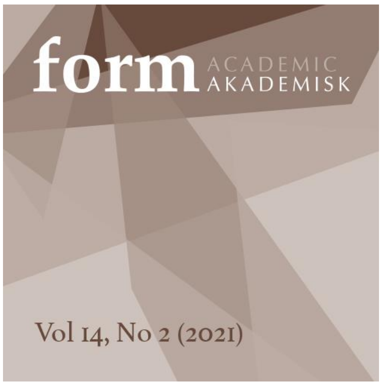

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Canoe-carving, Lamotrek style

An interdisciplinary study in crafting, design, engineering, and sustainability

ABSTRACT
Micronesian traditional canoe carvers of Lamotrek Atoll are one of the few Pacific communities whose canoe carving, ocean seafaring and indigenous navigation techniques are living traditions. They sail long distances on open ocean in these craft without instruments or maps, using traditional navigation techniques. Their building procedures involve no plans, no measuring devices or numbers. This kind of indigenous boatbuilding and seafaring was once practiced by virtually all Pacific island communities over hundreds or thousands of years, but the traditional knowledge has been eradicated in all but the most isolated and impoverished communities.

Keywords:
Micronesia proa Lamotrek canoe carving indigenous engineering sustainability

INTRODUCTION

I want here to outline what I understand of the remarkable sophistication of Micronesian canoe crafting, the engineering in their designs and precision in realization. This text focuses on what I learned in short stay of amateur fieldwork on the island of Yap in the Federated States of Micronesia (FSM) in late 2017, combined with years of study, previously and subsequently (in parallel with extensive design and building my own, unique, Pacific derived, sailboat Orthogonal. See simonpenny.net/Orthogonal.) While my field research period was limited, and there is far more to be documented, this paper gives an overview of the special qualities of the craft and underlying design aspects.

As a sculptor, sailor and amateur shipwright, I bring to this study a lifetime of making experience. As such I am deeply familiar with the embodied cognitive processes involved in materially realizing complex geometries, and the skills and techniques required to check dimensions and correct symmetry, etc. This experience has been invaluable in making sense of the description and the procedures, which for an academically trained scholar without artisanal experience, must simply be taken at face value, or whose significance might be missed entirely. (I have recently had an extended correspondence with a linguistic anthropologist whose propounds theories about the development of Austronesian craft, but has evidently never sailed, nor built anything.)

Traditions of Pacific boatbuilding are part of a larger set of indigenous traditions that were once central to life across the pacific, and included navigation techniques, knowledge of weather patterns and weather forecasting, as well as terrestrial and ocean environmental knowledge, much of which has been lost (eradicated) in the colonial period. Exemplary of efforts to save, document and revive these traditional knowledges can be found at the Pacific Traditions Society website vaka.org. For a larger more historical context, references are provided at the end of this paper (D’Arcy, 2008 Di Piazza & Pearthree, 2007; Eckstein & Schwarz,2018, Haddon & Hornell, 1936-8; Hicks & Nagaoka, 2004; Lewis, 1994; Nuttall, D’Arcy & Philp, 2014; Nuttal, George & Penny, Forthcoming; O’Connell, 2013).

FIGURE 1. Two Yapese proa, Kolonia 2017. Photo-author

The special qualities of the proa.

Many of the aspects of these traditional craft are entirely unlike western sailcraft. These craft, generically known as *proas* or *prau*, are efficient, environmentally adapted, and very fast. They have extremely shallow draft, permitting them to sail over reefs, across shallow lagoons, passages and estuaries and be easily drawn up on the beach for maintenance or safety in storms. So it is highly adapted to a work of lagoons and atolls without deep harbors. The deep V hull shape works against the leeway potential of a shallow draft hull, compensating for lack of deep keel or foil.

For maneuvering through the eye of the wind, they ‘shunt’, reversing end for end, rather than turning by ‘tacking’. They have asymmetrical hulls with an outrigger on one side to provide stability. Viewed from a Pacific perspective, the western requirement to *tack* demands that the vessel hull be bilaterally symmetrical below the waterline. This is not the case for proas, and as a result many groups build hulls of asymmetrical cross-section and exploit the available design possibilities. Indigenous sail shapes, such as the 'crabclaw' continue to reveal secrets of aerodynamic sophistication. (Some of the images in this paper are off Yapese proa. In this discusssion, they can be taken to be more or less interchangeable.)

