The WAM Proa

— Construction Manual —

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Dedicated to the resilient community of Waan Aelōn̄ in Majel - Canoes of the Marshall Islands (WAM) and the Marshallese people, whose commitment to revitalizing traditional knowledge ignites hope for climate justice. WAM, a grassroots non-governmental organization mainly active in the Republic of the Marshall Islands and the Pacific region, works in various ways to contribute to the fight against climate change and rising sea levels.

Contents

Foreword

In the vast expanse of the Pacific Ocean lies the Marshall Islands, a small archipelago comprising 29 atolls and 5 islets, scattered across a staggering 810,800 sq. mi. (2.1 million square kilometers). The remoteness of these islands makes sea transport not just an economic necessity but a lifeline for the Marshallese population, delivering essential supplies and services to sustain their communities. Traditionally, our people are navigators, utilizing wind, stars, and wave patterns on offshore canoes known as Walap to traverse the atolls for various purposes. Today, however, the majority of our communities have transitioned away from these traditional canoes to motorized vessels, contributing to environmental challenges. Under the *Transitioning to Low Carbon Sea Transport* project, we from *Waan Aelōñ in Majel* (WAM) have collaborated with organizations like *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) to achieve a change that is rooted in our traditions. As we navigate the challenges of our beautiful but fragile environment, we are acutely aware of the global impact of the changing climate on our islands and atolls. The Marshall Islands, contributing a mere 0.00005% of global greenhouse gas emissions, has boldly taken the lead in setting ambitious goals within our *Nationally Determined Contributions* (NDC) under the *United Nations Framework Convention on Climate Change* (UNFCCC). Our commitment includes a target to reduce emissions from domestic shipping by 40% in 2030, with the ultimate aim of achieving full decarbonization by 2050 - a pioneering move making the Marshall Islands the first country worldwide to undertake such a commitment. Our contribution to our country's goal is to revive the fading art of traditional canoe building and utilization of zero-emission sailing canoes - like our ancestors did for centuries. In the search of sustainable alternatives, the construction of sailing canoes has been a milestone, providing energy-efficient lagoon transportation within Marshallese lagoons. We at *Waan Aelōñ in Majel* (WAM) are working towards the vision of "One Family, One Canoe," ensuring access to water for transportation, food gathering, and livelihood support in remote islands and atolls. Through a comprehensive training program of proto-type sailing vessels designed specifically for our lagoons, we promote sustainable living but also preserves our rich cultural heritage. Over the period of three months, islanders learn traditional boatbuilding skills combined with modern techniques, resulting in durable sailing vessels. These vessels, including the WAM Catamaran and the WAM Proa, combine contemporary boatbuilding methods with our age-old maritime heritage. As we present this book, we invite you to embark on a journey through our efforts take on the task of building a WAM Catamaran or a WAM Proa. May this book inspire a shared commitment to sustainable practices and the preservation of cultural heritage for generations to come.

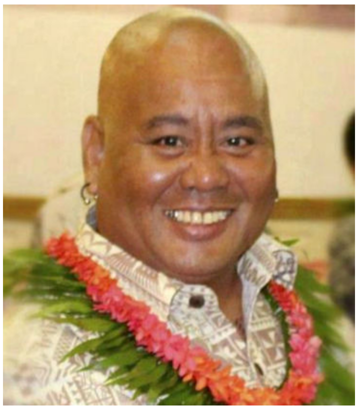
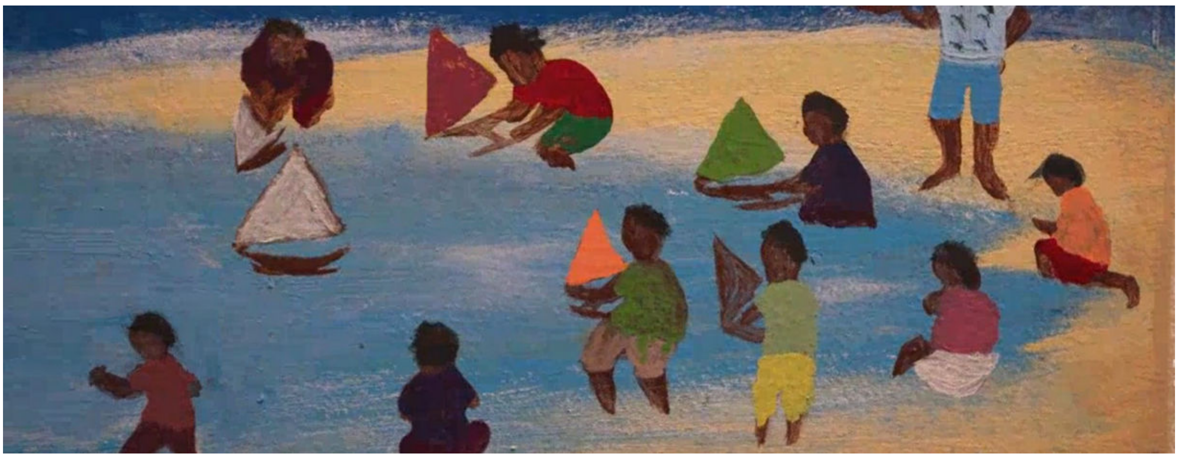


Figure 1: Alson J. Kelen, director of *Waan Aelōñ in Majel* (WAM)

The invention of the sailing canoe

Legends say that the first canoe was built by Leoa and Lamedal on Bikini, out of hard keno wood. But they did not know about the sails yet; they were towed by an *aolet* fish. They traveled to many islands like this but when they arrived in Rongerik, a man stood there in the entrance of the atoll and killed the *aolet* fish; then their canoe drifted away. Thereupon they used the paddles and by that means managed to reach Wōja in the Ailinglaplap atoll.[1] What happened there much later has been told by many great story-tellers before. These are the words of Kathy Jetn̄il-Kijiner:

There, Lōktan̄ūr lived in a kone tree; she had come from the sky and gave birth to ten sons who all lived on the island of Wōja. One day the sons argued, voices clapping like thunder against the trees. And they said Who will be Irooj[2] of this Island? And the eldest, Tūmur, said Why don't we have a canoe race to the island of Je? The first to reach the island will be Irooj, he said. As the brothers lined up on the beach, carved canoes pointed towards a sea swallowing the sun their Mother Lōktan̄ūr walked up to them. And Lōktan̄ūr struggling with a bundle in her arms asked My Son will you take me with you? And Tūmur looked at the bundle and said Ask my younger brother. And the younger brother said Ask my younger brother who said the same thing. She will only slow me down. And so on. Ask Jebro̧! The brothers laughed. He is the youngest! He will lose anyway! And Jebro̧, with his back to the swirling sea said Yes Mother I will take you with me. As the brothers paddled furious against the salt biting at the wood of their paddles Lōktan̄ūr, standing on the canoe with her son Jebro̧, began to unravel the bundle slowly the way the sun unravels its silky rays. And Jebro̧ said What is that Mother? And Lōktan̄ūr said Behold my Son. This shall be called the Sail.[3] Jebro̧ and Lōktan̄ūr overtook all of the brothers aside from the eldest brother Tūmur. On seeing Jebro̧ sailing effortlessly Tūmur demanded Jebro̧'s canoe. As the eldest he believed he deserved the fastest canoe. Jebro̧ gave the canoe to his eldest brother, however Lōktan̄ūr took away a *depakaak* (the part that locks the sail to the hull). Without the second *depakaak* Tūmur can only sail in one direction, and without understanding how to use the sail he can not finish the race. And so it was that Jebro̧ won the race and was crowned Irooj of Ailinglaplap. After his death he became immortal and can still be seen in the sky as a star constellation guiding the navigator at night.



[1] Adapted from Spennemann 1998.
[2] Marshallese: chief or king.
[3] Adapted from *Iep Jāltok - Poems from a Marshallese Daughter* by Kathy Jetn̄il-Kijiner.(Jetn̄il-Kijiner 2017)

1 Guide to this document

This manual is written as a detailed guide for anybody who wants to build their own WAM Proa. It is for people with and without boat building experience, as well as teachers and trainers of boat building workshops.

- Section 2 gives a brief overview of the canoe designs developed by WAM. Section 2.1 presents the designs side by side to help you to pick the right one for your needs. Section 2.2 gives a detailed description of the main characteristics of the WAM Proa design.
- Section 3 explains the manual's suggested educational approach to teaching students to build a WAM Proa through a hands-on boatbuilding workshop.
- Section 4, 5 and 6 cover the tools, materials and basic skills required for the construction of the WAM Proa.
- Section 7 informs readers how to keep themselves and others safe during construction, as well as how to protect the environment. It is strongly recommended that beginners and experienced builders read and understand these sections carefully to ensure a successful construction. If this is your first boat building project, the book *The Gougeon Brothers on Boat Construction*[4] can offer additional insight into boat building techniques, materials and practices.
- Section 8 provides a day-by-day guide through the entire construction process. It offers direct and specific guidance to novices, and a detailed daily schedule for teachers and trainers.
- Section 9 gives brief instruction on how to sail and maintain the WAM Proa.

This manual is published by *Waan Aelōñ in Majel - Canoes of the Marshall Islands* (WAM) as part of the *Transitioning to Low Carbon Sea Transport* (LCST) project implemented by the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ). Scientific advice was given by *Hochschule Emden-Leer, University of Applied Sciences* (HEL).

Waan Aelōñ in Majel (WAM) is a small non-governmental organization dedicated to the fight against climate change and sea level rise, as well as the revival of traditional sailing and canoe building in the Marshall Islands. To support the global ambitions on reducing greenhouse gas emissions, WAM provides this manual for a zero-emission watercraft for free.

If you need support with the construction of your WAM Proa or want to implement the teaching and training program at your site, do not hesitate to contact the master canoe builders of WAM.

[4] A free pdf download is available under `https://www.westsystem.com/the-gougeon-brothers-on-boat-construction/`

2 Design

2.1 The WAM canoe lineup

As part of the "Transitioning to Low-Carbon Sea Transport (LCST)" project *Waan Aelōn̄ in Majel - Canoes of the Marshall Islands* (WAM) developed two basic, affordable and emission-free watercraft for cargo and passenger transportation, as well as for subsistence fishing and leisure activities: the **WAM Catamaran** and the **WAM Proa**.

(a) The WAM Catamaran

(b) The WAM Proa

Figure 2: The WAM Catamaran and the WAM Proa.

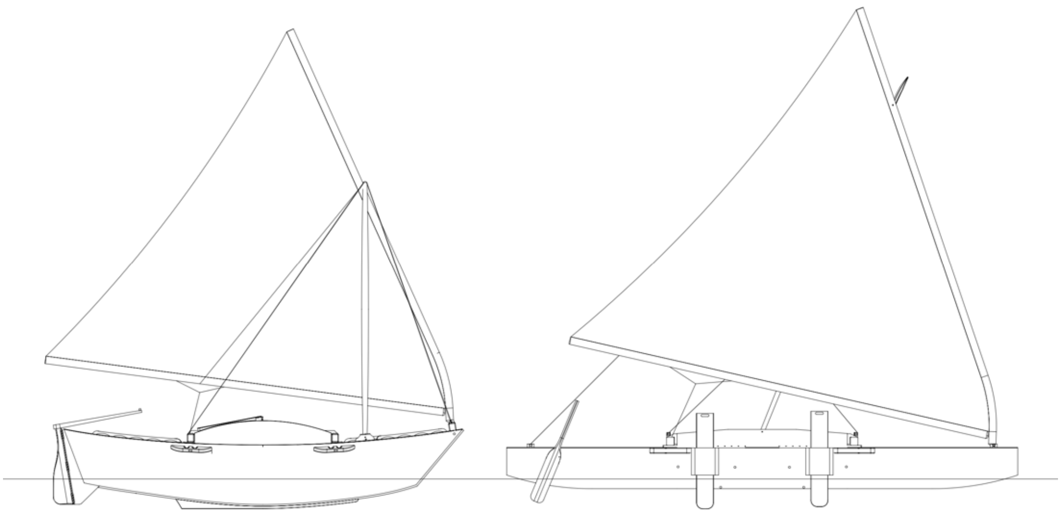


Figure 3: Side view of the WAM Catamaran (left) and WAM Proa (right).

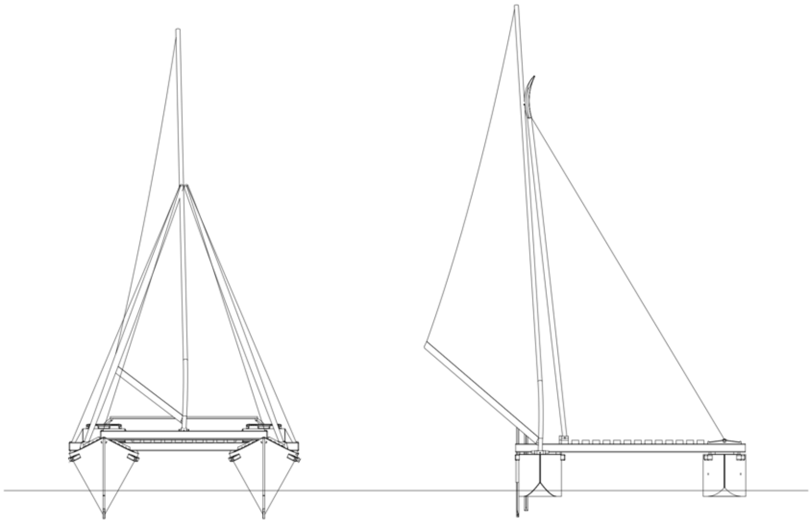


Figure 4: Front view of the WAM Catamaran (left) and WAM Proa (right).

The WAM Proa is an outrigger canoe with a larger main hull and a smaller outrigger hull, while the WAM Catamaran has two hulls of equal size and shape. The hulls of unequal size are a design feature native to Micronesia and some other Pacific islands and is characteristic of a proa design. Due to the requirement to always keep the outrigger hull on the windward side this design has no distinctive front and back end. Instead of turning around like a car it comes about by reversing the direction of travel (shunt). The WAM Proa is designed with fishing in mind and is equipped with an internal fish hold to keep the fish fresh as long as possible without the need for ice. Its outrigger design, sleek hull shape and the leeboards make it fast, but the paddle steering as well as the shunting maneuvers require practice, physical strength and a crew of at least three.

The WAM Catamaran is a good allrounder with very easy handling due to its rig setup and the rudder system. The hulls offer large dry cargo holds for dry goods and their shape make the WAM Catamaran stable and safe in strong wind. All maneuvers are executed swiftly without the need for special skills or physical strength. This makes the WAM Catamaran suitable for sailing alone or with an inexperienced crew.

Based on individual requirements the following table may help to pick the right design:

	WAM Catamaran	WAM Proa
Sailing speed:	★★★☆☆	★★★★☆
Easy handling:	★★★★★	★★★☆☆
Fishing:	★★★☆☆	★★★★★
Fish storage in fish hold:	★★☆☆☆	★★★★★
Cargo transport:	★★★★★	★★★☆☆
Dry cargo holds:	★★★★★	☆☆☆☆☆
Sleeping inside:	★★★★☆	☆☆☆☆☆
Sailing alone or with small crew:	★★★★★	★★☆☆☆
Suitable for beginner:	★★★★☆	★★☆☆☆
Safety against capsizing in strong wind:	★★★★☆	★★☆☆☆
Suitable for narrow waters:	★★★★☆	★★☆☆☆
Suitable for very shallow waters:	★★★☆☆	★★★★☆
Suitable for rough shoreline (coral, rocks etc.):	★★★★☆	★★☆☆☆
Easy construction:	★★★★★	★★★★★
Cost for material:	★★★★☆	★★★★★

Table 1: Comparison of the WAM Catamaran and the WAM Proa

Scan this QR code to watch a video about the WAM Catamaran and the WAM Proa:

Figure 5 shows a polar plot which presents the measured sailing speed of the WAM Catamaran and the WAM Proa in wind from different directions, medium loaded.

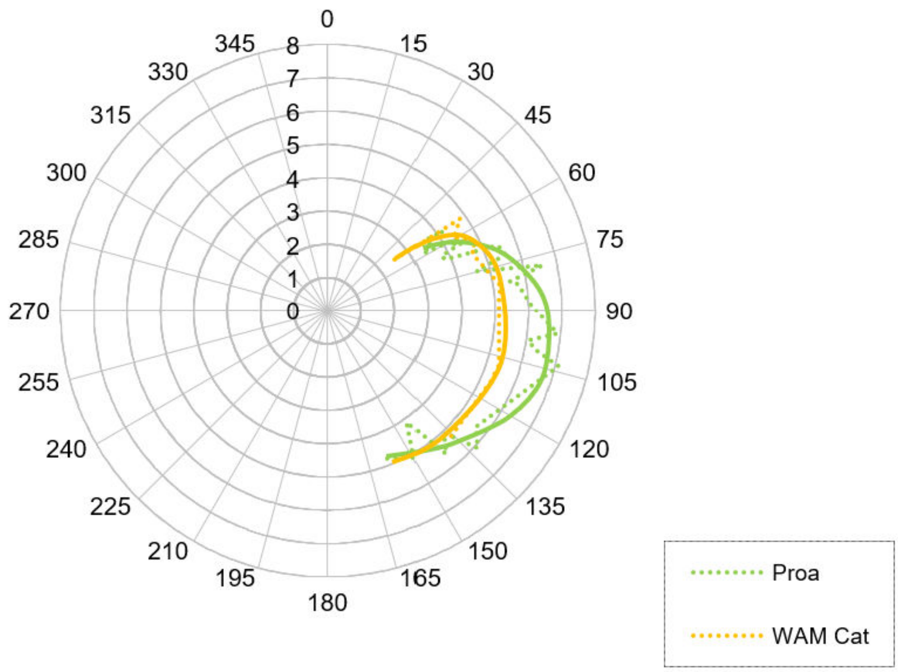


Figure 5: Polar plot of the measured sailing speed of the WAM Catamaran and the WAM Proa in 12 - 14 kn true wind speed, loaded with roughly 700 lbs (approx. 350 kg). Leeway is included. The further away from the centre the coloured lines are, the faster the sailing speed. The position around the circle (labeled in degree) indicates the true wind direction as experienced by the sailor. The top (twelve o'clock position or 0°) means the wind is coming straight ahead, three o'clock (90°) represents the wind from the side and six o'clock (180°) the wind from behind. See Richter-Alten 2021a and Richter-Alten 2023 for further information.

This manual is about the construction of the WAM Proa only. A similar manual has been published for the WAM Catamaran. Detailed information about the WAM Proa design can be found in the next section.

2.2 The WAM Proa

The WAM Proa was designed based on the traditional *tipnōl* canoe. The following changes were made:

- The hulls are now easy to build box sections with flat bottoms. The very shallow draft allows the canoe to be brought closer to shore to ease cargo handling;
- The buoyancy of the outrigger (*kubaak*) has been increased dramatically;
- The hulls are only connected by two lashed on cross-beams;
- The space between the hulls and the beams is covered by a large platform.

The entire construction relies on plywood and the use of epoxy as glue instead of screws and nails. Non- metal fasteners are used instead. Epoxy (in combination with fiberglass cloth) is used to encapsulate all wooden parts and protect them from water, and it is an effective rot prevention. Beam to hull connections and the rigging are made with flexible rope lashings in a traditional fashion. The WAM Proa has a self-draining cockpit in the outrigger hull and a wet fish hold in the main hull. The platform deck between the hulls offers space for passengers as well as for handling fishing equipment without being covered by parts of the rig (except for the windward shroud *tokubaak*).

The rig and its handling is entirely traditional and not substantially different from a Marshallese canoe. Like all Pacific proa designs, the WAM Proa always keeps the smaller hull on the windward side and therefore never turns to come about. Instead the direction of travel is reversed by performing a maneuver called a shunt (*diak*). Front becomes back and vice versa by re-stepping the sail on the other side of the hull. Compared to the WAM Catamaran this makes the WAM Proa more difficult to handle and requires some practice as well as physical strength to fully master. If you are not familiar with shunting sailing canoes, plan to sail single-handed or use the vessel for beginner training, the WAM Catamaran is the better choice.

Figure 6: The WAM Proa sailing in front of Tobal, Aur

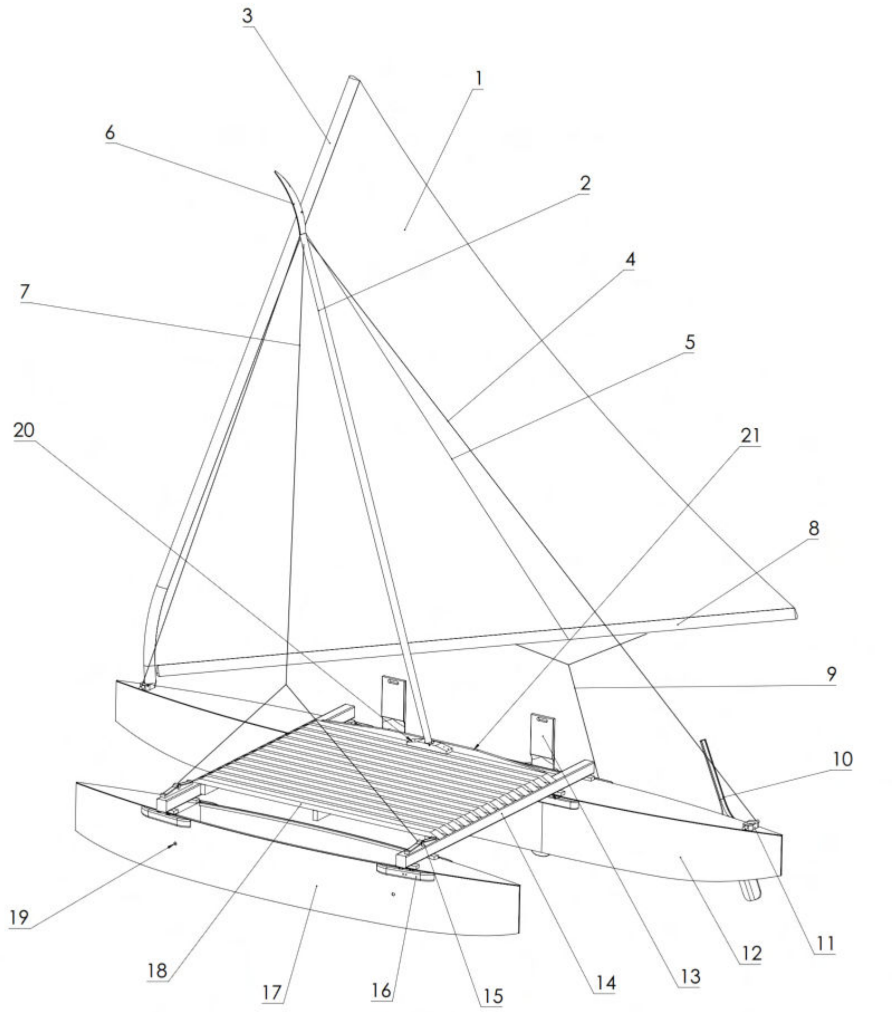


Figure 7: The parts of the WAM Proa (with labels corresponding to table 2)

Label	English	Marshallese	Label	English	Marshallese
1	Sail	Ujela	12	Leeward hull	Wa
2	Mast	Kiju	13	Leeboard	
3	Yard	Rojak maan	14	Primary beam	Kie
4	Backstay	Jomur	15	Stay attachment	
5	Spilling lines	Tiliej	16	Beam cleat	
6	Mast head	Lot	17	Windward hull	Kubaak
7	Windward stay	Tokubaak	18	Platform	Ere
8	Boom	Rojak kōrā	19	Drain hole	
9	Main sheet	Iep	20	Mast step	Bōklap
10	Steering paddle	Jebwe	21	Turtle chest	
11	Tack socket	Depakaak			

Table 2: Parts of the WAM Proa (with labels corresponding to figure 7)

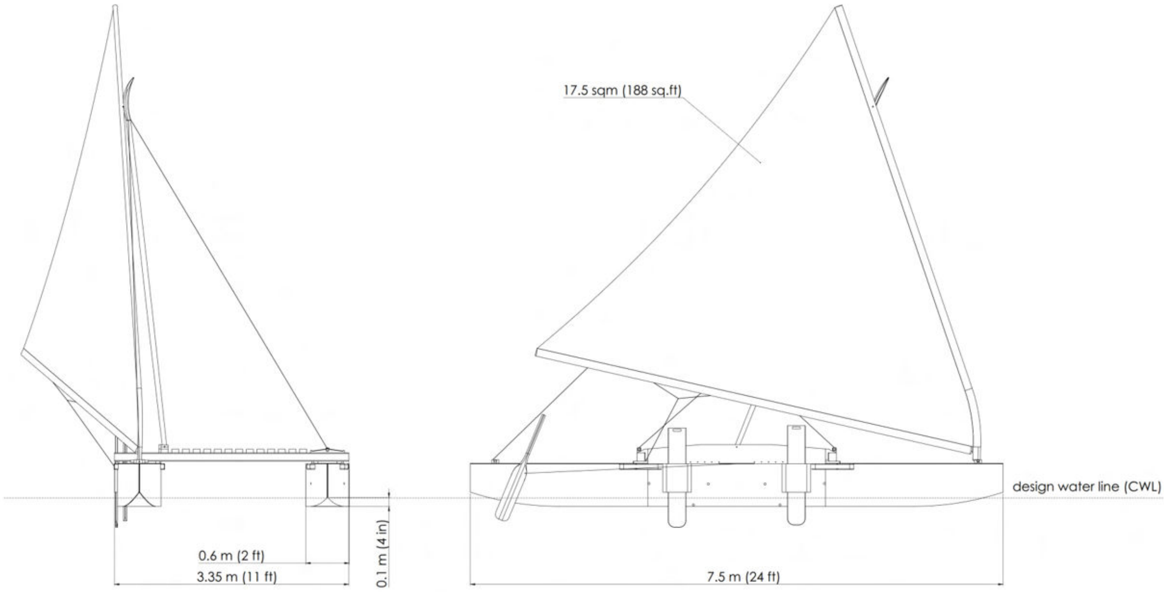


Figure 8: The main dimensions of the WAM Proa (as shown in table 3)

WAM Proa main dimensions

Length overall:	7.25	m	24.0	ft
Waterline length:	7.25	m	24.0	ft
Beam overall:	3.35	m	11.0	ft
Beam between centerlines:	2.75	m	9.0	ft
Breadth hull:	0.60	m	2.0	ft
Light ship weight:	380.00	kg	840.0	lbs
Max. loading capacity:	1000.00	kg	2200.0	lbs
Loading capacity at CWL:	350.00	kg	770.0	lbs
Breadth hull CWL:	0.60	m	2.0	ft
Breadth hull at max. capacity:	0.60	m	2.0	ft
Draft empty (no leeboard):	0.07	m	3.0	in
Draft CWL (no leeboard):	0.10	m	4.0	in
Draft max. capacity (no leeboard):	0.30	m	12.0	in
Draft leeboard:	1.00	m	3.0	ft
Sail area:	17.50	m^2	188.0	ft^2

Table 3: Main dimensions of the WAM Proa.[5]

The WAM Proa is not designed to win races. The design goal is a safe and comfortable boat for cruising, which maintains a good performance in all conditions. Despite all that, the WAM Catamaran can still go fairly fast, and double-digit speeds have already been logged regularly. The figure below shows a polar plot which presents the measured sailing speed of

[5] Richter-Alten 2021b

the WAM Proa in different wind speeds, medium loaded.

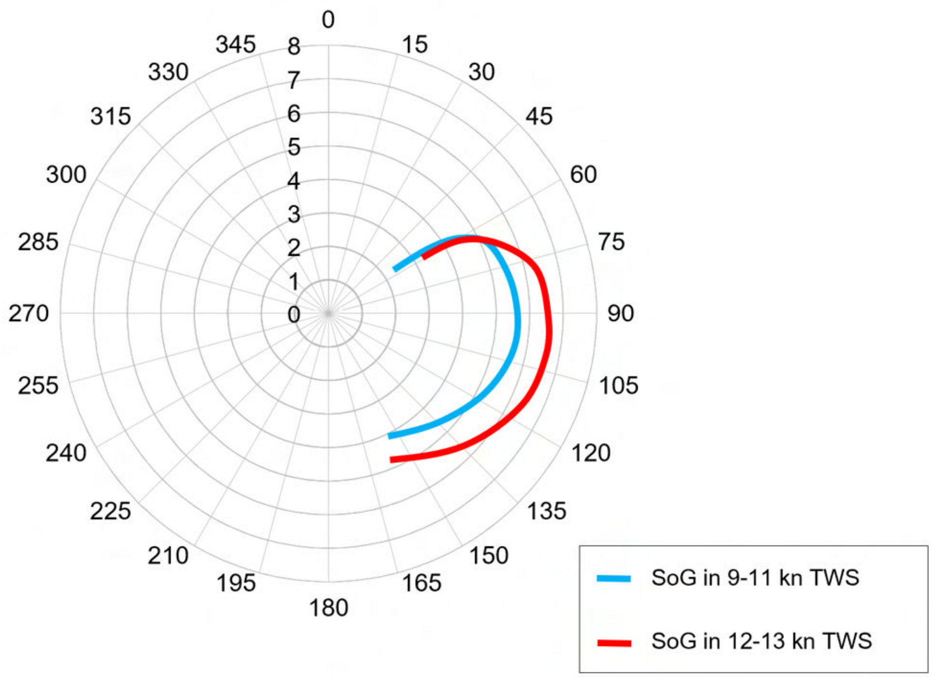


Figure 9: Polar plot of the measured sailing speed of the WAM Proa in different true wind speeds, loaded with roughly 700 lbs (approx. 350 kg). Leeway is included. The further away from the centre the coloured lines are, the faster the sailing speed. Each color represents a different wind speed. The position around the circle (labeled in degree) indicates the true wind direction as experienced by the sailor. The top (twelve o'clock position or 0°) means the wind is coming straight ahead, three o'clock (90°) represents the wind from the side and six o'clock (180°) the wind from behind.[6]

[6]See Richter-Alten 2021a and Richter-Alten 2023 for further information.

3 Teaching method

This section is for teachers and trainers only. It contains valuable information about an educational approach towards teaching students to build a WAM Proa as part of a course.

The WAM Proa[7] was initially designed as part of a three-month training course on contemporary plywood boat building. A three-month workshop is a very short time for comprehensive boat-building training. Therefore, the keystone of the training program was the focus on the most crucial skills:

- the stitch and glue technique
- plywood and epoxy composite construction
- rot prevention
- safety and maintenance
- sailing

These topics were taught using a see one - do one - teach one approach.[8]

See one - do one - teach one (SODOTO) is a way of teaching and learning skills and best practices by watching a task, gaining hands-on practical experience performing the task and solidifying learning by teaching the task to another person.

While "see one" seems to indicate watching a solitary example, this part of the process can also include lessons from experts, texts and interactive media. This step is complete when the student has completed thorough observations of the building process in preparation for practical experience.

In the "do one" phase, the student puts their theoretical understanding into practice. The student performs the task, often under supervision. Learning is developed through experience, by facing unpredictable obstacles which are typical of the real world and through testing by mentors.

In the "teach one" phase, the student applies their new learning and experience and transfers it, by teaching another student. Teaching the skill or task helps reinforce the knowledge learned and helps the student develop even further toward mastery.

An average group of trainees is usually composed of very different people with different experiences, skills and abilities. It is important to start with the basics to lift the entire group to a common level. Additional basic theoretical and practical lessons may be taught in the first two weeks - as required - to achieve that goal. Theoretical lessons can be held as auditoriums with visual support. Practical training should cover an introduction of the different tools, as well as a safety briefing and supervised hands on practice. In addition,

[7] The original HarryProa Mini Cargo Ferry designed by Rob Denney was upgraded, tweaked and fine tuned into the WAM Proa after comprehensive sea trials.
[8] SODOTO is widely used to train medical professionals and engineers.

