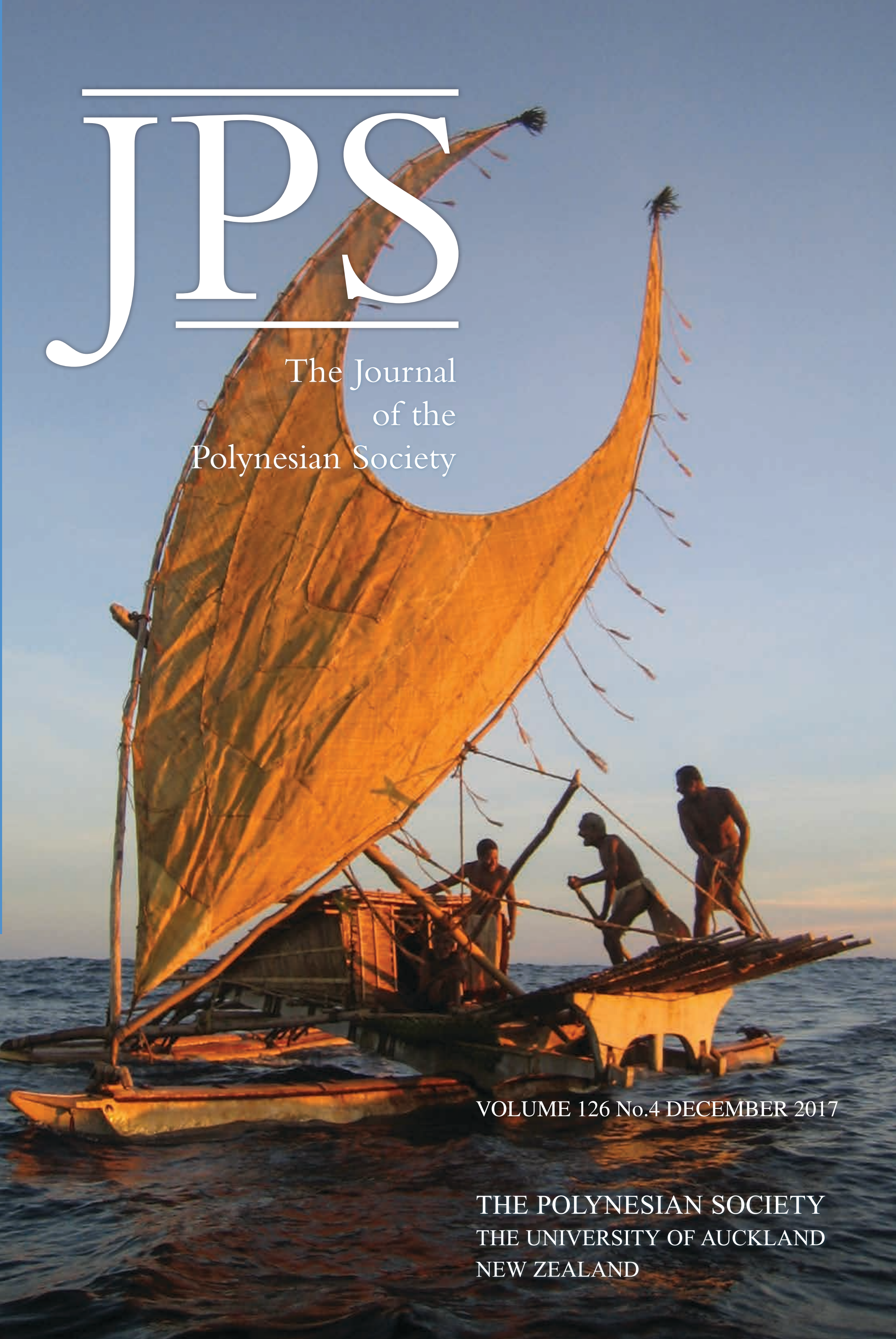
Te Laa o Lata of Taumako: Gauging the performance of an ancient Polynesian sail

Article · December 2017

DOI: 10.15286/jps.126.4.377-416

1 author:

Marianne George
Pacific Traditions Society



JPS

The Journal of the Polynesian Society

VOLUME 126 No.4 DECEMBER 2017

THE POLYNESIAN SOCIETY
THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

TE LAA O LATA OF TAUMAKO: GAUGING THE PERFORMANCE OF AN ANCIENT POLYNESIAN SAIL

MARIANNE GEORGE
Vaka Taumako Project of the Pacific Traditions Society

We know that Austronesian and Polynesian voyagers made many types of sailing craft (Clunie 2015; Dodd 1972; Haddon and Hornell 1997; Howe 2006; Lewis 1972; Neyret 1974; Rieth 1993), but we know very little about what their vessels could do. How fast did they go under varied conditions? How much did they carry? What stories and relationships did they embody? Today there are only a few fragments of ancient voyaging canoes to examine (Johns *et al.* 2014; Sinoto 1979), some petroglyphs, observations by the likes of James Cook (Beaglehole 1955), Joseph Banks (Banks 1998) and Ignacio Andia y Varela (Corney 1915: 284-87), and sketches by their artists. Some songs and stories about voyaging were recorded, and some are still remembered. However, in these there are precious few specifics of vessel design, construction methods and materials, and descriptions of how the vessels were sailed, to what purpose and with what performance capabilities (Clunie 2015; Irwin and Flay 2015). From such partial and sketchy information, some researchers have made models of what may have been ancient sail shapes and tested them in wind tunnels, in hopes of gauging which canoes could have sailed which routes, and what migrations could have been made (Di Piazza *et al*. 2014; Irwin and Flay 2015).

In recent decades the only Polynesian canoes being made and sailed using only ancient designs, materials, methods and types of tools are those of Taumako (Duffs Group) Islanders (Fig. 1) (George 1998, 1999, 2012).[1] These seagoing vessels are called Vaka o Lata 'Voyaging Canoes of Lata'. Lata is their ancestral hero who made the first voyaging canoe and sailed it to distant islands.

Nineteenth-century European depictions of canoes in the Santa Cruz Group of the Southeast Solomons (D'Urville in Dodd 1972: 135; Pâris in Rieth 1993: 114-15) are what contemporary elders of these islands recognised as being Vaka o Lata (Koloso Kaveia pers. comm., 1998; Joann Hahala pers. comm., 2000). However, these elders also observed that the European artistic renderings are vague and fanciful compared with what they know of their ancestral designs from their own building and voyaging. Contemporary Taumakoan voyagers use the same design features, materials and measurements that their elders showed them and told them about.

Journal of the Polynesian Society, 2017, 126 (4): 377-416;
DOI: http://dx.doi.org/10.15286/jps.126.4.377-416

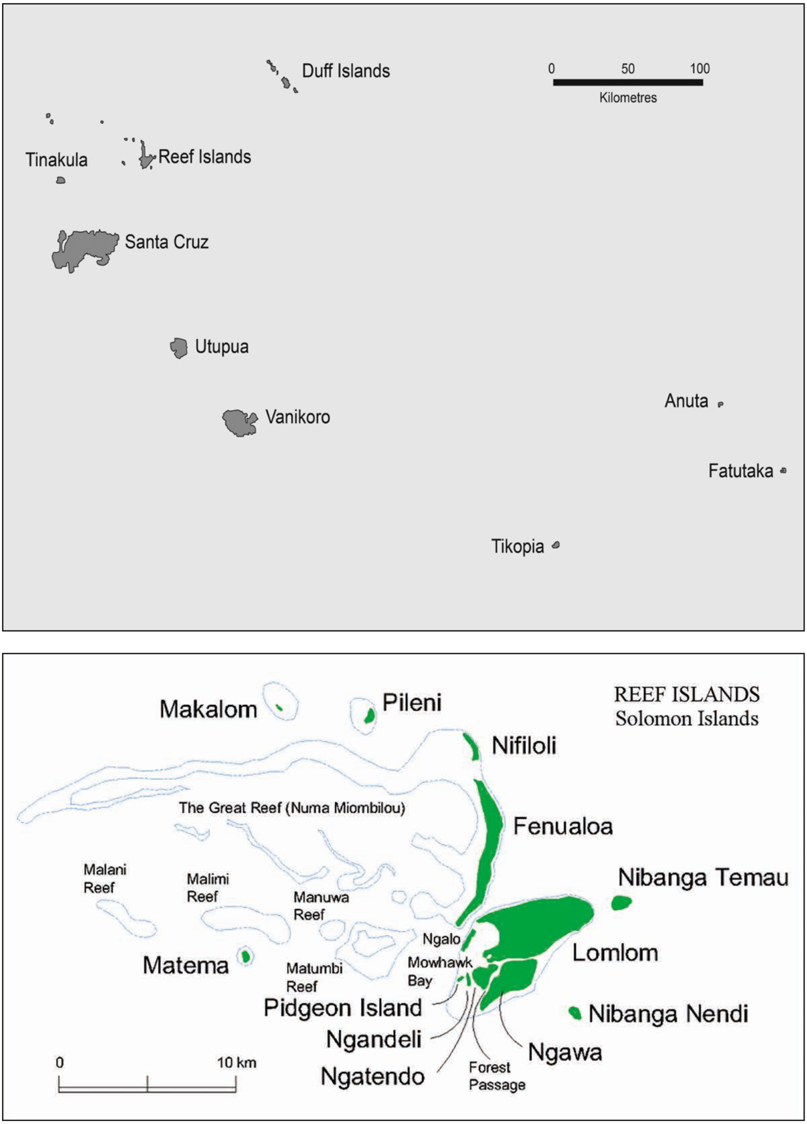


Figure 1. Maps of Temotu, Southeast Solomon Islands (top) and the Reef Islands (bottom).

Sporadically overcoming a chronic lack of money to pay for school fees and adequate food to support the labourers, Taumakoans have built several sailing vessels for training within the Duff Islands during 1996–2016.[2] They also made inter-island voyages in 1970, 1980, 1998, 2000, 2012, 2013 and 2017. We now consider how the memories and recent practices of experienced Taumakoan voyagers can help us better understand how to measure the performance of the overall vessel, and some key parts of the vessel. Taumakoan knowledge about ancient sail structures and uses, and their oral traditions and experiences as sailors, shines a light on the limits of what we have learned from recent wind-tunnel studies, and suggests possibilities we have for gauging the performance of at least one ancient sail and the vessels to which it is integral.

BACKGROUND

Vaka o Lata Origin Story

Episodes and fragments of the "Story of Lata" are told in oral traditions from Indonesia to Rapa Nui, from New Zealand to Hawai'i. Petroglyphs, such as the one of a sail at 'Olowalu, Maui (Fig. 2), show what Taumakoan chief Koloso Kaveia regarded as definitive evidence that Lata reached Hawai'i in his Vaka o Lata. Names and images depicting various Lata traditions show how the parts of *vaka* work and honour the good and bad examples set by the various characters who participated in building the first one and making voyages.

Taumakoan versions of the pan-Polynesian "Story of Lata" often start with the efforts of Lata's father to provide freshwater eels to his pregnant wife to satisfy her cravings. After killing every other eel on Taumako, he finally agrees to kill a spirit eel (*te tuna*), who instructs Lata's father how to cut up his body and put the end of his tail in a wooden bowl with water. After being orphaned, Lata suckles on this tail and grows precociously. The story goes on to explain how Lata builds the first Te Puke (the largest Vaka o Lata) with help from a friendly bird, then chooses a crew and voyages to other islands.

