The WAM Catamaran

— Construction Manual —

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About the authors

Henrik Richter-Alten
Naval architect and mechanical engineer, from Kiel, Germany, specializes in sailing and ship design. Raised on Norderney island, he's involved in most water-related activities. As part of the *Transitioning to Low Carbon Sea Transport* (LCST) project, he designed the WAM Catamaran and aided in establishing a training program in the Marshall Islands. He is the lead author of this construction manual.

henrik@richter-alten.com

Alson J. Kelen
Director of *Waan Aelōn̄ in Majel - Canoes of the Marshall Islands* (WAM), is deeply involved in preserving Marshallese canoe culture and documenting its construction process. He has served in various key positions in the Marshall Islands, including as Mayor of Bikini Atoll and Chairperson for the RMI Nuclear Commission. Kelen is widely recognized as a prominent climate stakeholder, influencing policies in the Pacific region.

alsonjkelen@gmail.com

Editing and proofreading
Jasmine Tompkins

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For further information, please contact: **Project Director**, Mr. Raffael Held (`raffael.held@giz.de`)

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 Aelōn̄ 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 Aelōn̄ 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.

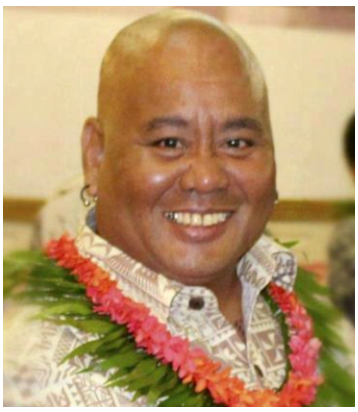


Figure 1: Alson J. Kelen, director of *Waan Aelōn̄ in Majel* (WAM)

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 Jebrọ! The brothers laughed. He is the youngest! He will lose anyway! And Jebrọ, 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 Jebrọ, began to unravel the bundle slowly the way the sun unravels its silky rays. And Jebrọ said What is that Mother? And Lōktan̄ūr said Behold my Son. This shall be called the Sail.[3] Jebrọ and Lōktan̄ūr overtook all of the brothers aside from the eldest brother Tūmur. On seeing Jebrọ sailing effortlessly Tūmur demanded Jebrọ's canoe. As the eldest he believed he deserved the fastest canoe. Jebrọ 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 Jebrọ 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 Catamaran. 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 Catamaran design.
- Section 3 explains the manual's suggested educational approach to teaching students to build a WAM Catamaran 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 Catamaran.
- 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 Catamaran.

This manual is published by *Waan Aelōn̄ 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 Aelōn̄ 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 Catamaran 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**[5].

(a) The WAM Catamaran

(b) The WAM Proa

Figure 2: The WAM Catamaran and the WAM Proa.

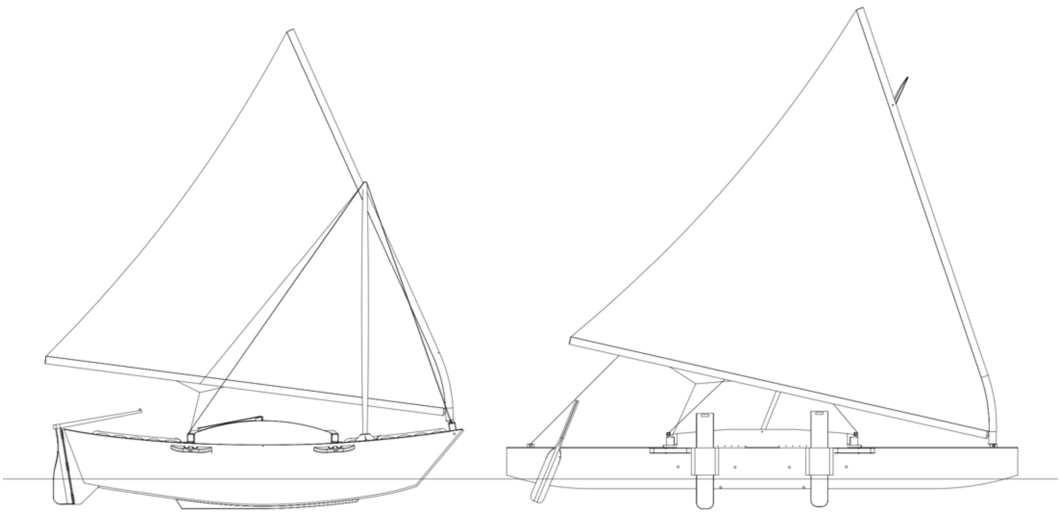


Figure 3: Side view of the WAM Catamaran (left) and WAM Proa (right).

[5]The WAM Proa is based on the *HarryProa Mini Cargo Ferry*, designed by Rob Denney for WAM.