Teaching

first samples of epoxy applications (glued join, fillet, glass fiber sandwich) can be prepared to demonstrate the strength of epoxy in breaking tests (see 20, 23 and 25).

Building a proa with two almost similar hulls is especially suited to the SODOTO approach, as: the first hull can be used for explanations and demonstrations (the “see one” phase) and the first hands-on training under close supervision (the “do one” phase); then, the second hull can be used for hands-on training and can almost autonomously be constructed by the trainees (for the “do one” and “teach one” phases).

After a couple of weeks, at the latest when beginning the second cat hull, certain project parts should be gradually made the responsibility of individual trainees or groups of trainees. This procedure leads eventually to a widely autonomous organized group of workers at the end of the workshop, who only require minimal guidance and advice.

4 Tools

For the workshop, only simple and inexpensive hand-held tools are required. The total number of tools was limited to a minimum. Figure 10 gives an overview of every tool used during the construction. Detailed photos of every tool can be found over the following pages.

If necessary, all construction work could be done without power tools but in a significantly longer period of time.

Figure 10: All tools used for the construction

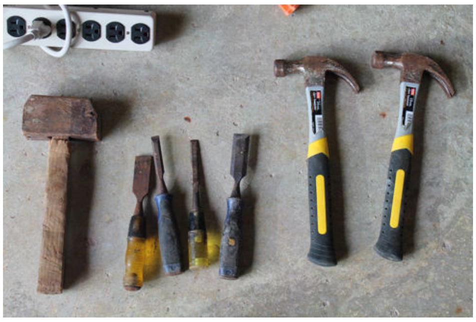
(a) Measuring and lofting equipment

(b) Big angle grinder (double hander) with sandpaper disk

(c) Small angle grinder with sandpaper disk

(d) Hot melt glue gun

(e) (Orbit)sander.



(f) Hammer, mullets and chisels (more were used, only an example is shown)

Figure 11: Tools used during the workshop

(a) Power cords and connector strips

(b) High pressure cleaner (handy to clean dust off glassed hulls, but not really necessary)

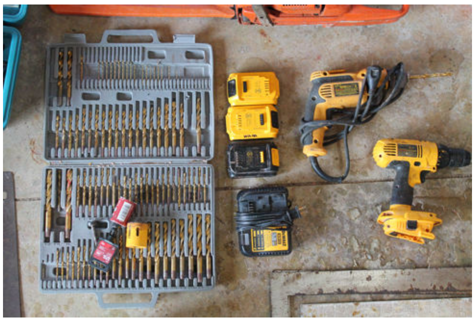
(c) Recipro saw (not really necessary)

(d) Router with over-round bit

(e) Jigsaw

(f) Handsaw (only one on display as example)

Figure 12: Tools used during the workshop



(a) Cord(less) drill and drill bits)

(b) Electric planer

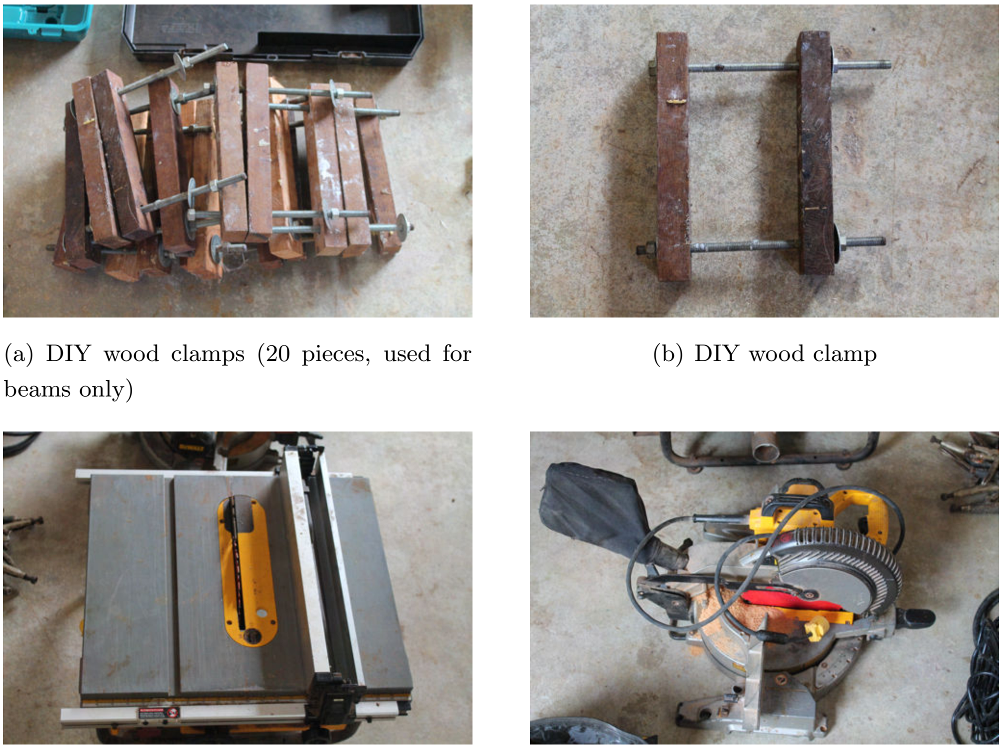
(c) F-clamps (various sizes 40+ pieces)

(d) C-clamps (various sizes 15+ pieces)

(e) DIY pipe clamps (30 pieces)

(f) Locking clamps (15 pieces)

Figure 13: Tools used during the workshop



(a) DIY wood clamps (20 pieces, used for beams only)

(b) DIY wood clamp

(c) Tablesaw

(d) Chopsaw

Figure 14: Tools used during the workshop

5 Materials

Everything you need to build a WAM Proa is listed in figure 4 below.

Category	#	Item description	Specification		Total amount		Further information
			U.S.	metric	U.S.	metric	
Plywood	01	Marine plywood, WBP certified	1/4 in	6 mm	12 sheets	12 sheets	It is strongly recommended to use marine grade plywood
	02	Marine plywood, WBP certified	3/8 in	9 mm	1 sheets	1 sheets	
Lumber	03	Dimensional lumber	1x1 in	25x25 mm	18x11 ft	18x3.7 m	Look for fir, spruce, pine or similar. This is the total amount that need to be produced. The dimensions doesn't matter when you go shopping because the lumber will be cut anyway. Quality is more important.
	04	Dimensional lumber	1x1 in	25x25 mm	11x16 ft	11x5.4 m	
	05	Dimensional lumber	1x1 in	25x25 mm	20x24 ft	20x8 m	
	06	Dimensional lumber	2x4 in	100x50 mm	16x10 ft	16x3.4 m	
	07	Dimensional lumber	3x3 in	75x75 mm	18 ft	6 m	
	08	Dimensional lumber	1.25x5 in	30x120 mm	7.5 ft	2.5 m	
	09	Dimensional lumber	2x3 in	50x75 mm	3x6 ft	3x2 m	
	10	Hardwood	6x4 in	150x100 mm	3 ft	1 m	
Epoxy	11	Epoxy & slow hardener	30 min.	30 min.	9 gal	35 kg	Must be suitable for high temperature/tropical conditions if used in the RMI. Min. 30 minutes of pot life at 86 °F (30 °C). Simple mixing ratio by volume (e.g. 2:1).
	12	Baking flour			33 lbs	15 kg	
Fibers	13	Glassfiber cloth	7 oz./sqft	200 g/sqm	915 sqft	85 sqm	Plain or twill both work
Paint	14	Exterior house paint			4 gal	15 l	Water based. If possible use two component marine paint instead
Rigging	15	Dacron sail cloth	6 oz./sqft	170 g/sqm	269 sqft	25 sqm	Polytarp can be used instead
	16	Rope for standing rigging	1/2 in	12 mm	130 ft	40 m	Low stretch
	17	Rope for running rigging	1/2 in	12 mm	100 ft	30 m	Sheet material (soft touch)
	18	Sheet pulley	1/2 in	12 mm	7 pcs	7 pcs	
	19	Trampoline net	1-1.5 in	25-35 mm	45 sqft	5 sqm	Low stretch
	20	Lashing rope	1/8 in	3 mm	656 ft	200 m	Should be very stretchy
Consumables	21	Brush	1 in	25 mm	10 pcs	10 pcs	
	22	Brush	2 in	50 mm	10 pcs	10 pcs	
	23	Velour roller			5 pcs	5 pcs	
	24	Dust mask	N95/FFP2	N95/FFP2	20 pcs	20 pcs	
	25	Mixing cups	8 oz.	200 ml	50 pcs	50 pcs	
	26	Acetone			1 gal	4 l	Tool cleaner
	27	Vinegar			2 gal	7 l	Skin and tool cleaner
	28	Paper cloth			20 rolls	20 rolls	Toilet paper or kitchen wipes
	29	Rubber gloves	size L	size L	300 pcs	300 pcs	
	30	Angel grinder sand-paper disc	40 grit	40 grit	15 pcs	15 pcs	Should fit to the available tool
	31	Orbit grinder sand-paper disc	120 grit	120 grit	30 pcs	30 pcs	Should fit to the available tool
	32	Orbit grinder sand-paper disc	180 grit	180 grit	30 pcs	30 pcs	Should fit to the available tool
	33	Sandpaper	40 grit	40 grit	1 roll	1 roll	
	34	Sandpaper	60 grit	60 grit	1 roll	1 roll	
	35	Sandpaper	120 grit	120 grit	1 roll	1 roll	
	36	Drill bits	0.04-1.2 in	1-13 mm	1 set	1 set	
	37	Forstner drill bits	1 in	25 mm	1 pcs	1 pcs	
	38	Rubber or plastic squeegee	4 in	100 mm	5 pcs	5 pcs	
	39	Jigsaw blades			10 pcs	10 pcs	Should fit to the available tool

Table 4: List of materials for a 24 ft (7.5 m) WAM Proa (larger versions may require more material)

5.1 Lumber

Wooden boatbuilding requires high quality lumber. Lumber of this quality is rarely available in the Marshall Islands, and if it is available it is very expensive. To make boat building more cost effective, the WAM Proa was designed to be built with the kind of wood commonly available from hardware stores internationally. Commonly available wood suited to boat building includes: Douglas fir, cedar, spruce and pine. Poplar and whitewood are not suitable as they are too soft. Unfortunately, in some parts of the world (especially the USA and the tropics), the lumber sold at hardware stores is almost entirely for construction work and cannot be used for boat building because of its heavy rot prevention treatment (you can identify this by a green color. Epoxy does not stick to wood treated in this way). Untreated lumber is only used as cast material for concrete construction and therefore is a very low quality. Common problems with lumber which affect the suitability for boat building are:

- knots in the wood
- irregular grain
- high moisture content

Suitable lumber should be hand-picked from the stockpile at the store. The quality of the wood is more important than the wood's dimensions at this point. Only dry pieces of wood with straight grain and very few knots are worth taking home. Usually, a pile of wood in a hardware store in Majuro or anywhere else in the world will contain at least a few suitable pieces of wood. Back in the workshop, the lumber should be cut lengthwise on a table saw into many battens (see figure 31). The dimension of each batten should be adapted to the original dimension of the lumber to minimize waste.[9] All exposed knots should then be removed from the battens and the remaining lumber should be planed if necessary. If some battens are not long enough anymore for their intended purpose (which is very common) a bevel for a scarf joint should be cut using a fixture on the table saw (see figure 31 b and c). These (scarfed) battens are the raw material for wooden parts like stringers, frames, keels and beams.

5.2 Plywood

Plywood panels are made from peeled lumber veneers glued on top of each other. While the number of plies is always uneven (three, five, seven layers and so on) the grain of the individual layers is orientated 90° to each other. This stabilizes the shrink and swell of the wood and balances the mechanical properties.

Plywood is almost always sold in 4 x 8 ft (1200 x 2500 mm) sheets, in various thicknesses and with different numbers of plies. Larger sheets are available, but usually at considerably higher prices. When big plywood panels are required, regular sheets are scarfed to size (see 6.3).

[9] 1x1 in (25 x 25 mm) or close to that is a suitable batten size.

A quarter-inch plywood (6 mm) may be constructed with three or with five plies of veneer. The 5-ply is more difficult to make and therefore more expensive, but it is also more evenly balanced, with greater stiffness and strength in both directions.[10] The thickness of imported plywood may be listed in millimeters. A 6 mm panel is roughly equivalent to a 1/4 in panel, while 9 mm is slightly thinner than 3/8 in.

In general, all exterior and marine grade plywood is suitable for boat building to a certain degree. Important characteristics are:

- type of wood
- straightness of the grain
- quality of the plies (knots and voids)
- waterproof glue

Plywood

Suitable types of wood for boat building are soft woods like Douglas fir, cedar, spruce and pine, and to a lesser degree poplar (light but weak) and birch (strong but heavy). Medium-density tropical woods like okoume (gaboon), utile (sipo), lauan (Philippine mahogany), meranti and mecore are generally even more desirable for boat building than Douglas fir and pine because they do not have distinct growth rings and the problems associated with them.

Voids within the plywood may cause failure and rot, and the glues used in marine applications must be waterproof (often referred to as “weather and boil proof” or WBP).

Grading rules for plywood differ according to the country of origin. The most popular standards are the British Standard (BS 1088) and the American Standard (ASTM). In the following table some general indications of grading rules are listed:

[10] The more layers the better for boat building.

Grade	Description
A	face and back veneers are practically free from all defects.
A/B	face veneers are practically free from all defects. The reverse veneers have only a few small knots or discolorations.
A/BB	face is as A but the reverse sides permit jointed veneers, as they have large knots, plugs, etc.
B	veneers have a few small knots or discolorations on both side.
B/BB	face veneers have a few small knots or discolorations. Reverse sides permit jointed veneers as they have large knots, plugs, etc.
BB	Both sides permit jointed veneers, large knots and plugs.
C/D	is used for structural plywood. This grade indicates the face has knots and defects filled in and the reverse may have some that are not filled. Neither face is an appearance grade, nor are they sanded smooth. This grade is often used for sheathing the surfaces of a building prior to being covered with another product like flooring, siding, concrete, or roofing materials.
WBP	Weather and boil proof glue as used in marine ply

Table 5: Different grades of plywood

Marine plywood is manufactured from durable face and core veneers, with few defects so it performs longer in both humid and wet conditions and resists delamination and fungal attack. Its construction is such that it can be used in environments where it is exposed to moisture for long periods: each wooden veneer will be a tropical hardwood and have negligible core gap, which limits the chance of trapped water in the plywood and hence provides a solid and stable glue bond. It uses an exterior weather and boil proof (WBP) glue similar to most exterior plywood.

Marine plywood can be graded as being compliant with BS 1088, which is a British Standard for marine plywood and IS:710, which is a Bureau of Indian Standard (BIS) for marine grade plywood. There are few international standards for grading marine plywood and most of the standards are voluntary. Some marine plywood has a Lloyd's of London stamp that certifies it to be BS 1088 compliant.

For prototype workshops, the use of marine grade plywood from a wood such as okoume and compliant with BS 1088 is strongly recommended.[11]

5.3 Epoxy

Epoxy refers to any of the basic components or cured end products of epoxy resins. They are widely used in modern boat building for coats, fiber reinforced plastics (GRP if glass fiber is used[12]) and structural adhesives.

[11] To be safe WAM is using marine quality plywood for everything.
[12] See section 5.4 and 6.6

	Epoxy	Light wood	GRP
Modulus of elasticity in fiber direction (GPa):	2.7 - 3.4	8.8 - 10.8	44
Modulus of elasticity transverse to fibers (GPa):	2.7 - 3.4	0.5 - 0.8	13
Tensile strength in fiber direction (MPa):	60 - 80	60 - 80	1000
Tensile strength transverse to fibers (MPa):	60 - 80	2 - 3	50
Compression strength in fiber direction (MPa):	60 - 80	40 - 50	900
Compression strength transverse to fibers (MPa):	60 - 80	5 - 10	120
Density in g/cm^3:	1.2	0.4 - 0.5	2.0

Table 6: Typical mechanical properties of epoxy resin, light wood (such as pine and spruce) and glass fiber reinforced plastic (GRP - a mixture of epoxy and glass fiber) compared to each other.[13]This table shows that epoxy surpasses the strength of typical light wood, and therefore is suitable as a structural glue without the need for screws or nails. It is important to note that the properties of wood and GRP highly depend on the fiber orientation of the material. This is explained in detail in section 6.1.

Epoxy

The mechanical properties of epoxy resin are at least as strong, in most cases far superior, compared to common light woods used for boat building. This makes it an excellent adhesive for structural joints and allows for construction without any metal fasteners like nails or screws. A well designed and manufactured epoxy joint is usually much stronger than the surrounding wood.

Epoxy is durable and waterproof. Therefore, it is used as coating and a protective layer to protect lumber and plywood from water and other aging influences.

In combination with glass fiber (see 6.6) epoxy's useful mechanical properties are significantly enhanced.

Epoxy surfaces must be protected from exposure to sunlight as epoxy is not UV stable resistant long term.

5.3.1 Toxicity and safety

The primary risk associated with epoxy use is often related to the hardener component and not to the epoxy resin itself. Amine hardeners, in particular, are generally corrosive and may also be classed as toxic or carcinogenic/mutagenic.

Liquid epoxy resins in their uncured state are mostly classed as irritant to the eyes and skin, as well as toxic to aquatic organisms. Solid epoxy resins are generally safer than liquid epoxy resins, and many are classified as non-hazardous materials. One particular risk associated with epoxy resins is sensitization. Exposure to epoxy resins can, over time, induce an allergic

[13]The mechanical properties are averages for comparison only, real properties depend on the actual material composition. The numbers where compiled from Eichler 2017 and *Handbuch Faserverbundkunststoffe/Composites* 2014.

reaction. Sensitization generally occurs due to repeated exposure (e.g. through poor hygiene in the workplace or lack of protective equipment) over a long period of time. An allergic reaction is often visible in the form of dermatitis, particularly in areas where the exposure has been highest (commonly hands and forearms). To reduce the risk of cancer, as well as the risk of sensitization, direct exposure to uncured epoxy resin must be avoided. Disposable gloves are mandatory for all jobs involving uncured epoxy.

Acetone works as cleaner for tools while vinegar is a less aggressive alternative for skin. Spilled hardener, resin or mixture can be removed by soaking it into sawdust and cleaning afterwards with acetone.

Resin and hardeners are toxic to aquatic organisms. Empty containers and leftover components must be disposed of with care according to local law.

The curing of mixed epoxy resin is an exothermic reaction and, in some cases, produces sufficient heat to cause thermal degradation or even start burning if not controlled!

Figure 15: Resin and hardeners are toxic to land and water organisms. Epoxy must not be disposed into nature.

5.3.2 Mixing and curing

Epoxy resins can be reacted (cross-linked) with co-reactants. These co-reactants are often referred to as hardeners or curatives, and the cross-linking reaction is commonly referred to as curing. Curing may be achieved by forming a copolymer with resin (component A) and polyfunctional curatives or hardeners (also referred to as component B). This means component A (resin) reacts with component B (hardener) to become a solid state. For a full cure (or copolymerization) the right ratio of A and B must be mixed carefully together. If the mixture contains either too much A or B, some uncured resin or hardener will be left over (without a reaction partner) and the mix will never fully cure.[14]

[14] Unlike polyester more hardener doesn't mean faster cure!

Epoxy

Figure 16: The correct amount of resin (component 'A') and hardener (component 'B') must be measured and mixed carefully. More hardener doesn't mean faster curing. Any error of the mixing ratio will result in no curing at all!

The correct amounts of resin and hardener are either measured by volume (e.g. two cups of resin to one cup of hardener for a 2:1 ratio or 100:50 ratio) or by weight (e.g. 100 grams of resin and 50 grams of hardener). The mixing ratio is usually given on the container and on the specification sheet of the resin system.

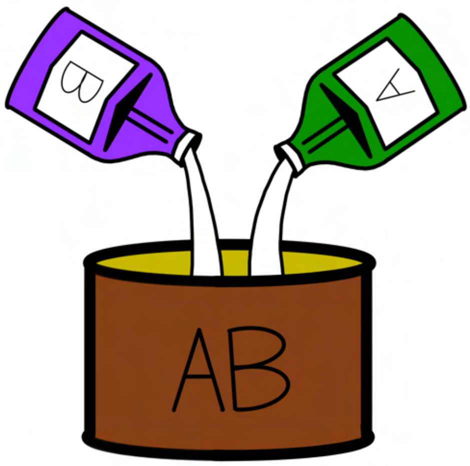


Figure 17: Component ‘A’ and ‘B’ are carefully measured and mixed. The mixing ratio is critical and must be correct.

It is important to check whether the ratio is given by volume or by weight.[15] Mixing ratios by weight and by volume are usually different as the density of resin and hardener varies.

Resin and hardener must be mixed carefully. Make sure to mix in the bottom, side and edges of the container. A general rule of thumb for hand mixing is mixing for about 60 seconds for batches up to 5 fl.oz. (150 ml).[16]

An increased ambient temperature accelerates the reaction of epoxy mixtures (in hotter temperatures the epoxy will set faster). Speaking generally, an increase by 18°F (10°C) results in a reduction of the pot-life[17] and the curing time by 50%. Curing of epoxy resins is an exothermic reaction and in some cases produces sufficient heat to cause thermal degradation if not controlled!

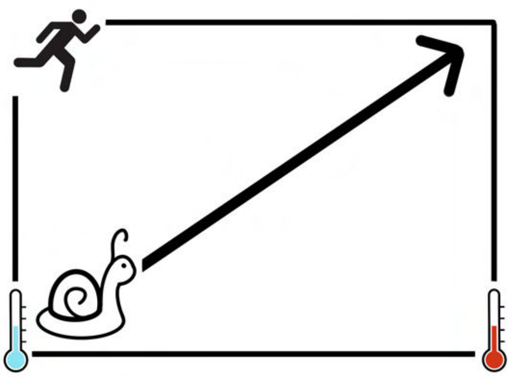


Figure 18: Heat does greatly accelerates the curing of epoxy!

[15]Some manufacturers supply both.
[16]As a reference, most cans of tuna tends to be around that size.
[17]Time to work with the mixture.

5.3.3 Blushing and blooming

Ambient cured epoxy sometimes appears sticky, tacky, and less glassy and smooth on the surface, when compared to oven cured samples. The cause is most likely due to a chemical side reaction of moisture (humidity) in the air, interacting with a curing agent. This phenomenon is known to epoxy chemists as “amine blush” or “amine bloom”.

Amine blush can be described as a sticky, oily, or waxy appearance on the surface layer of cured epoxy. It can appear as greasy white spotting, or even as salt-like, crystalline deposits. Many times, it can also be cloudy, milky or gray colored, with opacity and dullness.

Amine blush and bloom generally yield the same unwanted cured appearance but differ in their chemical mechanism. Blush refers to moisture condensing on the surface of the epoxy. Whereas, bloom or leaching is essentially the converse reaction, where water-soluble compounds migrate, or leach to the surface, resulting in sticky deposits or patches, like water marks in the sand.[18]

The result of this side reaction with water is that amine compounds, which were intended to react with the epoxy compounds, are being consumed. As a consequence, not all epoxy groups react with the curing agent, the mixing ratio (stoichiometry) is compromised and the end result is under-curing.

Due to its hygroscopic characteristics, hardener must always be kept dry and stored in airtight containers. As soon as it gets exposed to the ambient atmosphere, side reactions with the moisture in the air begin, as explained above.

The ambient humidity is a major factor affecting whether blooming occurs or not. High humidity mean the the risk of blooming is higher, as do slower hardeners or a colder ambient temperature as the system has more time for unwanted side reactions before it is cured.

5.3.4 Practical application in the workshop

The epoxy system must suit the local temperature and humidity conditions. For the average conditions of the tropical Pacific (e.g. Majuro atoll, 86°F or 30°C) a very slow system with a pot life[19] of 60 minutes under those conditions is required. Although it is possible to work with faster resins, a system with at least 60 minutes pot life leaves more time for training and teaching.

In the humid tropical conditions, blooming[20] inevitably occurs, especially on rainy days. A resin system with reduced blooming, especially developed for the tropics, should be used. Wet on wet layers have to be applied within a short time to ensure a chemical bond. Cured surfaces have to be sanded carefully and cleaned with fresh water and soap to ensure a proper bond of the next layer.

[18] Amine cure agents being hygroscopic (absorbing moisture), can react with moisture in the air to form ammonium carbamate by-products.(Epoxy Technology Inc. n.d.)

[19] Time to work with the mixed epoxy before it starts to cure.

[20] Waxy surface on cured resin surfaces, see above.

Resin and hardener must be stored in air tight containers and always kept closed.

Correct ratios must be measured (either by weight or volume) and resin and hardener must be mixed carefully, taking into account the bottom, side and edges of the container. A general rule of thumb for hand mixing is about 60 seconds for batches up to 5 fl. oz. (150 ml).

Acetone is used as cleaner for tools and surfaces to remove uncured epoxy. Vinegar is used as a less dangerous alternative to acetone, especially to clean skin. Epoxy resin should always be cleaned off immediately. Cured resin is very difficult to remove.

Curing of epoxy resins is an exothermic reaction and in some cases produces sufficient heat to cause thermal degradation if not controlled! Large batches go off significantly faster than small ones. For longer pot life, use containers with a large surface area e.g. paint trays.

5.4 Glass fiber

Glass fiber is an artificial fiber material made from very thin glass threads. Glass fiber appears like white hair, sometimes like spider web. It is commonly used as reinforcement in combination with epoxy (see GRP).

(a) Using scissors to cut glass fiber cloth

(b) Rinsing glass fiber cloth with epoxy resin to make GRP

Figure 19: Working with glass fiber cloth

Multiple types of glass fiber with different mechanical properties are available but the type used in this manual is E-Glass, which is by far the most common type. Usually glass fiber is offered in a processed form as one of these three products:

- glass fiber tow
- glass fiber mat
- glass fiber fabric

Tow is a thread made from multiple (usually a couple of thousand, depending on the thickness of the tow) individual glass fibers. It is offered as spools by weight. Tow can either be used right away with epoxy for GRP or as raw material for mat and fabric.

Glass fiber mat is the most common glass fiber product. It is a cloth-like product made from chopped glass fiber tow sold on rolls by length. The chopped fibers are fixed in place by a special glue. **Glass fiber mat is designed for polyester resin, it does not work with epoxy!** It can not be used for this manual.

Glass fiber tow can be woven into different types of fabric, just like any other fiber material. For this manual either plain or twill cloth (from now on referred to as glass fiber cloth) can be used. Glass fiber cloth is sold on rolls by length. The standard width for the rolls is either 3 ft (1 m) or 4 ft (1.3 m).The thickness of the cloth depends on the tow used and is expressed as oz. per sq. yd. (respectively g/sqm).[21] For this manual glass fiber cloth of 7 - 8 oz. per sq. yd. (200 - 220 g/sqm) is used.

All glass fiber products can be cut to the required size and shape by using sharp scissors. Glass fiber cloth, especially twill, should always be handled very carefully. The material should not be folded or wrinkled at any time (after all its still glass), the weaving pattern should not be disturbed. Always store your glass fiber in a dry and clean place away from the resin. If spilled on a roll, one drop of epoxy easily sinks through multiple layers of cloth and ruins it.

[21] Often only the weight is stated even when weight per area is meant.

6 Basic construction techniques

6.1 Understanding materials' mechanical properties

Many materials show different mechanical properties (i.e. strength and stiffness) depending on the direction a load is applied. Wood is a common example of an anisotropic material: depending on the orientation of the grain (or in other words the wood fibers) its strength does greatly vary. This can be easily tested with a piece of wood and a knife or ax. It is very easy to split the wood along the grain while it is very difficult to split it perpendicular to the fibers. In this example the load applied by the knife or ax is directed sideways to each side of the blade. Hence, the wood is much stronger if the load is directed into the direction of the fibers instead of being perpendicular to them. These characteristics are also reflected by table 6 in the previous section by the different numbers for the strength in fiber direction and transverse to the fibers. These anisotropic characteristics are also present in plywood and GRP (glass fiber and epoxy). For the practical application in boatbuilding this means that the fibers (i.e. wood grain and glass fiber) should always be oriented in the direction of the prevalent loads. The grain in a stringer for example is directed longitudinally because the purpose of a stringer is to make the hull stiff for longitudinal loads such as bending. The task of the boatbuilder is to think about direction of the loads that each part will see and orient the material accordingly to make best use of its properties.

6.2 Epoxy as glue

As already introduced in 5.3, epoxy resin is an excellent structural adhesive because of its good mechanical properties compared to lumber and plywood. From now on, 'resin' will always refer to the ready-to-use resin and hardener mix (components A and B). Pure epoxy resin has a comparably low viscosity (it is liquid and runny) to wet out fibers (like glass fibers) or work as a coating.

For structural bonds, a mass of higher viscosity (something between tomato sauce and peanut butter) is needed to fill gaps in a joint and ensure the resin stays in place. The viscosity of epoxy can be adjusted by adding colloidal silica and/or cotton fibers to the mixture. Horizontal and flat joints require glue which has only been thickened slightly, while vertical and imprecise joints (larger gaps) require substantially thickened glue so it stays in place.

Gentle pressure applied to joins (using clamps or weight) helps to ensure a strong bond. Excess glue should squeeze out all around. This is a clear indicator enough glue has been used. If no glue squeezes out, more should be applied to fill all voids.

Surfaces for structural bonds must be prepared well to ensure proper strength. In general, they should be sanded and cleaned (free of dust, grease and oil). End grain or porous wood may need a coat of unthickened resin before the glue is applied to avoid absorption of resin resulting in a dry joint.

Figure 20: Breaking test for an epoxy joint. Two pieces of wood are glued together with epoxy. The chisel is placed on the glue line to split the blocks apart. The epoxy itself and its adhesion to the wood should be stronger than the wood and therefore result in the wood splitting right next to the joint.

Lumber and plywood must be dry to avoid unintended and weakening side reactions of hardener and moisture (see 5.3, Blushing and blooming).

Construction technique

The strength of epoxy joints can be tested by gluing two blocks of lumber together and splitting them apart at the joint (after the resin is fully cured) with a chisel (see 20 below). The epoxy itself and its adhesion to the wood should be stronger than the wood and therefore result in the wood splitting right next to the joint. Treated lumber, in general, is not suitable for epoxy bonds as the epoxy may not stick to the treatment. However, some treatments may work but it should always be confirmed with a tests, as described above.

In case colloidal silica and cotton fibers are unavailable, baking flour can be used instead. Tests indicated no negative effect on the adhesive strength.

6.3 Scarfing

Scarfing is a special technique to connect lumber and plywood pieces together. In modern boatbuilding it is widely used with epoxy resin as adhesive to make long boards and plywood panels out of shorter ones. A well-made scarf joint bonded with epoxy can be as strong as the material it joins.

Although there are several different kinds of scarf joints, only one, the simplest and most reliable one is used to build a WAM Proa (see 21).

Figure 21: Scarf joint of a lumber batten (side view). The long bevels increase the bonding surface and therefore the strength of the connection.

Identical bevels are machined at the ends of the pieces to be joined. These matching bevels fit together, and are then permanently bonded with epoxy. The main objective of the bevel is to develop enough surface bonding area to exceed the strength of the wood itself.

The correct size of the scarfing bevel depends on the thickness of the parts to be joined. For most boat building applications a ratio of 8-to-1 is sufficient, so a 1 in (25 mm) thick board will have a bevels 8 in (200 mm) long.

