in (*24*) above. Although R. C. Green [*Science* **187**, 274 (1975)] says that archeological evidence in Samoa and Tonga is close to demonstrating prolonged two-way contact between those groups, the archeological evidence available from Hawaii and Tahiti does not yet allow comment on two-way voyaging between these groups.
32. J. H. Parry, *The Discovery of the Sea* (Dial, New York, 1974).

33. The voyage to Tahiti and return was sponsored by the Polynesian Voyaging Society as an official Bicentennial event of the state of Hawaii. I thank H. Kane, who developed the overall design of Hōkūle'a and supervised its construction; R. Choy and W. Seaman, who designed the hulls; Capt. K. Kapahulehua (both voyages); first mate D. Lyman and navigators P. Piailug, R. Williams, and D. Lewis (Hawaii to Tahiti voyage); first mate G. Piianaia and navigators L. Puputauki and J. Lyman (Tahiti to Hawaii voyage); Capt. R. Birk and navigator L. Burkhalter of the following yacht Meotai; E. Doran, Jr., D. Scelsa, R. Sprague, and C. Yates, who assisted in the instrumented trials; M. St. Denis and R. Rhodes for taking the lines off Hōkūle'a and Nalehia; and the other crew members of Hōkūle'a, Nalehia, and Meotai who participated in the project. The 1966 Nalehia trials were supported by NSF grant GS-1244, the University of California, Santa Barbara, and the B. P. Bishop Museum; the 1975–1976 instrumented trials of Nalehia and Hōkūle'a were supported by NSF grant SOC 75-13433.