FIGURE 2. Yapese proa, Kolonia harbor, 2017. Photo-author

Western monohulls and Pacific outriggers - where to put the weight?

There are several radically non-western design aspects of proas, the most obvious being the asymmetry of a large and a small hull. One way to understand the major differences between these two styles of craft is to understand the *tam* (outrigger) as comparable to the keel of a western monohull, rotated 90 degrees so it is parallel with the water surface, instead of perpendicular. In proas, the outrigger is not a float (so technically not a hull). It is a counterweight, ideally of neutral buoyancy in water. Being on a horizontal lever-arm, the mass more effectively counteracts the force of the wind on the sail which would otherwise easily capsize the narrow main hull.

FIGURE 3. *Heo*, yoke and *Tam* of a midsize Yapese proa. Photo-author.

As a device for maintaining stability against wind forces on the sail, this is far more efficient than the western boat's 'keel'. The keel works like a pendulum and requires a large mass low down in the hull. This is turn demands a large enclosed air volume (the hull proper) to keep it afloat. This unavoidably increased volume, which induces drag, and it requires deep water to operate in. The proa, on the other hand, has minimal mass and minimal volume, thus reducing drag. The connection between the *tam* (counterweight) and the hull (the *heo* or crossbeams) are out of the water, mitigating drag. As wind strength increases, the outrigger will lift out of the water, this reduces drag further and thus increases speed (also pushing the apparent wind to windward). If the wind further increases in strength, *intelligent ballast* (a man or boy) is deployed out on the *tam*. In some cases, a rope is used similarly to a western skiff's 'trapeze'.

Tacking, shunting and asymmetric hulls

All these advantages entail one special condition – the outrigger must always be on the windward side of the craft to function effectively as a counterweight. If the craft is backwinded (wind coming from what is normally the leeside), it is likely to capsize. (These craft can be righted, but it is not easy). Instead of tacking through the eye of the wind, as a western boat would do, the canoe reverses direction. This procedure demands craft with double ended symmetry: while a western craft is bilaterally symmetrical about a longitudinal centerline, the axis of symmetry of the outrigger sailing canoe (or 'proa') is rotated 90 deg. Instead of tacking, the craft must 'shunt', reversing end for end. In shunting traditional craft, this entails moving the yards and sail to the other end of the boat and steering from the end that was previously the bow. This requires strength, skill and coordination (of at least 3 crew members). Since the *tam* is heavy, there is significant danger of capsize if backwinded, the halyard for the yard is tied on the mast with a slip-hitch, so it can be dropped in a split second.

FIGURE 4. Mathou Maram II Yapese proa. Tam is seasoning underwater, held up by floats. Photo – Author.

Indigenous Hydrodynamics of the Micronesian voyaging canoe

These canoes are not just beautiful, finely crafted objects, they are hydrodynamic machines which have been refined over hundreds if not thousands of years. The designs demonstrate sophisticated understanding of hydrodynamics and other forces a sailcraft is subject to and deploy complex polyhedral *tensegrity* structural triangulation. The hulls have specialized shapes which improve speed, maneuver-ability and tracking. Not only are the arrangements of the hull and outrigger asymmetrical but the hull itself is bilaterally asymmetrical. Such hull asymmetry counteracts the drag of the *tam* (outrigger) and thus make steering a straight line ahead easier. (Otherwise the craft would rotate about that drag, causing to boat to pull to windward). The asymmetry, like an airplane wing on end, causes the hull to crab or climb to windward (analogous to the 'lift' gained by an aerodynamic wing in air). If the hull shape achieves all these, it is indeed hydrodynamically sophisticated.

There is evidence of even more sophisticated hydrodynamics in the so called '*rollers*': subtle cavities in the hull sides which occur at the places where the bow wave will curve back against the hull. This wavelength is determined by waterline length alone, so a longer hull will have more rollers. (A 20 ft hull might have 3 or 4). Purportedly, these rollers have the effect of harnessing the energy in the bow wave (as it passes back along the hull) to push the boat forward. If this is correct, it is similar to the recently discovered way that large fish like tuna leverage vortices to propel themselves faster than their theoretical maximum speed according to conventional hydrodynamic theory, but as explained by contemporary nonlinear dynamics (made possible by supercomputer calculation).