6.3.1 Lumber

It is difficult to get lumber free of the quality issues discussed in 5.1, but it is almost impossible (and if it is possible, it is expensive) to get this high-quality lumber in the right length required for boat building. Scarf joints are used as a work around to overcome these issues and make long, knot free boards out of shorter ones. The WAM Proa is based on 1 x 1 in (25 x 25 mm) lumber. The required size is simply glued and scarfed together from prepared 1 x 1 in (25 x 25 mm) battens as described in 5.1.

The fastest and easiest way to make the 8-to-1 bevel is to use a scarfing jig for the table saw as shown in 31.

Before the glue (thickened epoxy resin as described in 6.2) is applied, the bevels (usually end grain) should be wet with unthickened resin to avoid too much resin getting absorbed out of the glue mix by the dry wood.

Scarfs can be kept in place with clamps but the bevels tend to slide if pressure is applied.

6.3.2 Plywood

The process of scarfing lumber and plywood panels is very similar. However, one significant difference is the standard dimensions of each: a 6 or 8 in (150 mm or 200 mm) wide scarf joint in lumber is considered large, but a 4 ft (1200 mm) or even 8 ft (2400 mm) wide scarf joint in plywood is standard. Plywood is usually much thinner than lumber and therefore plywood bevels are usually shorter

The table saw jig used for lumber to cut the bevel doesn't work for plywood panels. One option is to cut the bevel manually with an electric planer as shown in 34, another one involves a jig for a router.

Scarfing plywood is only necessary if a panel with no increase of thickness is required (i.e. the plywood for the beams of the WAM Proa). For all other purpose, a butt-join with doublet on one side and a glass tape on the other is a sufficient solution (i.e. the side panels of the WAM Proa hulls).

6.4 Laminating of lumber

A technique for creating high quality lumber out of low quality hardware store supplies is described in 5.1. For every application that requires a lumber cross-section larger than a single 1x1 in (25x25 mm) batten, a number of battens (scarfed to full length if necessary) are laminated (glued) together with epoxy glue (for laminating of lumber, see 31 and 35). The constructed laminated wood is free of knots and contains only selected straight grain. Because of the different orientation of the battens within the laminate, its shrinking is limited to a certain extent and the risk of cracks is low.

Construction technique

6.5 Fillets

The fillet has become one of the most versatile methods of bonding wood, especially for joining parts at or near right angles, to each other. Basically, a fillet is a continuous bead of thickened epoxy mixture applied to the angle between two parts to be joined (see figure 22).

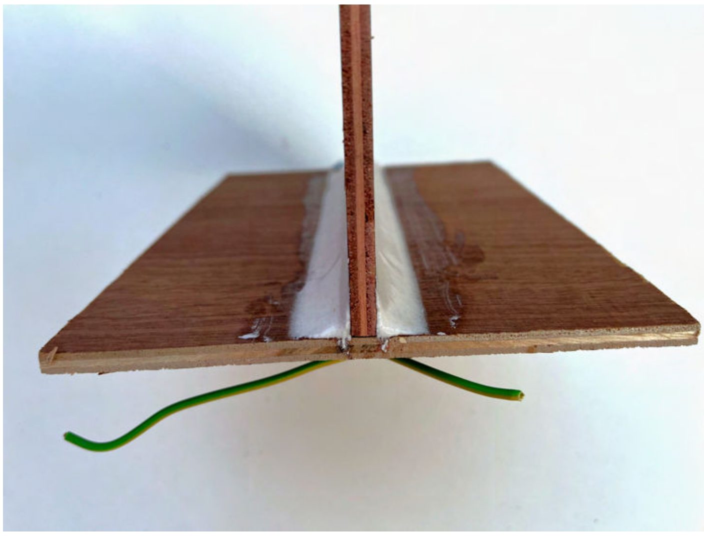


Figure 22: Cross section through a T-joint with a fillet on each side

It increases the surface area of the bond and serves as a structural brace. Filleting requires no fasteners of any kind and can result in a joint that is as strong as the parts being joined together.

There are some limitations with filleting however. The fillet cannot join two materials end-to-end, rather it is most successful for joining parts at roughly right angles. The fillet also works best when joining thinner wood material, such as plywood up to 1/4 in (6 mm). At this size, it is relatively easy to manufacture a joint that has equal strength to the material. As the material becomes thicker, the fillet size must increase accordingly to maintain this. A large fillet becomes less attractive because of material costs (wood is much cheaper than epoxy) and application difficulties (a large fillet becomes very unwieldy as its mass increases, due to the consistency of the material in the uncured stage). All joints which will be covered with fiberglass cloth will require a fillet to support the cloth at the inside corner of the joint.[22]

For a filleting mixture, epoxy resin is thickened with fillers up to the consistency of peanut butter (not runny). The density of the filler determines whether the mixture will result in high or low density fillets (see figure 22 for differences). Colloidal silica makes up a very strong but heavy high density fillet, while micro balloons make a light but weaker low density fillet.[23] Whether high or low density fillets are required for a specific application depends on the material to join. The higher the density the stronger the joint. Another important factor is the size of the fillet. Larger fillets are stronger than smaller ones.

The design goal is a bond which is slightly stronger than the wood it connects. As all lumbers and plywoods are different, the right size and density must be determined by breaking test samples as shown in figure 23 below.

[22]Gougeon 2005
[23]Colloidal silica and micro balloons are often blended to medium density filler.

(a) Breaking test of a fillet sample

(b) Broken fillet sample: if it breaks outside the join and the fillet remains clean and smooth, then the bond strength exceeded the material strength so the size and density are strong enough.

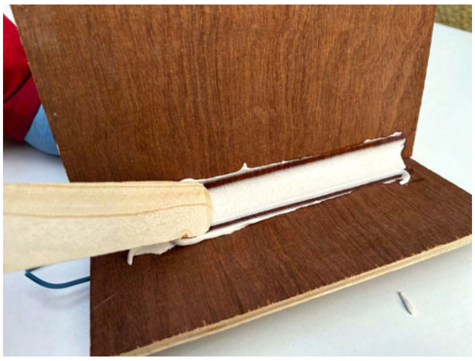
Figure 23: Breaking test of a fillet sample to determine the required fillet size.

If the sample breaks outside of the joint and keeps the fillet clean and smooth, then the bond exceeds the material strength, so the size and density are strong enough.

The application of fillets is explained in three steps by figure 24 below.

(a) The setup of a T-joint with two pieces of plywood. They are held in place by copper wire. The required tools, a wide spatula with round tip and a wedge or sharp spatula, are prepared.

(b) The fillet mix is applied to the joint.



(c) A spatula with a round tip is used to create a smooth radius.

(d) A sharp spatula or wedge is used to clean off any excess epoxy mix.

Figure 24: The application of fillets

If colloidal silica or micro balloons are not available - or too expensive - baking flour can be used instead for glue and fillet mixtures. The strength of flour fillets was proven by test samples as demonstrated above. No negative long-term effects were observed. Flour fillets should be coated with an extra layer of epoxy because the flour close to the surface may be susceptible to mold, which is a purely visual problem. The application of flour fillets turned out to be slightly more difficult compared to colloidal silica/micro balloons as there is not very much difference between 'too runny' and 'too dry'.

6.6 Glass fiber reinforced epoxy (GRP)

GRP Pure or thickened epoxy resin is an exceptionally durable and strong material for bonding, sealing, or filling applications. However, it is unsuited to construction on a larger scale due to its brittleness and limitations in layer thickness (because too thick a layer of epoxy may produce too much heat while curing and risk degrading the material).

Glass fiber reinforced epoxy is a composite (mixed) material made from epoxy and glass fiber. In theory, the mechanical properties of glass fiber are far superior to any other common material and are only matched by high-tech fibers like carbon or Kevlar. Unfortunately, glass fibers, like all fibers (i.e. ropes or strings), carry tensile loads very well but cannot handle loads in any other direction, because they get bent and displaced. Once combined with epoxy, the fibers are kept in place by the cured resin which allows them to carry loads in all directions. The combination of glass fiber and epoxy (also referred to as a composite material, glass fiber reinforced plastic or GRP) offers by far better properties than each material alone and is therefore widely used in modern boatbuilding (a demonstration of the strength of a single layer of glass fiber cloth is shown in figure 25 below).

Figure 25: Sample to demonstrate the strength of glass fiber. The right (broken) strip is untreated 3/8 in (9 mm) marine plywood, the left sample is a plywood strip of the same dimensions but covered with a layer of 180 g (6 oz) glass fiber cloth on each side. The glass fiber covered sample on the left was able to carry twice the load of the right sample before the plywood in between the glass layers collapsed.

Construction technique

GRP is commonly used to reinforce and/or stiffen panels and make local reinforcements, as well as to protect against abrasion, impact and damages (i.e. the entirety of the outside surfaces of the prototypes were glassed. Edges, corners and exposed areas like the keel were doubly reinforced with additional patches).

The various techniques of practical work with GRP take some practice but can be easily mastered by anybody. During the workshop, only the hand layup process (most basic technique) was applied. Glass fiber cloth is wetted out manually with epoxy resin until the white fibers become clear and almost invisible (see figure 42). The surface must be prepared for glassing the same way as for any bonding.

6.7 Rot prevention

Rot prevention measures are a crucial part of plywood boat building and important for the longevity of a craft. Well-made and maintained boats are likely to survive for 50 years or more, while poor construction quality can lead to a lifespan of five years or less.

Rot is mainly caused by fresh water. To keep a boat free of rot, the exposure of wood to water must be prevented. The following factors play a role in rot prevention and should be always kept in mind:

Design

- Places which allow rainwater to bead (collect) should be avoided (e.g. toe rails without drain holes on the deck or puddles on flat deck or roof panels).
- Abrasive contact between parts will eventually break through the protective layer of epoxy and expose the wood to water.

Ventilation

- If possible, all compartments should be accessible (at least by small inspection hatches). The trapped air inside of closed compartments always contains humidity that eventually will condensate and potentially cause rot in a hidden place.
- Flat surface contact (e.g. beams directly mounted on top of a flat deck) should be avoided as water trapped in a small gap hardly vaporizes.

Surfaces

- Surfaces should be covered with at least three layers of epoxy or glass cloth as proper sealing against water.
- Glass fiber greatly reinforces surfaces and makes cracks or scratches less likely to expose the wood.

Edges

- Edges, especially if they expose end grain, must be treated even more carefully than surfaces. They should always be reinforced by at least three layers of glass fiber cloth.
- All edges must be rounded (the rounder the better) as sharp edges can not be coated by resin properly and are at risk of getting damaged on impact.

Holes

- The inside of any hole must be sealed and waterproof. Holes are pre-drilled bigger than needed and filled entirely with epoxy resin. The holes are drilled again, after the epoxy has cured, at the required (smaller) diameter without cutting the wood.
- If pre-drilling is not an option, holes can be coated from inside by closing them on one end and filling them up with unthickened resin. After a while (holes usually expose end grain which absorbs a lot of resin) the closed side is opened again and the leftover resin runs out.

Construction technique

Nails and screws
Nails and screws should be avoided as they can potentially cause rot. Furthermore, a well-made epoxy joint is far superior when it comes to strength.

Internal barriers

Between each part of a bonded structure is an impermeable layer of glue. The glue layers act as internal rot barriers and separate all wooden parts from each other. This means that if the protective coating of one part gets cracked, only this one will rot, without damaging the surrounding structure. Nails and screws usually penetrate these internal barriers and should therefore be avoided.

Maintenance

- Epoxy resin is not UV stable stable and must therefore be protected from sun light. A coat of paint (exterior house paint is already sufficient) must always be applied and maintained.
- Cracks or damage which exposes any wood must be repaired as soon as possible. The wood will absorb water at the damaged spot and rot may potentially spread inside.

6.8 Stitch and glue

Stitch and glue is a simple boatbuilding method, which consists of plywood panels being stitched together, usually with copper wire or wire straps, and then glued together with epoxy resin. It combines all of the basic techniques described above and is the backbone technique of the WAM Proa. This type of construction can eliminate much of the need for frames and ribs. Plywood panels are cut to shape and stitched together to form an accurate hull shape without the need for forms or special tools. Seams between panels are reinforced with thickened epoxy (see 6.5) and/or fiberglass tape (see 6.6). See figure 26 below for further information.

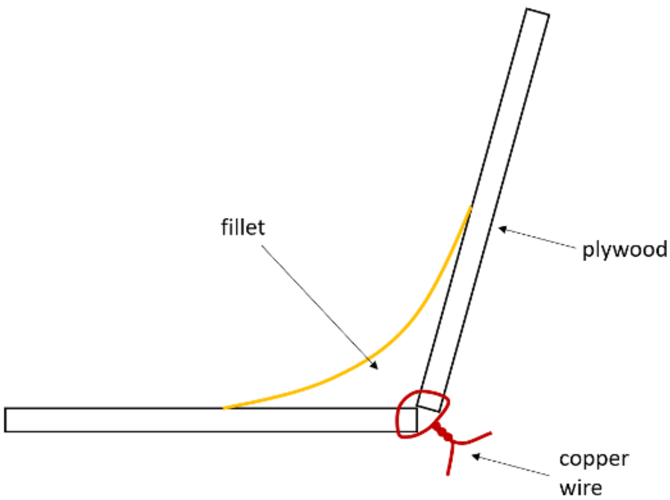


Figure 26: Schematic representation of a stitch-and-glue joint cross section

7 Safety

As with many DIY activities, there are injury risks and health hazards associated with boat building. Read and understand the following sections carefully before starting any construction activities.

Figure 27: Establish good practices in the workshop: make sure personal protective equipment (PPE) is used and the workshop is properly set up. The work shop should be ventilated and escape routes should be known, marked and unblocked. A first aid kit, fire extinguisher and freshwater should also be on site.

7.1 Personal protective equipment (PPE)

Appropriate personal protective equipment is mandatory for all construction tasks in the workshop. For your own safety, carefully follow figure 28 below.

(a) Read the instructions in this manual before starting any construction. Also, read the instructions for the power tools you are using, as well as your epoxy resin.

(b) Protect your ears when you use machines which make a loud noise.

(c) Use safety goggle to protect your eyes when you use machines or epoxy.

(d) Use gloves for tasks which involve epoxy and paint.

(e) Wear overalls when grinding, sanding, using epoxy or painting.

(f) Wear a dust mask when grinding, sanding or cutting especially if epoxy and glass fiber is involved!

Figure 28: Mandatory personal protection equipment (PPE)

7.2 Workshop

The workshop must be ventilated, escape routes known, marked and unblocked. A first aid kit, fire extinguisher and freshwater must always be on site.

7.3 Epoxy

While cured epoxy is not harmful, uncured resin, in particular the hardener, is toxic to marine life and potentially carcinogenic for humans (it may cause cancer), see figure 29. Handle uncured epoxy carefully and avoid skin contact. Always wear personal protective equipment as stated in figure 28 and 29. Clean spilled resin immediately. Use vinegar to wash it off skin if necessary.

Uncured leftover resin (component A and B) and any used containers must be disposed of carefully, as they are classed as hazardous waste by many legal systems.

The chemical reaction when epoxy cures is exothermic (releasing heat). Large portions of mixed epoxy may get very hot and can be self-igniting. Never leave large amounts of epoxy in a bucket, and never leave buckets with leftover resin unattended.

Figure 29: Warning labels commonly found on epoxy containers

7.4 Dust

Sanding and grinding is inevitable in boat building. The dust produced by these activities is hazardous to your lungs. The dust of glass fiber and the fine dust of hardwood especially constitute serious health risks. Wear a dust mask whenever dust is produced.

7.5 Handling of tools and machines

The tools specified by this document have the potential to cause serious injuries if not used properly. Before you use any of these tools, carefully read and understand their manuals.

Always wear your personal protective equipment (PPE). Before plugging in any tool, check that it is switched off. Never operate any tools under the influence of alcohol or other drugs.

7.6 Environment

Epoxy resin is an environmentally hazardous substance and must be handled with care according to the data sheet of the product. Study the data sheet of your epoxy carefully and apply it according to local law.

In dust form, epoxy is a microplastic. Avoid any emission of this dust into the environment.

8 Construction manual - day by day

The day-by-day manual leads the inexperienced builder step-by-step through the entire construction process. Teachers and trainers may find it useful too, as it gives a clear schedule for each day.

This manual divides the entire construction process into small, easy tasks. For each day, a schedule of different tasks is composed. Tasks each day are allocated because they work well together and are planned to ensure smooth progress. The schedule for each day is designed for either two builders with intermediate experience, or one trainer with six trainees. If you work alone, you may find it difficult to finish all proposed tasks in a day. This is no problem at all, as long as you keep the order of the tasks.

Preparation All materials (as listed in 5) and tools (as listed in 4) should be readily available for use. The construction of the WAM Proa requires a rain protected and dry workshop of at least 26 by 13 ft (8 by 4 m). A sufficient number of power plugs as well as freshwater should be available.

8.1 Day 1

8.1.1 Task 1: Prepare the plywood

The work on the WAM Proa starts with the preparation of the plywood for the hulls. At this point the builder has to decide the size of the canoe. It is recommended to base it on the 8 ft standard length of plywood sheets. The resulting options are 16 ft (2 sheets long), 20 ft (2.5 sheets long) and 24 ft (3 sheets long). **The following guide is based on 3 sheets (24 ft)**. For a 24 ft Proa 12 sheets of 1/4 in (6 mm) plywood are required overall. In the first step of preparation, all 12 sheets should be cut in half lengthwise as shown in figure 17) by using a (hand-held) table saw.[24]

[24] If possible already purchase the sheets split lengthwise. Most suppliers offer one or two complimentary cuts for easier transportation.

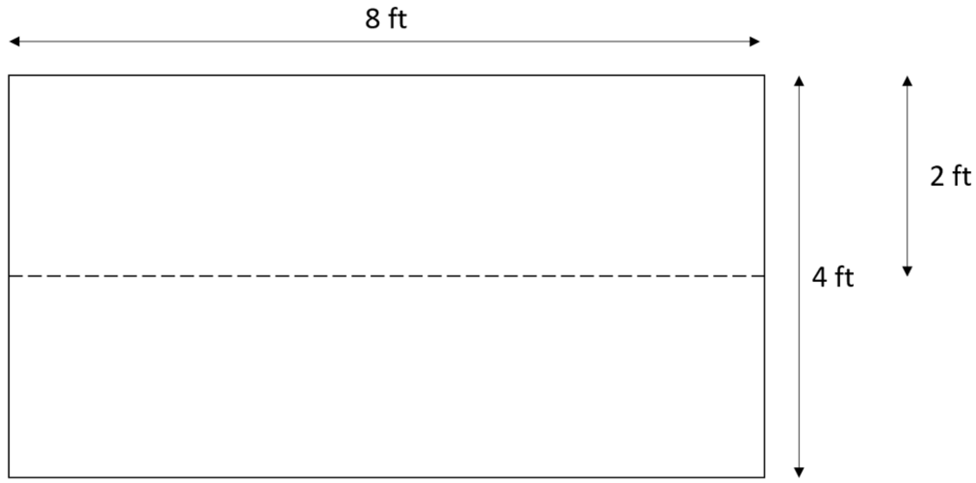


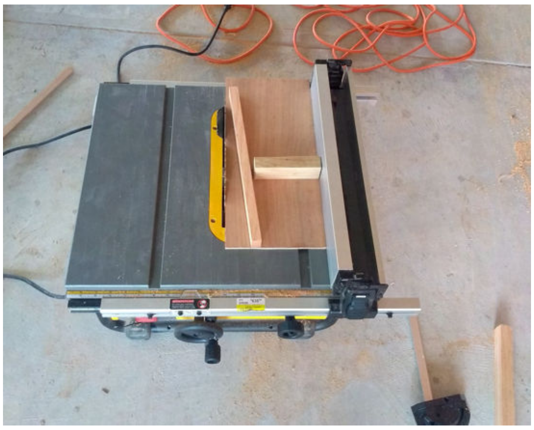
Figure 30: Splitting standard plywood sheets lengthwise

8.1.2 Task 2: Prepare the clamps

Prepare approximately 30 pipe clamps as shown in 13 e) and 20 wood clamps as shown in 14 a) and b).

8.1.3 Task 3: Prepare the lumber battens

The WAM Proa mainly uses lumber of the size 1x1 in (25x25 mm). Cut the purchased lumber lengthwise by using a table saw to the required size of 1x1 in (25x25 mm). Slightly larger or smaller is fine, depending on the original size of the procured lumber, as long as consistent throughout the entire construction. Cut out all knots with the chop saw (very small knots are fine). The battens will have to be scarfed to make longer ones. Make a scarfing jig for the table saw (see figure 31 a) below) and aim for a scarfing ratio of 1:8 (see 6.3). Cut scarfs to the off-cut battens: produce enough cuts for at least eighteen 11 ft battens, eleven 16 ft battens and twenty 24 ft battens. Puzzle them together as shown in figure 31 b) below.



(a) Table saw with DIY jig for scarf cuts

(b) Cutting scarfs

(c) Puzzling together full-length battens by using scarf connections

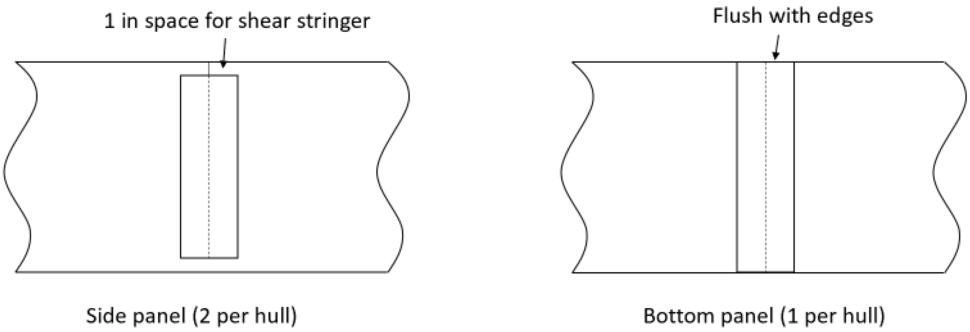
Figure 31: Preparation of the beam lumber

Keep the off-cut wedges from the scarf bevels - they will be used as spatulas to apply glue.

8.1.4 Task 4: Glue the side and bottom panels

Place fifteen of the half plywood sheets on a flat and even floor. For the bottom and the two side panels of the main hull three sheets should be connected lengthwise for each panel. For the shorter windward hull only two sheets are required for each panel as shown in figure 32 a) below. The doublets are now glued on (see 6 Basic Construction Techniques, Epoxy as Glue). Prepare two sizes of doublets: The doublets for the bottom panels should be as long as the bottom is wide (2 ft) to end flush with the plywood edge on each side. The doublets for the side panels should leave 1 in (25 mm) of space on each side (see figure 32 b) for reference). Use wax paper or a plastic sheet underneath each seam to prevent the side panels from sticking to the floor. Weight should be applied to ensure a proper bond and glue must squeeze out everywhere (see figure 32 c) and d) below).

(a) Layout of the required bottom and side panels



(b) Size and placement of the doublets

(c) The position of the doublet is marked with a pencil.

(d) The ply sheets are joined by glued on doublets. Water bottles are used as weight to keep everything in place.

Figure 32: Preparation of the side and bottom panels

8.1.5 Task 5: Scarf the beam battens

The battens prepared earlier are now scarf joined. The construction of two beams requires 16 11 ft long battens of the size 1x1 in (25x25 mm). Apply unthickened epoxy first and spread glue after a couple of minutes. Use F- or C-clamps to apply gentle pressure on each scarf joint. The battens may slide when pressure is applied - take care that the joints line up. Remove excess resin and reuse it for other scarf joints. Allow the glue to cure overnight. Details on how to properly scarf can be found in 6.3.

8.2 Day 2

8.2.1 Task 6: Prepare the beam plywood

The crossbeams of the WAM Proa are rectangular hollow box shapes made from lumber and plywood as shown in figure 33 below.

Figure 33: The rectangular and hollow cross section of the beams. The lumber is positioned on the top and bottom to take the bending loads while the vertical plywood works as a shear web.

The width of the entire platform and therefore the length of each cross beam is 11 ft (3.3 m), which is 1.5 sheets (12 ft) minus one foot for the overlap of a scarf. Cut six stripes of a sheet of 3/8 in (9 mm) plywood lengthwise with a width of 5 in (125 mm). Cut two strips in the middle to get four 4 ft long strips. Each full-length strip will be scarfed to one half-length piece to eventually get four strips of 11 ft (3.3 m).

The scarf joints of the plywood are made according to 6.3 with a scarfing ratio of 1:8. The bevels are best cut by using an electric planer as shown in figure 34 a) and b) below.

(a) Cut scarf bevels into plywood strips for beams using a planer.

(b) The scarf bevels depicted are halfway through being planed. Every line of the steps should be parallel for a good result.

(c) Three scarf joints waiting for glue. Clamps or something heavy will be sufficient to keep them in place until the epoxy has cured. Wax paper is used to separate both joints from each other.

Figure 34: Scarf joints of the beam plywood

Place all plywood strips on top of each other on a table. Make them look like a stair with every step approximately six fingers (3 in, 75 mm]) long (scarfing ratio of 1:8) and clamp them down. Run an electric planer down the stairs until an even bevel is cut.

8.2.2 Task 7: Clean scarfed battens

Clean the joints of the sixteen battens scarfed yesterday by using an angle grinder.

8.2.3 Task 8: Reinforce the side panels

Flip the hull panels (task 4, 8.1.4) carefully around. Clean up the butt-joints with a grinder. Fill the outside seams with thickened epoxy and reinforce the butt-joints with tapes from 7 oz. (200 g) glass fiber cloth. Place the glass fiber tapes (approx. one hand width wide) on top of each seam and wet them out with epoxy resin as explained in 6.6.

8.2.4 Task 9: Glue the beam lumber and beam plywood

Glue the scarf joints of the plywood strips (task 6, 8.2.1) together. As always, apply unthickened epoxy first, followed by glue a couple of minutes later. Apply pressure (weight or clamps) and make sure the strips do not slide and line up perfectly (check by using a long ruler e.g. the edge of a plywood sheet).

Take eight of the 12 ft (3.6 m) long battens scarfed yesterday and cleaned in Task 3, see 8.2.1. Glue four of them side to side to create two 4x1 in (100 x 25 mm) boards as shown in figure 35 below. Make sure they don't slide when the clamps are tightened and line up with each other. It may be helpful to clamp lumber sticks (wrapped in wax paper) on top and below to force the individual battens into one board with a smooth surface. Make sure resin is squeezed out everywhere and the bonds are free of voids and dry spots. Scrape off excess glue.

(a) Spreading epoxy glue on the lumber strips

(b) Glue the lumber strips together to form a beam plank. Clamps keep everything in place.

Figure 35: Preparation of the beam lumber

8.2.5 Task 10: Scarf the windward hull stringer

Scarf four 16 ft long 1x1 in (25x25 mm) battens from the prepared lumber. Details on how to properly scarf can be found in 6.3.

8.2.6 Task 11: Prepare copper wire

Take AWG 14 (2.5 mm^2) copper wire (regular for house wiring - try to buy off-cuts from the hardware store) and remove the outer insulation to get to the internal wires. Chop the individual wires (either two, three or four depending on the type of wire) into 1 ft (30 cm) pieces. Keep the insulation on. Those wires will be used for stitching the hull.

8.3 Day 3

8.3.1 Task 12: Plane the beam boards

Remove the clamps from the two lumber boards glued yesterday. Grind off squeezed out glue which has not been scraped off with an angle grinder. Plane the boards on a stationary planer (a hand planer if a stationary planer is not available) to get a smooth surface.

8.3.2 Task 13: Clean the beam plywood scarf joins

Remove the clamps/weight on the scarfed plywood strips glued yesterday. Grind off any squeezed-out resin with an angle grinder and sand the joins smooth.

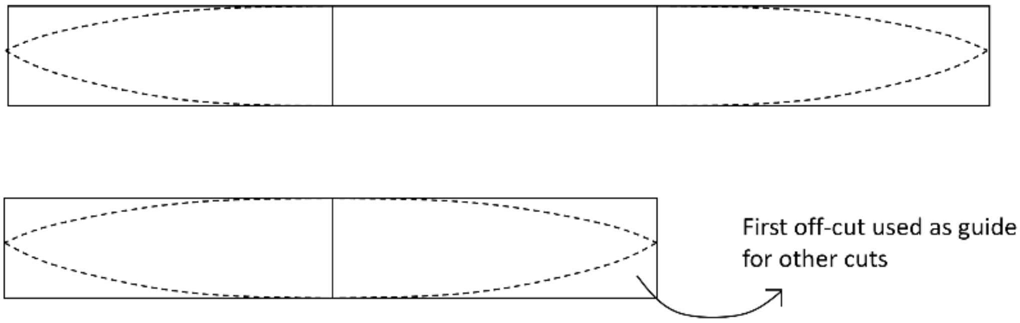
8.3.3 Task 13: Clean the windward hull stringer

Clean the scarf joints of the windward hull stringer using an angle grinder.

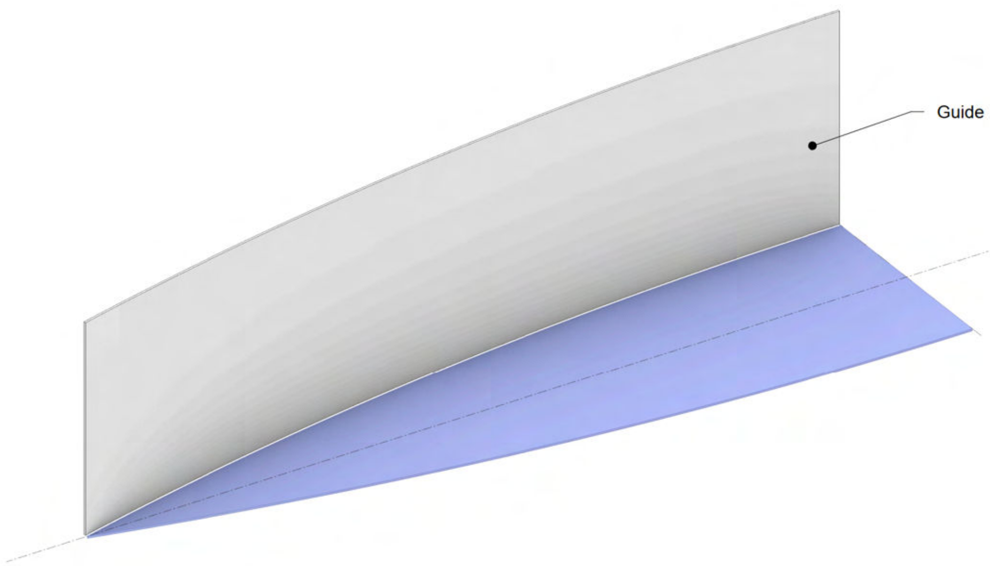
8.3.4 Task 14: Loft and cut the bottom panels

The outline of the hulls follows the shape of the bottom panels (see figure 36 a). The shape is determined by using the side panels as rulers (see figure 36 b). This is only necessary to mark the first line. After the first bow outline is marked, the bottom panel is cut using a jigsaw.[25] The off-cut is now used as guide to mark the other lines.

[25]Make sure it is really the bottom panel you are about to cut! The bottom panel has doublers flush on both sides while the side panels have doublers spaced 1 in (25 mm) on one side.