This story is very long, often funny and very thought-provoking. It highlights Lata's generous, clever and creative behaviours, as well as disrespectful mistakes and tricks, including one that results in Lata being unable to return to Taumako. However, Lata does "return" whenever people do what he did. The story is told when people are actually in the process of building or voyaging. Present-day crewmembers behave like, and so are, characters in the story. So are people who hear (or read) the story. A summary of the pre-voyaging part of the story can be found in George (1999: 50), and a somewhat longer version, with excerpts of several variations, are in Davenport (1968: 175-77) and Davenport *et al.* (1979: 8-35).

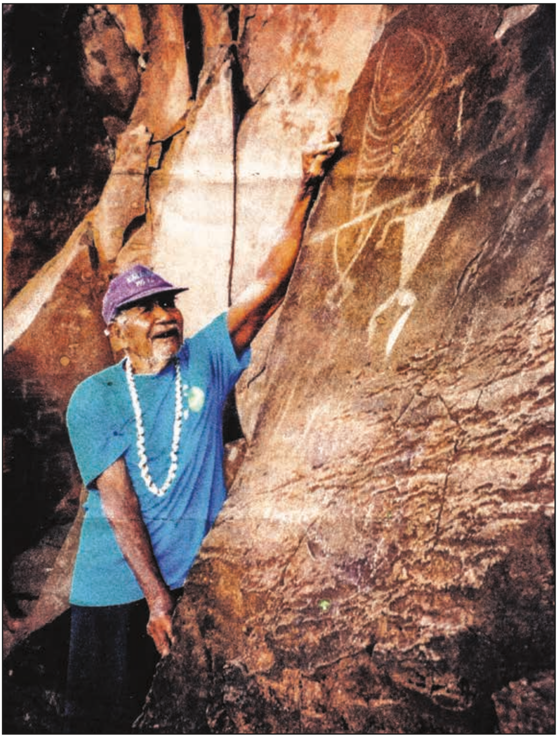


Figure 2. Koloso Kaveia identifying the sail in a canoe petroglyph at ‘Olowalu, Maui, Hawaiian Islands, as Te Laa o Lata. Photo by H. Wyeth.

Vaka o Lata Definitions, Literature, Types and Experts

The voyaging canoes that explored and colonised two-thirds of the world made many deep-sea inter-island crossings. They were capable of carrying enough people and cargo for exploration, migration and/or trade. Such voyaging canoes were sailed, not paddled, and their inter-island range far exceeded that for fishing or birding at nearby islands, such as Feinberg (1988) reported for Anutan canoes in the 1970s.

There is little written about Vaka o Lata prior to 1998. The oldest photos I know of clearly show views of two Vaka o Lata designs. These were taken by J.W. Beattie in 1906 (Fig. 3) and Haddon and Hornell in 1933 (1997). But none of these show a Vaka o Lata under sail. A diagram by Toshio Asaeda of the Crocker Expedition (1933) lacks proportionality and some details (Haddon

Figure 3. This Te Puke was built by Longopuni, a famous and long-lived voyaging canoe builder of Taumako. The photo location is in the lagoon at Vanikoro and the crew in the photo are from Pileni (K. Kaveia, pers. comm., 1997). Photo by J.W. Beattie 1906, Rautenstrauch-Joest-Museum.

and Hornell 1997 [II]: 48), as diagrams often do. Descriptions of Santa Cruz Group canoes in Haddon and Hornell are partial and often confused (see 1997 [II]: 40-50). Even more problematic, paintings of canoes at Vanikoro by Pâris (Rieth 1993: 114-15) and Dodd (1972: 135) portray the outrigger in fanciful curvatures, the crossbeams as impossibly long, the supports for the deck completely mysterious, the long tips of the sail too straight, the sail panels laid out straight in line rather than curving around the centre. Experienced Taumakoan elders, who built Vaka o Lata between the 1920s and 2008, say that the vessels in these photos are similar to Vaka o Lata and must have been Vaka o Lata. But these elders were certain that Vaka o Lata were never built with such unproportional and weird features by anyone in the Santa Cruz Islands (Koloso Kaveia, Wilson Longopuni, pers. comm., 1997).

The largest Vaka o Lata is what Taumakoans call Te Puke (Figs 3 and 4). The smaller types are called Te Alo, including the Te Alo Lili (Fig. 5; see also Figs 10 and 11), which is smaller and is paddled, or sailed, inshore. Duff Islanders are specific about what is, and is not, a Te Puke. However, the literature follows the unspecific usage of Outer Reef Islanders, Santa Cruz Islanders and others, who make no naming distinction between Te Alo and Te Puke and call them all Tepuke or Tepukei or Te Puki.[3] Outer Reef Islanders and Solomon Islands Pijin speakers often say "Puki" without the respectful article "Te". The late chief Te Aliki Koloso Kaveia, who built and sailed both types of Vaka o Lata, said, "Te Puke are like trucks", i.e., they can carry heavy loads and at least 9 to 12 people. They used to load as many as three Te Alo Lili as cargo on one Te Puke according to several elders, including the late Koloso Kaveia, the late Ini Taupea, Charles Lagapau (pers. comm., 1997), the late Joann Hahala (pers. comm., 1998) and Peter Taea (pers. comm., 2012).

During the last two centuries, the vast majority of Te Puke in the Santa Cruz Group were built by Duff Islanders: Koloso Kaveia, Wilson Longopuni, and Jonas Holani of Duffs; Joann Hahala of Pileni (pers. comm. 1998); and Peter Taea of the Outer Reefs (pers. comm. 2012). Davenport wrote that around 1920 there were at least 200 "Puki" in the Santa Cruz Islands (1968: 177). Construction of Vaka o Lata decreased with colonial suppression, the advent of economic globalisation and World War II. The last Te Puke for traditional use was built in the 1950s (K. Kaveia pers. comm., 1993).

In 1959 a Te Alo Lili was built on order by the Solomon Islands Government and sailed to Santa Cruz Island to show to a visiting duke. The duke was not impressed with its submarine hull and did not want it, so a Santa Cruz Islander acquired it (K. Kaveia pers. comm., 2005). Soon after that it was wrecked. Another Government order, this time for a Te Puke, was filled in 1980, and this Vaka o Lata was sailed to Vella Lavella. The Government took possession of it there and shipped it back to Honiara, where it sat on the seaside rotting until a cyclone destroyed it.

The Vaka Taumako Project started in 1996 and over the last 20 years three Te Puke and five Te Alo Lili were completed. One Te Puke (1998) and one Te Alo Lili voyaged from the Duffs to the Outer Reef Islands in 2012. The Te Puke made the return voyage in 2001. In 2012–2013, nine Te Alo Lili voyages were made within the Outer Reefs (see "Holau Kaveia" reports on http://vaka.org). One Te Puke voyage from Taumako to Santa Cruz Island was made in June 2017. Others are planned from Santa Cruz to Vanikoro Island and/or Taumako in December 2017, and from Taumako to Vanuatu in November 2018.

Numerous models (*nga wauwau*) of Vaka o Lata have been made over the last several decades. These ranged in length from a half metre Te Alo Lili *wauwau* to a 7 m long Te Puke *wauwau*. Some were made as traditional toys to interest small children in sailing. Others were made for sale to tourists and for display in museums, such as the *wauwau* purchased by Te Papa Museum in 1998.[4]

Since 1996 I have observed the construction of various Te Puke and Te Alo Lili. I sailed alongside a Te Puke voyaging from Taumako to the Outer Reef Islands in 1998. In 2012 and 2013 I crewed on Te Alo Lili during eight inter-island voyages of distances ranging from 3 to 80 nautical miles, and the Te Puke voyage of about 130 nautical miles from Taumako to Lata, Santa Cruz Island, in 2017. I led, and aided, Taumako efforts to document how these *te vaka* are made and sailed, including over 300 hours of video recordings, half by Taumakoan videographers.

Until now I have not written a detailed account of any part of the vessels because the makers and users of Vaka o Lata are concerned for the safety of people who do not know what is authentic and seaworthy. Experienced Taumakoan voyagers know that when the ancient specifications and standards of construction are not met, vessels can be very dangerous at sea.[5] They do not want outsiders to get hurt by using measurements taken from a disproportionate model. Key proportions and methods must be demonstrated to students and not just described. Innovations require the collaboration of experts who know the seagoing performance of each part and each lashing, the characteristics of each natural material used, and how to wildcraft (gather), cultivate, harvest and process the materials. Knowledgeable Taumakoans want their heirs to benefit from the sharing of their intangible heritage and intellectual property. They regard themselves as the ultimate authority on these designs, and they know that several design features of Vaka o Lata perform more efficiently, and more safely, than modern designs. They also know that the modern maritime industry pays for knowledge of superior technology. Taumako experts expect to be recognised and compensated fairly for proprietary aspects of Lata's technology.

Some basic design specifications for two Vaka o Lata, and especially for the sail (*te laa*) that power them, are described below. I reveal these in collaboration with the late Te Aliki Koloso Kaveia, the current directors of the Vaka Taumako Project of the Solomon Islands/Vaka Valo Association, and in accordance with the terms of the Vaka Taumako Project of the Pacific Traditions Society's research permit and mission statement and Memorandum of Understanding with Temotu Province (http:/vaka.org). I worked with and under the direction of Kaveia for 16 years, until he died in 2009. He asked me to document the voyaging knowledge for young people and to help Taumako

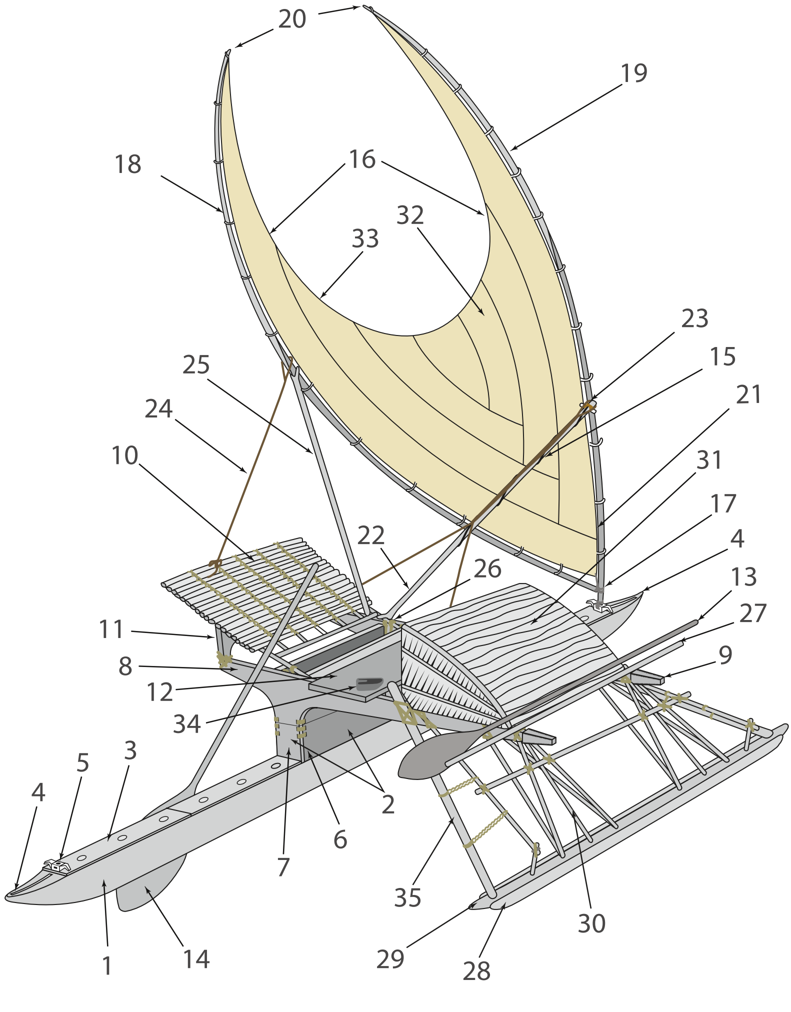


Figure 4. A Te Puke with the Taumako names for the major parts. Diagram by Daniel Jackson from drawings by M. George.