FIGURE 5. Mathou Maram II hull showing asymmetry and scalloped chines. Photo- author

On the Lamotrek canoes, the underwater (leading or trailing) edge of the prows are not smoothly tapered, but have a chine of about 3”. It was explained to me that feature, which would seem to create turbulence and drag, was crucial for maneuverability when the steering oar was adjacent to it. Again, if this is true it is indicative of highly sensitive and sophisticated ‘folk hydrodynamics’. Only careful flow tank testing would determine the truth of these assertions.

Western boats are rigid (though Viking longboats were quite bendy). Proas have designed-in flex that release stresses. In particular, the yoke and springing of the attachment of the *tam* to the *heo* (crossbeams is a highly sophisticated system to permit the *tam* to move in only one of six degrees of freedom – allowing it to rock slightly in relation to the main hull.

Limited means – parsimonious engineering

Pacific boatbuilding is a situated technology - in each location it was adapted to suit the local landscape, vegetation, resources and maritime conditions. Each local canoe tradition developed on the basis of its environment and available resources (though there is recent genomic archeological evidence that settlers carried and cultivated crops of special value in canoe making). Part of the genius of this tradition is the ability to develop the requisite range of materials for a boat from available resources. Big islands tend to have forests of large trees, atolls are usually not so lucky. But all have the ubiquitous coconut which provides fibre for binding lashings, without which the canoe would fall apart. Traditional Pacific cultures had no metal for tools or fasteners. Almost all pacific boats are lashed together with handmade coconut fiber rope using sophisticated lashing techniques without which there would be no canoe. Lashing is used in a permanent way to join hull planks, and to join parts of the boar in a way that provides flexibility and allows for repairs while at sea. In extremis, in a storm, the boat can be disassembled and the parts tied together in a long chain – an improvised sea anchor. The hull is then filled with water and the crew sit in the hull-full-of-water. When the storm passes, the boat is reassembled.

How to carve a canoe, Lamotrek style [1]

The making of a sailing canoe entails many sequential or concurrent tasks involving the entire community. The preliminary part is to plant a garden to feed the canoe makers. The sail materials are grown, harvested, prepared, woven into panels and stitched together. All the ropes for lashing and for running and standing rigging are made of coconut fiber, seasoned in seawater then twisted into two-ply cordage using an ingenious method of rolling on the thigh.

Stage 1. *Fatangal wol* – the man of the forest [2]

1.1 The main hull is carved from the trunk of (usually) a breadfruit tree, or a native mahogany. The tree is carefully chosen, with an understanding of how the shape and internal structure of the trunk is influenced by local forces. For instance, a tree on the windward side of the island will bend leeward, and the position of the soft heartwood will not be central.

The canoe is visualized in the trunk before felling. When the tree is felled, the impact is likely to cause longitudinal splitting, which can take an l, y or x shape in the end of the log. When the section of the trunk for the main hull is cut, both ends of the log are examined for signs of this splitting, as well as for location of the heartwood. The shape of the canoe is envisaged in the optimum location in the log, so that the heartwood will become waste (carve out) and splits which cannot be in the waste will not occur at high stress points in the hull, such as at the notch where the prow fits.

FIGURE 6. Lamotrek men roughing keel in the forest. Photo – Isayah Yarofayan

1.2 Other parts of the tree will be identified for other parts of the canoe, the prows, the side planks and other timbers. For instance, a limb with a curve approximating the curvature of the gunwale of the canoe will be identified for making a side plank, so that the grain of the wood follows this curve, to maximize strength. (The *heo* (crossbeams) and *tam* (outrigger) are usually of different, heavier or stronger timbers, the crossbeams are often native mahogany, the tam a variety of mangrove. Mangrove wood is heavy (desirable of the *tam*) but because it is laden with minerals, and so blunts tools quickly. Breadfruit wood, on the other hand, is chosen for its lightness and workability. Mahogany is more durable, but at least in Yap rare.