(a) Outline of the bottom panels



(b) Side panel used as guide to determine the bottom panel shape

Figure 36: Determining the bottom panel shape

8.3.5 Task 15: Glass tapes for beam plywood

Cut tapes of 7 oz. (200 g) glass fiber to the size of the plywood strips for the beams (Task 6, see 8.2.1). Laminate them on with epoxy resin.

8.3.6 Task 16: Glass the side and bottom panels

Glass the inside (the side with the doublers on) of the side and bottom panels of the windward hull with 7 oz /sq yd (200 g/sqm) glass fiber cloth. Apply thickened resin to the edges of the doublers to allow the glass fiber cloth to smoothly attach without any bubbles.

8.3.7 Task 17: Glue the beam lumber

Take eight of the 12 ft (3.6 m) long 1 x 1 in (25 x 25 mm) battens. Glue four of them side to side to create two 4 x 1 in (100 x 25 mm) boards as shown in figure 35 and explained in 8.2.4. Make sure they don't slide when the clamps are tightened and line up with each other. It may be helpful to clamp lumber sticks (wrapped in wax paper) on top and below to force the individual battens into one board with a smooth surface. Make sure resin squeezes out everywhere and the bonds are free of voids and dry spots. Scrape off excess glue.

8.3.8 Task 18: Coat the beam lumber

The side of the beam lumber which will later be inside must be protected from rot with a thick layer of epoxy. Take slightly thickened resin (like syrup) and brush it on the two already-planed beam lumber boards. This is a good opportunity to use up leftover glue and resin from previous tasks.

8.4 Day 4

8.4.1 Task 19: Plane the beam boards

Remove the clamps from the two lumber boards glued yesterday. Grind off squeezed out glue which has not been scraped off with an angle grinder. Plane the boards on a stationary planer (hand planer if not available) to obtain a smooth surface.

8.4.2 Task 20: Sand the side and bottom panels

Sand the glassed surface of the side and bottom panels with 180 grid. This works best with an orbit grinder. Sand the glassed side of the beam plywood stripes too.

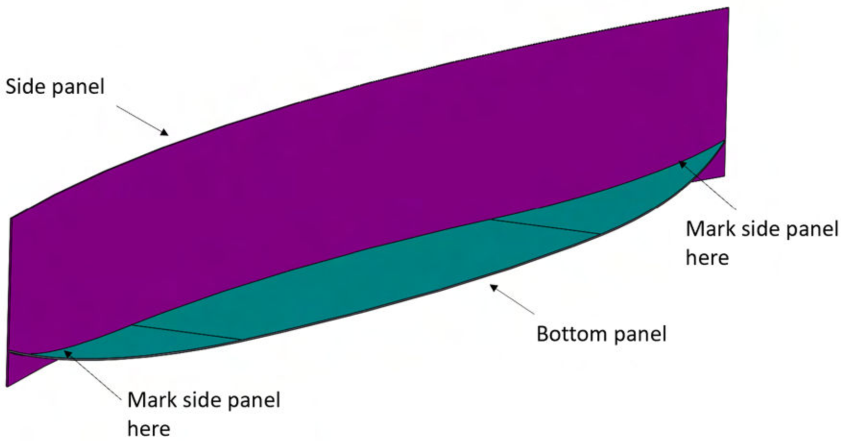
8.4.3 Task 21: Set up the bottom panel of the smaller windward hull

Place the bottom panel of the smaller windward hull on a long, flat table, the glassed surface with the doublers facing up. Use a string to mark the center lines, length wise and across. The tips are raised by 5 in (200 mm) by pushing blocks under the panel to create some rocker as shown in figure 37.

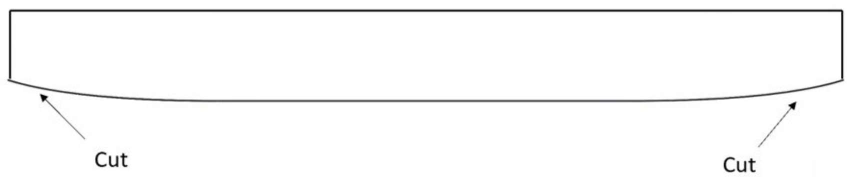
Figure 37: Bottom panel setup

8.4.4 Task 22: Cut the rocker line of the side panels for the windward hull

Take the side panels of the windward hull and place them on their edge on the table. Make them follow the outline of the bottom panel. Take a pencil and mark the intersection of bottom and side panel from below. Make sure the side panel is facing with the glassed surface to the inside of the hull. Cut the side panels at the marked line.



(a)



(b)

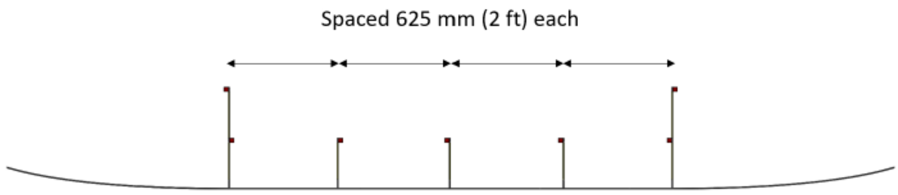
Figure 38: The bottom panel outline is transferred to side panel

8.4.5 Task 23: Prepare the bulkheads of the windward hull

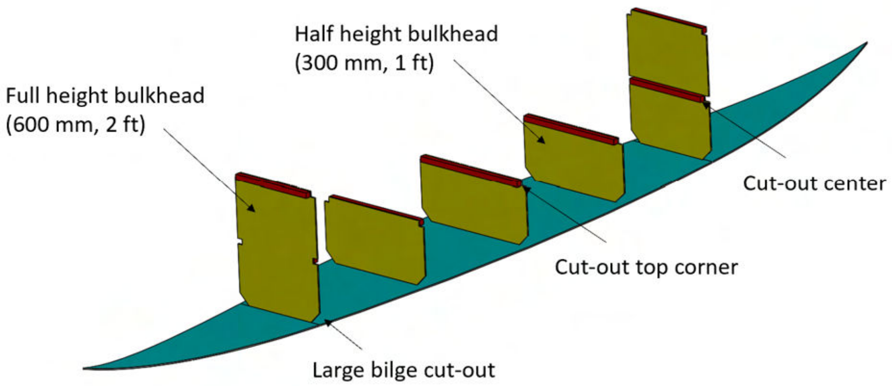
Mark station lines perpendicular to the center line on the bottom panel of the windward hull as shown in figure 39 a).

Cut three half height (1 ft high) bulkheads from a half sheet of ply. These are the cockpit bulkheads, they go on the three station lines in the center. Trim the width of the bulkheads to match up with the width of the bottom panel at the respective station line. The center bulkhead needs to be trimmed as well to allow for the doublers of the side panels (i.e. 2/4 in or 12 mm has to be trimmed off).

Cut two full height (2 ft high) bulkheads from a half sheet of ply. These are the cockpit end bulkheads. Trim the width of the bulkheads to match up with the width of the bottom panel at the respective station line. Figure 39 b) shows the setup of the bulkheads on the bottom panel.



(a) Positions of the bulkheads



(b) Bulkheads set up on the bottom panel

Figure 39: Setup of the bulkheads of the windward hull

All bulkheads have 1 in (25 mm) cut outs in the top corner for the stringers. In addition, the full height bulkheads also have cut outs on the edges at the same height as the half height bulkheads for a middle stringer. All bulkheads should have large triangular cutouts in the lower corner, so cut off the corners. These cutouts allow water to flow in between the individual hull sections and make it possible to bail the hull.

Day 4

The easiest way to make all these cuts is to stack the bulkheads together, clamp them and make all the cuts at the same time.

8.4.6 Task 24: Prepare lumber for the windward hull bulkheads

The bulkheads are equipped with lumber battens to attach the deck panels later. Prepare a batten for the top edge of each bulkhead as shown in figure 39 b). The full height bulkheads require an additional batten at the same height as the half height bulkheads.

8.4.7 Task 25: Glass the windward hull bulkheads

Glass the windward hull bulkheads from one side with glass fiber cloth. Glue the lumber battens on while the glass fiber is still wet.

8.4.8 Task 26: Glue the first beam

Take the two beam boards, which were coated on one side yesterday, and two plywood strips (glassed on one side). Sand the glassed side of the plywood and the coated surface of the lumber board to rough it up for a proper bond. Before mixing any resin or glue, prepare a sufficient number of clamps (see figure 40 below). The DIY wood clamps (see 14) are especially useful.

Day 4

(a) (b)

Figure 40: Ply and lumber are clamped together to form a beam. Wood clamps are perfect for making beams as they help to align everything.

Mix slightly thickened resin (like syrup) and brush it on the ground surfaces of the lumber and ply as further rot protection. Spread epoxy glue on the two smaller sides of the lumber boards and place all four parts as shown in figure 33. The glassed surfaces of the plywood and the coated surfaces of the lumber must face inside the beam. Clamp everything and check for squeezed out glue as indicator of a good bond (see figure 40). It is important to check that lumber and ply line up the full length. Scratch off excess glue and try to keep the clamps (especially the threads) clean.

8.4.9 Task 27: Coat the beam lumber

The side of the beam lumber which will later be inside must be protected from rot with a thick layer of epoxy. Take slightly thickened resin (like syrup) and brush it on the two already planed beam lumber boards. This is a good opportunity to use up leftover glue and resin from previous tasks.

8.5 Day 5

8.5.1 Task 28: Grind the first beam

Remove the clamps from the beam which was glued yesterday. Remove all glue from the outside and grind it smooth with an angle grinder. Take a router with a round-over bit (see figure 12 d) and run it along all edges to round them. The beam is ready to be glassed on the outside. This will be done later, together with the other beams.

8.5.2 Task 29: Prepare the lumber for the steering paddle and the leeboards

Prepare lumber battens to glue a board for the steering paddle. The board for the steering paddle should have a size of approx. 8x60 in (200x1500 mm). It does not have to be rectangular, a paddle shape saves wood (see figure 41). If larger lumber boards are available on site they can be used too.

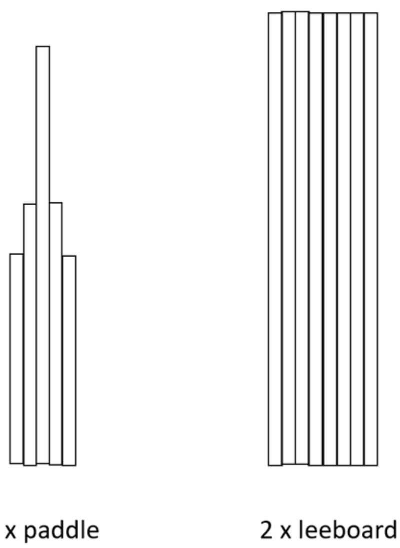


Figure 41: Lumber boards for paddle and leeboards

The WAM Proa is equipped with two leeboards. Each leeboard has a size of 1x5 ft (300x1600 mm). Prepare 1x1 in (25x25 mm) knot-free lumber battens to glue two boards of this size.

8.5.3 Task 30: Glass the second side of the windward hull bulkheads

Glass the second side of the windward hull bulkheads. Apply thickened resin to the edge of the cut out of the bottom corner. This edge will later be exposed. It is very important to cover it with a very thick layer of resin.

Glue the second set of battens on the other side of the full length bulkheads while the glass is still wet.

8.5.4 Task 31: Scarf the leeward hull stringer

Scarf four 24 ft long battens 1x1 in (25x25 mm) from the prepared lumber. Details on how to properly scarf can be found in 6.3.

8.5.5 Task 32: Glue the second beam

Glue the second beam in the same way as the first one (see Day 4, Task 26, 8.4.8).

8.5.6 Task 33: Glue the steering paddle and leeboards

Glue the boards for the steering paddle and leeboards. If the job can't be finished today (e.g. due to a shortage of clamps) continue it over the following days and try to use up leftover resin and glue. It is easier to glue the battens step by step anyway.

8.6 Day 6

8.6.1 Task 34: Grind the second beam

Remove the clamps from the beam that was glued yesterday. Remove all glue from the outside and grind it smooth with an angle grinder. Take a router with a round-over bit (see figure 12 d) and run it along all edges to round them. The beam is ready to be glassed on the outside. This will be done later, together with the other beams.

8.6.2 Task 35: Clean the leeward hull stringer

Clean the scarf joints of the leeward hull stringer glued yesterday by using an angle grinder.

8.6.3 Task 36: Sand the windward hull bulkheads

Sand the windward hull bulkheads with the overlapping glass fiber from their edges.

8.6.4 Task 37: Glass the beams

For further reinforcement and rot protection, all three beams are covered by glass fiber. Mount the beams on sawhorses as shown in figure 42. For simplicity, cut 7 oz. (200 g) fiberglass cloth from the roll to the length of the beams. Wrap it around a stick, or something similar, for handling. Coat the entire beam with resin. Take the prepared glass cloth and apply it as shown in figure 42 a). Wrap it around the beam and wet it out with epoxy. Repeat this process one side at a time until a total of at least three layers has been applied to every side of the three beams.

(a) Beam is glassed with a 3 ft (1 m) wide piece of 7 oz. (200 g) glass cloth

(b) Beam after flow coat with epoxy resin

Figure 42: Beams are glassed and finished

Apply another coat of resin (flow coat) within one hour of the glassing being finished. Timing is critical!

8.6.5 Task 38: Set up the bulkheads of the windward hull

Set up the windward hull bulkheads on the bottom panel as shown in figure 39. Fix them in place by either using wooden sticks as braces (glued into place with hot melt glue) or strings/wires. Make sure the battens of the full height bulkheads are facing the end of the hull. Make sure the full height bulkheads are exactly one plywood sheet length (8 ft or 2500 mm) apart. Glue the bulkheads in place by applying fillets as shown in figure 43.

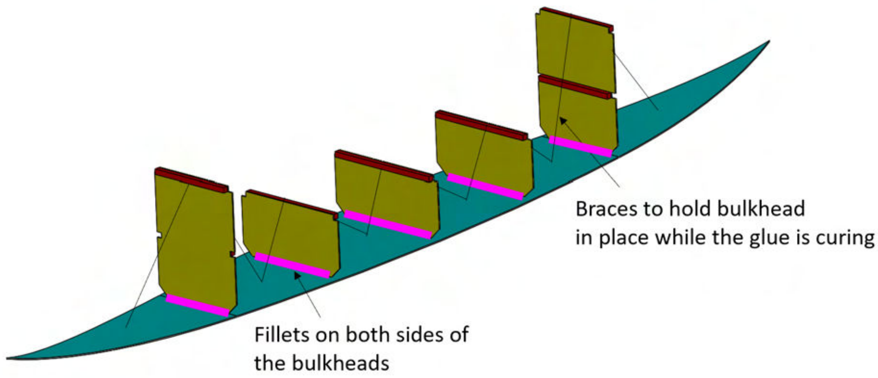


Figure 43: Bottom panel setup

Apply fillets to all corners between bulkheads and the bottom panel as explained in 6.5. The fillets stick better if the plywood is brushed with resin first. Wedges which have been ground round at the pointy end work perfectly as application tools.

The "thickness" of the epoxy mixture is critical, especially if flour is used. A runny mixture will run off and leaving a weak joint. It is helpful to make test fillets first to get the mixture and technique right.

Be careful with the fillet mix. Epoxy cures exothermic, which means it releases heat. Fillet mix especially is known for getting very hot, starting smoking and eventually even self-igniting. Spread all fillet mix quickly and never leave large amounts of mix in a bucket.

All fillets should be as smooth as possible for proper strength.

8.6.6 Task 39: Glue the steering paddle and leeboards

Finish gluing the boards for the steering paddle and leeboards (see Day 5, Task 33, 8.5.6).

8.7 Day 7

8.7.1 Task 40: Shape the steering paddle

Use a jigsaw to cut the outline of the paddle from the glued board. Use an angle grinder, planer and sander to shape the paddle. Drill a 3/8 in (9 mm) hole for the paddle leash, as shown in figure 44. Oil the paddle with boiled linseed or coconut oil.

Figure 44: Steering paddle with leash attachment

8.7.2 Task 41: Shape the leeboards

Like on the traditional canoes, the leeboards are shaped asymmetrical with a rounder windward side (*retam*) and a flat leeward side (*kaja*).

First, clean off all excess resin and glue from the raw planks by using an angle grinder. Now cut the outline and shape the *retam* side round by using a planer and angle grinder. Only the lower sections of the leeboards need to be shaped since the upper parts always remain in the leeboard case.

(a) Only the lower 3 ft (1 m) of the leeboards are shaped. The upper part, which always stays in the leeboard case, remains rectangular.

(b) Round *retam* side (facing up) and flat *kaja* side (facing down)

Figure 45: Proa leeboard

8.7.3 Task 42: Glue the windward hull stringers in the bulkheads

The 16 ft long 1x1 in (25x25 mm) wooden stringers for the windward hull have already been prepared (Day 1, Task 3, 8.1.3). Put the stringers into the cut-outs in the bulkheads and fix them in place with the prepared copper wire as shown in figure 46.

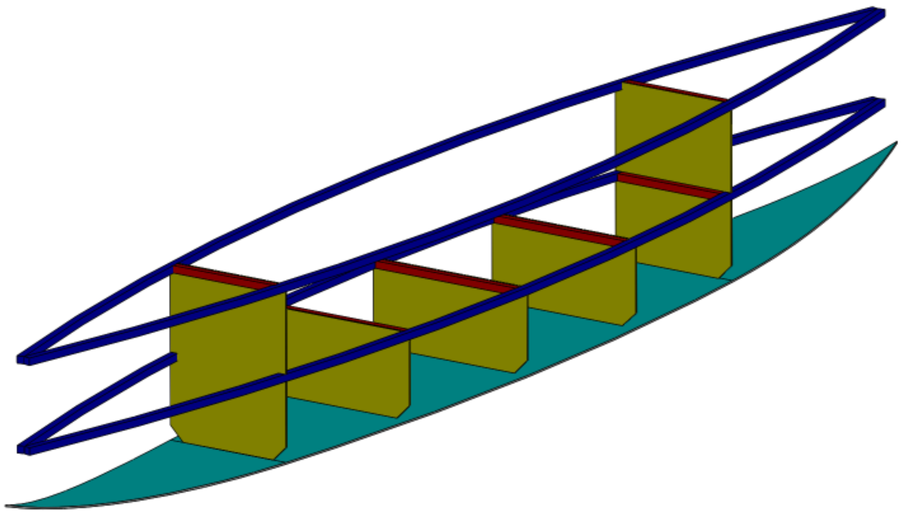


Figure 46: Stringers (blue) fixed to the bulkheads of the windward hull

The outside of the stringers must align with shape of the bottom panels as closely as possible (see figure 47 for reference). The ends of the stringers might need some trimming for this.

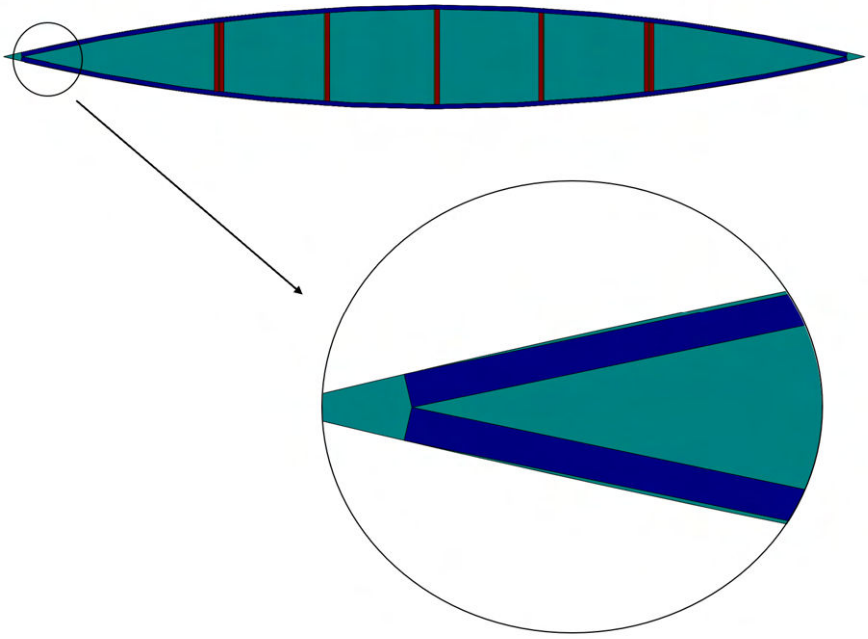


Figure 47: Stringers (blue) are trimmed to match up perfectly with the shape of the bottom panel.

The bows are reinforced by a solid piece of lumber as shown in figure 48.

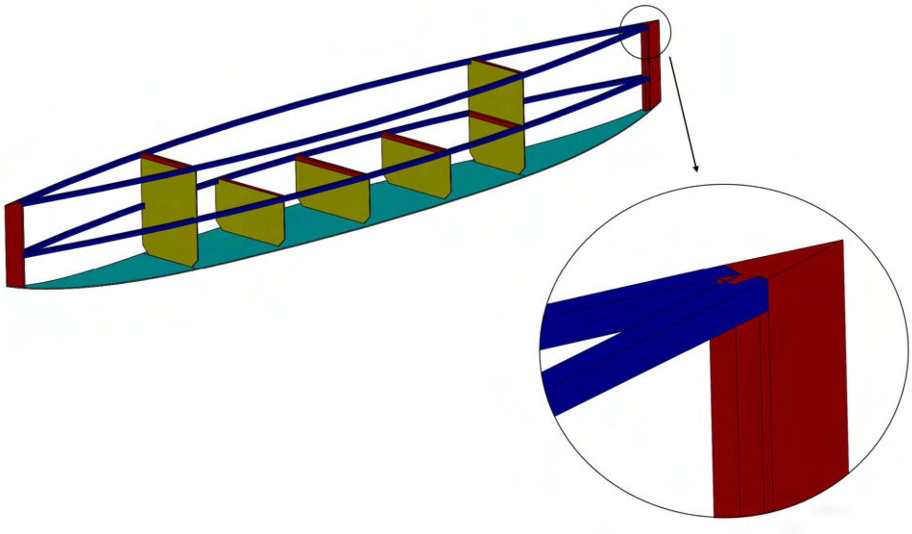


Figure 48: The stems (red) sit snugly between the stringers (blue). The stringers may need some trimming to allow the stem pieces to slot in between them.

The stem pieces are shaped to fit in between the stringers and allow the stringers to clamp onto them either side. The stems are shaped to match the outline of the bottom panel. With all parts fixed in place, apply fillets between stringers and bulkheads and glue the stem pieces in place.

8.7.4 Task 43: Close the beam ends

The open ends of the beams expose the end grain of the beam lumber and plywood (see 33). To protect this part from any damage and subsequent rot, close the beam ends by gluing pieces of plywood on them. Glass the plywood from the inside or coat it 3 times wet in wet before applying it.

8.7.5 Task 46: Grind and round beam cleats

Remove the clamps from the beam cleats. Grind off all glue and use the angle grinder to round the outer edges. Sand the beam cleats smooth, especially the center hardwood part, as this is where the lashing rope will be wrapped around.

8.8 Day 8

8.8.1 Task 44: Cut the cockpit floor of windward hull

Take a half sheet of 1/4 in (6 mm) plywood and place it in the cockpit on top of the half-height bulkheads in between the full height bulkheads. The sheet should fit in neatly and rest on the middle stringer with some overlap as shown in figure 49. Take a pencil and mark the overlap of the stringer. Trim the floor panel to be flush with the middle stringer using a jigsaw.

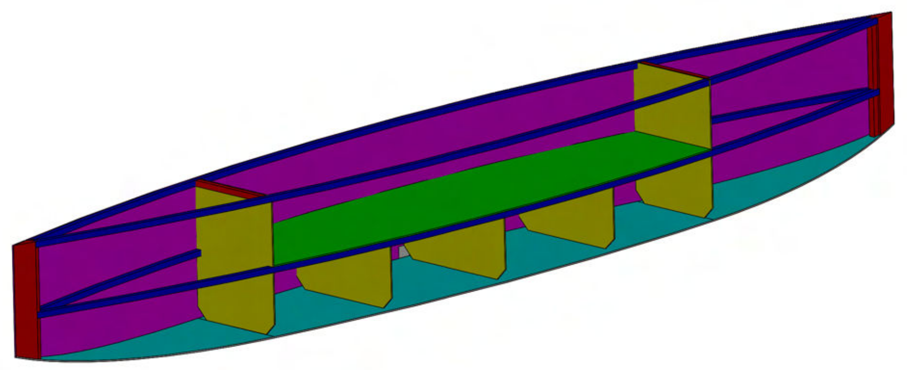


Figure 49: The windward hull cockpit floor panel is fitted into the framework

8.8.2 Task 45: Glue the side panels on the windward hull

Remove the clamps and the copper wire from the framework of the windward hull. Take the side panels and check their fit onto the framework.

The doublers of the side panels will not properly fit to the lower stringers yet. Take an angle grinder and grind a recess for the doublers into the stringers.

Now clamp the side panel to the upper stringer. Next, drill holes for copper wire lashings to connect the side panel with the lower stringer, bulkheads and bottom panel. Stitch the side panel on temporarily with a few copper wires to make sure the location and number of holes is sufficient to hold the side panel in place. When the panel fits on smoothly and no large gaps are visible anymore remove the copper wire and mix resin/glue.

First, apply glue to the stringers and the stems. Then, clamp the side panel to the upper stringer and attach it to the lower stringer by tightening the copper wire. Glue should squeeze out (scrape it off and reuse it) and no gaps or voids should be visible. If necessary use more copper wire.

Repeat this process with the other side panel.

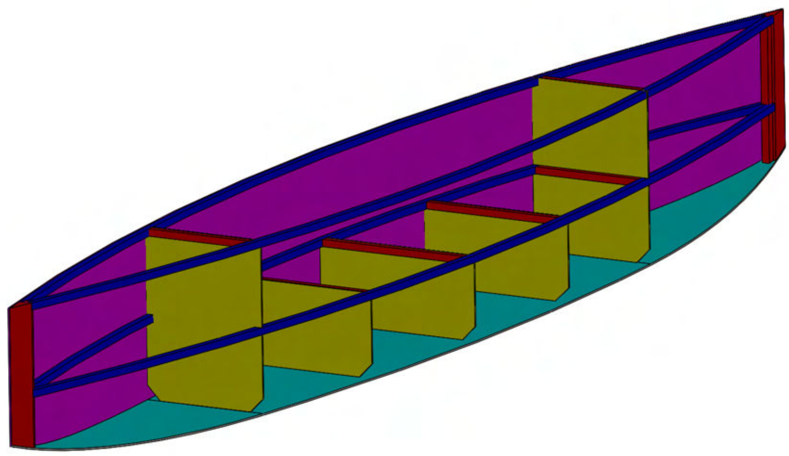


Figure 50: First side panel mounted on the framework

When both side panels are glued on, as outlined above, apply fillets wherever the side panel, bottom panel or bulkheads meet. The fillets will stick better if the plywood is brushed with resin first. Wedges which have been ground round at the pointy end work perfectly as application tools. As an alternative the tools shown in the pictures below can be used.

The “thickness” of the epoxy mixture is critical, especially if flour is used. A runny mixture will run off a vertical fillet leaving a weak joint. It is helpful to make test fillets first.

Work from top to bottom for a clean result. All fillets should be as smooth as possible for proper strength.

Take care to fill all gaps, holes and corners, especially in places difficult to see or access. This is important for the durability of the hull!

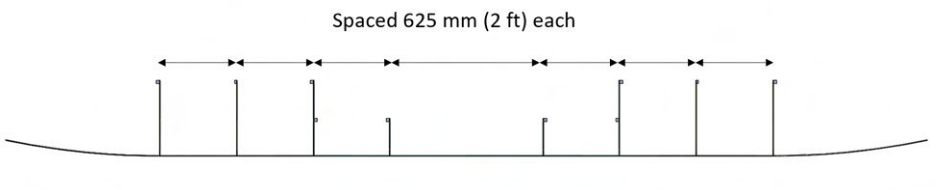
8.8.3 Task 46: Set up the leeward hull bottom panel

Place the bottom panel of the larger leeward hull on a long, flat table, the glassed surface with the doublers facing up. Use a string to mark the center lines, length wise and across. The tips are raised by 5 in (200 mm) by pushing blocks under the panel to create some rocker, similar to the way it was done for the windward hull.

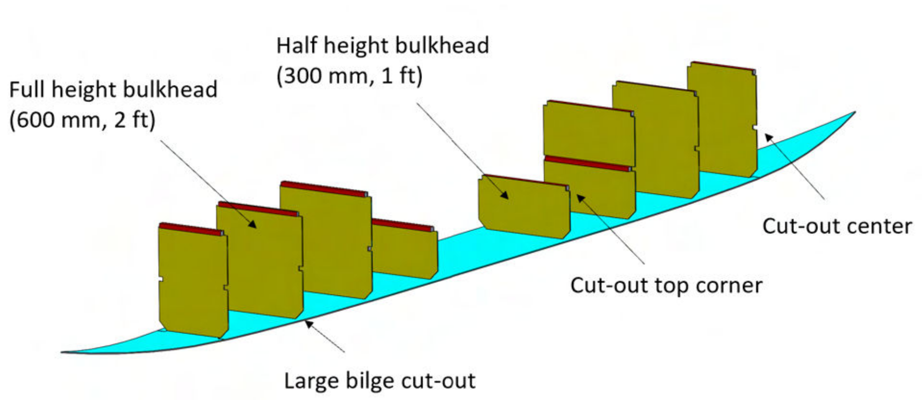
8.8.4 Task 47: Prepare the bulkheads of the leeward hull

The process for the leeward hull is essentially the same as for the windward hull. Mark station lines perpendicular to the center line on the bottom panel of the leeward hull as shown in figure 51 a).

Cut two half height (1 ft high) bulkheads from a half sheet of ply. These are the cockpit bulkheads which go on the two station lines next to the center. Trim the width of the bulkheads to match up with the width of the bottom panel at the respective station line. Cut six full height (2 ft high) bulkheads from a half sheet of ply. Trim the width of the bulkheads to match up with the width of the bottom panel at the respective station line. Figure 51 b) shows the setup of the bulkheads on the bottom panel.



(a) Positions of the bulkheads



(b) Bulkheads set up on the bottom panel

Figure 51: Setup of the bulkheads of the leeward hull. No bulkhead in the center is required, this will be the fish hold.

All bulkheads have 1 in (25 mm) cut outs in the top corner for the stringers. In addition, the full height bulkheads also have cut outs on the edges at the same height as the corner cut-out of the half height bulkheads. All full height bulkheads have large triangular cutouts in the lower corners (simply cut off corners). These cutouts allow water to flow in between the individual hull sections and make it possible to bail the hull. The half height bulkheads do not have these drain holes!

The easiest way to make all these cuts is to stack the bulkheads together, clamp them and cut all at the same time.

8.8.5 Task 48: Prepare the lumber for the leeward hull bulkheads

The bulkheads are fitted with lumber battens to allow the deck panels to slot on later. Prepare a batten for the top edge of each bulkhead as shown in figure 51 b). The two full height bulkheads facing the center require an additional batten at the same height as the half height bulkheads.

8.8.6 Task 49: Shape and glass the beam ends

Trim the edges of the beam ends - especially the new plywood covers. Use an angle grinder and a sander for a round and smooth finish. Glass the beam ends with at least 3 layers of glass fiber cloth.

8.8.7 Task 50: Glass the leeward hull bulkheads

Glass the windward hull bulkheads from one side with class fiber cloth. Glue the lumber battens on while the glass fiber is still wet.

8.8.8 Task 51: Glass the cockpit floor panel of the windward hull

Apply a layer of glass fiber cloth to the windward hull cockpit floor panel. Apply another layer of epoxy while the glass fiber is still wet (flow coat, wet in wet).