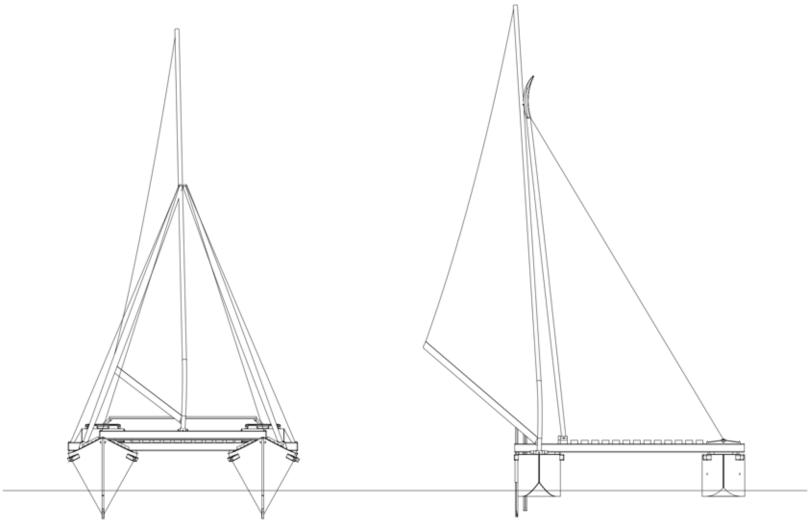


Figure 4: Front view of the WAM Catamaran (left) and WAM Proa (right).

The WAM Catamaran is a double hulled-canoe canoe with two hulls of equal size and shape while the WAM Proa is an outrigger design with a larger main hull and a smaller outrigger hull. This design feature is 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.

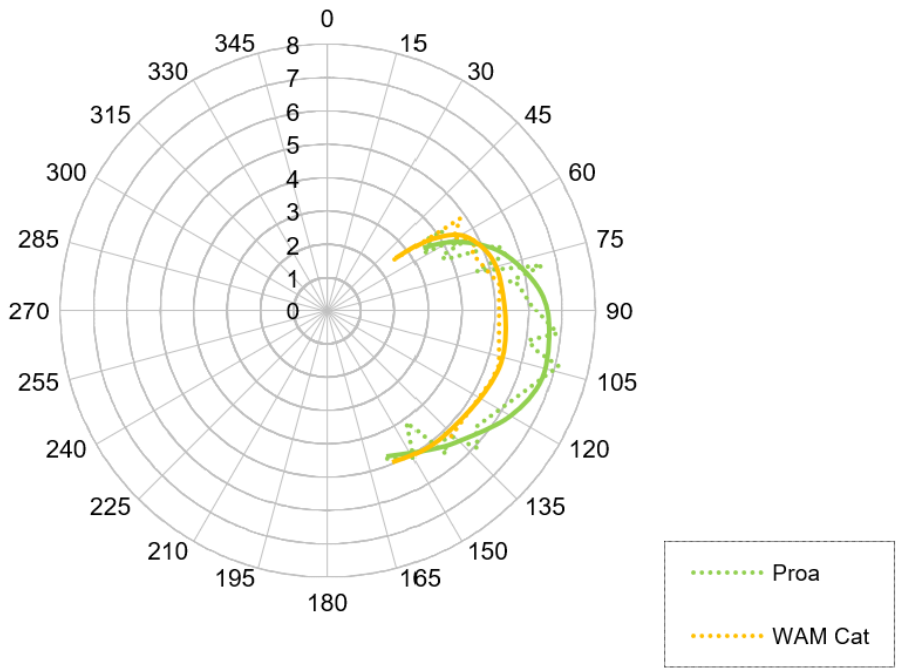


Figure 5: Polar plot of the measured sailing speed of the WAM Catamaran and the WAM Proa in 12 - 14 kn true wind speed, loaded with roughly 700 lbs (approx. 350 kg). Leeway is included. The further away from the centre the coloured lines are, the faster the sailing speed. The position around the circle (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 Catamaran only. A similar manual has been published for the WAM Proa. Detailed information about the WAM Catamaran design can be found in the next section.

2.2 The WAM Catamaran

The WAM Catamaran is an easy and safe to sail double hulled-canoe canoe. The simple but efficient sail and the twin rudder setup turn every trip into a pleasant adventure and allow single-handed sailing in all conditions. The direction of travel is changed by turning the catamaran around like a car by doing a tack and jibe. These rapid and simple maneuvers make the WAM Catamaran suitable for narrow waters. Due to the low center of effort of the sail and the special hull shape, the catamaran is very stable in strong wind. So far there have been no reported capsizings of a WAM Catamaran.