1 Te Vaka - main hull
2 Te Hano Noho - riser box
3 Te Tau - coverboard
4 Te Moamoa - birds head shape at ends of vaka
5 Te Manumanu - Te Ube bird carving
6 Te Matai - the wooden planks that sit on the gunnels and form the sides of the riser box
7 Te Taupua - the wooden planks that form the front and back of the riser box
8 Te Lakau halava - crossbeam
9 Te Pua'a - pig's head carving
10 Te Katea - leeward platform
11 Te Alunga - "headrest" that supports the highest, leeward, end of the leeward platform
12 Te Pola - carved wooden plank that is the windward platform between riser box and shelter
13 Te Foe Ama - small steering blade used on the ama side of the vaka
14 Te Foe Vaka - large steering blade used on the vaka side of the vaka
15 Te Lele - lines that raise the mast
16 Te Laa - the sail that has the shape of Lata holding arms overhead
17 Te Lango Vaka - the two booms together
18 Te Manga Iti - leeward boom
19 Te Sila - windward boom
20 Te Ukui - top sections of booms
21 Te Kawolo - bottom section of boom
22 Te Hanaa - mast
23 Te Tata - halyard (to raise sail)
24 Te Haha - sheet (line to control sail)
25 Te Kapemanga - reaching pole
26 Te Li'i - windlasses (there are 6 inside riser box, 3 forward and 3 aft)
27 Te Tokomanga - poling pole
28 Te Utongi - side float
29 Te Ama - central float
30 Te Hakatu - vertical connector
31 Te Haehale - half shelter
32 Nga Laula - woven sail panels
33 Te Hanga - boltrope inside sewn fold
34 Te Saa - oceanic bailer
35 Te Lou - main strut from crossbeam to end of middle float

Figure 5. A Te Alo Lili in low wind conditions with its “arms” in a default position. Photo by Wade Fairley.

youths who wanted to learn to do video documentation. He requested and approved all of my illustrations and required that there be ongoing video documentation and production. Since then his elderly and mature students continue to teach a new generation how to build and sail Vaka o Lata, and how to pass on the knowledge to the next generation.

Basic Design Specifications of Vaka o Lata

All types of Vaka o Lata have a massive outrigger, which is always kept to windward when the vessel is sailing. The main hull is axially and transversally symmetric (both fore-and-aft and beam-to-beam). Both Te Puke and Te Alo Lili designs of Vaka o Lata have the same hull, rig and sail shapes. The hull is dug out and topped with cover boards (*nga tau*) fore and aft of the crossbeams (*nga lakau halava*). These embody the freshwater eel (*te tuna*), which will not let go by mouth or tail unless noosed in the middle of the body. Lata suckled on the nipple-like end of the tail of *te tuna*, which is represented in the serrations carved into the ends of the crossbeams.

The main hull of a Te Puke is Lata's body. It is made from the trunk of Te Tamanu tree (*Calophyllum inophyllum*). Taumako builders prefer these trees, which grow in the high forest of their 300-metre-elevation island. The main hull of a Te Alo Lili is usually made from Te Pulopulo wood. This tree, of which I do not know the scientific name, is a stringy hardwood that is much lighter than Te Tamanu.

A riser box joins to the top of the Te Puke hull at the mid-section (Fig. 4). Four large rectangular planks make up the front and sides of the box. The box is open at "floor" and "ceiling", providing access to the otherwise watertight hull. The outside corners of the front and back (fore and aft) pieces (*nga taupua*) have an arm that seats tightly on, and around, the gunnels of the main hull. Larger, longer planks (*nga matai*) also sit along the top of the hull, forming the sides of the riser box. The leeward *te matai* is taller than the windward one, and so supports the high side of the canted leeward deck (*te katea*). Te Alo Lili have no riser box. The crossbeams comprise the fore and aft walls of the enclosed section rather than *nga taupua*. *Nga matai* are fitted to the tops of the sides of the hull.

Vaka o Lata have an Oceanic lateen rig. The sail has two long sides, each of which is supported by a boom. The windward boom (yard) (*te sila*) is supported by the mast, such that the axis of the sail cants at an angle to the hull. The leeward boom (*te manga iti*) is tied to the yard with a lashing called *te kalikau*. An Oceanic lateen sail is usually rigged so that the axis of the sail is between 40 and 70 degrees of tilt. The axis of the sail of a Vaka o Lata is not usually adjusted at lower than 60 degrees of tilt.

Like many other Oceanic lateens, Vaka o Lata are proa-rigged, which means they shunt rather than tack to change direction when heading to windward. Tacking is done by "changing sides", specifically turning the bow through the eye of the wind, and sailing on with the wind on the other side of the sail(s). Shunting is done by lowering the sail, carrying it to the other end and re-stepping it there. The outrigger is kept to windward, and the after end of the vessel is manoeuvred to windward to become the new front (bow) end. The sail is moved to the new bow. The vessel sails on with the wind still blowing on the same side of the sail and the outrigger still to windward of the main hull (see diagram in Howe 2006: 124).

Many proa rigs have masts that are permanently stepped in the middle of the length of the vessel and that lean toward whichever end of the boat is the bow. Others, like the Vaka o Lata, have a shorter mast (*te hanaa*), the foot of which is moved (re-stepped) past the midline of the vessel toward the new bow. The top leans toward the bow at an acute angle from the hull, and the windward boom (yard) of the sail is drawn to the top of the mast. The halyard (*te tata*) is drawn through a hole near the top of the mast, and ties to the yard about three fifths of the way up it. When shunting, the crotch at the foot of the mast is re-stepped onto the crossbeam (*te lakau halava*), or a structure parallel to the crossbeam (*te ouwaa*), near the new bow—so that the mast can support the yard. A reaching pole (*te kapemanga*) is also set to hold the sail as far to leeward and forward as desired.

This type of sailing rig has been called a crane spritsail (Doran 1981), an Oceanic lateen (Di Piazza *et al.* 2014; Marchaj 2003) and a "kite-sail" type of Oceanic lateen (Haddon and Hornell 1997 [III]: 46). Di Piazza *et al.* (2014) described the sail as a "triangular sail with a very large bay in it". David Lewis (pers. comm., 1993) called the same sail an "inverted, triangular claw sail" with "a deeply incurved free edge". This latter description describes the sail, not the rig. Lewis was noncommittal about categorising the rig (pers. comm., 1993, 2000). He, and the others, never saw the rig, or sail, of a Vaka o Lata in use.

A traditional unit of measurement is the length from fingertip to fingertip with both arms fully extended from the sides of the body (*te loha*). The length of each *te loha* in metres depends on the length of the arms and width of the body of the person who is measuring. Usually one *te loha* is about 1.6 to 1.8 m. Measurements will vary from vessel to vessel depending on who made them. The important measurements for Taumako builders are the proportions between parts, i.e., each part must be in the right proportion to the other parts.

The minimum length of a Te Puke is six *nga loha*, which is roughly 9.5 to 11.5 m. However Te Puke that were eight *nga loha* were remembered by elderly Taumako and Outer Reef Island voyagers. The maximum length of a Te Alo Lili is 5.5 *nga loha* (K. Kaveia pers. comm., 1997).[4]

Ideally, the main hull of Te Puke is trimmed to run about 90% submarine, so that all but the carved images of the nose, ears and eyes of the bird at the end and top of the front of the vessel (*te moamoa*) are submerged. I estimate that Te Alo Lili trim by about 30% less submarine than Te Puke. The inboard side of the leeward deck rests above the level of the top of the riser box. The leeward deck (*te katea*) cants upward at about 25 degrees, so the crew who work and rest there enjoy a relatively dry platform that offers heights above the sea ranging from about 1 m (inboard) to 2 m (outboard).

The buoyancy of the primary float (*te ama*) is added to by attaching additional floats (*nga utongi*). Two to four of these may be fitted and lashed to the *te ama,* as needed. If a main hull is not buoyant enough, *nga utongi* are lashed along the upper sides of the main hull fore and aft of the riser box. Te Puke have a shelter (*te haehale*), while Te Alo Lili may or may not have one. Both Vaka o Lata types employ the sail of Lata (Te Laa o Lata). When beating to windward in choppy or rough seas, Te Alo Lili cannot head as close to the eye of the wind (the direction the wind is coming from) as can Te Puke (K. Kaveia pers. comm.).

Remembered Voyages and Transfer of Knowledge

The most experienced older person on a Vaka o Lata is called "Lata", and usually sits on the windward deck (*te pola*) fronting the shelter (*te haehale*). This Lata may be the owner of *te vaka* or the wayfinder/navigator. The Lata control(s) who may or may not go into the shelter, who sleeps with which hosts at the destination island(s) and other voyaging protocols.

Kaveia told me that the last pre-Vaka Taumako Project Te Puke broke up in 1963 near Nifiloli Island in the Outer Reefs. In 1958–59, Kaveia led the building of a Te Alo Lili and sailed it to Lata for the visit of the "Dukie" (perhaps the Duke of Edinburgh). Kaveia also led the building of a Te Puke six *nga loha* long in 1980 and sailed it about 400 nautical miles to Vella Lavella, en route to the Pacific Arts Festival in Port Moresby. From the 1960s until 2009, the people who led the building and sailing of Vaka o Lata in the Duff Islands had themselves experienced long-distance voyaging as children.

William Davenport told me there were over 2,000 residents in the Duff Islands prior to an epidemic that occurred around 1919. Kaveia, who was about nine years old at the time, and Joslyn Sale, who arrived at Taumako on a Te Puke during the epidemic, told me that only 37 residents of Taumako survived. Today, detailed genealogies going back more than four or five generations are not remembered by Duff Islanders, but by some miracle, there was never a break in the chain of experiential knowledge of ancient voyaging arts. Kaveia's father was a master of canoe building, and he, among others, survived the epidemic. Kaveia began learning the voyaging arts by crewing on his sister's family vessel operating out of Pileni in the Outer Reefs. Until the passing of

Kaveia in 2009 there were always individuals who had built and sailed Vaka o Lata and who could go to sea and show others every skill and step. Now there are dozens of younger Taumako who can build Vaka o Lata. Two elders and one younger man have led inter-island voyages. Now one septuagenarian can still do so, and the younger man is planning to lead more voyages soon.

This continuous chain of experiential practice distinguishes Taumako builders and sailors from most, if not all, Pacific revivalists. The design of *Hokule'a*, for example, was traditionally inspired and intended to be "performance-accurate" (Finney *et al*. 1994: 50), but there is little evidence to support that assertion since *Hokule'a* and most other revivalist vessels relied on sketchy evidence of traditional designs. Also, they used modern materials and power tools, and their building and voyaging efforts were largely supported by governmental and charitable organisations rather than traditional social entities and protocols.

Experienced Taumako voyagers tell stories of Vaka o Lata that were made well over 100 years ago. Kaveia (pers. comm., 1999) said that the late Longopuni of Taumako led the building of the Te Puke photographed in 1906 by Beattie and the Te Alo Lili illustrated in Haddon and Hornell (1997 [II]: Fig. 33). Some of the most experienced voyagers of Taumako (the late Koloso Kaveia, Wilson Longopuni and Ini Taupea) and the Outer Reefs (the late Drummond Vaea, Joslyn Sale, and Joann Hahala of Pileni Island) were told that their grandparents learned how to build Vaka o Lata from their grandparents. The oldest of these nine generations of ancestors were building Vaka o Lata before the mid-1800s.The basic design of the vessels in these images appears identical to contemporary vessels.