8.9 Day 9

8.9.1 Task 52: Sand the cockpit floor of the windward hull

Sand the glassed surface of the cockpit floor with 180 grid.

8.9.2 Task 53: Cut the decks for the windward hull

Cut the fore and aft deck from plywood (see figure 52). Get the shape by placing half plywood sheets on the hull and marking the shape with a pencil.

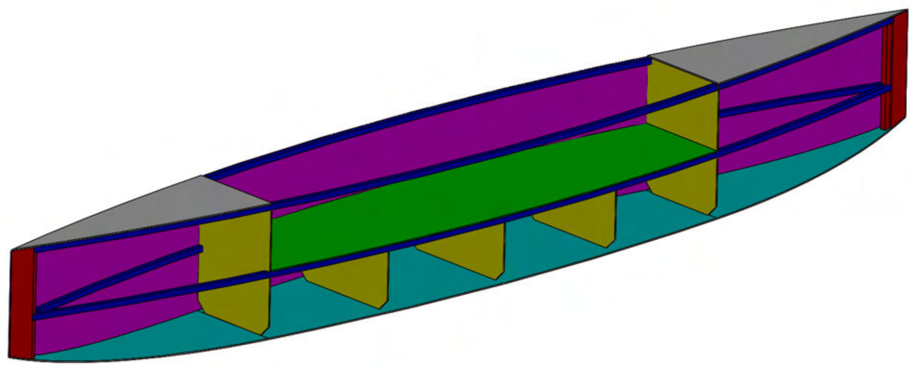


Figure 52: Deck panels (grey) trimmed to fit the hull shape

8.9.3 Task 54: Glue the windward hull cockpit floor into place

Glue the windward hull cockpit floor onto the middle stringer and the half height bulk- heads. Make sure the floor panel sits on the stringer and bulkheads evenly without major gaps.

Paint all bare wood under the floor panel (stringer, bulkhead top edges etc.) three times with epoxy before gluing in the floor panel. Make sure you cover every single bit of wood - especially from below! The three coats can be applied wet in wet within a few hours. The next two tasks can be done in between applying layers.

After all wood is coated, apply glue to the middle stringer and the half height bulkheads. Press the floor panel on top and weigh it down with heavy weights while it cures.

8.9.4 Task 55: Glass the second side of the leeward hull bulkheads

Glass the other side of the leeward hull bulkheads. Apply thickened resin to the edges of the cut outs in the bottom corners. These edges will later be exposed, so it is very important to cover them with a very thick layer of resin.

Glue the second set of battens on the other side of the full-length bulkheads while the glass is still wet.

8.9.5 Task 56: Glass the windward hull decks

Apply glass fiber cloth on the inside surface of the windward hull decks.

8.9.6 Task 57: Reinforce the windward hull for the beam cleats

The areas of the hull to which the cross-beams will be tied require some reinforcement to handle the loads. The side panels are therefore reinforced with plywood doublets from both sides. Prepare pieces of 3/8 in (8 mm) plywood, approx. 6 x 10 in (150x250 mm) and glue them to the inside of the side panels in the corner between the top stringer and the full-height bulkhead as shown in figure 73. Don't forget to sand the side panels before applying any glue. The reinforcement pieces might require some trimming to properly fit to the fillets. Use an angle grinder to machine a bevel along the edges which does not touch the bulkhead or stringer.

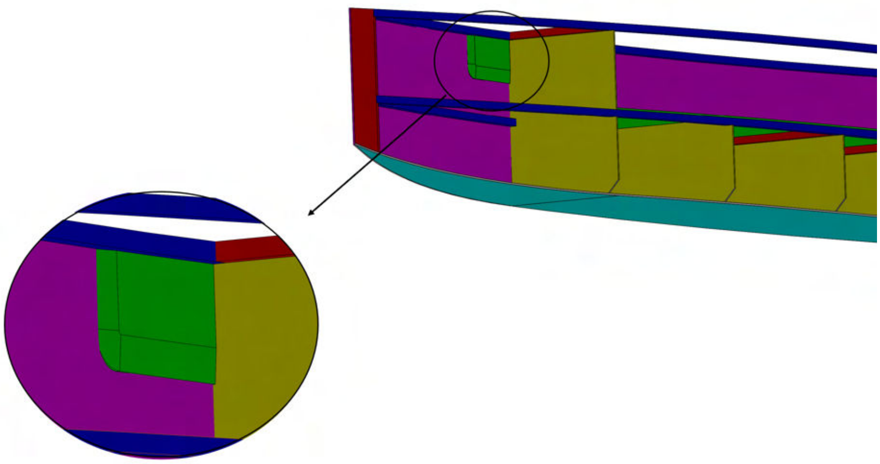


Figure 53: Reinforcement for beam cleats glued into the hull

The leeward hull needs the same type of reinforcement. Cut four extra reinforcements for the leeward hull.

8.10 Day 10

8.10.1 Task 58: Apply fillets and glass the windward hull cockpit floor

Remove the weights from the cabin floor. Apply fillets all around the panel. Apply two layers of glass fiber cloth covering the entire floor with sufficient overlap on the sides.

8.10.2 Task 59: Sand the leeward hull bulkheads

Sand the bulkheads for the leeward hull and the deck panels of the windward hull with 180 grid.

8.10.3 Task 60: Set up the leeward hull bulkheads

Set up the leeward hull bulkheads on the bottom panel in the same way as it was done for the windward hull. Apply fillets to the edges between bulkheads and bottom panel as shown in figure 54.

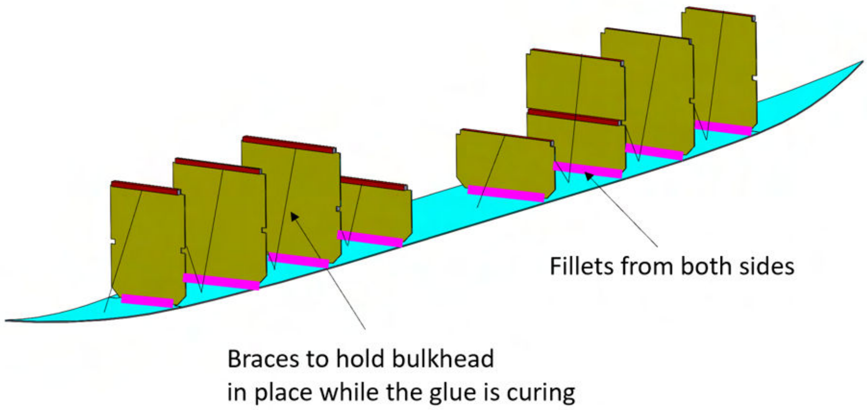


Figure 54: Bottom panel setup

8.10.4 Task 61: Prepare and glue the beam cleats

The beams are lashed to beam cleats on every side of the hull. The cleat design is shown in figure 55 and 56.

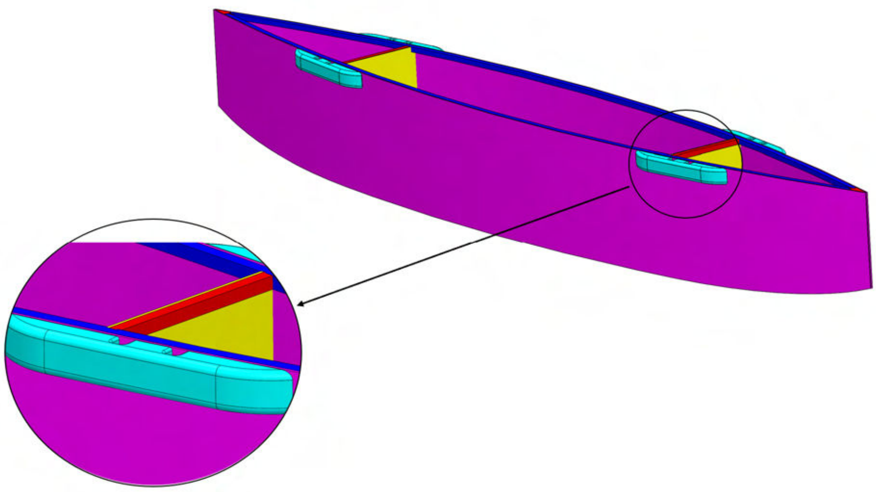


Figure 55: Beam cleats on the windward hull

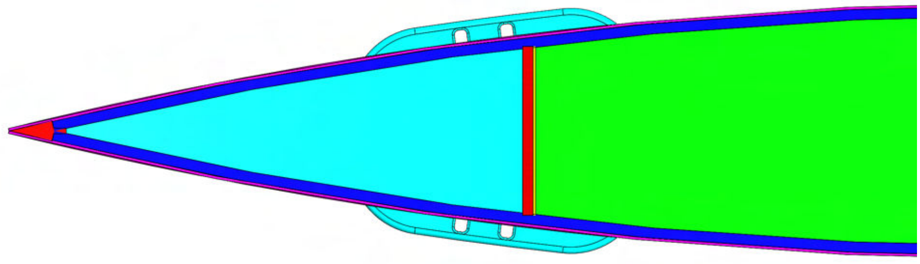


Figure 56: Beam cleat design

The easiest way to make the cleats (light blue protrusion of the hull in figure 55 and 56)) is to cut each one from four individual parts of lumber. Figure 57 shows the different parts.

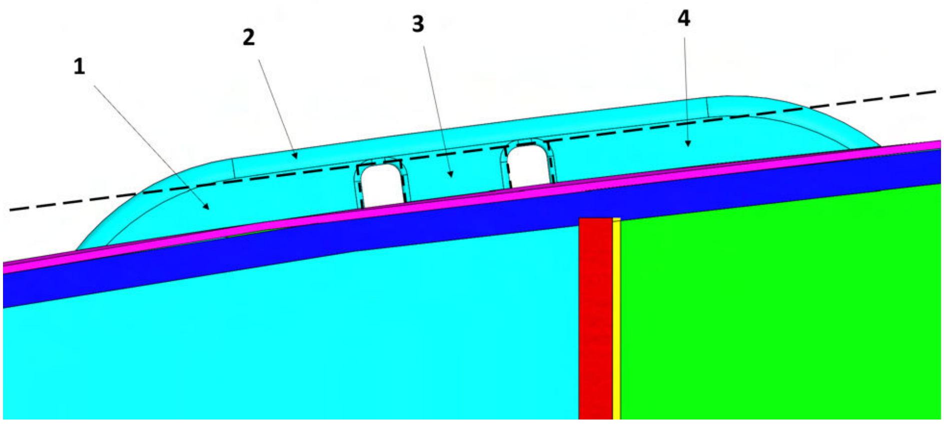


Figure 57: Individual parts of the beam cleats

The beam cleats are important structural components of the proa. The platform is tied to them, so if they fail the entire boat fails. Therefore, use only the best lumber for these parts. The center piece (labeled with '3' in figure 57) should be made from dense and heavy hardwood.

Prepare parts for eight beam cleats (four for each hull) according to the dimensions shown in figure 58.

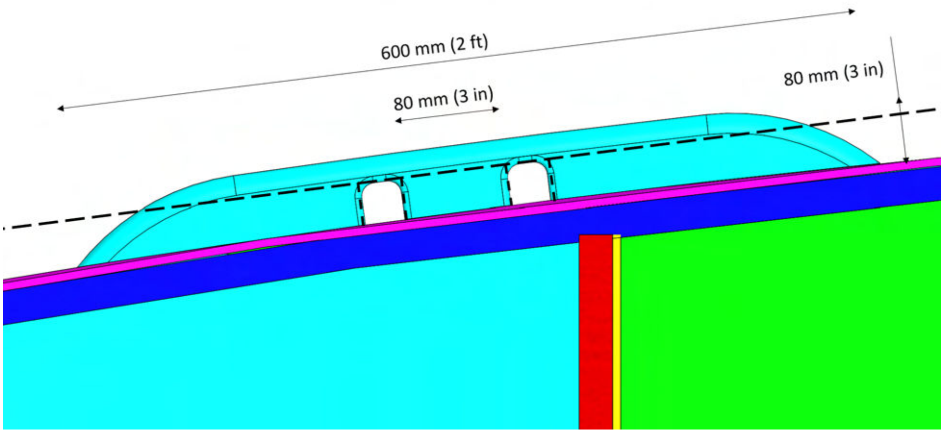


Figure 58: Dimensions of the beam cleats

Glue the beam cleats for the windward hull carefully in place by clamping on the individual parts. Make sure glue squeezes out and there are no voids or gaps. Scrape off the excess glue and apply fillets all around the cleat.

8.10.5 Task 62: Carve the stay attachments

Carve the attachments for the windward stay from good quality hardwood as shown in figure 59.

Figure 59: Windward stay attachments

8.11 Day 11

8.11.1 Task 63: Drill and coat the windward hull drain holes

The windward hull cockpit is self-draining. Therefore, drain holes are located in each corner as shown in figure 60.

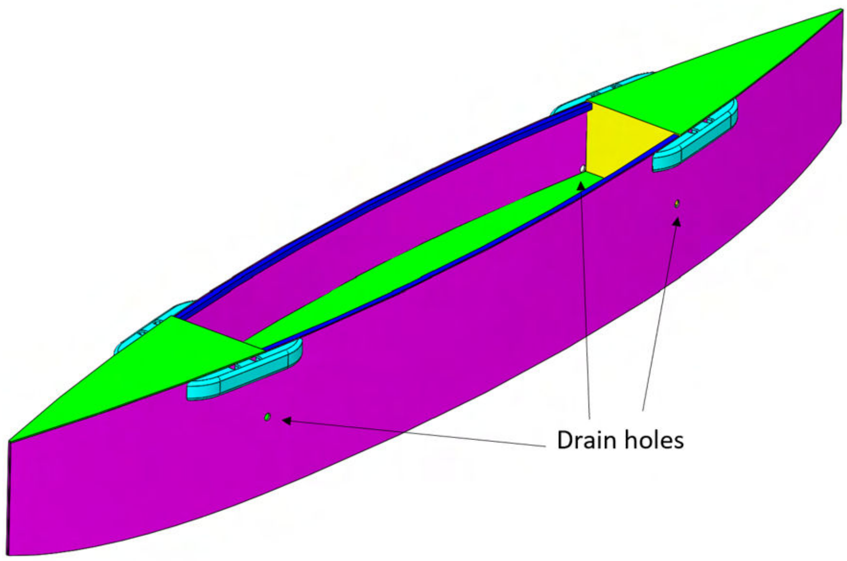


Figure 60: Drain holes are located in each corner of the cockpit floor.

Day 11

Drill holes of 1 in (25 m) diameter right into the four corners of the windward hull cockpit. Carefully sand the edges round with sandpaper. The exposed plywood edge needs very thorough treatment with epoxy. Coat at least five times, either wet in wet or with sanding in between the coats.

8.11.2 Task 64: Make the beam cleat pins

The beam cleats are reinforced by hardwood dowels. Prepare 16 hardwood dowels with the thickness of about 3/4 in (20 mm) and a length of 3 in (80 mm).

Figure 61: A hardwood dowel is cut using an angle grinder. The end of the dowel will be cut off later anyway so there is no need to shape it all the way, as long as the diameter is constant over a length of 3 in (80 mm).

8.11.3 Task 65: Prepare the beam blocks

The beams will rest on wooden blocks - one above each cleat. The blocks separate the beams from the deck, which creates a a big gap which is easy to clean and always able to dry (this is important as it allows rot to be avoided).

Cut the beam blocks from hardwood as shown in figure 62 below. Make them at least two fingers high, three fingers wide and slightly longer than the beams' width.

Figure 62: Eight hardwood blocks of the same size are cut as support for the cross-beams.

For an easy assembly, and to prevent the beams from sliding, alignment blocks will be glued below the beams. The alignment blocks are placed to fit right in between the beam blocks on the hull. Prepare eight hardwood sticks to be glued on later. They should be approx. 1 x 1 in (25 x 25 mm) with the length of the beams' width.

8.11.4 Task 66: Carve the mast foot

Carve the mast foot from a good piece of lumber as shown in figure 63. It is possible to glue the mast foot from pieces of lumber. The dimensions of the mast foot are not important, but the main things is that the mast foot protects the lumber below and holds the mast in place.

Figure 63: Mast foot glued from two pieces of lumber

8.11.5 Task 67: Glue the leeward hull stringers in the bulkheads

The 24 ft wooden stringers for the windward hull have already been prepared previously. Put the stringers into the cut-outs in the bulkheads and fix them in place with the prepared copper wire as shown in figure 64.

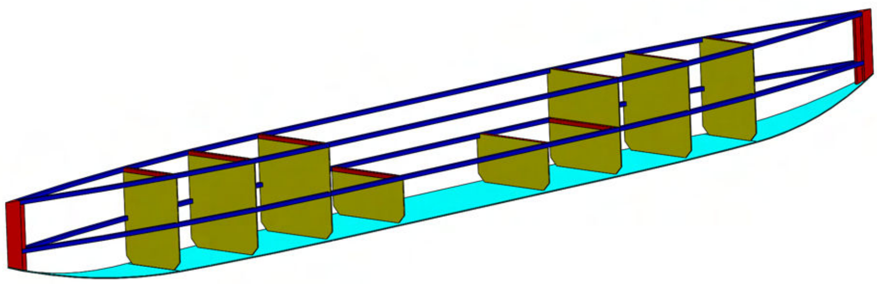


Figure 64: Stringer (blue) fixed to the bulkheads of the windward hull

The outside of the stringer must match the shape of the bottom panel as closely as possible (see figure 65 for reference). The ends of the stringer might need some trimming for this.

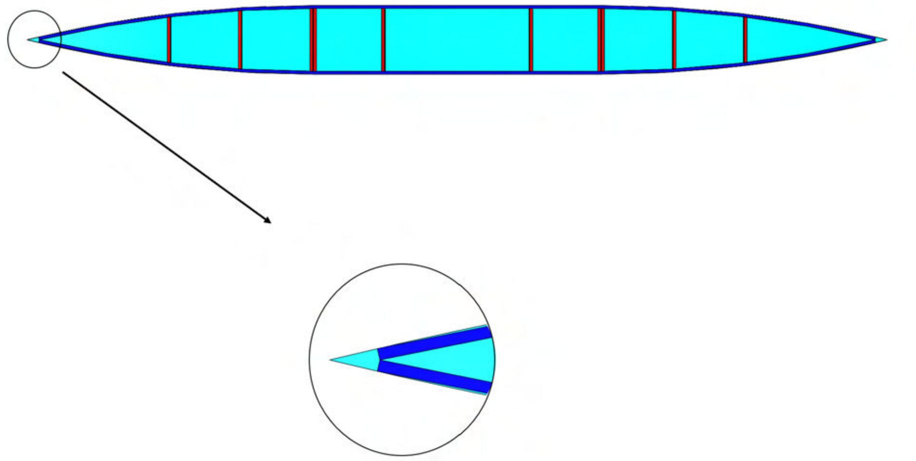


Figure 65: Stringers (blue) are trimmed to match up perfectly with the shape of the bottom panel.

The bows are reinforced by a solid piece of lumber as shown in figure 48.

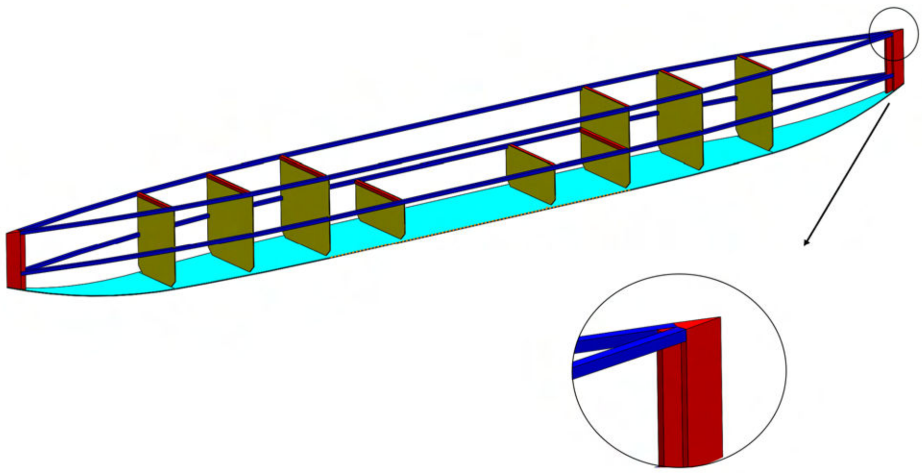


Figure 66: The stringers (blue) clamp the stem (red). The stringers require some trimming to allow the stem piece to fit in between.

The stem pieces are shaped to fit in between the stringers and to allow the stringers to clamp them on either side. The stems are shaped to match the outline of the bottom panel. With all parts fixed in place, apply fillets between the stringer and bulkheads and glue the stem pieces in place.

8.11.6 Task 68: Glue the deck of the windward hull

Glue the windward hull deck panels on the top stringer and the full height bulkheads. Make sure the deck panels sit on the stringers and bulkheads evenly and without major gaps before applying any glue.

Paint all bare wood under the deck panel (the stringers, bulkhead top edges etc.) three times with epoxy. Make sure you cover every single bit of wood - especially from below! The three coats can be applied wet in wet within a few hours.

Apply glue to the top stringer and the full height bulkheads. Press the deck panels on top with the glassed side facing down. Weigh the deck panels down with heavy weight while it cures.

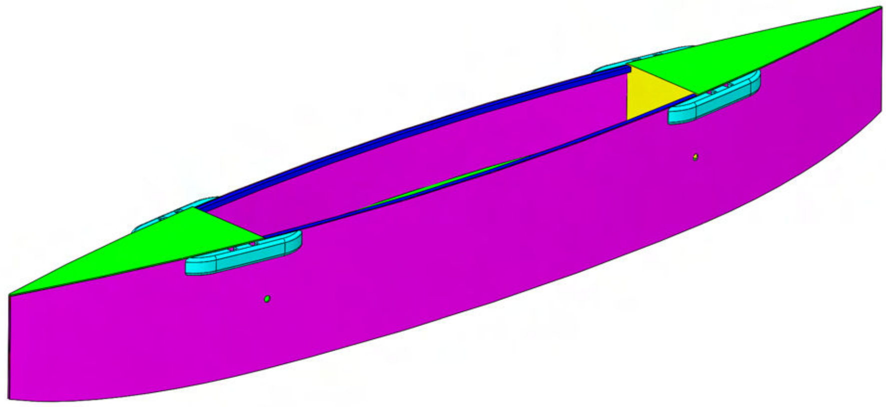


Figure 67: Deck panels (green) glued onto the windward hull

8.12 Day 12

8.12.1 Task 69: Cut the leeward hull floor panels

Take a half sheet of 1/4 in (6 mm) and cut panels for the leeward hull floor as shown in figure 68 (green). The center of the leeward hull will become a fish hold and therefore is not covered with a floor. The sheets should fit snugly into the framework and rest on the middle stringer with some overlap. Take a pencil and mark the overlap of the stringer. Trim the floor panel to be flush with the middle stringer by using a jigsaw.

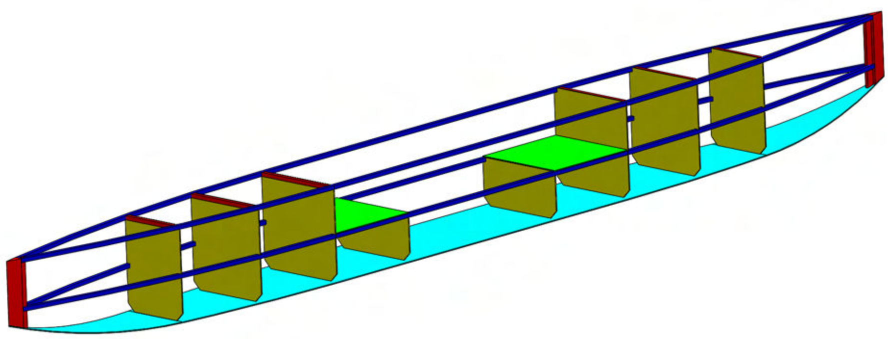


Figure 68: Leeward hull cockpit floor panels are fitted into the frame

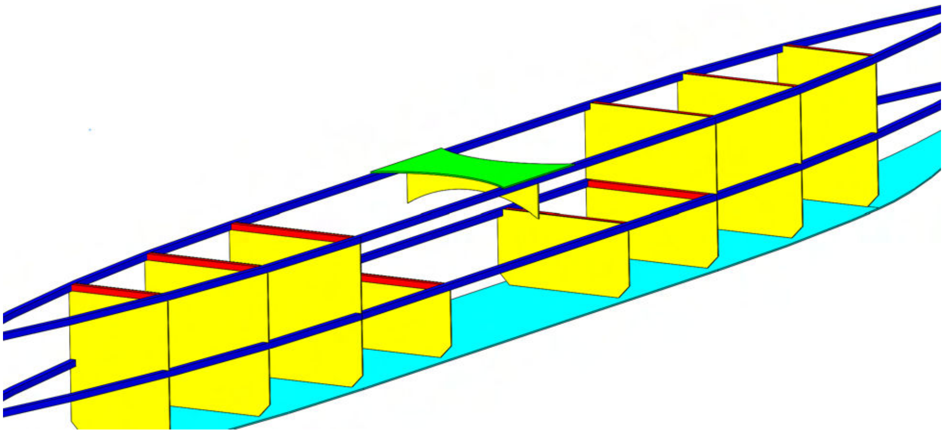
Glass the panels from the inside.

8.12.2 Task 70: Prepare the deck panels of the leeward hull

Take a half sheet of plywood and place it on each end of the leeward hull. Run a pencil around it to copy the shape of the top stringer. Cut and glass the deck panels from one side.

8.12.3 Task 71: Prepare the central stiffener of the leeward hull

Cut the two parts of the central stiffener from 1/4 in (6 mm) plywood to a shape similar to the one shown in figure 69. Glass both plywood parts from both sides.



Day 12

Figure 69: Leeward hull central stiffener (green) and bow support (yellow)

8.12.4 Task 72: Glue the side panels of the leeward hull

Stitch and glue the side panels of the leeward hull to the bottom panel and bulkheads in the same way as it was done for the windward hull (see Day 8, Task 45, 8.8.2).

8.12.5 Task 73: Round the windward hull edges

Eventually the entire external surface of the WAM Proa will be glassed. It is impossible to apply glass fiber cloth around sharp edges, therefore all edges (shear and chine) must be rounded, with voids filled and edges sanded smooth. A good approximation is the roundness of a finger or those of already applied fillets. Follow the general instruction of figure 70 below.

(a)

(b)

(c)

(d)

Figure 70: Preparation of the exterior edges and surfaces. All edges are rounded and voids filled with thickened resin (if needed). A router (see 12 d) for the main part of the job is very helpful in addition to a sander for final smoothness (figure a and b). The entire deck and cabin surface is sanded in preparation for glassing. The photos show the WAM Catamaran being sanded. The WAM Proa is sanded in the same way.

8.12.6 Task 74: Glue pins into the windward hull beam cleats

Flip the windward hull on its side. Drill holes slightly larger than the diameter of the prepared hardwood dowels into the beam cleats as shown in figure 71.

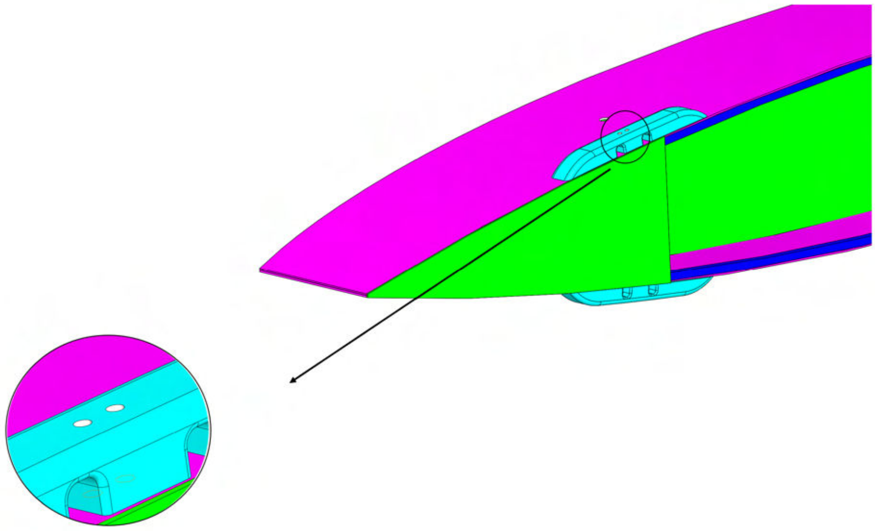
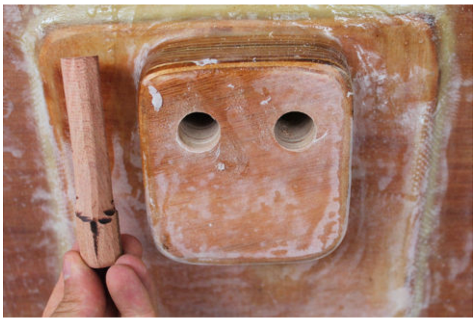


Figure 71: Holes drilled for the beam cleat dowels

Be aware - the holes are not drilled all the way through! The inside must remain closed! The drill is stopped 1/8 in (3 mm) before it breaks through on the inside. A mark on the drill bit indicates the maximum depth. This works best with a drill bit which produces flat holes (i.e. Forstner bits).

(a) Beam cleat glued outside on the reinforcement doublet on the hull

(b) Holes (at least 3/4 in) are drilled into the cleats through the cleat base in the hull. Be aware, the holes are not drilled all the way through! The inside must remains sealed! The drill is stopped 1/8 in before it breaks through on the inside. Mark the drill bit so you know the maximum depth this hole should be.



(c) Hardwood pins fit to the holes

Figure 72: Reinforcement of the beam cleats to the hull. Please be aware that these figures show an old beam cleat design which is not recommended anymore. However, the design of the beam pins and the general principle of their reinforcement is the same.

Clean the holes from all dust and fill them partly with epoxy resin. Let the resin sit for a while and refill if necessary, the wood will take up a good share of it. Take the dowels and push them all the way into the holes. Resin should squeeze out and the gap between dowel and beam cleat should be completely filled with resin.

8.13 Day 13

8.13.1 Task 75: Sand the central stiffener parts

Sand the glassed parts of the central stiffener with a 180 grid.

8.13.2 Task 76: Remove clamps and wire

Remove all clamps and wire from the leeward hull.

8.13.3 Task 77: Glue the leeward hull floor panels

Sand the glassed side of the leeward hull floor panels with 180 grid. Glue the leeward hull cockpit floor panels onto the middle stringer and the half height bulkheads. Make sure the floor panels sit on the stringer and bulkheads evenly without major gaps.

Paint all bare wood under the floor panel (stringer, bulkhead top edges etc.) three times with epoxy. Make sure you cover every single bit of wood, especially from below! The three coats can be applied wet in wet within a few hours. The next two tasks can be done in between the layers.

Apply glue to the middle stringer and the half height bulkheads. Press the floor panels on top and weigh them down with heavy weights while it cures.

8.13.4 Task 78: Glass the bottom of the windward hull

The windward hull is essentially finished. Flip it upside down and glass the bottom with three layers of glass fiber cloth. There should be an overlap of at least 3 in (7.5 cm) around the chine over to the side panels. The bow area should be reinforced with at least five layers of glass fiber cloth. Apply another layer of epoxy resin after a while (flow coat, wet in wet).