FIGURE 7. Lamotrek men roughing sideplank in the forest. Photo – Isayah Yarofayan

FIGURE 8. Lamotrek men roughing prow in the forest. Photo – Isayah Yarofayan

1.3 The keel section of the log is placed so the canoe inside is upside down, keel up. A narrow flat surface is made so the keel line is can be marked, using a taut string**.** Rough carving then begins, in the forest, while the wood is green, to relieve stresses which might cause splits in the drying process, and to make it lighter for moving. Carving work always begins from the center, and usually on the leeward side. The hull shape is subtly different on the windward and leeward sides. The hull shape has two chines, called speedlines. The chine on the leeward side is longer, wider, and at a steeper angle to the keel than the chine on the windward side.
1.4 The keel line is divided into 4 sections, marked using the modulus string folded thrice to make 1/8ths. The Lamotrek carvers call the 9 significant points ‘the nine men’. These ‘men’ are used in proportioning the canoe. In the Lamotrek way of thinking about proportions, the dividing lines between parts are more important than the section thereby created. So if we took a string, and folded it into equal halves, the ends of the string and the center point would be 3 significant marks. When the coconut leaf ‘ruler’ is made on the basis of the hand of the carver (see below), it is also folded thrice to make 8 equal sections.
1.5 From the 1st and 3rd quarter points on the keel line, the angle for the bows is decided and symmetry is checked**.**
1.6 The leeside speedline is marked and the first chine is carved away.
1.7 The windward side speedline is marked and the chine carved away
1.8 The bow sides are roughed out. The bows begin at the quarter marks, leaving the keel line on the center half of the original keel line.
1.9 The curves of the outer upper hull sides are roughed out.
1.10 The canoe is turned over and the inner cavity is roughed out. To do this the curve of the log is flattened and line parallel to and above the keel line is marked. This provides a rough guide for carving, leaving a wall thickness of around 6”.

Stage 2. Seasoning

The log is then dragged to the canoe house, where it is soaked in the sea for 3 months. This seasons the wood and kills any bugs (termites, etc).

FIGURE 9. Lamotrek men carrying plank out of forest. Photo – Isayah Yarofayan

Stage 3. Fine carving of the exterior of the main hull

3.1 The log is brought into the canoe house and set up, keel up. More precise carving then begins. Much of stage 3 involves checking and refining work done in stage 1.
3.2 Straightening the speedlines by the *'fat matam'* eyeballing technique
3.3 Symmetry is checked by 'comparing the diagonals'.
The chines are then 'scalloped' by the '*tal urue'* (moving rope) technique
The angle of the bow quarters is set, checked and made symmetrical.
3.4 Scalloping the chines
3.5 Curving the sides using the 'iterated flexible stick' technique

FIGURE 10. Fine carving keel in Lamotrek canoehouse after seasoning. Isayah Yarofayan in foreground. Photo – Isayah Yarofayan

Stage 4. Turning the canoe right side up

4.1 Carving out the heartwood at the ends. The heartwood has been carved out in the main body of the keel log, but has been left in at the ends and sometimes in the middle to act as a clamp, to maintain the log shape as it seasoned. Carving out the heartwood at the ends leaves the ends open, and the hull looking V shaped in cross section. Prow pieces which angle away and upwards are inserted into these hollows.
4.2 Positioning and shaping the prows
4.3 Checking symmetry and proportions again. A point vertically above the center-point of the keel line is projected at the height of the top edge of the log. Equal radii are projected from this point to determine the location of key points on the prows, preserving symmetry from the side view.
4.4 Add and shape side planks. The top edge of the log (which would be the gunwale if the planks were not added) is beveled outwards (the inboard edge of the side is higher than the outboard edge). This is to ensure that the bottom edge of the plank cannot slip sideways (as it might if the top edge were horizontal. Planks are then removed.
4.5 Interior of canoe is carved. To reduce wall thickness to 1”- 1.5”

Stage 5. The side planks and prow pieces that have been carved concurrently, are joined and lashed in. the main hull is now complete. What remains is the fitting of the *heo (crossbeams)* the *Tam* and its complex suspension system, *Pep* (leeside platform) and decking *on heo*, mast and yards, sails, rigging, steering oar, etc.