Figure 6: The first WAM Catamaran prototype waiting for high tide in front of the WAM campus, Majuro

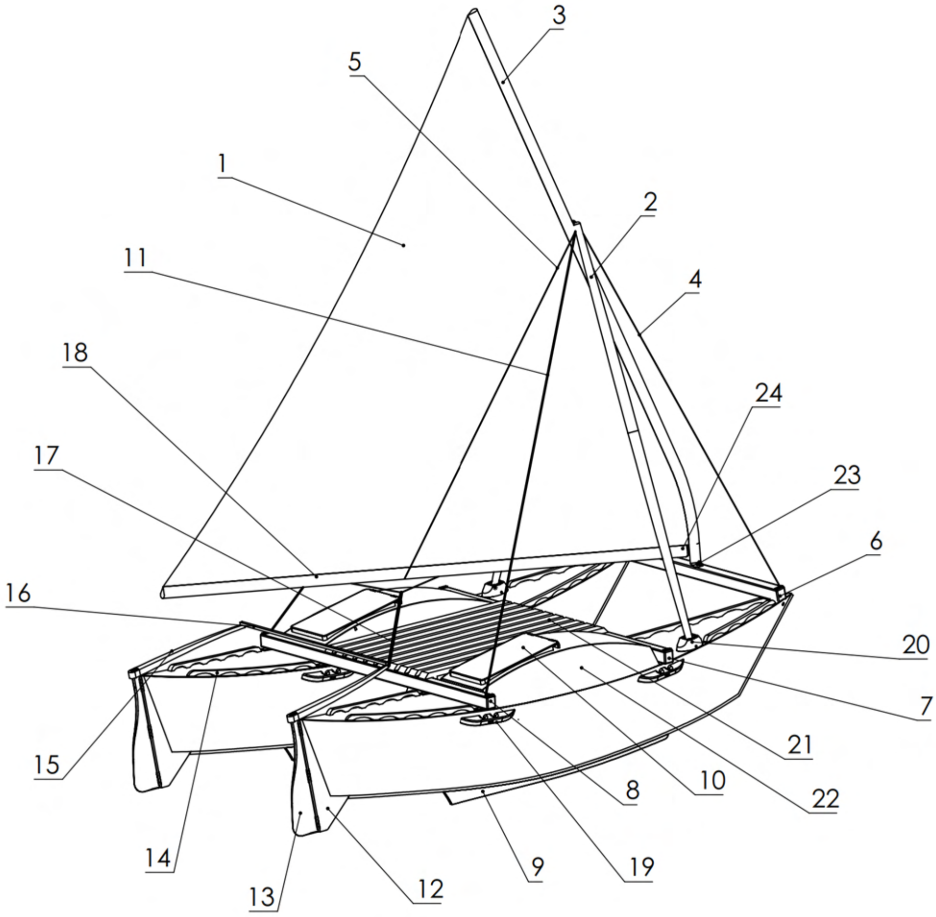


Figure 7: The parts of the WAM Catamaran (with labels corresponding to table 2)

Label	English	Marshallese	Label	English	Marshallese
1	Sail	Ujela	13	Rudder	
2	Mast	Kiju	14	Toe rail	
3	Yard	Rojak maan	15	Rudder handle	
4	Forestay	Jomur	16	Rudder crossbar	
5	Spilling lines	Tiliej	17	Main sheet	Iep
6	Fore beam	Kie iṃaan	18	Boom	Rojak kōrā
7	Main beam	Kie ioḷapin	19	Beam cleat	
8	Aft beam	Kie itulikin	20	Mast step	Bōklap
9	Keel shoe	Erer	21	Platform	Ere
10	Hatch	Aj	22	Cabin	
11	Backstay	Jomur	23	Tack socket	Depakaak
12	Skeg		24	Tack	Kōpālpel