8.13.5 Task 79: Reinforce the leeward hull to support the beam cleats

The parts of the leeward hull where the cross beams will be tied are reinforced in the same way as described for the windward hull (Day 9, Task 57, 8.9.6). Take the already prepared plywood doublers and glue them to the inside of the side panels in the corner between the top stringer and the first full-height bulkhead as shown in figure 73. Don't forget to sand the side panels before applying any glue. The reinforcement pieces might require some trimming to properly fit to the fillet. Use an angle grinder to machine a bevel along the edges which does not touch the bulkhead or stringer.

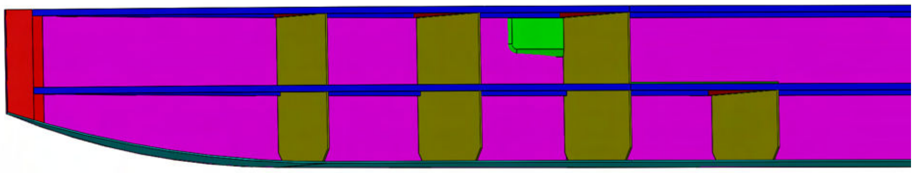


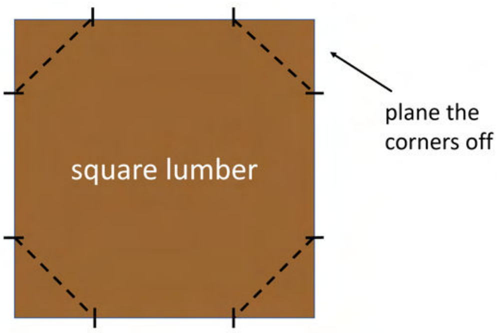
Figure 73: Reinforcement for beam cleats (green) glued into the hull

8.13.6 Task 80: Plane the mast

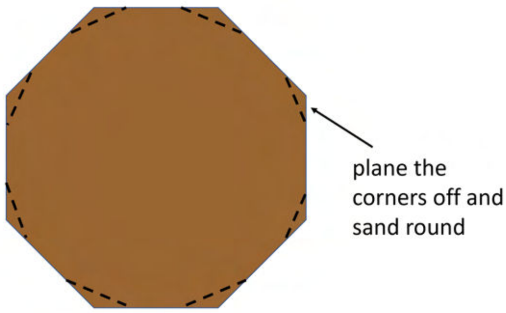
For the mast, a lumber 3x3 in (75x75 mm) with a length of 20 ft (6 m) is required. The lumber must be straight grained and without significant knots, cracks or a crown (natural curve). If not available, the mast can be scarfed from two or more pieces with a scarfing ration of 1:12.

Start by tapering the ends from 1/3 of the length down to 2x2 in (50x50 mm). Now plane the edges as shown in figure 74 a) below, to obtain a shape with eight edges. Continue in the same manner to obtain a shape with 16 edges (see figure 74 a) below). Sand the edges round until the entire mast has a smooth round shape.

Day 13



(a) Step 1



(b) Step 2

(c) Finished mast shape (round with tapered ends) after sanding

Figure 74: The WAM Proa mast is shaped from lumber

8.13.7 Task 81: Shape the mast top

Marshallese masts have a pointy mast top called *lot*. Shape a *lot* from hardwood as shown in figure 71 from hardwood. The curved shape is important for the function of the mast. The *lot* points to windward (away from the sail) and therefore ensures that the mast doesn't catch the sail during a *diak* (tacking maneuver). Cut a scarf bevel (ratio 1:12) to the *lot* and the upper end of the mast. Glue the *lot* to the mast as shown in figure 75.

Figure 75: Hardwood mast top (*lot*) scarf-glued to the top of the mast

8.14 Day 14

8.14.1 Task 82: Glue reinforcement pins into the windward hull beam cleats

Glue reinforcement pins into the remaining beam cleats in the same way as was done on the other side (see Day 12, Task 74, 8.12.6).

8.14.2 Task 83: Glue the beam cleats to the leeward hull

Glue the beam cleats to the leeward hull in the same fashion as was done for the windward hull. The cleats go on the right outside of the open central part of the leeward hull, spaced the same distance apart as the cleats of the windward hull (see figure 76).

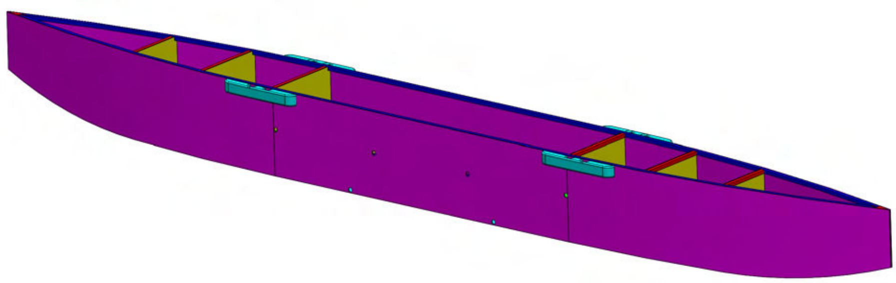


Figure 76: Beam cleats of the leeward hull (light blue)

8.14.3 Task 84: Glue central stiffener into leeward hull

Fix the prepared and glassed parts in place with copper wire as shown in figure 77 and apply fillets to glue them into place.

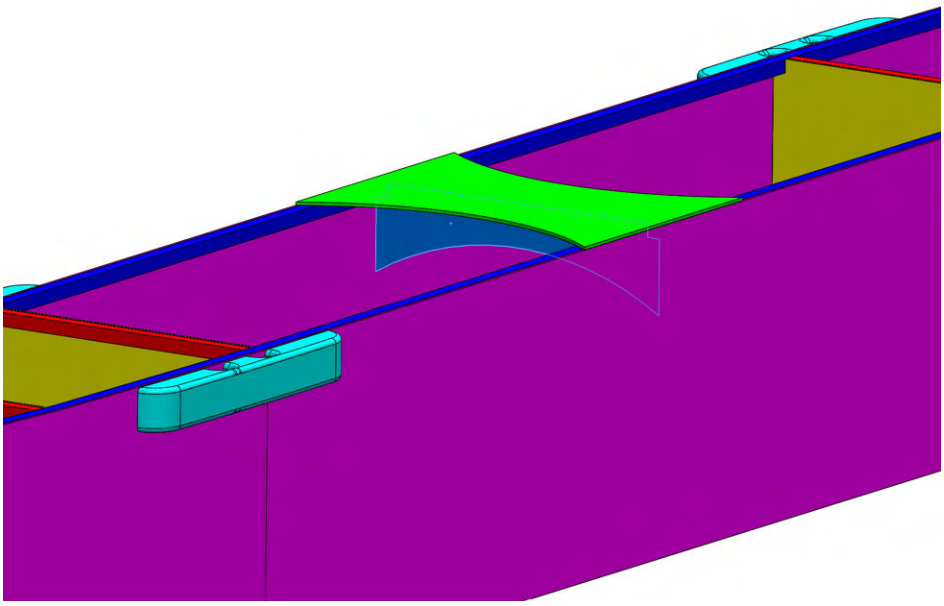
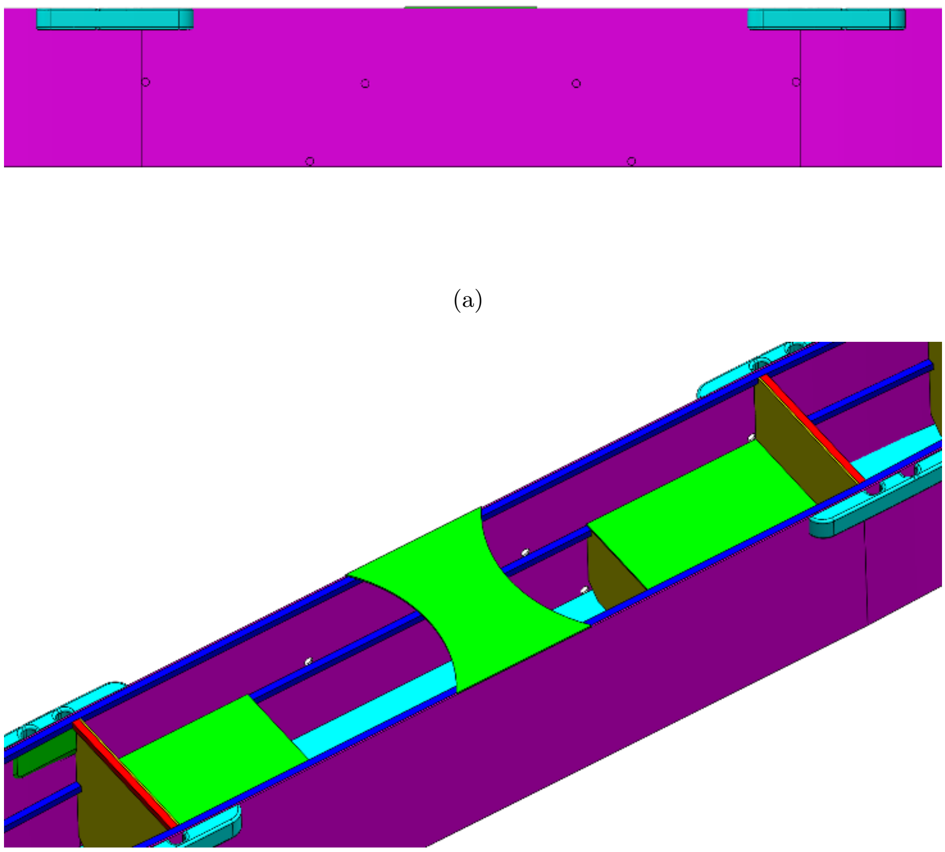


Figure 77: Central stiffener of the leeward hull (green and blue)

8.14.4 Task 85: Drill and coat the leeward hull drain holes

The leeward hull cockpit is designed as a fish hold. Therefore drain holes are located in each corner of the later leeward side (outside of the proa platform) as shown in figure 78.

Day 14



(a)

(b)

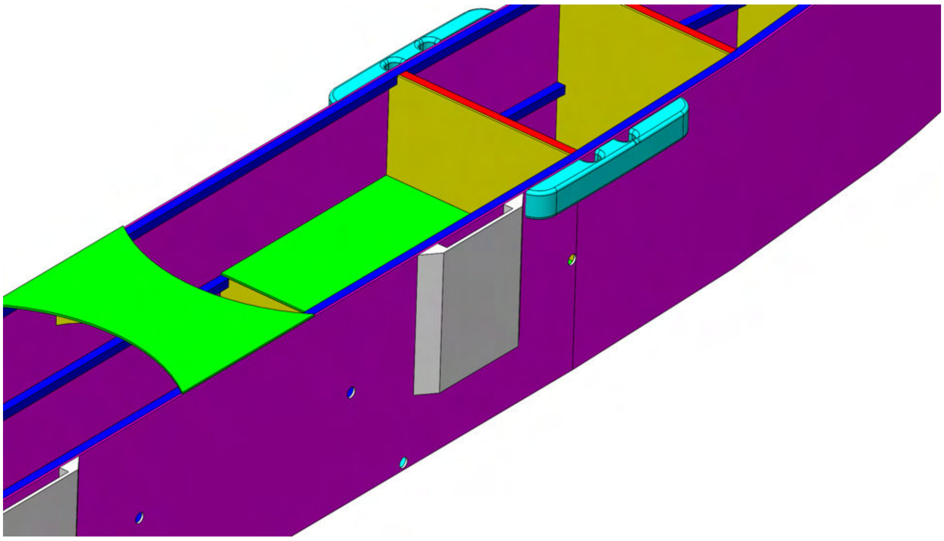
Figure 78: Drain holes of the leeward hull. The lower holes are closed with plugs cut from the foam of yellow fishing floats if the fish hold is not in use. Only the later leeward side (outside of the proa platform) is equipped with drain holes.

Drill holes of 1 in (25 mm) diameter at the locations shown in figure 78. Sand the edges round carefully with sandpaper. The exposed plywood edge needs a very good treatment with epoxy. Coat at least five times, either wet in wet or sanding in between.

8.14.5 Task 86: Prepare leeboard mounts for the leeward hull

Prepare the mounts for the leeboards as shown in figure 79. They go on the outside (the side not facing towards the other hull) of the leeward hull right next to the beam cleats. Prepare a piece of plywood and two pieces of lumber with a trapezoid cross-section for each mount. The mount should end 8 in (200 mm) from the hull bottom. he leeboards prepared previously should fit right into the mounts with some space on all sides. Glass the inside of the plywood with three layers of glass fiber and glue the side lumber on when the resin is still wet.

(a)



(b)

Figure 79: Leeboard mounts (grey) attached to the outside of the leeward hull right next to the beam cleats

8.15 Day 15

Day 15

8.15.1 Task 87: Prepare to glass the windward hull side

Sand the windward hull bottom and the overlaps on the sides with 120 grid.

8.15.2 Task 88: Glass the windward hull side

Flip the windward hull on the side and glass the side facing up with two layers of glass fiber cloth. There should be an overlap of at least 3 in (7.5 cm) around the chine over to the side panels. Apply another layer of epoxy resin after a while (flow coat, wet in wet).

8.15.3 Task 89: Glue the spars

Take the 16 remaining 1 x 1 in (25 x 25 mm) lumber battens prepared back on Day 1. They will be glued to a hollow square as shown in figure 80to cut the upper and lower boom (*rojak maan* and *rojak korra*) from.

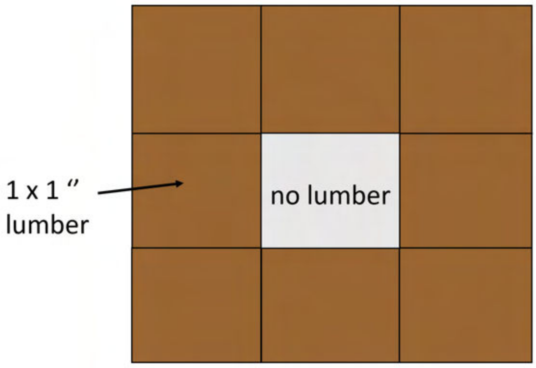


Figure 80: Raw shape of the WAM Proa spars: Eight 1 x 1 in (25 x 25 mm) lumber battens are glued into a square. The center is left hollow for weight reduction.

As it is difficult to glue more than three individual parts at a time (they slide uncontrollably) start by gluing four boards (two for each spar) from three battens each.

8.15.4 Task 90: Clean the central stiffener of the windward hull

Clean the central stiffener of the leeward hull by removing the copper wire and sanding all edges and surfaces. Apply proper fillets and cover all edges and surfaces with glass fiber. Apply an extra layer of epoxy resin wet in wet.

8.15.5 Task 91: Glue the deck of the leeward hull

Glue the windward hull deck panels on the top stringer and the full height bulkheads, glassed side facing down. Make sure the deck panel sit on the stringer and bulkheads evenly without major gaps before applying any glue.

Paint all bare wood under the deck panels (stringers, bulkhead top edges etc.) three times with epoxy. Make sure you cover every single bit of wood - especially from below! The three coats can be applied wet in wet within a few hours.

Apply glue to the top stringer and the full height bulkheads. Press the deck panels on top and weigh them down with heavy stuff while the glue cures.

8.15.6 Task 92: Stay lashings

The mast is supported by a fore- and a backstay (*jomur*) as well as a windward stay (*to kubaak*) close to the mast head. The stays are attached to special lashings. They are tied to the bare poles without any holes or bolsters as shown in figure 81 below.

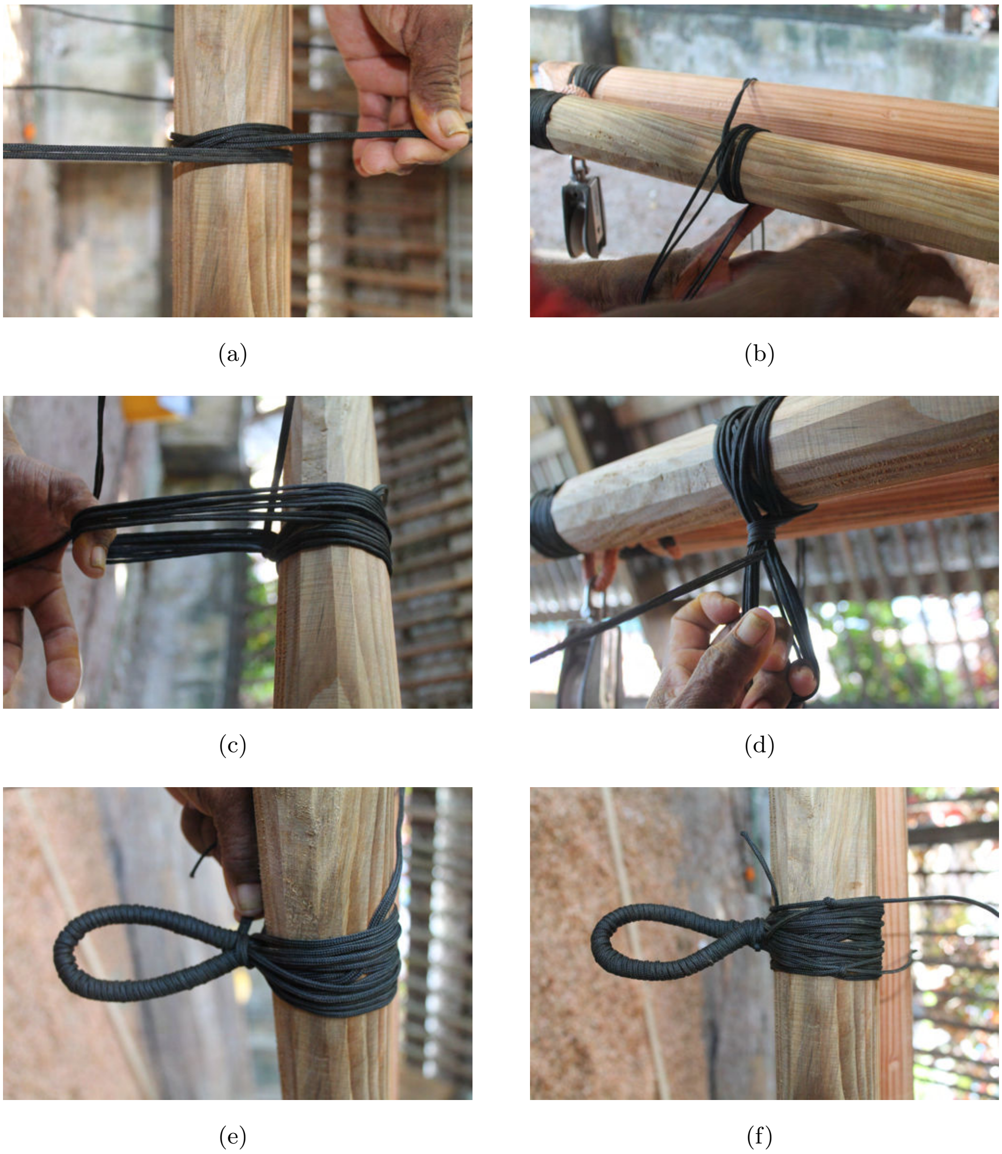


Figure 81: Lashing for the stay attachment

8.15.7 Task 93: Halyard cleats

The halyard (*maan*) and the spilling lines used for reefing (*tiliej*) are cleated at lashed-on clamps approx. 3 ft (1 m) above the mast foot as shown in figure 82 below. Lash two clamps to the mast.

(a) Preparing the cleat from hardwood

(b) Lashed on cleat at the mast

Figure 82: Halyard and spilling line cleats

8.16 Day 16

8.16.1 Task 94: Glue reinforcement pins into the beam cleats of the leeward hull

Glue the reinforcing pins into the beam cleats of the leeward hull in the same way as it was done for the windward hull (see Day 12, Task 74, 8.12.6).

8.16.2 Task 95: Glass the second side of the windward hull

Glass the second side of the windward hull. Make sure all overlaps to the already glassed surfaces are sanded before applying any glass fiber.

8.16.3 Task 96: Glue the spars

Take the four boards glued yesterday from three battens each. Glue them, using the remaining battens, to create hollow square beams as shown in figure 80. Insert a 1.5 ft (450 mm) long 1 x 1 in (25 x 25 mm) batten into each end of the spars to close them.

8.16.4 Task 97: Lash the deck

The space in between the hulls and the beams of the WAM Proa is covered by a solid slat deck made from lumber. The solid slat deck is shown in figure 83 and 84 below. Cut the slats from lumber with the dimension 2x4 in (50x100 mm) and to the length between center and aft beam. The slats should be long enough to rest on the beams and flush with the front and aft edge. Make them slightly longer at this point, as they will be cut later once the boat is assembled to its final length. Cut as many slats as required to fill the space between the hulls - keeping a distance of approx. two fingers in between the slats. The slats are held in place by three crosspieces made from 2x4 in (50x100 mm) lumber. One crosspiece is placed on each end so the deck is locked in between the two beams of the proa for the slats to be fastened to. The third cross-piece reinforces the center of the deck. All connections are made by rope lashings.

(a)

(b)

(c)

(d)

Figure 83: Pre-lashed deck slats treated with boiled linseed oil

The entire deck complex is treated with boiled linseed or coconut oil for rot prevention and preservation. Apply at least five layers (one layer every 24 hours). Reapply linseed oil repeatedly to keep the wood protected whenever the lumber looks dry. Epoxy is not suitable to use as coating for the deck, as a damage to the epoxy coat is very likely to happen (as there are lots of edges and people will be walking on it) and a damaged epoxy coat accelerates the rot process.

Figure 84: Slat deck (red) mounted between hulls and beams

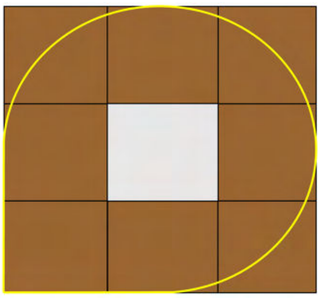
8.17 Day 17

8.17.1 Task 98: Glue reinforcement pins into the beam cleats of the leeward hull

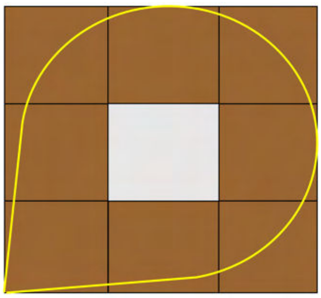
Flip the leeward hull on its side and glue the second set of reinforcement pins into the beam cleats in the same way as was done for the windward hull (see Day 12, Task 74, 8.12.6).

8.17.2 Task 99: Plane and shape the spars

Plane the spars glued yesterday according to figure 85 to obtain a teardrop shape.



(a) Plane off all wood outside the yellow line



(b) Use an electric planer to machine the teardrop shape (yellow line). Sand both spars smooth.

Figure 85: Teardrop shape of the WAM Catamaran spars

8.17.3 Task 100: Drill the spars

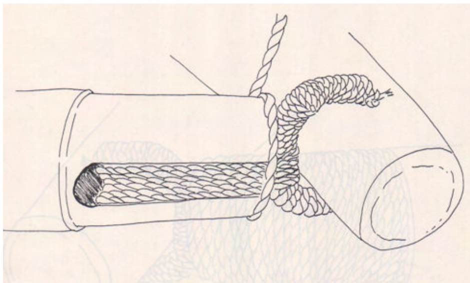
The sail is lashed to the spars. Therefore, drill lashing holes into the pointy side of the spar. The sail will be lashed on with 30-lb fishing line, the lashing holes can be small. Place them approx. one hand width apart from each other.

Figure 86: Lashing holes for the sail

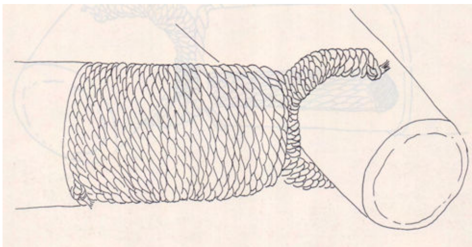
8.17.4 Task 101: Lash the spars

In the next step the front ends of the spars *rojak maan* and *rojak korra* are lashed together (*kapelpel*). Shape the ends of the spars and lash as shown in figure 87 and 88 below.

Figure 87: Lashing of the spar front ends (*kapelpel*)



(a)



(b)

Figure 88: *Kapelpel* lashing as documented by Denis Alessio[26]

8.17.5 Task 102: Sand and round the leeward hull

Sand the entire surface of the leeward hull. Round all edges - as was done for the windward hull - in preparation for glassing.

Day 17

8.17.6 Task 103: Glass the leeward hull bottom

Glass the bottom of the leeward hull with three layers of glass fiber cloth in the same way as was done for the windward hull. Make sure the glass fiber overlaps on all sides.

[26] Alessio 1989

8.17.7 Task 104: Glass the windward hull top

Glass the top of the windward hull. Make sure all surfaces, including those of the overlaps at the edges, are sanded before applying any glass fiber.

8.17.8 Task 105: Oil the spars and mast

Treat the spars and the masts with boiled linseed oil as rot protection. Repeat the oiling procedure over the next few days to apply a total of five layers. The treatment must be repeated whenever the wood looks dry to keep the protection active.

8.18 Day 18

8.18.1 Task 106: Sand the windward hull

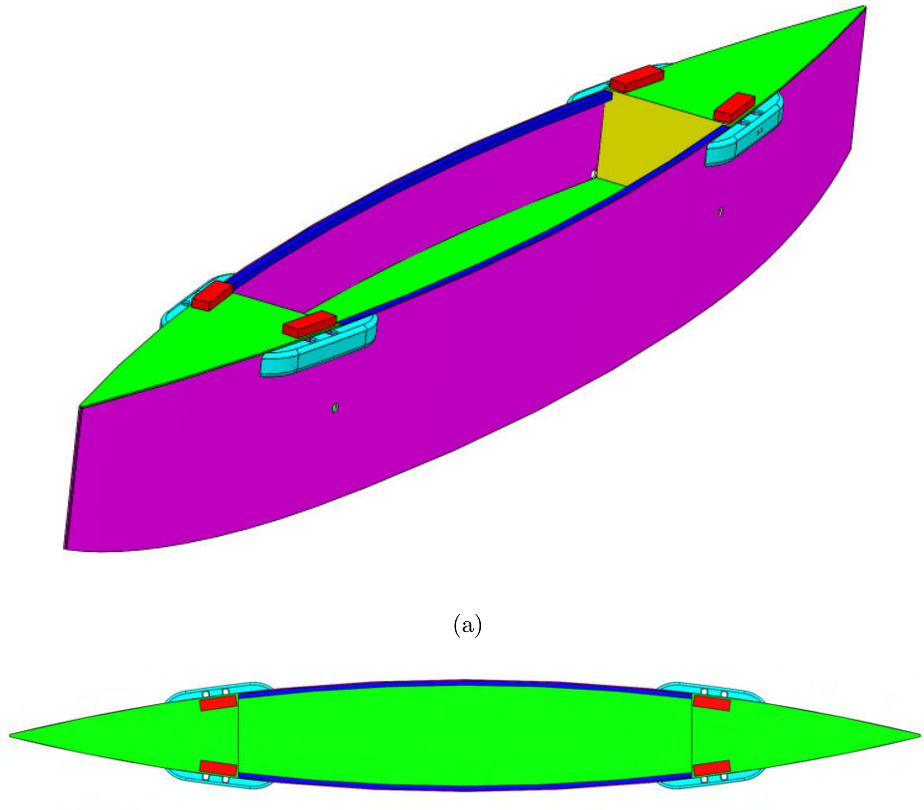
Sand the entire windward hull (all surfaces) with 180 grid in preparation for painting.

8.18.2 Task 107: Prepare to glass the leeward hull side

Sand the leeward hull bottom and the overlaps to the sides with 120 grid.

8.18.3 Task 108: Glue the beam blocks to the windward hull

Glue the beam blocks to the windward hull as shown in figure 89.



(a)

(b)

Figure 89: Location of the beam blocks (red) on the windward hull

The beam blocks are made from dense hardwood. Cut eight blocks (four for each hull) of approx. 8x2x1 in (200x60x30 mm).

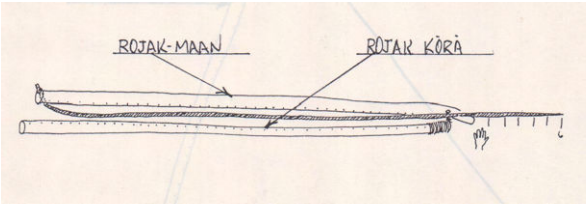
8.18.4 Task 109: Glass the leeward hull side

Flip the leeward hull on its side (the side without the drain holes facing up). Glass the side facing up with two layers of glass fiber cloth. There should be an overlap of at least 3 in (75 mm) around the chine over to the side panels. Apply another layer of epoxy resin after a while (flow coat wet in wet).

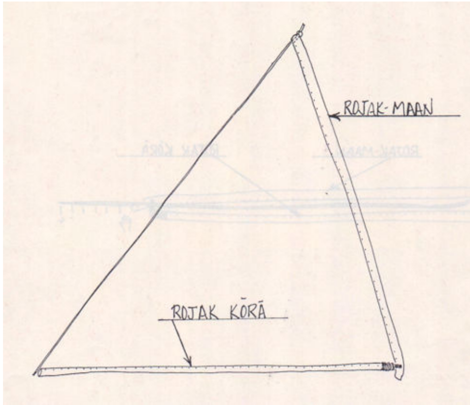
8.18.5 Task 110: Measure and cut the sail

Cut the sail cloth[27] according to figure 90 below.

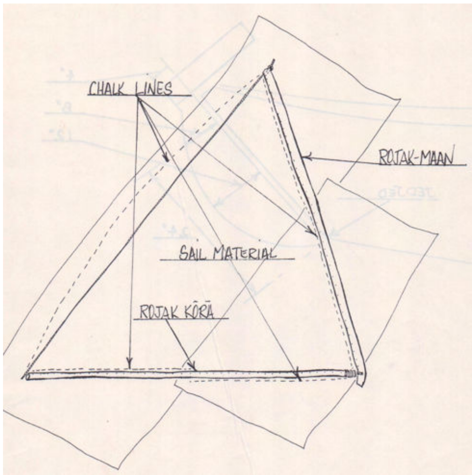
[27] For this manual it is assumed that dacron (polyesther sail cloth) is used. Alternatively polytarp or canvas can be used for the sail.



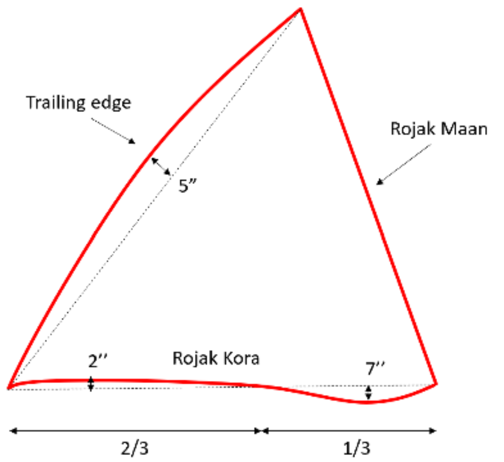
(a) Attach a string to the top end of *rojak maan* (upper spar), measure it six hand spans longer than the *rojak maan*. Attach the loose end to the tip of *roja kora* (lower spar or boom).



(b) Pull the spars apart to create a triangular shape.



(c) Place the triangle of spars and string above the laid out sail cloth. Mark the outline of the sail with chalk or a sharpie.



(d) Draw a line on the inside of *rojak maan* and a convex shape along the string. The line along *rojak kora* starts at the apex of both spars, bends outside the triangle, crosses the lower spar approx. 1/3 of its length, bends slightly to the inside and ends at the tip of *rojak kora*.