Clever things to do with a piece of string

In the Lamotrek method, and presumably other schools of traditional canoe carving, there is no use of standardized measurements for lengths or angles. There are no numbers, no inches, centimeters or degrees. and no drawn plans. There is a series of procedures. Almost all the proportions, angles and arcs of the canoe are marked out using a piece of string. There are two separate moduli, that of the keel and that of the hand of the maker.

When the keel log is roughed out and proportioned, a string, a length of sennit, is cut to the length of the keel edge. This is then folded three times, we would say into eighths. Interestingly, on Lamotrek, it is not the sections that are named, but their divisions – the fold marks, and the ends. These are known as the 'nine men'. They all have names, the first is *fatangal wol*, the 'man of the forest'. (I don't know the others, but I understand that they represent the stages of production, the last man, presumably, is the 'man of the launching' or some such). So the divisions of the string are simultaneously a measuring device and a mnemonic for the chronology of the stages of building.

This length of cord and its divisions determine, by known and fixed procedures, every other proportion on the boat, from the depth of the hull to the length of the crossbeams to the height of the mast. Construction of the outrigger, crossbeams, steering oar, spars, sail and rigging is not covered in detail here, but the system of proportions extends to all other dimensions. This has the remarkable result that all canoes of a certain type are scale models of each other, from the children's toy to the large war canoe.

The string is used in a variety of trivial and sophisticated ways. Most obviously, a taut string provides a straight line. Second, a line segment fixed at one end is a radius, and a string folded once, twice, thrice, performs division by 2 – 1/2, ¼. 1/8. There are many procedures: the congruity of rectangles is checked by comparing diagonals. The *tal urue* method deploys a string with pigment (like a western chalk line) to mark places on the log which protrude – these are removed iteratively to create flat planes. More sophisticated and specialized procedures relate to the use of the string to define the complex curved planes and the curves of chines that connect them - such as the way the concavity of the slight scallop in the lower chine is marked out.

The hand modulus is found by stretching a string from the tip of the thumb, around the tips of fingers to the heel of the hand at the wrist. This gives a cubit-like length with minor idiosyncratic variations due the relatively standard size of adult male hands.

The 'line'

On each island an on various islands, there are or were different designs of canoe for different purposes – fishing, voyaging, transporting goods, and war canoes. One of my informants told me that the term used to designate a style of canoe is 'rope'. (I took this to word to be interchangeable with 'cord' or 'line). In any case, the use of the term relates literally to the use of the string line to specify plane and angles and proportions, the way we remark on the pleasing lines of a sports car.

An ongoing conversation with a big chunk of wood

Natural materials have particular qualities and these qualities can change with time. A maker must know these qualities and transitions and work with them intelligently. The reason Michelangelo roughed out his sculptures in the quarry at Carrara is that marble fresh out of the mountain is quite soft (and damp). So large amounts of material can be removed quickly. As the marble seasons in the air, it become harder and more brittle – sustaining finer carving and ultimately, polishing. A tree-trunk has similar qualities. This is why the canoe hull is roughed out 'green', in the forest, as soon as it is felled. Also, it is made lighter for moving to the shore – an arduous process involving ropes and large teams of people.

The log is not a neutral and unformed mass. The tree itself has grown in a context of prevailing winds and the master carver knows that the 'heartwood' will not be absolutely central, even in a straight cylindrical trunk. The carver envisions the location of the heartwood and knows which part of the trunk will be used for the main hull and what the orientation of the hull will be in the trunk.

The log has grain. Ensuring that the grain runs parallel to the part, the plank or hull side, is crucial for maximising strength. The log, inevitably, has curvature, taking the grain on an arcing path. These arcs are capitalized upon in choosing the orientation of the *pun* in the log. The log also, inevitably, has splits, knots and weak spots. The carver observes proportions of convention, but there is always negotiation with the specificities of the log to, for instance, avoid placing a high stress part of the hull at such a split or weakness.