Kaveia speculated that Te Laa o Lata (Lata's sail) was part of an innovation made by his ancestor Lata. Kaveia also speculated that when Lata made the first Te Puke, it may have been the innovation of a switch from double-hulled to single-outrigged design. However, it could be that the invention of Vaka o Lata occurred millennia earlier when Austronesian voyagers first ranged through Micronesia and Indonesia, or when Tongans were first adapting their biggest double-hulled vessels (*kalia*) to proa rig with a shortened hull and massive outrigger to windward.

Te Laa o Lata Design, Manufacture, Rig and Shunting

The overall perimeter of Te Laa o Lata forms an inverted teardrop shape. There is a large circular void in the top 40% of the sail. This void is formed by the top edges of the sail panels. The outer edge of two outer panels run the full length of the curving booms, and the top edges of all the other panels are shorter. These long, graceful members, and the area they contain, make up 40% of the shape of the sail. They are what astonish people who are accustomed to triangular or rectangular sail shapes.

According to experienced Taumako voyagers, the distinctive shape of Te Laa o Lata is “like a bird’s wings”. More specifically, it is the shape of the wingtips when nearly touching each other, such as the nearly circular shape that the forward edge of a pigeon’s wings make when lifted up above their heads in a momentarily still pose before stroking back and down. This radical positioning of its wings is done when the pigeon positions itself in the air, kite-like, before flying off in some direction or before landing. In other words, when it puts its wings in this position the wings passively act as a sail and the wind provides the force that lifts them, as opposed to the up-and-down flapping of the wings as active “engines” creating their own air flow. In the story of Lata it is the pigeon, Te Ube, who identifies the tree that Lata should cut for his Te Puke. Te Ube does this by flapping her wings, making a clapping sound when her wingtips meet above her head.

The type of *Pandanus tectorius* leaf that Taumako weavers use is tough and slightly thicker than most. It grows near the ocean and has thorns (Fig. 6). It does not grow on some islands, like Tikopia and Anuta (Koloso Kaveia, Peter Taea, pers. comm.), but is seen in Figure 5 growing at Nifiloli Atoll in the Outer Reef Islands. It is called Te Paku, which may be translated as “wild pandanus”. It is not boiled or dried prior to cutting or weaving. Two hours of sunning the leaves, or scraping them with a knife, or very briefly passing them over fire, is sufficient to soften them, after which they are sliced into strips.

Usually a sail is composed of eight panels (*nga laula*), which are woven from pandanus (*P. tectorius*) leaf strips. Taumako sail panels and sleeping mats are usually woven in a single layer (Fig. 7). Women weave the sail panels into pairs that are two, four, six and eight *nga loha* long.

Men loft (lay out) the woven mat panels to be sewn and lashed to form an elongated axisymmetric shape, with long extensions that frame at the top 40% of the shape. The ends (tips) of these extensions touch, or nearly touch, each other. Taumakoans call the extended parts of the sail “Lata’s arms” or “Lata standing with both (slightly bent) arms” (*nga lima o Lata*) or “wings” (*nga papakau o Lata*). The suggestion is that Lata is “reaching overhead to grasp the wind”.

Men sew the sail panels together. First the longest mat panels are staked out in the teardrop shape (Fig. 8). Then the other panels are laid out and weighted down in place. The panels are then sewn together side to side using double-strand twist sennit and a running stitch along overlapping or overturned edges. The matting may be stretched to fit as needed.

Each panel is about a metre wide, and the outer panels are the longest. The length of the longest panel is the same length as that of the main hull. Moving from the outside edges to the central axis of the sail, each panel is shorter than the one outside of it.

Figure 6. The variety of *Pandanus tectorius* used for sails. Photo by M. George.

Figure 7. Women and girls weaving a single-weave mat sail panel. Photo by M. George.

Maintenance of Te Laa o Lata includes periodic sunning, and wrapping up and storing in the rafters of a kitchen, where the cooking fires keep the matting from moulding or being eaten by insects or rats. If any part of the sail is damaged or rots, it is easily repaired. If rain wets a sail it will be soaked in seawater before drying in the sun. A well maintained mat sail should last ten years (Koloso Kaveia, Peter Taea, Moses Memuana, Joann Hahala, pers. comm., 1999), which is the same length of time that Dacron cruising sails can last.

The sail is tied to a boom with two-metre-long ties (*nga vakavei*) that are looped through the outer edge of the sail. *Nga vakavei* are much longer than needed to tie a knot so that they attract or "tempt" wind (*tapa matangi*), and they serve as one type of decoration on the sail (*te kapapaka*).

In the top 40% of the sail, and along the inner edge of the arms of the sail, a circular shape is created (*te hanga*) with a rope that is the same length as the outer edges of the entire sail. The tops of the inner six sail panels are cut to fit the circular shape and then folded over the rope. Thus the rope becomes a boltrope. The pulling and shaping of the boltrope and sail panels continues until a shape appears that is like the upper lip of the mouth of the shark (*te dama pakeo*). Then the folded edge is sewn to the sail. This hem forms an overall shape like the full moon (*te kaha mahina*).

The shape of the lower 60% of Te Laa o Lata is an upside down curve-sided triangle that narrows about 0.3 m from where it is lashed near the tack end. In the centre of the middle part of the triangle is the area that Taumako sailors call "Lata's belly" (*te tokomanga*). *Te tokomanga* is the image of the sail pouching forward in a bowl shape when moderate to strong winds blow from the quarter or further aft of the vessel so that the wind hits the sail at 70 to 90 degrees angle of incidence. *Te tokomanga* is also the name of a long stick that is used to pole a vessel over a reef. Taumakoans invoke this image to describe a powerful, driving force.

The windward boom (yard) is stepped into the shallow, circular divot (about 2 cm deep), called *te manumanu*, in the back of a carving of Te Ube. Te Ube is the specific forest bird who helped Lata build the first Te Puke. The bird on any *vaka* is more generally called *te manumanu*, and is located on both ends of the main hull. The Te Ube carving is lashed to the top of *te manumanu.* Within the hull, the "teeth of Lata bite" the "legs" or base of Te Ube, which provides a secure foundation (step) for the mast.

The lowest few centimetres of the tack of the sail are usually narrowed by being lashed tightly around the bottom of the mat panels before being tied down to the tack joint of the yard and the boom. The overall tack angle of the sail is about 85 degrees.

Near the tops of the "arms" the curve increases, forming an inverted teardrop shape at the upper perimeter of the sail. Theoretically, the tips of the arms touch each other in the centre. The curve of each boom fits the curve of the outside edge of the sail. This curve is pegged out at the start of the lofting process (Fig. 8).

Te hito toi is the name of the two-boomed rig of Te Laa o Lata. Each of the two booms is made from flexible saplings that have been scarfed and lashed together with braided sennit. Each has grown in a gentle curve that matches the curve of the outer edges of the sail. The top piece (*te ukui*) is smaller in diameter and more flexible than the longer one it is lashed to (*te kawolo*). This scarf and tie is called *te lango vaka*. If there is a strong, sudden wind in the sail, such as a strong squall, the end piece will bend over and spill the air out of the sail. The tree for *te ukui* is named Te Ngifanda. The tree for *te kawolo* is called Te Tsoa*.* *Te sila* is the yard and *te kawolo* is the boom. *Nga tau lili* are ropes that tie *te sila* and *te kawolo* to the tack of the sail.

The Vaka o Lata sail rig can lean forwards and backwards and to either side, and can twist. The mast height is adjusted by tightening or loosening its twinned backstays (*nga lele*). The bottom end of the yard (windward boom) sits in (steps at) a shallow ball-joint, which allows it to lean and revolve freely.

Figure 8. Laying out inner panels after staking of the longest outer panels. Photo by M. George.

The mast is raised to a roughly 40 degree angle and secured in this stationary position by tightening the two stays (*nga lele*) that are attached to it. The halyard runs through the top end of the mast, raising or lowering the yard and securing it to the mast. Like a crane, the mast does not move when the halyard (*te tata*) is pulled or slacked to hoist or lower the yard/sail (Fig. 4).

The rig of Vaka o Lata differs from most others in that the mast is not stepped in the centre of the hull. Tongan, Fijian and Micronesian vessels that fly Oceanic lateen sails have relatively long masts that are stepped in the centre of the hull. The relatively short mast of a Vaka o Lata is stepped off-centre—nearer the end of the vessel that is currently the bow, but within the central third of the length of the vessel. The mast is moved and re-stepped every time the vessel changes ends (shunts).

When shunting, one crewperson releases the halyard while another crewperson, who has walked out onto the bird's-head bow (*te moamoa*), un-steps the sail from Te Ube's back and guides the tack forward. Another person or two receive the top ends of the sail and booms as they fall aft towards the deck. The sail bearers turn and face toward the house (*te haehale*) and carry the bottom end of the sail and booms over the roof to the other end of the canoe, which is now to be the new bow. The sail and booms are made of materials that are light enough so that one strong person can do it. Others will help guide the structure over the shelter, and another will walk the tack end out to the new bow. One or two others lift the mast to the new bow end of the shelter and step its forked base onto one of the structural members that support the leeward deck.

The leeward head of the sail is controlled by a sheet (*te haha*) and a reaching pole (*te kapemanga*). This pole holds the leeward boom outboard and forward. The position of the pole can be adjusted to hold the sail at a desirable angle of incidence (to the wind). Adjustments can be made to change the camber in the sail as well as to prevent it from flopping back and forth in uneven seas or winds.

A TECHNICAL ANALYSIS OF SAIL PERFORMANCE

Camber, Leading Edges, Deformability

The sail matting can stretch out when the wind is strong enough, and then return to a tighter weave when the wind reduces. So, the tack angle of Te Laa o Lata varies with the camber in the sail, which depends on wind and sea conditions, how high the mast is raised, where the base of the mast is stepped, how far the boom is held out by a reaching pole, and how tightly that same boom and area are held in by a sheet (a line controlling the leeward boom of the sail). The base of the yard can stand near vertical (90 degrees), or can be raked forward or to leeward at 80 degrees or more. The camber and the tack angle are determined by the curved leading edge of the yard, the tension of the boltrope, the strength and angle of the wind in the sail and the placement and tension of the sheet(s).

Te Laa o Lata has an aerodynamic "radical delta-wing" shape, which is an extreme and curvilinear extension of the shapes of swept-back, delta-wing kites, hang-glider sails and aircraft. This shape has preoccupied designers of high-performance jets, cars and powerboats since the 1930s. Flying-wing and blended-wing designs increase speed and efficiency. Still, as yet no commercial planes have so radically aerodynamic a shape as Te Laa o Lata.

If radically swept-back delta wings fly too slowly they succumb to drag and stall. Swing-wing aircraft shape-shift to perform well at both high and low speeds. The airfoil assumes a delta shape to go fast and shifts to a more traditional spread-eagle (fixed-wing) shape for stability during landings and take-offs (Hansen 2009: 111, 217-18). The arms of Te Laa o Lata are far more flexible and curvilinear than the swept-back wings or the wing extensions that usually comprise delta shapes.

Another factor in how efficiently a sail engages airflow is the hydrodynamic character of the vessel. The sail of a Vaka o Lata is supported by an outrigged vessel, and its attitude to the wind is supported and stabilised by both the hull in the water and the outrigger on the water. The outrigger floats are buoyant enough to ride lightly on the surface of the water, which avoids creating drag, but also provide enough support to keep the main hull upright. The result is a very stable structure that spans waves and swells and reduces rolling.