Figure 90: Measure and cut the sail cloth.[28]

Cut the sail cloth panels along the lines drawn in figure 90 with an offset of three fingers (2 in, 50 mm) to the outside (cut the panels larger than measured).

8.18.6 Task 111: Sew the sail

Sew the panels together, either by hand (which takes time) or with a sewing machine (in zigzag mode). Work carefully and precisely, as the panels must be stitched exactly the way they were laid out and marked. Otherwise, the sail shape will be compromised. Double sided tape or pins can be used to hold the panels in position while they are sewn.

[28] Alessio 1989

In the next step, the edges of the sail are reinforced by sewing a string into all three leeches. The string (not too stretchy and with a diameter of approx. 1/8 in or 3 mm) is placed on the marked lines (see figure 90 c) above) and the offset of three fingers (2 in or 50 mm) is folded around it. It helps to pre-fold the offset without the string first.

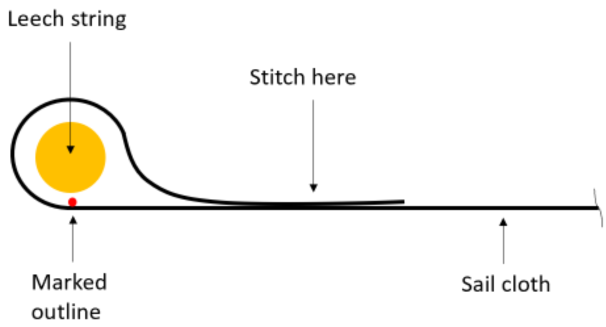


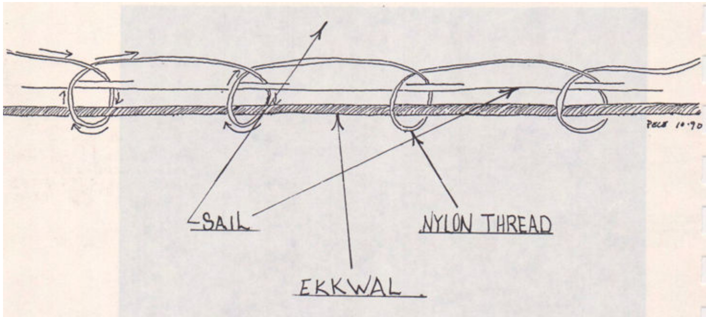
Figure 91: The edges of the sail are reinforced by leach strings.

Stitch the strings which run along the spar sides to the sail cloth close to the tips of the sail. Keep the ends at the apex loose and cut them 2 ft (600 mm) longer than the leech. They will be tightened later to trim the sail shape. The string at the trailing edge is not stitched to the sail cloth on either side. It is important to adjust the trailing edge tension later and will be mounted directly to the spars. Cut it 3 ft (1 m) longer than the trailing edge on each side.

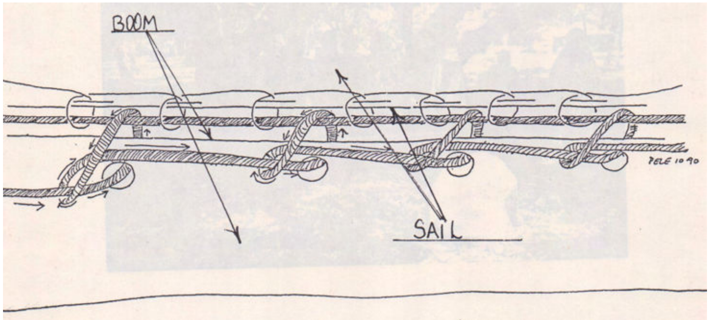
8.18.7 Task 112: Stitch the sail to the spars

In the final step, the sail is eventually connected with the spars. First, attach a second string to the leeches which will be mounted to the spars as shown in figure 92. The nylon thread (fishing line) is wrapped around the sewn-in leech string and the external connector string (in figure 92 from *ekkwal*[29] but any other material can be used as well).

[29]Traditional coconut fiber rope.



(a)



(b)

Figure 92: The way the sail is stitched to the spars as documented by Denis Alessio.[30]

The external leech lines are now sewn to the spars as shown in figure 92 above. A 30-lb (15 kg) fishing line works well.

As already mentioned in the previous task, the trailing edge leech line is now mounted to the ends of the spars.

[30] Alessio 1989

(a) The sail is stitched to the spars with 30-lb fishing line.

(b) Loose end of the trailing edge leech line

(c) A hole for the leech line is drilled into the end of the spar.

(d) The leech line is locked in the hole with a knot. The tension of the leech line is important for the sails trim and therefore occasionally adjusted.

Figure 93: Stitching the sail to the spars and setting up the trailing edge leech line

Assemble sail and masts as shown in figure 94 below for a dry test. The leech lines of *rojak maan* and *rojak kora* (the upper and lower spar) are set up with proper tension now. The trailing edge leech line might need some adjustment, too.

(a) (b)

Figure 94: Indoor test of the rig

8.18.8 Task 113: Drill and fill the holes for the mastfoot support piece lashing

The mast foot is supported by a board lashed to the windward gunwale of the leeward hull. Drill holes of 1 in (25 mm) diameter spaced approximately 4 in (10 cm) under the sheer stringer of the side of the hull currently facing down as shown in figure 95.

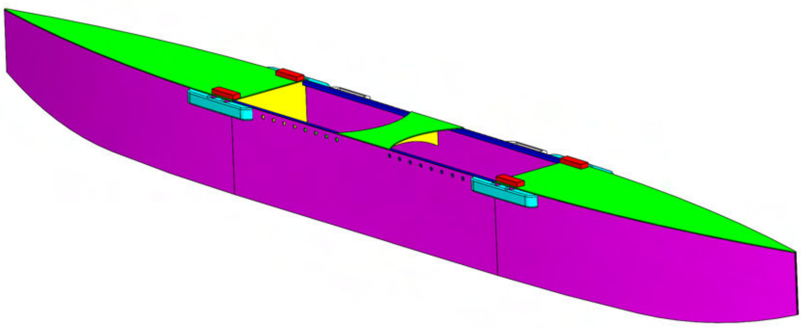


Figure 95: Holes drilled into the windward gunwale of the leeward hull

Carefully close the holes with masking tape from below and fill them with thickened resin. It might be necessary to clamp a piece of plywood or lumber under the holes to support the masking tape.

8.19 Day 19

8.19.1 Task 114: Glass the second side of the leeward hull

Glass the second side of the leeward hull. Make sure all overlaps on the already glassed surfaces are sanded before applying any glass fiber.

8.19.2 Task 115: Glue the leeboard cases to the leeward hull

Glue the leeboard cases to the outside (the side with the drain holes) of the leeward hull as shown in figure 79 while the glass is still wet. Use some weights to keep the parts in place while curing.

8.19.3 Task 116: Carve the sail steps

Carve the sail steps (*depakaak*) from hardwood.

8.19.4 Task 117: Lash the main sheet bridle

The main sheet is directly attached to the lower spar. To spread the bending load of the spar, a bridle is used. Lash the bridle as shown in figure 96 (below) to the lower spar. The center of the bridle should be located approx. 2/3 of the spar length from the apex where the spars meet.

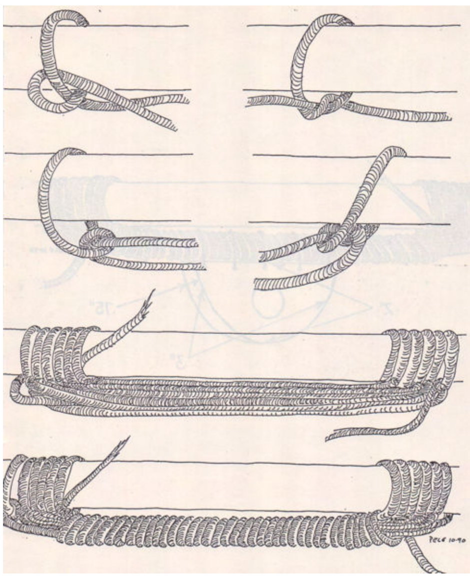


Figure 96: Main sheet (*iep*) bridle[31]

[31] Alessio 1989

8.19.5 Task 118: Lash the tiliej loops

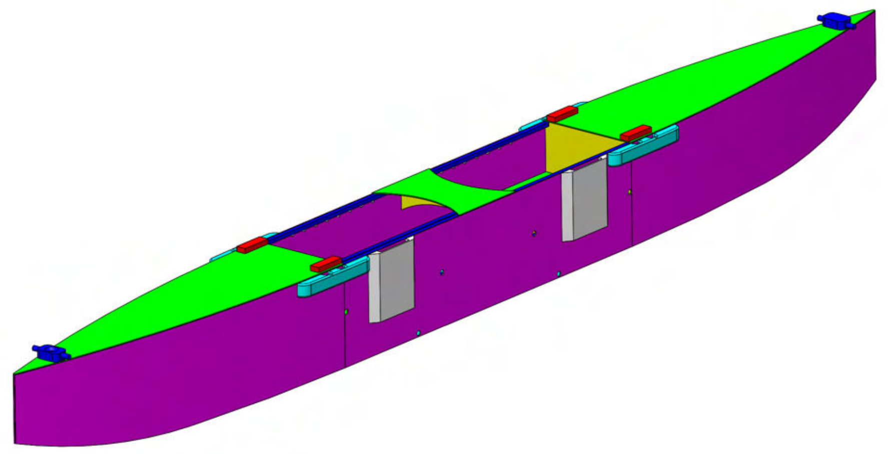
The *tiliej* or spilling lines are used to depower the sail and catch the upper spar when the sail is lowered (like lazy-jacks). Lash attachment loops to the lower spar in the center of the main sheet bridle the same way as it was done for the shroud loops (see figure 81).

Figure 97: *Tiliej* loops in the center of the sheet bridle

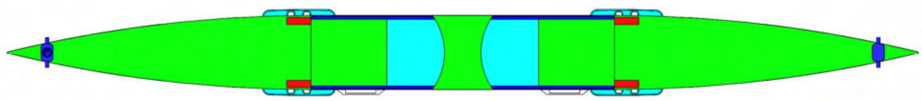
8.20 Day 20

8.20.1 Task 119: Glass the leeward hull top

Glass the top of the leeward hull in the same way as was done for the windward hull. Glue the beam blocks and the sail steps (*depakaak*) to the leeward hull as shown in figure 98 as long as the glass fiber is still wet.



(a)



(b)

Figure 98: Location of the beam blocks (red) and the sail steps (blue) on the leeward hull

8.20.2 Task 120: Finish other tasks

Use the rest of the day to finish other uncompleted tasks.

8.21 Day 21

8.21.1 Task 121: Sand the leeward hull

Sand the entire Leeward hull with 180 grid.

8.21.2 Task 122: Put the WAM Proa together

Assemble the WAM Proa as shown in figure 99 to make sure all parts fit. Line up the hulls parallel. Take the beams and place them on top of the beam blocks. Fit the lashed deck in between the beams and the hulls.

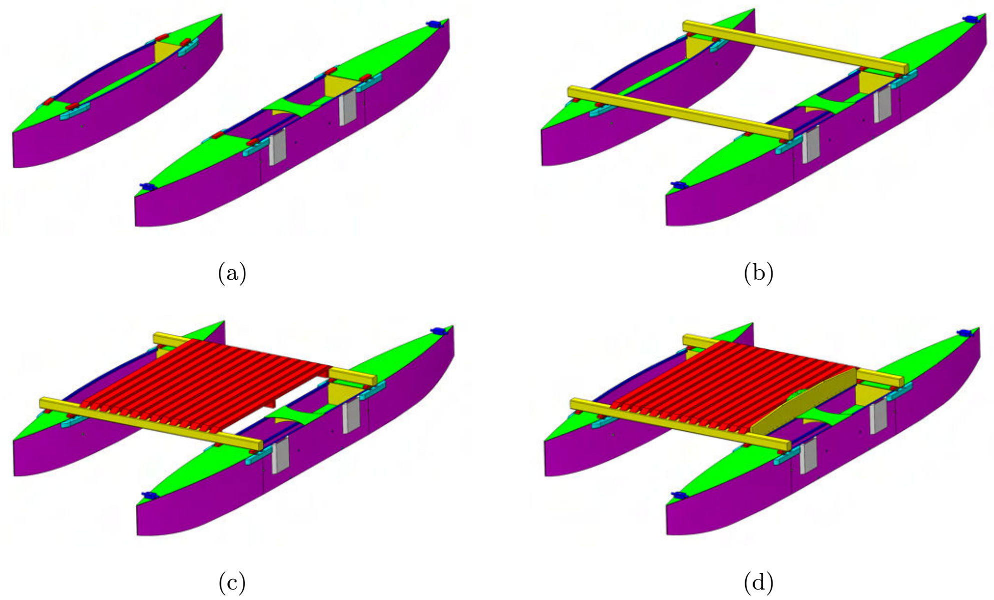
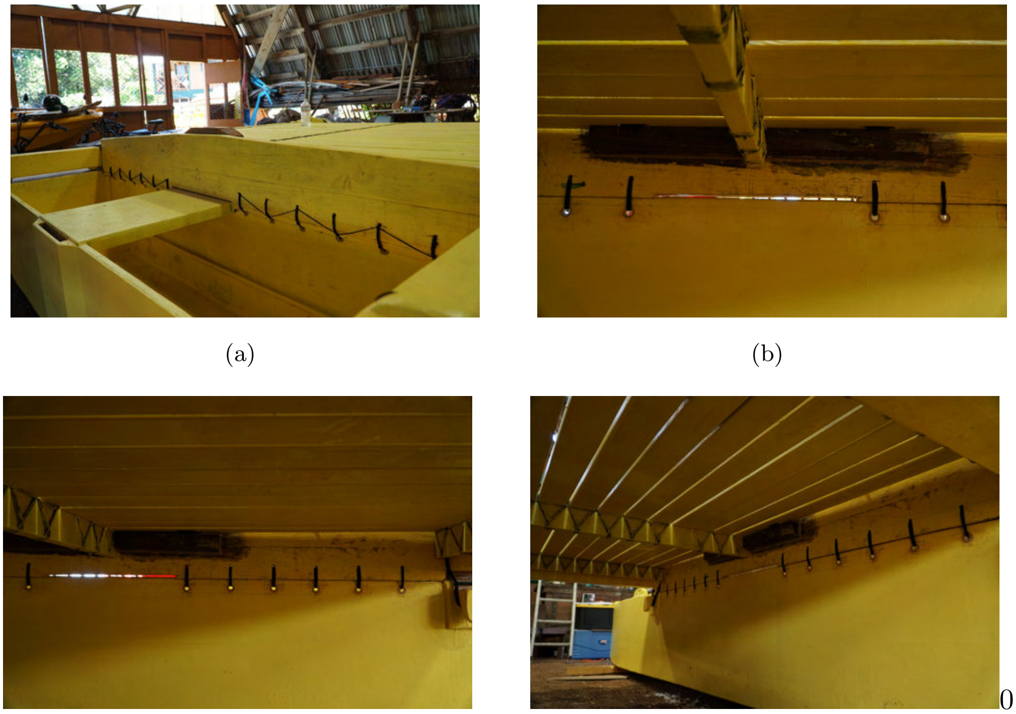


Figure 99: Assembly of the WAM Proa

8.21.3 Task 123: Make the turtle-chest

The mast foot is mounted on top of the deck in between the hulls. To support the deck (the mast puts a lot of compression force on the deck) a long board called “turtle-chest” is lashed to the top of the leeward hull as shown in figure 100. The turtle-chest board locks under the deck and supports the mast foot mounted on top of it.



(a) (b) (c) (d)

Figure 100: The turtle-chest board lashed to the top of the windward gunwale of the leeward hull. The locks under the deck and supports the mast foot mounted on top of it.

Make a turtle-chest board as shown in figure 100. Make sure the lashing holes meet up with the drilled and filled holes in the gunwale. Re-drill the filled holes.

8.21.4 Task 124: Glue on the beam alignment blocks

The beams are equipped with alignment blocks on the bottom side. They are shaped like the end blocks, but positioned in a way that they lock in between the beam blocks (glued on the hull) when the beams are placed on the hulls. The alignment blocks stop the beams from sliding and restrict their movement while the shock absorbing flexibility of the lashings is maintained.

Mark the position of the beam blocks on the beams. Glue beam alignment blocks from hardwood to the beams according to the marks.

Figure 101: Alignment blocks on the bottom of the beam. The contact area of beam and beam blocks is reinforced with additional glass.

8.21.5 Task 125: Paint

Clean both hulls and beams with soap and fresh water. Wash the soap water and the last remaining dust off with fresh water. Apply exterior house paint to the dried hull as recommended by the paint manufacturer.

(a) Painting equipment: regular exterior house paint, brushes and big rollers

(b) Brushes are used for detail work only

(c) The main surface is painted with the rollers.

(d) Painting the beams and turtle-chest

Figure 102: Painting the hulls. The photos show the WAM Catamaran but the process for the WAM Proa is the same.

The main purpose of the paint is to protect the epoxy/glass fiber coating of the WAM Proa from sunlight.

8.21.6 Task 126: Cut plugs for the leeward hull

Cut plugs for the drain holes of the leeward hull from foam (e.g. fishing floats).

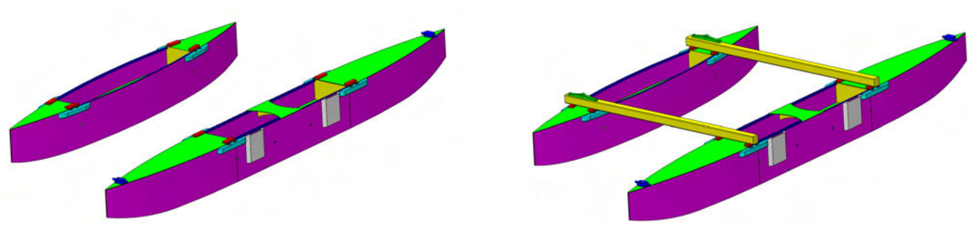
8.22 Day 22

Spare day to dry the paint and catch up with other tasks.

8.23 Day 23

8.23.1 Task 127: Lash the beams to the hull

Place the hulls on an even ground. Place the beams at their designated positions. The alignment blocks on the bottom of the beams should fit right in between the beam blocks on the deck.



(a) (b)

Figure 103: Alignment of hulls and beams

Temporarily lash the beams loosely in place. Measure the line up of the hulls: The hulls must be parallel, otherwise the drag of the proa is significantly increased. The parallelism of the hulls is simply measured with a string: The hulls should be apart by the same distance at both beams. Adjust the position of the hulls if required.

Lash the beams permanently to the hulls. The beam lashings are critical as they keep the platform together. Lash them carefully and clean. String from PE or PP fibers with a diameter of 1/8 in (2 - 3 mm) works best. Pick a stretchy rope, as stiff ropes (e.g. dyneema) are unsuitable for lashings.

Start the beam lashings with a double overhand knot (stopper knot) as stopper at the end of the lashing string. Now loop the string around the beam and close the loop with a simple overhand knot. Pull it tight. The stopper knot should lock the knot. Now loop the string around beam and beam cleat at least 18 times as shown in figure 104 a) below. Pull each loop as tight as possible. Finish the lashing by wrapping the end of the string horizontally around the lashing. Pull it tight to further tighten it. Close the lashing with a couple of overhand knots. Secure the end of the string with a stopper knot.

(a) Loop the lashing rope around beam and beam cleat.

(b) Loop the lashing rope around the beam and beam cleat.

(c) The connector for the windward stay bridle is included into the beam lashing of the windward hull.

(d) Pull the wrap tight to further tighten the entire lashing. Finish off with overhand knots.

Figure 104: Lashing of beams and hulls

8.23.2 Task 128: Mount the deck

Place the deck in between the beams and the hulls as shown in figure 84 and 105. Secure the deck with a light lashing on each corner to the beams.

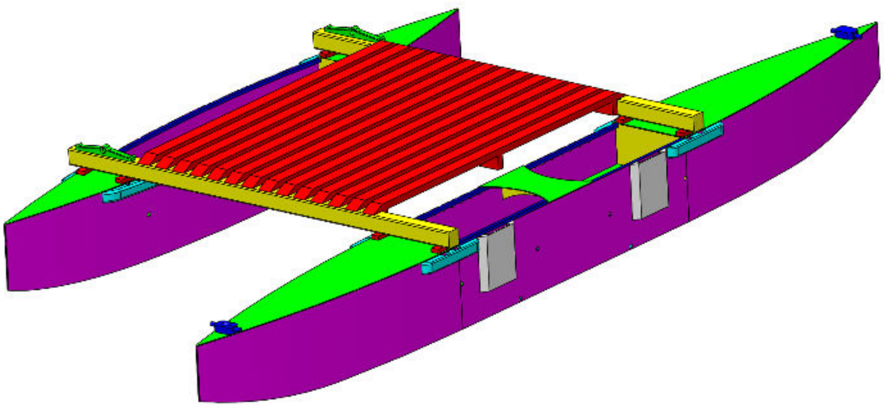


Figure 105: Deck mounted in between the hulls and beams

8.23.3 Task 129: Lash the turtle-chest

Lash the turtle-chest board on as shown in figure 100 and 106.

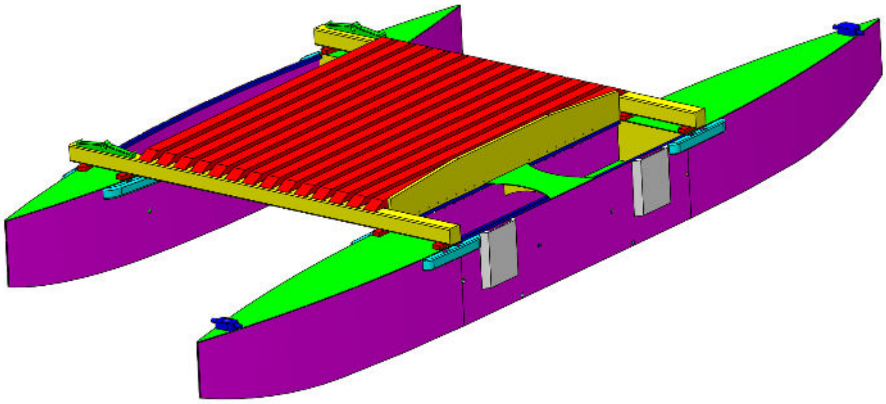


Figure 106: Turtle-chest board (yellow) lashed in place

8.23.4 Task 130: Lash the mastfoot

Lash the mastfoot on top of the deck as shown in figure 107. Secure the mastfoot to the turtle-chest board with an additional lashing.

Figure 107: Mastfoot lashed on top of the deck and secured to the turtle-chest board

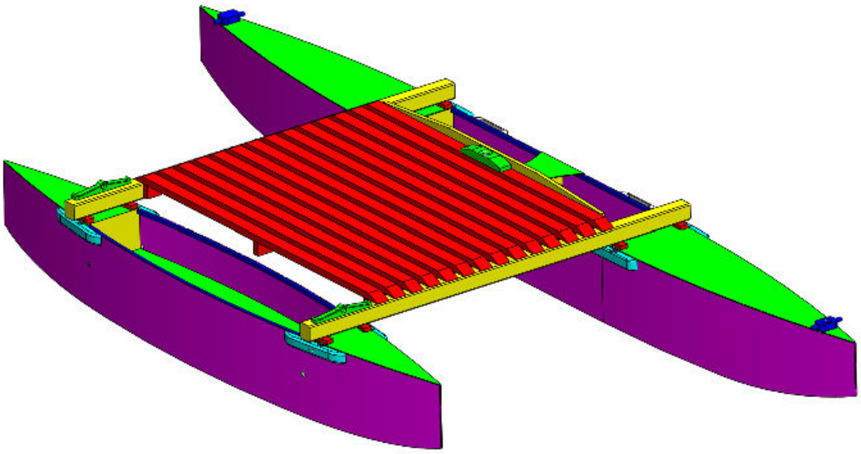
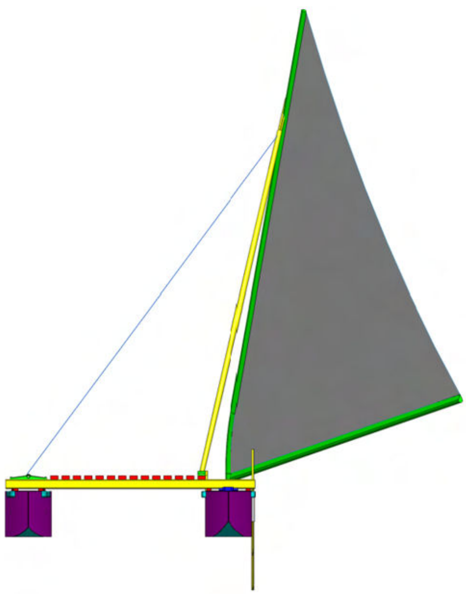


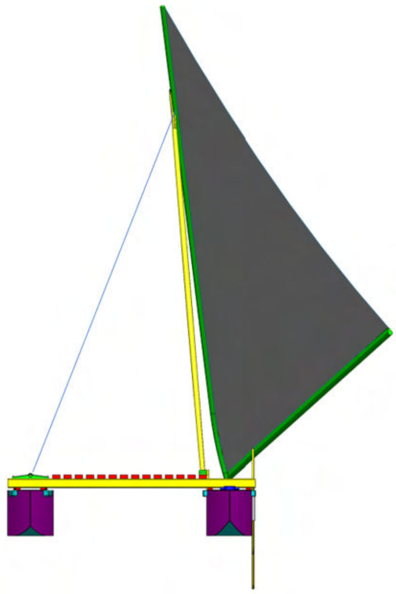
Figure 108: Mastfoot (green) lashed in place

8.23.5 Task 131: Set up the rig

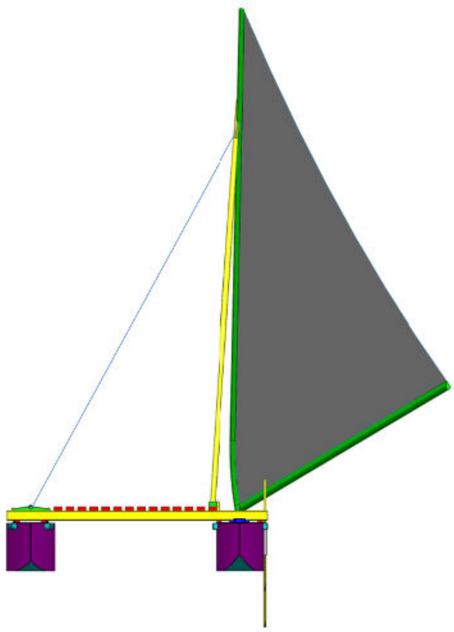
The mast is held in place by three stays: The windward stay (*tokubaak*) connecting the mast top and the and the windward hull splits above the windward hull into a bridle which is fastened to the connector pieces lashed to the top of the beams. It is important to set the windward stay up with a proper length as shown in figure 109. In the basic setup the upper spar (*rojak maan*) should be vertical, i.e. not leaning to either side. A longer windward stay causes the sail to lean over to leeward resulting in increased weather helm. A short windward stay pulls the sail over to windward, reducing weather helm but increasing the risk of the entire rig tipping over to windward. The windward stay can be used to fine tune the balance of the proa. Stretch in the windward stay might even make this necessary on the water.



(a) When the windward stay is long, the sail leans to leeward.



(b) When the windward stay is short, the sail leans to windward.



(c) Basic setup of the windward stay: the sail is not leaning either way.

Figure 109: Proper adjustment of the windward stay (blue line)

The mast pivot to each bow is controlled by the bow stays (*jomur*). These are running stays attached to the mast top and secured to the mast step (*depakaak*) on each bow. The *jomur* are essential for the shunting maneuver, because they are used to control the mast swinging from one end to the other.

(a)

(b)

(c)

(d)

Figure 110: Rig setup

The upper boom (*rojak maan*) is hoisted by the halyard (*maan*) which runs through a hole in the mast top down to the cleats on the mast. The lower boom (*rojak kora*) is attached to the spilling lines (*tiliej*), which run down from the mast top on each side of the sail. The spilling lines control the shape of the sail by lifting the lower boom. They can be used to create a rounder, more powerful sail in light wind by pulling the boom up with the windward line, or to depower the sail in strong wind by tightening the leeward line and creating a sharp kink in the sail. The spilling lines also act as lazy jacks, catching the sail and the upper boom when the sail is lowered as shown in figure 110.

The power of the sail and its angle to the wind is adjusted with the main sheet (*iep*). It is attached to the sheet bridle on the lower boom (see figure 96).

9 Sailing and maintenance

9.1 Setting up

Set up the rig as described above. Tie a string to the steering paddle and the central stiffener as shown in figure 111. The string secures the steering paddle which reduces the load when sailing. The steering paddle is generally kept on the leeward side of the hull.

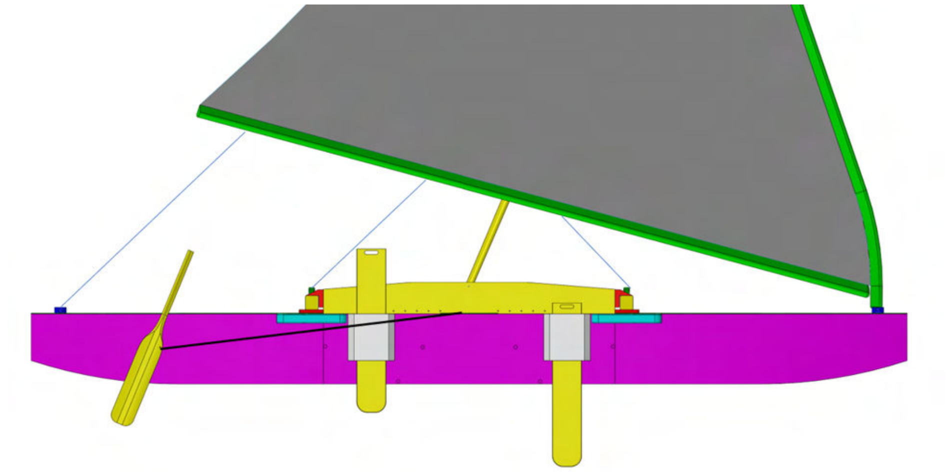


Figure 111: The steering paddle is tied to the central stiffener of the main hull. The string should be long enough to allow comfortable steering

Plug the drain holes of the leeward hull.

9.2 Launching

The WAM Proa is best launched down a beach or a ramp. Do not pull it over the ground. Rocks, coral, concrete and even sand will damage the hull bottom. Always use either something to slide (plywood, lumber or coconut leaves) or roll on (PVC pipes or fishing floats) as shown in 110.

Be careful in gusty conditions or when launching behind trees: The sail must never catch wind from the wrong side! The mast is only supported by the windward hull. Wind from the wrong side could easily knock over the entire rig. If in doubt, better to paddle away from the shore and pull up the sail in predictable wind.

The leeboards can only be used in deep water. Be very careful in shallow water or close to reefs as they get damaged easily when crushed. The WAM Proa doesn't sail very well without them. If in doubt, it would be better to paddle away from the shore and start using the boards in deep water.

9.3 Sailing

The WAM Proa is, like traditional Marshallese canoes, sailed with the smaller hull always kept on the windward side (hence it is called the windward hull). The smaller windward hull must never be on the leeward side and the sail must never catch wind from that side either.