A different approach to seasoning

All timber-getters confront the problem of splitting when a live tree is felled. The drying out of the wood occurs in the outer layers first, and this drying cause shrinkage and thus splitting. In the western tradition, the log is usually quartered to relieve these stresses, then sealed with paint or tar, and left to dry very slowly to relieve internal stresses (an inch of radius per year, depending on type of wood and weather conditions) before further milling. The islanders take a different approach. The rough carving in the forest creates a form of roughly V cross section, relieving the stresses by removing the heartwood, leaving a relatively thin wall. This V shape necessitates complex shaping of the prow pieces and joinery to the keel. Sections of heartwood are left at ends and in the middle, to act as clamps to prevent warping, to be cut out later. Drying is likely to cause warping, which is why the wall is kept thick till after soaking for 3 months. (This may be more important with breadfruit than with mahogany).

FIGURE 11. Adzes on the canoehouse floor. Sodacan top for scale. Photo - author

The Oceanic adze

Almost all the work is undertaken with just one tool (albeit in two or three sizes). Wielded by a master, or an adept at least, the Oceanic adze is a tool of precision, efficiency, versatility and ergonomic parsimony. I watched a craftsman smooth a face, taking off slivers of wood so thin they were translucent, like fine plane shavings. Like riding a bicycle or tying a bowline or kneading dough, adze technique is learned only by doing. Muscles and nerves and tendons learn. In Gilbert Ryle's terms, it is the difference between *knowing that* and *knowing how*. Such skills inhere, as Merleau Ponty put it, *muscular gestalts*.

FIGURE 12. Pacific adze, haft detail. Photo – author.

In the small adzes, the length of handle and angle of bend are precisely suited to the scale and mobility of the arm, and although the motion is reciprocating, it has a pendular oscillation to it, and an ensuing bioenergetic efficiency, not unlike human bipedal walking. The blade, travelling in an arc, strike the wood at a precise angle. Because the works surface is tangent to that arc, from the blades impact, contact moves quickly from edge to increasingly up the polished back of the adze. So the edge bites, and then lifts infinitesimally off, taking a shaving with it. It is not driven into the wood like a wedge or an axe, or for that matter a chisel. Its action is more like that of a plane, but moving in an arc, to which the workpiece is tangent. The adze often does the kind of work in the west we would do with a chisel, but it requires only one hand. So the other hand can function as a dynamic clamp or vise. The heavier adzes – of the weight of a small to medium size axe – are wielded with two hands, with the back and torso involved, but in using the smaller adzes, the torso remains quite still.

FIGURE 13. Carlos demonstrating proportions of a small adze. Photo – author.

CONCLUSION

The Micronesian canoe is an artifact of sophisticated design and skillful crafting. It is a preeminently clean and sustainable technology, being wind powered and utilizing only local renewable resources. The most important thing I learned in Yap is that, although the building procedures involve no plans, no measuring devices or numbers, not only were the craft built to a high degree of precision, but that precision was entirely repeatable. When I asked about design innovation, Larry responded with a wry smile, "*we don't copy the canoes that don't come back*". This remark belies the pragmatism of a tradition that has been refined over hundreds, if not thousands of years.

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I am indebted first to Larry Riegetal for inviting me to Yap and being my primary guide to Yap and Lamotrek ways. Larry, having attend university in USA and UK, has a foot in both worlds, and functions as a translator between cultures and as cultural ambassador. He is also leader of the cultural organisation Waa-gey. I am indebted to Julie and Callistus Habichmai for their hospitality and to Peter Itiral for describing some of the traditional canoe building process in several meetings; to Isiah Yarofayan for his welcoming friendship and for sharing his photos; to Master Navigator Ali Haleyur and chief Bruno for making me welcome, Joe and Carlos for showing me various aspects of technique and process, and to all the boys and men at the Waa'gey canoe house for making me welcome and sharing stories. Inevitably, at times I have had to interpolate. In doing so I have tried vigilantly not to impress my idea of what a process 'must be' in place where my understanding was unclear. But inevitably I must have failed.

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1 My goal here is to capture process, the design constraints and the layout and construction methods, rather than simply describe the final product. This description of canoe design is follows interviews with Peter Itiral, a Lamotrek man, a trained canoe carver and elementary school teacher, who was resident on Yap when I met him. By Peters' own admission it's a while since he built a canoe. But his father (Pakamai) was a master carver and navigator and his brother Larry is also.

2 Fatangal wol and other Lamotrek words occurring in italics in the text are my own transcriptions.