The crossbeams of a Vaka o Lata sit at least a metre above the sea surface. So seas pass below them, and above the submarine hull. Thus, the trajectory of the vessel is not subject to the frictions and wave forces that a wave-breaking vessel encounters. SWATH (small-waterplane-area twin hull) designs have long been used in military, yacht and ferry vessels. Greater stability makes it easier to keep the sail at a favourable angle of incidence. Sail efficiency is also optimised by strategic positioning of the weight of crew, passengers and cargo.

The yard of Te Laa o Lata is stepped in a fixed position, but it does rotate at least two centimetres one way or the other in its step. This rotation of the yard rotates the leading edge of the sail and causes twist in the sail, which changes the camber. Also the yard is free to lean more fore or aft, to one side or the other. Changing the position of the mast changes the uprightness of the yard and the sail.

The camber of Te Laa o Lata changes as the position of the "arms" of the sail auto-adjust to wind and sea conditions and the booms change position relative to each other. The camber of the upper sail changes when the arms of the sail flex or bend. Also, the materials themselves have strengths and flexibilities that result in multi-variant changes in camber and sail performance.

The strips of sail matting that comprise the very long, thin "arms" at the top 40% or more of this sail are supported by a relatively rigid curving boom on their outside edge. They do not have enough width to develop camber no matter which way they are curving, extending or leaning. The top edge boltrope is flexible in itself, but it is held in its circular shape under tension, because its outer edges (Lata's arms) are tied to the semi-rigid booms. When the booms flex or straighten, the boltrope is loosened or tensioned. Movement or stretch in the arms of the sail may change the camber, or the shape, elsewhere in the sail.

The angle and the shape of the "arms" change to accommodate the wind angle and strength. Twist in the top third of the sail is introduced mostly by the curve of the boom tips as they respond to wind. The curve in the windward arm is gradual enough that vortex lift stays attached all along that leading edge. C.A. Marchaj (2003: 161-2) theorised that "vortex lift works by capturing the vortices generated along the leading edges of the sail, keeping them attached to the surface and retarding the stall".

In the realm of jets, US Navy aerodynamic engineers call the type of wing that adjusts to take advantage of the strength of the wind a "variable camber leading edge airfoil system" (http://www.google.com/patents/US4040579). In the realm of sail-driven craft, kites and windsurfer rigs have booms that bend and load (deflect with wind) in line with the centre of effort (CL) of the sail. Loading occurs proportionally (rather than inversely) to the ability of the sail to capture wind force. So when sailing to windward, for example, the leading edge of the sail creates vortices that the following edge builds upon (like the second goose drafting behind the one flying in front).

When the wind comes from forward of the beam, or abeam, on a Vaka o Lata, the curve in the leeward "arm" of Te Laa o Lata straightens up vertically, and falls back—outboard and out of the plane of the windward arm (Fig. 9). The leeward arm curves over so that the inner (medial) edge of that arm of the sail becomes a windward edge. When that happens, the stiffness or laxity of the new leading edge would depend to some extent on the rigidity of the boltrope/folded mat structure (*te hanga*) between the arms.

With regard to sail performance, we wonder if the shape and position of the leeward arm prevents the leading edge of the windward arm of the sail from creating as much lift as it would have if it were alone—or if the leeward arm is itself generating lift with its inverted leading edge. If so, is the lift it creates greater than the drag it creates? It is also possible that there are complementary interactions between the two arms that create more lift and/or decrease drag, as the windward arm creates vortices that increase the capacity of the leeward arm.

In very light winds the body of the sail can hang slackly, and the leeward "arm" leans forward. It can twist so much that it presents its face to the wind.

Figure 9. Te Laa o Lata in 20 knots of wind, making camber, at the 1997 launching ceremony. Note that the windward edge is curled and the leeward edge has straightened. Photo by Jim Bailey.

In that configuration the reversed leeward arm may be driven as if it were a square sail. I have only seen this happen in less than 12 knots of wind, which is barely enough wind to tempt Taumako sailors to go to sea. With 12 knots of wind or more, when the vessel is on any point of sail from hard to windward to a beam reach, the top section of the leading edge (windward "arm") is driven back into a deeper curve. Then the leeward arm stands up more vertically. The leading edge arm is dominant in creating lift, and the leeward arm should not disturb the airflow over the windward arm. The leeward arm appears to conveniently move out of the plane in which the windward arm is operating (Fig. 10).

In the case of strong gusty winds the windward arm may curve over at more than 60 degrees. When there is an overpowering gust, such as uneven winds of a squall, the top section of the boom bends sharply and disarms the airfoil. The sail, in effect, reefs itself. The saplings at the top section (*te ukui*) of the booms are selected for their ability to return to previous shapes as well as their degree of flexibility: that is, they take the right degree of curve for particular amounts of wind force, and then come back to their previous

Figure 10. The two "arms" of the sail of a Te Alo Lili in different positions. The leeward head curves to right (leeward) and the windward head curves to left (windward). Photo by M. George.

shape. They do not bend completely over unless a gust is too strong for safe operation (self-reef). If sailors see that the wind will be too strong, they will untie the sail from *te ukui.*

The entire sail is slack when there is very light wind (8 knots or less), and the "arms" of the sail either stand straighter than usual or slightly splay forward or back out of the same plane. This is what we see in numerous photos when crewmembers have put up the sail to show it to a dignitary or to accommodate photos when there is less than 10 knots of wind and not really enough to sail (Fig. 11). The arms appear to stretch up straighter (stand up more vertically) and lose much of the circle-closing curve that was their original form when lofted. The slight curve of the booms and the greater curve of the upper pieces of each boom also become straighter when the sail is not tied tightly enough or is not well fitted to the booms.

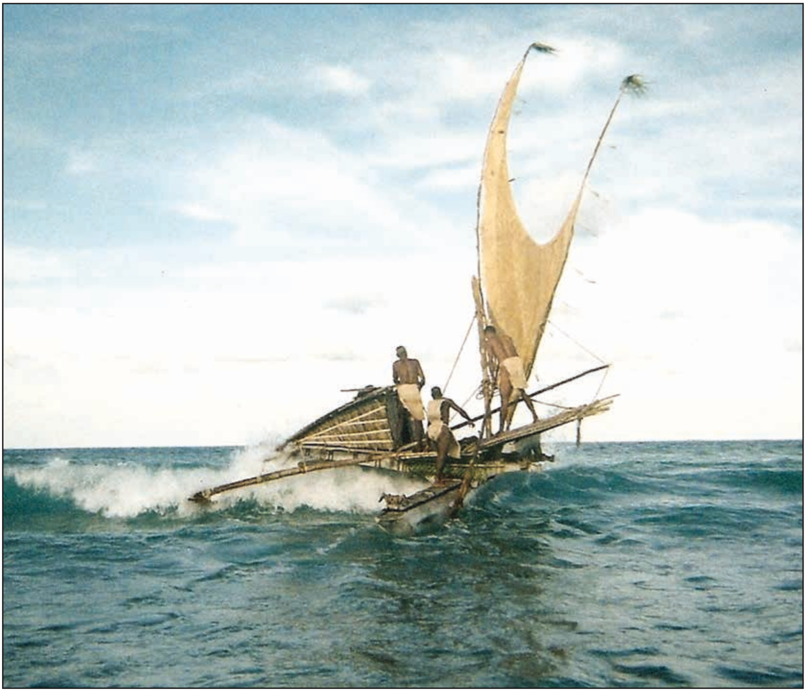


Figure 11. Wind blowing the sail of a Te Alo Lili from behind, and both arms more straightened. Photo by H. Wyeth.

With 15 knots of wind, camber begins to happen in the "belly" of the sail—the centre part of the roughly triangular shape that is located below the "arms". In 12 to 13 knots I observed half a metre of camber in the "belly". It pops out into a bowl shape and stands well proud of the body of the sail. Experienced Taumako sailors want to see the belly appear because, they say, this happens when the performance of the sail is maximised (K. Kaveia, Moses Memuana, pers. comm.). I have rarely, and only fleetingly, seen the sail heading nearly downwind in a strong wind. No photos of it were taken when it happened.

If the vessel is heading downwind and the wind is light to moderate, then both "arms" lean forward and both become leading edges. When the wind is blowing from the beam, or forward of the beam, then the windward arm is the primary leading edge (Fig. 9). I was told by those who sailed the Te Alo Lili from Nukapu to Nifiloli that when the "belly" distended radically in those very strong winds, both arms of the sail elongated slightly and bent back toward the centre of the vessel. They said it seemed that the wind was redirected down to the belly by the arms. In light air conditions there is no "belly" in this sail. Vertical folds form as the sail matting is pulled by tension between its attachment points at the top ends of the booms and at the tack. When there is enough wind in the sail it begins to take a more functional airfoil shape. In the case of Te Laa o Lata the best shape is virtually flat in light airs and billowed (bellied) out in stronger winds. Thus Te Laa o Lata has elastic deformability in response to both more and less wind force. In moderate to strong winds the weave of the mat sail stretches and forms the "belly". The belly shape is several centimetres deep. In light winds the weave of the sail stays tight and flat.

Elastic deformability and mobility of the rig are major features of the design of Te Laa o Lata. The materials that the sail and rig are made from are chosen for just those qualities. The stretch and give of natural materials contrast greatly with the stiffness and tension of modern materials and designs. There is a virtual lack of stretch in sails made of conventional synthetic sailcloth materials. Dacron, for example, is either too stiff or not stiff enough, since when it wears, it deforms into a "baggy" shape that will not reform to its prior shape. Thus, it cannot adjust to such significant advantage in varying wind strengths and points of sail. David Lewis observed that Pacific Islanders prefer mat sails over cloth or rice bag sails for racing performance because woven mat sails are faster (pers. comm., 1981). Aerodynamic experts know that dimpling on the surface of aircraft increases lift by thickening the boundary layer, which inhibits stalling. That boundary layer decreases the separation of vortex lift from the wing or body of the aircraft. The increase in boundary layer occurs because of the rough texture of woven pandanus mat.

Multi-dimensionality and Interactions, Stability and Airflow

There may be other ways the "belly" interacts, or coordinates with, the "arms" at the top of the sail. The movements and elastic deformability of each part may somehow reinforce the others so overall performance of the sail is enhanced. This possibility can be investigated by measuring performance when the belly and the arms are in various positions.

The camber of the lower 60% of the sail changes substantially when there is moderate to strong wind. That is, the camber in the "belly" increases radically while the camber of the narrow "arms" increases a little bit. In moderate winds the sail has the more closed-tips, teardrop shape into which it was lofted. With stronger winds the arms straighten, and the tips move outward from the centre axis.

Because the width of the "arms" is very thin and the boltrope stiffens the inner curve of the moon shape, the arms do not "belly out" much. Rather, they appear to present two leading edges—one by each arm—and these may produce lift by virtue of the vortices that they draw up them as they curve. Powerful vortices occupy the leading edge of both the arms after the fashion of delta-wing shapes. It might be that the belly produces a lot of backwash turbulence and the arms provide the structure to siphon it off.

Te Laa o Lata is one of several Pacific sails that have very prominent tips at the top ends of the sail. The Vanuatu wing, Micronesian, Fijian, Tongan and Samoan Oceanic lateen, and Hawaiian (all symmetrical) and Tahitian (asymmetrical) types have been photographed or drawn with their upper corners coming very close to each other, producing extreme camber (such as the petroglyph that Kaveia saw). *Lakatoi* (or *lagatoi*) sails of Papua New Guinea (PNG) have the radical delta wing, with thin long "arms". All of these form a symmetrical, and almost full-circle crescent shape, when sailing. Photos of *lakatoi* with sails working show the upper corners close to each other producing more camber (Fig. 12). These major changes of camber, twist, shape-shifting and the combination of shapes designed into Te Laa o Lata point to the need for measurements that will clarify the following: (1) what angles of incidence and what configuration of the "arms" and "belly" produce what camber, and (2) whether the top and bottom of the sail work separately or in collaboration, and how this affects performance of the overall sail.