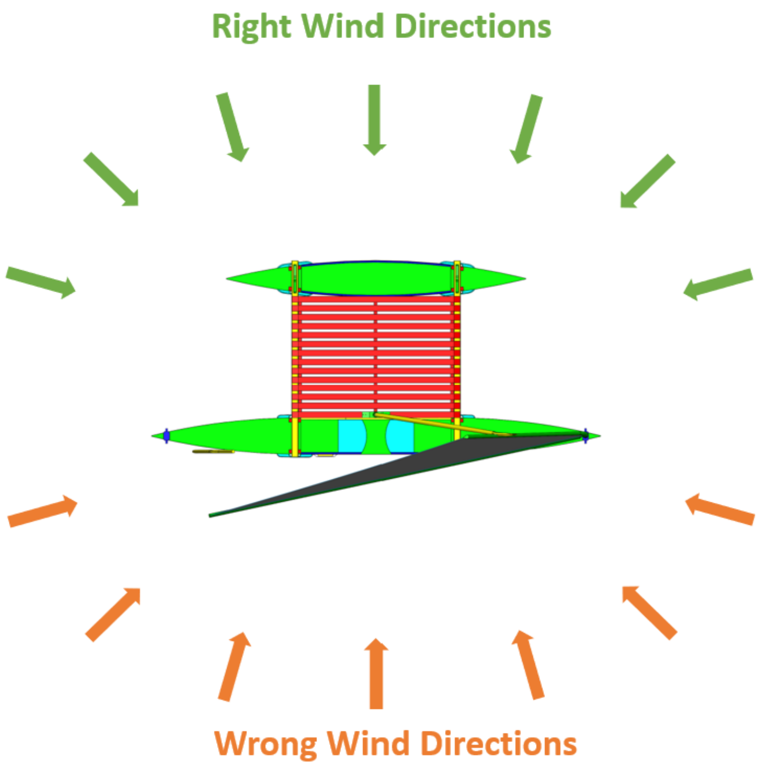


Figure 112: The WAM Proa must always face the wind with the small hull.

Pull up the sail all the way and make sure the halyard (*maan*) is as tight as possible after tying it to the cleat on the mast. The spilling lines (*tiliej*) should be loose, the ends tied to the second mast cleat. Pull the sheet (*iep*) firmly to start sailing. Wrap the sheet around the beam end twice to take the load off your hands. How close the sail is pulled towards the hull depends on the wind direction. Sailing to the wind (wind blows from ahead) requires a close hauled sail while sailing off the wind (wind is blowing from behind) requires a furled sheet (open sail).

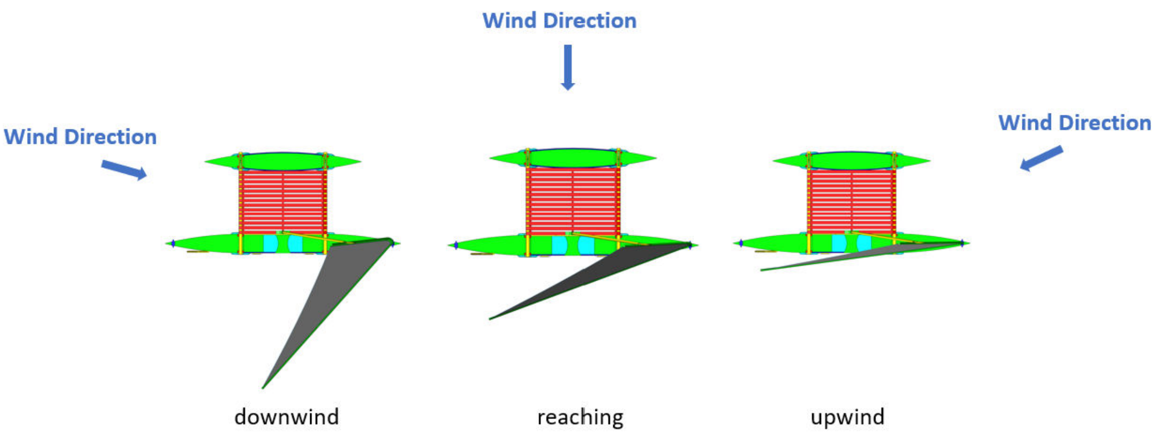


Figure 113: Sailing downwind with the wind from behind (left), reaching with the wind from the side (center) and upwind with the wind ahead (right).

Generally, as a rule of thumb, pull the sail so close that the cloth closes to the top of the upper spar (stops flogging and catches some wind). To sail efficiently the sheet needs constant attention and frequent adjustments.

The course of the Proa is controlled with the steering paddle. As shown in figure 111 it is always kept on the leeward side of the hull (the side with the leeboards on). The Proa is trimmed with a light weather helm on all points of sailing (see below how do do this), therefore the paddle is always pushed against the hull and can be handled comfortably by the helmsman. To turn downwind simply wedge the paddle in the water flowing past in a way that it is pushed against the hull even harder. To turn upwind it is sufficient to just lift the paddle out of the water. The Proa will turn into the wind by herself because of the weather helm.

The force of the wind in the sail will always try to tip the WAM Proa over (capsize it). The windward hull and the platform work as a counterweights to keep the WAM Proa upright. In strong wind this might not be sufficient and the windward hull may be lifted out of the water. Once in the air, the WAM Proa can capsize very quickly and the crew has only limited time to react. In this situation - they should dump the main sheet (release it all the way) as quickly as possible to depower the sail. To stop the windward hull from becoming airborne, make it more heavy. Place cargo or people in the windward hull to be on the safe side.

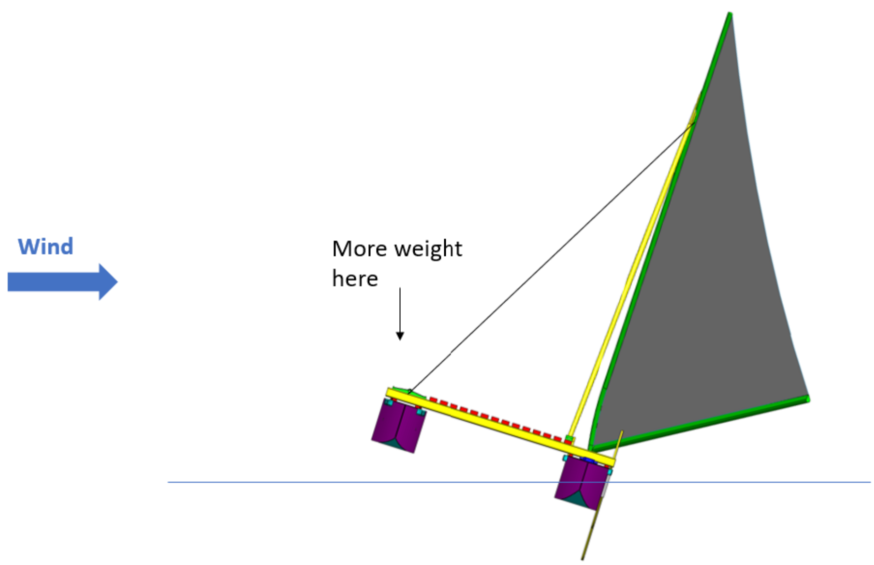


Figure 114: Place weight in the windward hull to prevent capsizing

The lower boom (*rojak kora*) is attached to the spilling lines (*tiliej*), running down from the mast top on each side of the sail. The spilling lines control the shape of the sail by lifting the lower boom. They can be used to create a rounder, more powerful sail in light wind by pulling the boom up with the windward line or to depower the sail in strong wind by tightening the leeward line and creating a sharp kink in the sail.

Like all sailing craft the WAM Proa can not sail directly against the wind. To reach a destination upwind zig-zag on a course close to the wind as shown in figure 115. Although it is possible to sail with the wind right behind it, it is not recommended for safety reasons. A small change of wind direction or a slight turn of the WAM Proa might cause the wind to catch the back of the sail and the boom to swing over. In this scenario, the spars will likely break and the crew may be injured.

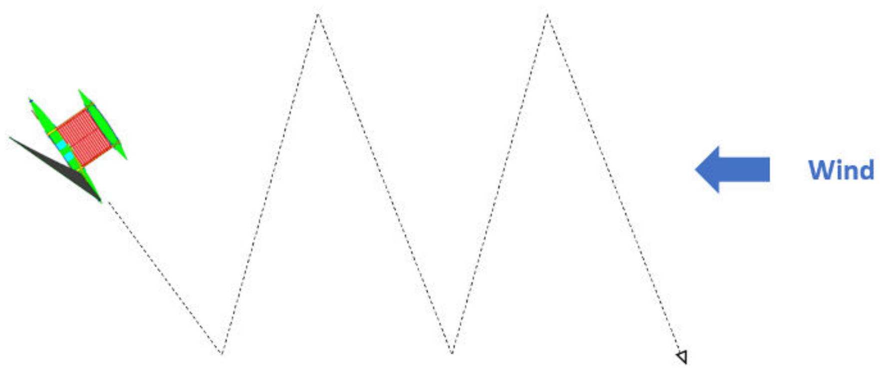


Figure 115: Sailing to a destination upwind in a zig-zag pattern

9.3.1 Shunting

Since the windward hull is always kept to windward, the WAM Proa does not change direction of travel by turning around (tacking or jibing). Instead, front and back is reversed by mounting the sail on the other end in a maneuver called a shunt (*diak*). This process is best done by at least two and requires some physical strength as well as practice. To do a shunt (*diak*):

1. Release the sheet all the way. The Proa will come to a stop in a stable position with the sail flagging.
2. Person 1 moves forward and unties the apex of the booms (*kapelpel*) from the sail step (*depakaak*).
3. After untying the sail, person 1 releases the for/aft stay (*jomur*).
4. Person 1 then lifts the sail out of the sail step and walks it over to the mast (center of the hull). Person 2 supports this by pulling on the second fore/aft stay. This helps to pivot the mast into a vertical position and reduces the weight person 1 has to lift.
5. After reaching the mast, person 1 passes over the sail to person 2.
6. Person 2 waits, if necessary, until the Proa turns around and the sail is flagging perpendicular to the hull and swiftly moves the sail to the other sail step. Person 1 supports this by holding on to the first fore/aft stay to take off some of the sail's weight.

7. Person 2 places the sail in the sail step and ties both sail and stay. Person 1 secures the stay on the other end.

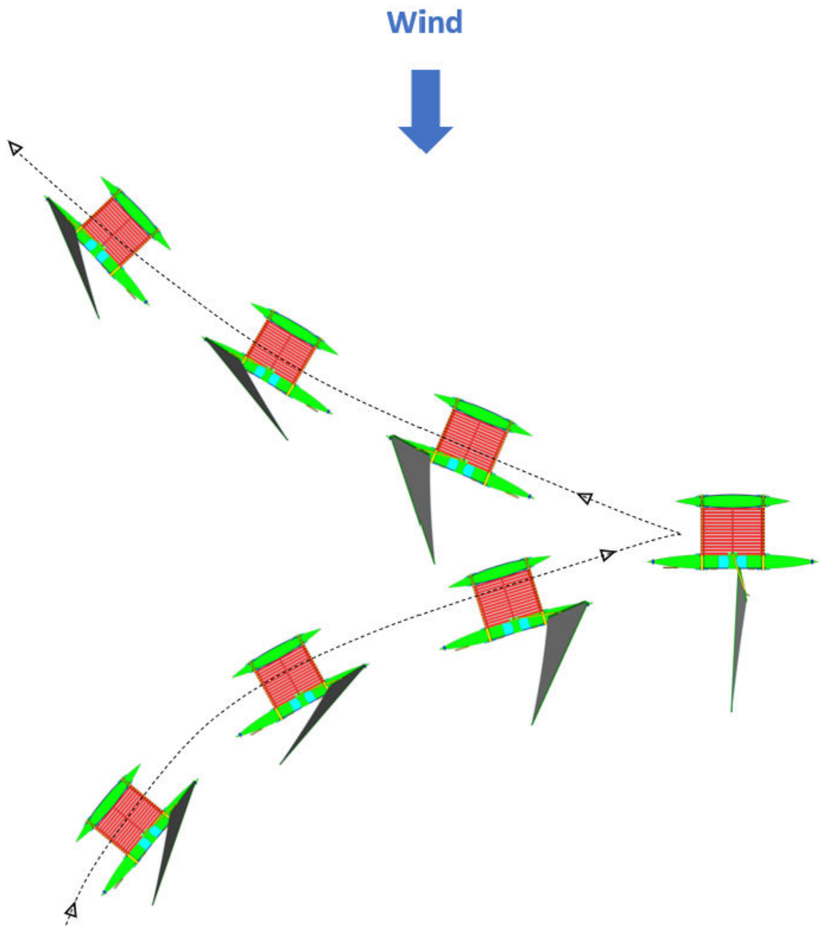


Figure 116: Shunting maneuver (*diak*) of the WAM Proa

Sailing

9.4 Balance and trim

A good balance (= the ability to sail in a straight line) is very important for the WAM Proa. Weather helm (the canoe wanting to turn in the wind) or lee helm (the canoe wanting to turn away from the wind) require the use of the steering paddle to maintain course, which is quite uncomfortable for the helmsman and slows the Proa down due to additional drag.

The balance of the WAM Proa can be influenced in four ways:

Mainsheet

Understanding the effect of the mainsheet is important because the sheet is adjusted constantly to make sure the sail is altered correctly to take the canoe on the desired course. A close-hauled sail pushes the bow leewards, which assists the boat to bear away (as shown in figure 117). An open sail, as commonly used for sailing downwind, can cause weather helm due to the long boom.

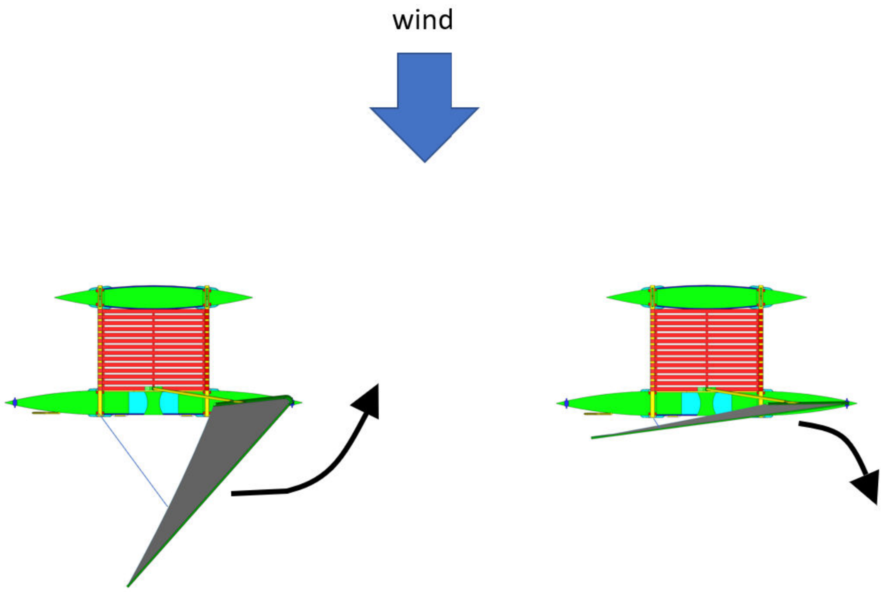


Figure 117: A close hauled sail (right) pulls the bow leeward, whereas a loose sheet with an open sail (left) causes weather helm.

Leeboards

The WAM Proa is equipped with two leeboards to fine tune the weather helm, depending whether the sail is close hauled or open. As shown in figure 118, lifting the rear board causes the Proa to luff while lifting the front board allows the bow to drift downwind.

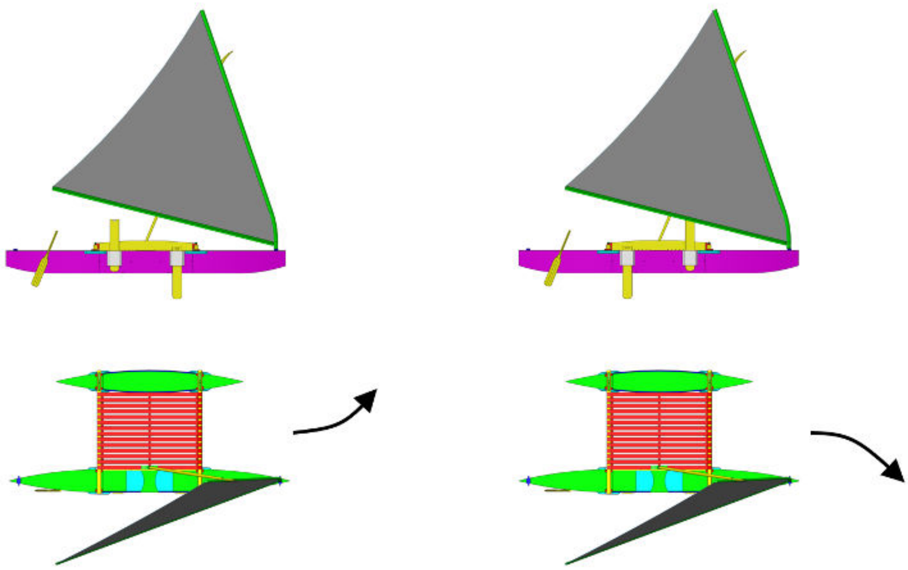


Figure 118: Lifting the rear board causes the Proa to luff while lifting the front board allows the bow to sail downwind.

Windward stay

The effect of the windward stay is similar to the one of the mainsheet. A shorter stay pulls the sail to windward (less weather helm), whereas a longer one makes it lean over to leeward (more weather helm) as shown in figure 119.

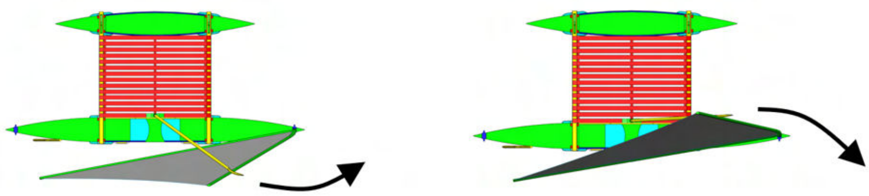


Figure 119: Influence of longer and shorter windward stay on the sail leaning to either windward or leeward, and the effect on the balance.

Weight Distribution

The weight distribution plays a role in two ways: By shifting weight between the windward and the leeward hull, the draft and therefore the drag of the hulls changes. A heavy loaded windward hull causes a lot of drag and "pulls around" the entire Proa windward (see 120). This effect is reduced by keeping the windward hull light.

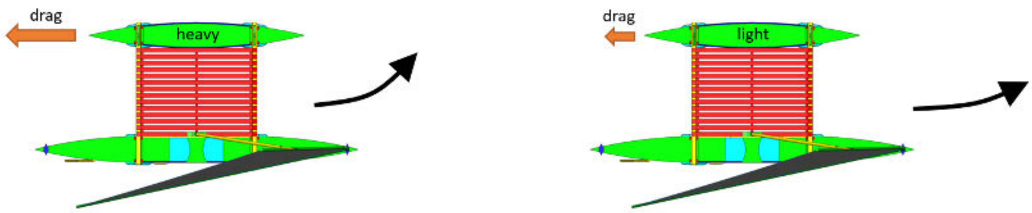
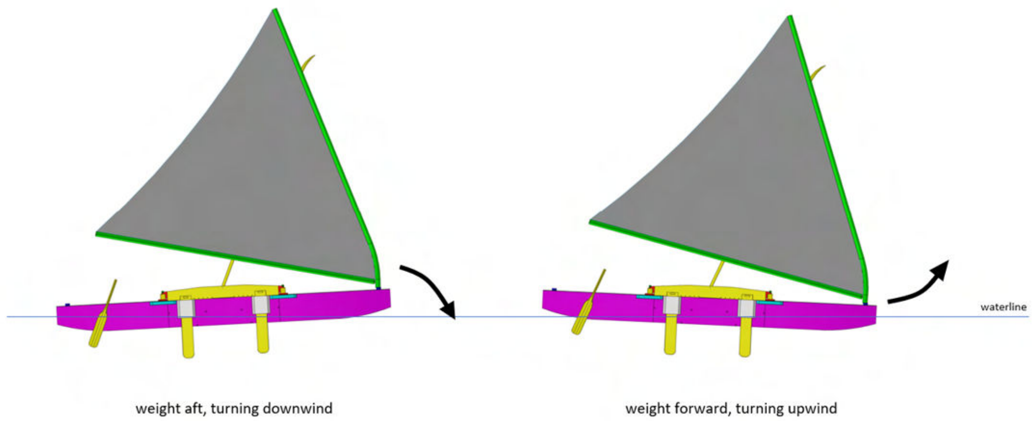


Figure 120: Influence of the distribution between windward and leeward hull

The fore-aft weight distribution has a similar effect. Shifting the weight to the front causes the proa to luff, while shifting it to the back makes it easier to bear away (as shown in figure 121).



Sailing

Figure 121: Influence of the fore-aft distribution of weight

The goal is to always balance the WAM Proa in a way that the helmsman feels:

- a light weather helm on the paddle, i.e. the paddle is always kept on the leeward side of the hull;
- the helmsman can easily hold it with one hand; and
- when it is lifted out of the water the Proa slowly turns into the wind.

To make sure the Proa has a neutral setting right from the start the length of the windward stay should be set up in a way that the upper spar is vertical when sitting in the sail step. The sail should not lean over to any side. Leaning leeward would result in additional weather helm while leaning to windward causes additional lee helm. Depending on the load and the conditions it might become necessary to make small adjustments to the length of the windward stay for a more comfortable balance.

While underway the two dagger-boards are pushed into the mounts on the leeward side of the large hull. The flat side of the boards face leeward, while the round side face the hull side. Their main purpose is to stop the shallow flat-bottom hull from sliding sideways. Therefore they are particularly useful for sailing upwind. Pulling up either the front or the back leeboards is another way to adjust the balance: Lifting the forward board will let the bow turn off the wind (increasing leeway) while pulling up the rear one increases weather helm. This is actively used for steering because the setting of the sail does influence the basic weather or lee helm of the Proa too. A close hauled sail (i.e. for sailing upwind) for example pushes the bow leeward. To mitigate this and stay in balance the rear board is lifted until the helmsman feels a slight weather helm on the steering paddle (the paddle is kept on the leeward side and has to work "against something"). When sailing downwind the wide open sail might cause a lot of weather helm due to its long boom. To stay in balance the forward dagger-board is lifted.

9.5 Returning to shore

Keep following things in mind when returning to shore:

- Lift the leeboards in time. They get damaged easily if they crash into reef or beach. Keep in mind that it might be difficult to lift them at high speed.
- When approaching a leeward shore the wind might become very gusty and can easily catch the wrong side of the sail and knock the rig over. If in doubt, drop the sail early and paddle the remaining distance.
- Do not sail onto the beach, always stop before the hull touches the ground. Sailing on the beach scratches the hull and might damage the protective glass fiber layer.
- Never drag the Proa over the ground, always use something to slide on (e.g. plywood or coconut leaves), or something to roll on (e.g. PVC pipes or fishing floats).

9.6 Maintenance

A craft built the way the WAM Proa is built can last a very long time of up to 50 years and more. To get such a long lifetime out of your WAM Proa, constant care and maintenance is required. Since the WAM Proa is built from, plywood and lumber, rot is its natural enemy. Rot is caused by microorganisms, such as bacteria and fungus, consuming the wood. They can only survive in a moist environment. Therefore, the most effective way to prevent rot is by keeping the wood dry. The construction technique used for the WAM Proa takes care of this by covering, and therefore encapsulating, all the wood in waterproof epoxy and fiberglass. Maintenance is focused on keeping this protective layer intact and undamaged:

- Holes, scratches and other damage which punctures the protective layer of epoxy and exposes the wood must be covered as soon as possible with epoxy and paint. The longer the wood remains exposed the more water may potentially leak behind the epoxy and pose the risk of starting rot under the coating.
- The edges of plywood and the end grain of lumber are particularly at risk of cracking the coating due to shrinking and taking in water. Cracks must be sealed as soon as possible and are best covered with fiberglass.
- Keep the inside of the canoe dry and ventilated. Freshwater and dirt from trees etc. will quickly turn into a smelly breeding place for mosquitoes and, despite the epoxy coating, infect the wood of the canoe with rot.
- If a damage has remained unattended for a while and the wood has already taken up some water, the wet wood must be cut out and replaced by dry wood. Never coat wet wood with epoxy, the water will be trapped under the coating and it will rot inside.
- Never use screws or nails! They penetrate the protective layer of epoxy and open the way for water to enter the wood.

- The sail must be stored dry and out of direct exposure to sunlight. Like your skin hurts and start to peel after overexposure to the sun the sail gets weak and ultimately ribs apart.
- Sunlight damages the paint of the canoe too, so it is important to repaint it every once in a while. Epoxy is waterproof and a very strong glue but it's not very strong if exposed to the sun. It will crack and crumble after a short while. The main purpose of the paint is therefore to protect the epoxy/glass fiber coating from sunlight.

Glossary

anisotropic A material is anisotropic when it shows different properties depending on its orientation. A typical example is wood. The strength greatly depends on the orientation of the grain. 29

batten A long flat strip of squared lumber. 19, 31

beam In this text 'beam' refers to the crossbeams connecting the two hulls of the catamaran. 19, 37

bevel An edge of a structure that is not perpendicular to the faces of the piece. 31, 32

box section Rectangular cross-section of a hull, i.e. a flat bottom and vertical sides. 6

butt-join A joint made by fastening the parts together end-to-end without overlap and often with reinforcement. 32

chine Edge between the bottom and the side of the hull. 80, 84, 89, 98

come about See tack. 6

Compression strength The amount of stress a material can withstand just before breaking if a pushing force is applied. 22

CWL Design water line. The waterline at which the ship will float when loaded to its designed draught. 9

diameter A straight line passing from side to side through the centre of a body or figure, especially a circle or sphere. 38

draft The distance of the deepest point of the hull to the surface of the water when the craft is floating. 6

epoxy Epoxy resin is a substance that can be mixed with another substance called a 'hardener' to make a strong glue. In more technical terms, it is a type of thermosetting polymer that, when mixed with a hardening agent, undergoes a chemical reaction resulting in a strong, durable, and adhesive material commonly used in various applications, including coatings, adhesives, and composite materials. 21, 22, 27, 29–32, 35–39, 42, 43

exothermic A chemical reaction that produces heat, such as the curing of epoxy. 25, 42

fillet A continuous bead of thickened epoxy mixture applied to the angle between two parts to be joined. 32–35

frame Like ribs, the frames run from the side of the hulls to the central keel. Frames support the hull and give the hull its shape and strength. 19

glass fiber Artificial fiber material made from numerous very thin glass threads. Glass fiber appears like white hair, sometimes like spider web, and is typically woven into cloth. It is commonly used as reinforcement for epoxy (see GRP). 21, 22, 27, 36

GRP Appreviation for glass fiber reinforced plastic. Refers to any material made from resin and fibers, e.g. epoxy resin and glass fiber. 21, 22, 27, 35, 36

hand layup Hand layup is the simplest and oldest open molding method for glass fiber. Dry materials are placed in a mold and a brush is used to apply resin to the fiber material. 36

jig A device that holds a piece of work (e.g. a wooden plank) and guides the tool operating on it. 32

keel The bottom-most longitudinal structural element on a watercraft. 19

leeboard A board pushed into the water to stop a boat from drifting sideways while sailing. 3

Light ship weight Weight of the empty watercraft. 9

luff Turning into the wind, sailing closer to the wind. 122

Max. loading capacity Maximum weight that can safely be put on the watercraft. 9

microplastic Microplastics are fragments of any type of plastic less than 5 mm (0.20 in) in length. They are dangerous for animals and plants as well as for humans. 43

perpendicular Two objects are perpendicular if they intersect at a right angle (90°). 29

polar plot Polar plots are used to show the speed of a sailing vessel in relation to wind speed and and wind direction. The distance from the center marks the vessel's speed in knots, the further from the center the faster it is going. The angular position of the circle indicates the wind direction the vessel is sailing in. The top is assumed to be zero (wind from the front), right is the wind from the left side and the bottom represents the wind from behind. The different colors of the lines indicate different wind speeds. 5, 9

pot-life Time to work with a mixture of epoxy before it begins to cure. 25

resin Component A of epoxy resin (not mixed with hardener). Depending on the context, the word 'resin' is also used to refer to the ready-to-use mixture of component A and B (epoxy resin and hardener). Component A or B are never used alone, except for when being mixed. 23, 29–31, 35–38

scarf joint A scarf joint is a method of joining two members end to end in woodworking or metalworking. The scarf joint is used when the material being joined is not available in the length required. It is an alternative to other joints such as the butt joint and the splice joint and is often favored over these in joinery because it yields a barely visible glue line. 19, 30–32

shunt A special sailing maneuver of a proa. The direction of travel is changed by reversing the front and back end of the vessel. 6, 120

stitch and glue A method to join plywood panels. The technique consists of stitching together plywood panels with some sort of wire or other suitable device - such as cable ties or duct tape and staples - and bonding the panels permanently with a fillet. 39

stringer Longitudinal reinforcement or stiffener. 19

tensile load Tensile load, which tends to increase the length of a material, is the opposite of compression, which tends to reduce the length of a material. 36

Tensile strength The amount of stress a material can withstand just before breaking if a pulling force is applied. 22

toe rail A batten glued to the edge of the deck to keep things or people from slipping off. 37

trapezoid A shape with four sides of which two are parallel. 88

UV stable UV stable refers to a material's ability to resist the damaging effects of ultraviolet (UV) light which is present in sunlight. Artificial products, such as plastics, rubber and synthetic fibres, are particularly vulnerable to UV damage. 22, 39

viscosity The liquidity of a fluid. Water has a low viscosity while oil has a high one (oil has a high viscosity and a thicker liquidity, whereas water has a lower viscosity and a thinner liquidity). 29

wet on wet A technique where a second layer of epoxy or glass fiber is applied before the first one is completely cured. If done within a certain time frame both layers bond chemically (which means they are very strong and there is no need for sanding). 26

wet out To rinse something completely with a liquid. Most of the time in this manual, the term is used to describe the process of rinsing glass fiber with epoxy resin. 29

windward hull The smaller outrigger hull that is always kept on the windward side on a Pacific proa design. 51

Bibliography

Alessio, Dennis (1989). *Waan Aelon Kein Reports 1-9*. Waan Aelon Kein Reports. Alele Museum and Archives, Majuro.

Eichler, Curt W. (2017). *Holzbootsbau*. 6. Edition. Heel Verlag GmbH.

Epoxy Technology Inc. (n.d.). *Tech Tip 28: Amine Blush*. URL: https://www.epotek.com/docs/en/Related/Tech%20Tip%2028%20Amine%20Blush.pdf. (accessed: 05.01.2024).

Gougeon, Meade (2005). *The Gougeon Brothers on Boat Construction (5th Edition)*. Gougeon Brothers Inc., Bay City, Michigan. ISBN: 1-878207-50-4. URL: https://www.westsystem.com/the-gougeon-brothers-on-boat-construction/.

Handbuch Faserverbundkunststoffe/Composites (2014). 4. Edition. AKV - Industrievereinigung Verstärkte Kunststoffe.

Jetñil-Kijiner, Kathy (2017). *Iep Jāltok - Poems from a Marshallese Daughter*. Arizona: The University of Arizona Press.

Richter-Alten, Henrik (2021a). *Development of a Measurement System for Performance Analysis of Small Sailing Cargo Vessels*. internal document. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

– (2021b). *WAM Prototype Workshop Documentation Report*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). URL: https://changing-transport.org/publications/low-carbon-sea-transport-prototype-workshop/.

– (2023). *Lagoon Prototypes Performance Report*. internal document. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Spennemann, Dirk H.R. (1998). *Marshallese Legends and Traditions*. URL: https://marshall.csu.edu.au/marshall/Marshalls/html/legends/frame-le-1-2.html. (accessed: 16.01.2024).

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