According to experienced Taumako voyagers, the fastest points of sail for Vaka o Lata are beam reach (side wind to the vessel) through downwind (wind from behind the vessel). Steering a Vaka o Lata downwind often requires two steering blades. A large steering blade (*te foe vaka*) is used on the leeward side of the main hull, and a small steering blade (*te foe ama*) is used on the outrigger side of the hull. The steersperson must avoid being "caught aback"—letting the wind get on the backside of the sail—which could destabilise the vessel enough to result in it capsizing. But Taumako steer close to the edge. I have seen the Vaka o Lata sailing 175 degrees off the wind for hours on end, and the incidence (angle) of the wind on the sail very close to 90 degrees. However the wind speeds at those times were generally less than 12 knots and the seas were not rough.

The sail on a Vaka o Lata is set with the reaching pole and the sheet acting as adjusters and preventers. The pole holds the leeward boom out further and more securely than would be the case if only a sheet were holding it out. Both are secured at the leeward end of the leeward deck. The sheet is either held in hand by a crewmember or tied into a slipknot, with a crewmember standing by to free it. The lazy sheet may also be secured elsewhere to leeward to aid in positioning the sail. If the sail is caught aback, the reaching pole and the sheet(s) keep the full force of the sail from lying against the mast until the halyard can be released and the sail lowered.

I observed Vaka o Lata keeping a more stable course in a seaway than mono-hulls. The track of the mostly submarine hull is less disturbed by surface chop and steep waves than a wave-breaking hull would be. With less rolling and yawing of the vessel, the more constant the productive engagement of wind and sails is. Another the factor affecting stability on a Vaka o Lata is the speed of the vessel itself. Proa-rigged (shunting) outrigged vessels are known for coming to high speed from a dead stop very rapidly. Submarine hulls are much faster through the water than wave-breaking hulls. A Vaka o Lata cruises at 10–15 knots, which is twice the speed of a wave-breaking mono-hull, such as my gaff cutter with 15 knot fair winds and moderate seas (pers. obs.).

As previously noted, the outrigger is designed to have enough buoyancy to skim over most seas. But it also allows seas to sweep over the *te ama/te utongi* assembly and pass between the various small diameter attachments without unduly dragging the vessel sideways. When seas work between two hulls of the same length, the stresses on the crossbeams and the need for powerful steering sweeps is extreme. When Vaka o Lata sail with a side wind in steady seas, the outrigger is not stressed, and steering may be achieved by sail adjustments and weight distribution alone.

The "arms" on Te Laa o Lata are very mobile and comprise a significantly larger proportion of the sail than the extended tips or claws of any other Oceanic lateen. The ideal airflow of a Te Laa o Lata may be radically different than what we know of other sail shapes. Bermudan sails have a single head (top corner that the halyard attaches to) and a long luff (leading edge) that is rigged on a straight up and down and supported by a permanently positioned mast or forestay. The foot (bottom edge) is shorter than the luff or leach (after edge) and is usually cut more or less horizontal to the deck of the vessel.

Sails with straight leading edges stall when the wind angle to the sail is about 60 degrees. By contrast, when the wind angle is more than 55 degrees of incidence to Te Laa o Lata, the yard begins to curve more. The curvature keeps the vortex lift attached along the leading edge of the sail. In other words, the bottom 60% of the curved and flexible booms and the upper 40% of the even curvier and more flexible "arms of Lata" bend into angles that keep the vortices attached to the leading edge of the sail, which keeps the sail performing. All parts of the sail and rig of Te Laa o Lata stretch, move and adjust independently. These movements may be complementary in ways we do not fully understand.

PERFORMANCE CHARACTERISTICS

Three contemporary reports of the speed, wind and sea conditions and points of sail held by Vaka o Lata during recent voyages give insights into their overall performance, and beg for research to clarify what the vessels are capable of. The first is from interviews with the crew and the captain of a vessel that paralleled the Te Puke. The second I observed from escorting the Te Puke in my own gaff cutter. The third is from interviews I conducted with crew of a Te Alo Lili.

1) In 1980 a Te Puke 12.5 m in length was observed by the captain of a Government ship for several hours during a voyage from Santa Cruz Island to San Cristobal Island (Captain Peter of the HMS *Butai*, pers. comm., 1996). The motor vessel matched the speed of the Te Puke at 10 knots in 8–12 knot winds on a broad reach (wind from the side and behind the beam) for several hours. Taumakoan sailors call any side wind *te fonu* or *te fona*, whether the wind is coming from ahead of the beam or from behind the beam. After the ship left the Te Puke, the main steering blade broke. They reshaped the bulk of it and re-lashed it to the shaft (Koloso Kaveia, Moses Memuana, Jonas Holani, pers. comm.).
2) In 1998 I escorted a 10.3 m Te Puke that was sailing from Taumako to Nifiloli, Reef Islands. We were both sailing as close to the eye of the wind as possible with no excessive leeway (crabbing). I made many visual observations paralleling the Te Puke and following in its wake. I compared our wakes, our sails and a compass. With GPS I confirmed that my vessel made only 65 degrees off the wind, while the Te Puke appeared to sail at better than 60 degrees off the wind with no crabbing. The wind was 6–12 knots and the seas moderate, though choppy (Captain's Log, 23–24 September 1998).
3) In 2013 students of Chief Jonas Holani of Taumako, including his son Ambrose Miki, Harry Mawae and Ini Bala Taea of Nifiloli, and Chief Jonas

> himself, sailed a 9.8 m Te Alo Lili from Nukapu Island to east Nifiloli Island in very rough seas, with strong side currents and winds estimated to be over 40 knots. Ambrose Miki wanted to see what the *te vaka* was capable of in such strong conditions. Using his wristwatch, Miki timed the voyage from when they cleared the reef at Nukapu until they reached the beach at Nifiloli. Sailing the distance of over 22 nautical miles (if travelled in a straight line) took an hour (Miki pers. comm., 2013). They made this voyage with the wind on the quarter (*te haka ino*). Nevertheless, they sailed into the lee of islands five times to rest and shunt. The total distance they sailed was closer to 44 nautical miles, and the total rest time was about 15 minutes. So excluding the time they were not sailing, they averaged about 15 knots, and they were sailing in conditions that other vessels normally would never venture forth in.

According to Miki, they sailed toward the Duff Islands until they reached the southern edge of the great reef (Te Akau Loa). Then they shunted and sailed to the lee of Motununga Islet, where they shunted and sailed to the lee of Matema Island, where they shunted and sailed toward Pileni Island. In the lee of Pileni they rested for eight minutes. Then they sailed toward Duffs again and reached the lee of Fenua Loa Island (near Tuo Village). They shunted there, rested about two minutes, and then sailed to Nifiloli. The voyagers saw this passage as a fulfilment of their dream to sail a Te Puke as it should be sailed—fast and fearlessly, "the way Lata did it".

Sail Dynamics and Wind-Tunnel Tests

The ability of the "arms" to take a variety of shapes could increase the overall sail performance significantly because the arms comprise a large proportion of the overall sail shape. When sailing downwind, how could Te Laa o Lata capture more wind force (achieve more lift that is not overcome by drag) than it does when reaching? Do both "arms" become two leading edges rather than one when sailing downwind? The shape and position of each part of the sail changes with different strengths of wind. As the "belly" of the sail takes different shapes, it pulls the booms into different configurations. Alternatively, the arms of Lata may intensify the lift produced by the belly, and how it works may chance on different points of sail.

In the Nukapu to Nifiloli account above, the "arms" were observed to be interacting with the "belly" in that the belly distended so greatly in the strong wind that the arms pointed back at the stern of the vessel, and the *te kawolo* to *te ukui* joint did not collapse at the base of the arms. The sailors observed that "the arms appeared to gather the wind into the belly" (Ambrose Miki pers. comm., 2014).

The top 40% of Te Laa o Lata is qualitatively different from any other sail except *lakatoi* (Fig. 12). Some images of *lakatoi* sails show longer, taller bellies and proportionately shorter arms than Te Laa o Lata. Thus the proportion of "arms" to "belly" on Te Laa o Lata may be bigger than the proportion of arms to belly on a *lakatoi* sail. If the arms are a smaller proportion of the sail than the belly, then *lakatoi* sails may be less dynamically multi-dimensional than Te Laa o Lata, since the shape-shifting design and the lift and drag created by various moving and stretching parts of the latter would play a larger role in its performance. But in any case, the *lakatoi* sail is rigged on a double-hulled vessel, which is difficult to tack. So even though the shape of Te Laa o Lata is similar, the coast-wise, barge-like performance that *lakatoi* are expected to render is different.

No seagoing comparisons have been made between the performance of any such long-armed sails on any points of sail in the same wind and sea conditions. Wind-tunnel and tank testing with multi-dimensional shape and

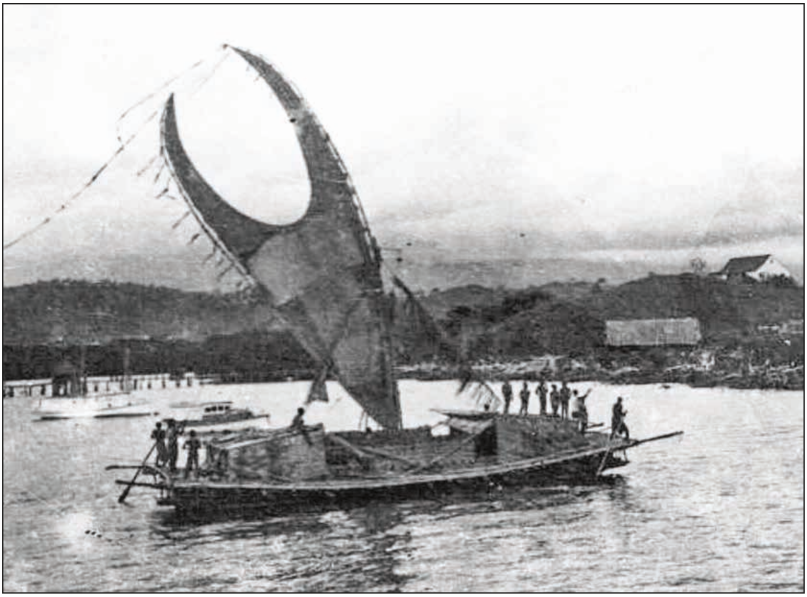


Figure 12. Papua New Guinea *lagatoi* sails with camber. Note that the body of sail (the undivided part that is under the extended arms of the sail) is longer than the body of a Te Laa o Lata. Photo by an unknown public servant under Hubert Murray, Papua, 1955.

flexible sails allow comparisons if enough of the performance factors are measured. The size of a shape that can fit in a wind tunnel or a tow tank is often a small fraction of the size of the sail or hull of a full-sized voyaging canoe. The models must be grossly simplified, but also must be true to the shapes of full-sized craft and exhibit the behavioural characteristics of the materials they are made of. If one does not know enough about how a design functions then the simplifications may eliminate key parts of the design.

C.A. Marchaj's (2003) wind-tunnel tests showed that delta-wing sails, made of modern sailcloth, on fore and aft rigs captured more wind force on side wind and downwind points of sail than Bermudan triangle sails. Marchaj hypothesised that the greater efficiency is caused by vortex lift generated along the axis of the delta-wing sail rather than by crossways airflow. Marchaj observed that what he called "crab claw" sails, and what is usually called Oceanic lateen sails, are not driven only by crossways airflow but also by the auto-adjusting curve of the leading edge, or edges, that keep the vortices attached. But Te Laa o Lata is not just a canted-over triangle. It is a much more complex and flexible shape. Marchaj did not test a delta shape nearly as radically long in the "arms" as Te Laa of Lata. Furthermore, no one has tested a delta shape at more radically downwind points of sail that experienced Taumako sailors celebrate.

Wagner (2012) and Di Piazza *et al.* (2014) were the first to publish tests of a shape more approximately like Te Laa o Lata, undertaking preliminary and comparative tests on a variety of sail shapes. Di Piazza *et al.* intended for one of their shapes to be like Te Laa o Lata, calling it the "Santa Cruz" type. The dimensions of this model were taken from measurements of what they thought were scaled paintings, diagrams or photos (pers. comm.).[6] Wagner was not aiming to create a scaled model of the Taumako sail shape. He was experimenting with aerodynamic shapes in search of a more efficient sail, and one of his shapes was similar to Te Laa o Lata. Both researchers were surprised that their models which were most similar to Te Laa o Lata performed best overall of the models they created.

All ten of the Di Piazza *et al.* models were made rigid, as epoxy forms with uniform twist and camber, whereas Wagner's model sail that was most similar to Te Laa o Lata was not rigid and changed camber. He made his model from spinnaker cloth with wooden battens for booms and a brace that held the tips from diverging from a single plane. Serendipitously, Wagner noticed that the sail performed better without the brace, which led him to suspect that the sail was meant to operate in a variety of shapes rather than in one fixed shape.

Di Piazza *et al.* (2014) and Wagner's (2012) work shone a light on the question of how theories of sail performance would explain the superiority of the shape similar to Te Laa o Lata. However, neither of their models was informed by how radically the parts of the actual Te Laa o Lata change shape. Both Wagner and Di Piazza *et al*. lacked detailed information about the deformability and flexibility of the materials, or about the rigging and vessel design of any of the types they tested. Wagner's model sail was not in scale with an actual Te Laa o Lata. Wagner's model had shorter, thicker arms and a smaller "full-moon" void between the arms than did Te Laa o Lata or Di Piazza *et al.*'s "Santa Cruz*"* model.

Di Piazza *et al.* standardised the camber of the airfoils, scaled the sails from measuring 2D photos and made rigid models that were 0.5 m tall. In their diagram of the ten sail shapes they tested, the "arms" on their "Santa Cruz" type are more flat and vertical than Te Laa o Lata. They lack the convex, graceful, almost completely circular curve to the inner and outer edges of the arms that Te Laa o Lata has when there is moderate to strong wind in the sail.[7]

Nevertheless, both Di Piazza *et al*. and Wagner found that their sail shapes most approximating Te Laa o Lata tested superior to all others when sailing on close reach to downwind headings, and at least a 55-degree angle of incidence. It was not in the scope of Di Piazza *et al.*'s research (not enough funding) to explore why this was the case, while Wagner was only able to follow up minimally. Also, Di Piazza *et al.*'s "Santa Cruz" type presented special problems that Wagner did not experience.

Nine of the Di Piazza *et al.* (2014) models were tested in a wind tunnel with the wind speed of 25 m/sec. As is normal in wind-tunnel testing with a less-than-full-sized model, the wind speed must be too fast for normal sailing in order to get the right proportion of boundary layer. But Di Piazza *et al.* found that at 25 m/sec. the "arms" of the "Santa Cruz"–type model created too much turbulence to make any measurements. So they reduced the wind speed for that particular sail shape, and no other, to 20 m/sec., which introduces questions regarding the comparability of the "Santa Cruz"–type model with the nine other model types. The turbulence may have occurred because the arms on their model were too straight and/or too upright or because the model sail was rigid; or it may have been for both, or other, reasons.

Siegfried Wagner decided that wind speeds of 15 m/sec. were adequate for testing all his models. In preliminary testing Wagner noticed that the model shaped like Te Laa o Lata performed best when it was leaned over so that the symmetry axis of the sail was 70 degrees to the wind. Wagner figured that since it is aligned flow that creates the boundary layer that dominates the performance of Bermudan sails, his Te Laa o Lata–like model at 70 degrees had too little boundary layer for it to work like a Bermudan sail. Wagner concluded that with a shape like Te Laa o Lata, a vortex system dominates over the boundary-layer mechanism when the airflow over the sail is aligned more horizontally.

Marchaj's (2003) wind-tunnel tests showed that shifting the verticality of the sail axis (aspect ratio) and the angle of incidence shifted the ratio between two mechanisms—boundary layer and vortex. Wagner (pers. comm., 2015) believed that when Te Laa o Lata is leaning slightly forward when sailing downwind, the long flexible "arms" and the two leading edges are drawing vortex lift into play over the whole sail rather than just the leading edge(s). Wagner wonders whether what he observed for his "Marchaj-shaped" model might be "true for other sails". In 1994 he wrote to me: "This (more horizontal) position proved very strong for the sail [graph 23, page 22, Marchaj of 2003]. I could imagine that if 'Te Laa o Lata' is tipped over a little bit to leeward on a downwind run then it could perform in a similar way."

Di Piazza *et al.* assumed that a Vaka o Lata cannot be sailed more nearly than 20 degree from dead downwind heading without an increase in drag, because the vortex lift along the top of the forward edges of the sail would stall. Di Piazza *et al.* followed Marchaj in testing the sail downwind, with the leading edge leaning to leeward at various angles ranging between 10 and 70 degrees. Wagner tested those angles as well as an almost fully horizontal axisymmetric angle. Wagner speculated that at a lean of 70 degrees and more, both the two leading edges of the sail draw the vortices up their side of the sail. If there is primarily vortex lift, rather than boundary-layer lift, happening when the leading edges of Te Laa o Lata are leaning forward at a 70 degree angle, and the axis of the sail is at 90 degrees to wind, then this might account for why Kaveia and other experienced Taumako voyagers said that the best point of sail is nearly dead downwind.

Reasons for these differing results could be clarified by measuring the airflow on the "arms" and "belly" at various points of sail, angles of rig and angles of incidence. But testing sails on downwind headings is the most challenging of tasks in a wind tunnel—even if the sail is an immobile form. As Di Piazza stated in a 2014 email to me, "measuring interaction between the heads would take additional wind tunnel work with the heads at different controlled angles" or "visualization of the turbulence with some smoke or lasers." She also noted, "Furthermore, it would be best to do this with full size and real sails—that stretch, twist, and change camber radically. To do this with rigid sails would mean making a whole series of them with varying twist in each head, not to mention in each belly."

However, Wagner (pers. comm., 2016) suggested that by testing Te Laa o Lata as a multi-dimensional and elastic shape we might find that the sail has different capabilities than have been measured to date: "Maybe the sail needs this (more) 3D shape to function properly. It could be that if the sail is made in the right shape with a flexible sheet, it would show these good strong-wind performances also in light airs". Wagner also observed that the flexible wooden booms on his Te Laa o Lata–like model were turning inward with strong wind. So initially he decided that it was necessary to brace the "arms" to keep them in a more 2D shape. When Wagner noticed that the performance of the sail was better when the arms were allowed to move, he hypothesised that the movement of the booms is necessary to the full performance of the sail (pers. comm., 2017).[7]

Wagner was concerned about the danger that this shape could produce too much power in strong winds. He noted, "The auto-reefing effect [of Te Laa o Lata] is dependent on the flexibility of the booms that support the arms, and the strength of wind required for the booms to bend over far enough to auto-reef" (pers. comm. 2014).

It is worth noting that gauging the strength and angle of wind required for the auto-reefing effect in Te Laa of Lata is a relatively simple matter. Measurements could tell us what strength and angles of wind it takes to trigger this automatic safety mechanism of an actual sail and rig. Another important measurement would be the elastic deformability of the sailcloth in various parts of the sail. Where, and how much, the weave of the sail mat/camber of the sail deepens can be measured. How much and where the booms bend, and how this changes the camber of the sail, can also be measured. Wind tunnels were developed to measure the comparatively stiff and inflexible materials and shapes of modern planes, cars and sails.

The results of wind-tunnel tests of a shape similar to Te Laa o Lata surprised both researchers. Wind-tunnel tests are only as good as the model being tested. Until now we can only guess what the differences in test results would be with a traditionally made and proportioned shape-shifting model of Te Laa o Lata, or by testing the real thing. Because of the expense of tank and tunnel testing, sail shapes are not usually tested in combination with the rig that positions and supports it when the shape is actually sailing. Furthermore, the sail and rig are not usually tested in combination with the hulls, or hull and outrigger(s), that they support and move. Knowing more about how an ancient vessel was constructed and operated helps one make a more appropriate model. Testing the sail, rig and hull simultaneously allows overall measurement of vessel performance, i.e., the combination of hydrodynamic and aerodynamic factors that make the vessel work. It also allows measurements of the movements and interactions of parts of the vessel.

Wind-tunnel tests have shown that when non–Te Laa o Lata shapes sail downwind the apparent wind shifts to the rear of the vessel, and the lift produced by sails of vessels that have one leading edge decreases by the value of the apparent wind. So if the apparent wind is 10 knots when the vessel is on a windward heading, then the total lift of the vessel will decrease by 10 knots when the wind comes from behind. Measuring the lift and drag relationships of Te Laa o Lata sailing downwind can confirm whether vortex lift along the axis of the sail makes the sail more efficient.

When wind-tunnel models have varying camber and the rigs are adjusting to change the airflow over various parts of the sail, measurements can be taken on both the “arms” and the “belly” of the sail on various points of sail to reveal if there is interaction between the arms and belly. Such measurements should also be taken under various sea and wind conditions, with the sail at various angles of incidence and points of sail. Measuring these variations would help us gauge how the parts, and the whole, of this airfoil works.

If we measure performance factors and interactions of the uniquely Vaka o Lata combination of sail shape, rig and mostly submarine hull, and the role of various positions and proportions between the sail, the hull and the outrigger, then we could begin to establish the role of various parts of the vessel in the productivity of the sail. By making simultaneous measurements of the water flowing around the hull and under and through the outrigger, and then correlating those measurements with those of the sail and rig, we could quantify the role of vessel stability.

Can we do all this in a wind tunnel with smoke, dyes and better models? Or would it be more productive to attach small air-pressure sensors and/or lighted telltales to the sails when they are in use at sea, and take photos of them to signal performance under various conditions? GPS and anemometer instruments aboard both the canoe and an escort vessel could record wind speeds, vessel speeds, headings and course made good, while the motivations, plans, models and strategic decisions of the voyagers can be documented.

* * *

To gauge the performance capabilities of Te Laa o Lata, the aerodynamics of the sail should be measured in terms of the multi-dimensional, dynamically shape-shifting structure that it is. If the measurements are taken on a model, then the plasticity, shape and proportion of the parts of the model should be correct. But the fact that some Taumakoans still make and sail Vaka o Lata today presents an opportunity to gauge not only the aerodynamic performance of an ancient Polynesian sail but also the hydrodynamic performance of an ancient Polynesian vessel. Measuring the performance of dynamically changing and proportionally correct models in tunnels and tanks may be more complex than measuring the performance of a real sail and vessel when they are sailing in various wind and sea conditions. Furthermore the real strategies and methods of sailing them can be observed. The unique opportunity to gauge the performance of an ancient Polynesian vessel should be taken advantage of quickly because contemporary Taumakoan voyagers experience political, environmental and financial stresses that could stop them from continuing to build and sail these vessels.

ACKNOWLEDGEMENTS

I am grateful to the late Te Aliki Koloso Kahia Kaveia, Te Aliki Jonas Holani and Heu'ionalani Wyeth for sustained documentation collaborations; Heu'ionalani Wyeth, Dieter Ludwig, Renate Westner, Steve Kornberg, Jan Tenbruggencate and Mike Kaminskas for discussions of content and editorial assistance; Simon Salopuka and Ambrose Miki for translation, content collaborations, and editorial assistance; and the late David H. Lewis, Ben Finney and C.A. Marchaj for discussions regarding issues and methods of evaluating performance of sails and vessels. Anne Di Piazza, Erik Pearthree and Geoff Irwin are thanked for correspondence regarding their research in early drafting of this article, and C. Siegfried Wagner for comments on a later draft. The National Science Foundation funded research during the 2007–2008 field seasons, and the Pacific Traditions Society, Terry and June Causey, Glenn and Jane Goldsmith, and Annica Foundation offered crucial support during this research. Daniel H. Jackson assisted with diagram illustrations and design collaboration, and Heu'ionalani Wyeth, Jim Bailey, Wade Fairley and the Auckland War Memorial Museum gave permissions to use photographic images.

NOTES

1. Perhaps there are some voyaging canoes in the Lau Group that are still using pandanus mat sails.
2. Prior to a 1970 photo of a Te Alo taken by then Government officer James Tedder (pers. comm. 2015), I know of no photos of Vaka o Lata located in the Duff Islands. But all the Vaka o Lata in 20th-century historical photos were taken in the Duff Islands (Kaveia, Longopuni, Joslyn Sale, pers. comm.).
3. Taumakoan builders and sailors of Te Puke insist that respect be shown by using the article *te* when naming Te Puke. Furthermore Taumako language speakers strongly prefer that the articles *te* or *nga* be used before any noun, even if an English-language article, such as "a" or "the", has already been used before the noun.
4. According to Te Aliki Kaveia, the 7 m vessel on display at the Folk Museum in Berlin since 1962 is too short to be a Te Puke, and does not have the requisite riser box. According to the builder of that vessel, the late Wilson Longopuni, it is a Te Alo Lili, not a Te Puke (pers. comm. 2005). The 6.8 m long model of a Te Puke in Te Papa Museum was made by a person who had never made a full-sized Vaka o Lata, nor ever made a voyage on any Vaka o Lata. He called his creation a "Te Puke", but the experienced builders and sailors of Taumako call it a model (*nga wauwau*) because the length of the main hull is too short, and also the sail and rig are ill-proportioned and misplaced, such that the vessel could not sail in even a light breeze without pitchpoling—the bow plunging into the sea such that the stern is thrown forward and over the bow—which I witnessed happening in Taumako Lagoon in 1998. In 2011 this same man hired others to make the parts of a second 7 m canoe that he also advertised as a "Te Puke". It was shipped to Honiara for the Pacific Arts Festival in 2012, then partially lashed and offered

for sale. The builders were never paid and the hull now rots in Heritage Cultural Park across the street from Solomon Islands Museum.

5. Te Aliki Kaveia and other experienced Taumako builders and voyagers were very concerned about the misrepresentation of a couple of Taumako-built creations that are now in museums. They regard themselves as the heirs of Lata, with complete knowledge about how to build and sail Te Puke and other Vaka o Lata. William Davenport wrote that the people of Taumako were the most expert builders and the people of the Outer Reefs were the most expert sailors (1968: 146, 174-75). Many Outer Reef Islanders agree, but many Taumakoans do not. Both agree that Lata did both. Te Aliki Kaveia and his crew sailed a Te Puke to Vella Lavella in the Western Solomon Islands and Kaveia sailed a scow to Port Vila in south Vanuatu, which is further in either direction than the celebrated navigator Basil Tevake had done.
6. Number 5 of a "Santa Cruz sail" in Di Piazza *et al.* (2014: 11) shows a slight point in the bottom middle of the "bay" edge of the sail. There was no such point on the model of this sail type, just as there is no such point on Te Laa o Lata. The point is a glitch in the diagram (Di Piazza pers. comm., 2016). Di Piazza *et al.* did not identify from which photo or artwork they took their measurements or proportions.
7. German anthropologist and circumnavigator Renate Westner made this summary of Wagner's work: "Wagner took four sail models of nearly the same unit of square measure in a relation of 1:5 (=0.3 m²) to the original sail size … The shape of the 'optimum crab claw sail' was roughly the shape of a Taumako sail. The wind speed was 15 meters/second … which translates to 2 on the Beaufort Scale for a boat in the original size. The sails were made from spinnaker cloth (see photo page 8 of Wagner). The crab claw sail was constructed with angular spars and with a cross brace of wood to be able to test the sail in various angles. In the wind tunnel he tested the power of the transverse axis and the power of the resistance of the leading edge angle from 0° to 90°" (pers. comm. by email, 2017).

REFERENCES

Banks, J., 1998. [Arranged by B. P. Sandford]. From the transcript of "The Endeavour Journal of Joseph Banks, 25 August 1768–12 July 1771". 2 volumes. Website (http://www.sl.nsw.gov.au/banks/series_03/03_view.cfm) of Mitchell Library, State Library of New South Wales, Sydney, Australia.

Beaglehole, J.C. (ed.), 1955. *The Journals of Captain James Cook on his Voyages of Discovery*, Vol. I. Cambridge: Cambridge University Press for the Haklyut Society.

Clunie, F., 2015. *Tongiaki* to *Kalia*: The Micronesian-rigged voyaging canoes of Fiji and Western Polynesia and their Tangaloan-rigged forebears. *Journal of the Polynesian Society* 124 (4): 335-418.

Corney, B.G. (ed.), 1915. *The Quest and Occupation of Tahiti by Emissaries of Spain during the Years 1772–1776*. Vol. II. London: Hakluyt Society.

Davenport, W., 1968. Social organization notes on the Northern Santa Cruz Islands, the Duff Islands (Taumako). *Baessler-Archiv, Neue Folge, Beiträge Zur Völkerkunde Band XVI*: 168-205.

Davenport, W., S.H. Elbert and B.F. Kirtley, 1979. *From the Eastern Islands*. Vol. 5 of *Custom Stories of the Solomon Islands.* Edited by Anna Craven, Salome Samou, and John Tealiklava. [Honiara]: Cultural Association of Solomon Islands, pp. 1-29.

Di Piazza, A., E. Pearthree and F. Paille, 2014. Wind tunnel measurements of the performance of canoe sails from Oceania. *Journal of the Polynesian Society* 123 (1): 9-28.

Dodd, Edward H. Jr., 1972. *Polynesian Seafaring. A Disquisition on Prehistoric Celestial Navigation and the Nature of Seagoing Double Canoes*. Lymington: Dodd, Mead, and Co.

Doran, E. Jr., 1981. *Wangka: Austronesian Canoe Origins*. College Station: Texas A&M University Press.

Feinberg, Richard, 1988. *Polynesian Seafaring and Navigation: Ocean Travel in Anutan Culture and Society*. Kent, Ohio: Kent State University Press.

Finney, B., 1994. *Voyage of Rediscovery*: *A Cultural Odyssey Through Polynesia.* Berkeley, Los Angeles and London: University of California Press.

George, M., 1998. The return of Lata: Building an authentic Polynesian voyaging canoe. *Sea History Journal* 84: 40-42.

——1999. The return of Lata: An authentic Polynesian voyaging canoe sails again. *New Zealand Sailing* 38: 49-53.

——2012. Polynesian navigation and *Te Lapa* – The Flashing. *Time and Mind: The Journal of Archaeology, Consciousness and Culture* 5 (2): 135–74.

Haddon, A.C. and J. Hornell, 1997 [1936, 1937]. *Canoes of Oceania*. Special Publication 27. Vols I-III. Honolulu: Bishop Museum Press.

Hansen, J.R., 2004. *The Bird Is on the Wing: Aerodynamics and the Progress of the American Airplane.* Centennial of Flight Series. College Station: Texas A&M University Press.

Howe, K.R. (ed.), 2006. *Vaka Moana*: *Voyages of the Ancestors*. Auckland: Bateman.

Irwin, G. and Richard G.J. Flay, 2015. Pacific colonisation and canoe performance: The science of sailing. *Journal of the Polynesian Society* 124 (4): 419-45.

Johns, D., G. Irwin and Y.K. Sung, 2014. An early sophisticated East Polynesian voyaging canoe discovered on New Zealand's coast. *Proceedings of the National Academy of Science USA* 111: 14728-733.

Lewis, D.H., 1972. *We, the Navigators: The Ancient Art of Landfinding in the Pacific.* Honolulu: University of Hawai'i Press.

Marchaj, C.A., 2003. *Sail Performance: Techniques to Maximize Sail Power.* Revised edition. London: Adlard Coles Nautical.

Neyret, J., 1974. *Pirogues Océaniennes*. Tome I and II. Paris: Association des amis des musées de la Marine.

Rieth, Eric, 1993. *Voiliers et pirogues du monde au début du XIXe siècle. Essai sur la construction navale des peuples extra-européens de l'amiral Pâris (1843).* Paris: Editions du May.

Sinoto, Yosihiko, 1979. Excavations on Huahine, French Polynesia: *Pacific Studies* 3: 1-40.

US Navy. Patent 4040579 A. http://www.google.com/patents/US4040579.
Wagner, C. Siegfried, 2012. Aerodynamische Untersuchung und Optimierung eines Krebsscheren-Segels im Windkanal, Schriftenreihe Schiffbau. *Technische Universität Hamburg Harburg. Institut für Fluiddynamik und Schiffstheorie (M-8)*. Von B. Sc. C.S.G. Wagner.
Wikipedia. 2016. https://en.wikipedia.org/wiki/Beaufort_scale

ABSTRACT

Voyaging canoes were the vehicles of ancient Pacific exploration, settlement and interactions. However, we know little about the ocean-going performance of those vessels. This account of Taumako (Duff Islands) voyaging technology draws on 20 years of collaborative research initiated by Koloso Kaveia, the late paramount chief of Taumako, during which a new generation learned to build and sail voyaging canoes using only ancient materials, methods, designs and tool types. Recent researchers have tested models of bifurcate tipped sail shapes in wind tunnels. The shapes they used, which appear similar to what Taumakoans call Te Laa o Lata, demonstrated outstanding efficiency compared to others. But one researcher noticed that a more flexibly tipped model performed better than a rigid model. Historical, cultural, technical and operational information about the proportions and the built-in flexibility and plasticity of the design, materials and rig of real Te Laa o Lata suggest that there is much more to learn about their performance. If a model of Te Laa o Lata is to be tested in a wind tunnel it must be shape-shifting and proportionally correct. It also should be rigged to allow it to align and adjust itself in the ways that it actually does at sea. Furthermore, the role of the mostly submarine hull and buoyant outrigger on sail and vessel performance should be measured in a tow tank. But since Taumakoans are still building and sailing Vaka o Lata (ancient Polynesian voyaging vessels) using centuries-old designs, materials and methods, it is still possible to measure the aerodynamic performance of Te Laa o Lata and the hydrodynamic performance of the overall vessel at sea, as well as to more fully understand how the vessel works and how it is sailed under various conditions and for various purposes.

Keywords: Polynesian voyaging, voyaging canoes, Pacific sail design, sail performance, ancient voyaging technology, Vaka Taumako Project, Southeast Solomon Islands

CITATION AND AUTHOR CONTACT DETAILS

George,[1] Marianne, 2017. Te Laa o Lata of Taumako: Gauging the performance of an ancient Polynesian sail. *Journal of the Polynesian Society* 126 (4): 377-416.
DOI: http://dx.doi.org/10.15286/jps.126.4.377-416

[1] Correspondence: Marianne George, PI of the Vaka Taumako Project of the Pacific Traditions Society, USA, Post Office Box 189, Anahola, Hawai‘i 96703, USA; Email: george.mimi@gmail.com