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

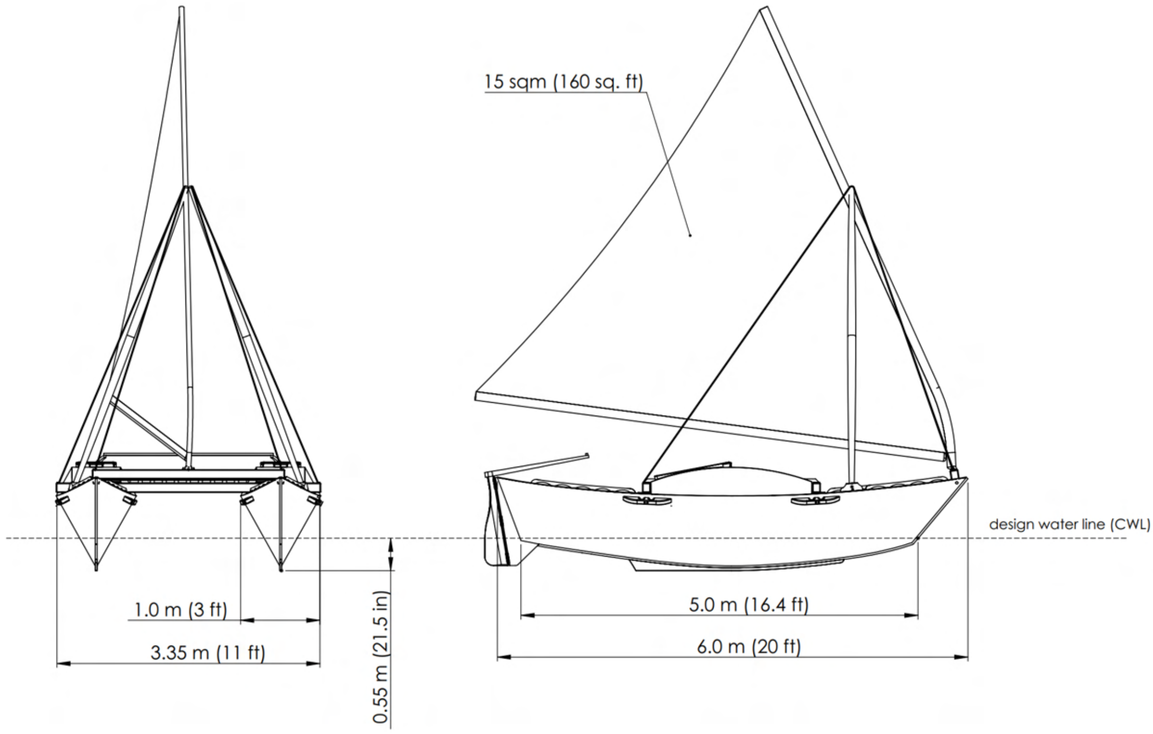


Figure 8: The main dimensions of the WAM Catamaran (as shown in table 3)

WAM Catamaran Main Dimensions

Length overall:	6.00	m	20.0	ft
Waterline length:	5.00	m	16.4	ft
Beam overall:	3.35	m	11.0	ft
Beam between center-lines:	2.30	m	7.5	ft
Breadth hull:	1.00	m	3.0	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 at CWL:	0.40	m	15.8	in
Breadth hull at max. capacity:	0.45	m	17.7	in
Draft empty:	0.47	m	18.5	in
Draft at CWL:	0.55	m	21.5	in
Draft at max. capacity:	0.60	m	23.6	in
Sail area:	15.00	m^2	160.0	ft^2

Table 3: Main dimensions of the WAM Catamaran, 20 ft (6 m) version[6]

The WAM Catamaran is designed as stitch and glue catamaran with deep V-shaped hulls. The stitch and glue technique is a fast and easy way to build boats from plywood, as well

[6] Richter-Alten 2021b

as a suitable technique to be adapted to building traditional Marshallese canoes. The entire construction relies on the superior strength of epoxy as glue. No metal fasteners (like screws or nails) are required. Epoxy (in combination with glass fiber cloth) is used to encapsulate all wooden parts and protect them from water and rot.

The WAM Catamaran has no metal parts at all. Hinges (for rudders and hatches), beam-hull connections and the rigging are all made with flexible and easily replaceable rope lashings.

In line with Marshallese canoe building traditions, the WAM Catamaran has been designed without any drawings or measurements in form of numbers and units. Instead, lofting is done with a string and all dimensions are developed based on their relation to the hull length. This unusual approach has some advantages compared to the traditional western way with drawings, plans and static measurements:

- the main dimensions are not given by a plan but are flexible to a certain extent. This allows the catamaran's size to be adapted to suit the dimensions of the material on site (in this case the standard size of plywood sheets);
- it is very easy to scale the design up and down: every dimension is a fraction of the overall length. By changing the overall length, the ratios stay the same;
- by using a string for lofting no numbers and units are involved in the entire construction process and no confusion between the imperial and metric systems occurs;
- the entire construction requires only a couple of different relations between dimensions. This system can easily be memorized and applied to canoes between 20 and 30 ft (6 - 10 m). Compared to a plan consisting of a set of drawings, this is more sustainable.[7]

The keels are protected by a lashed-on keel shoe from local hard wood. They can withstand frequent beaching and even being dragged up and down rocky beaches without scratching the hull itself. Once worn off or rotten they are simply replaced with new ones. This, in combination with the optimized rocker-line, makes the WAM Catamaran the perfect design to launch from a beach.

The WAM catamaran has a 10-ft (3 m) long internal cargo hold with flat removable floorboards accessible by a big hatch. The floorboards give access to the bilge compartments, which can be used to store fish or fishing equipment.

The rig is developed based on the traditional Marshallese canoe. The main difference is the second mast (both masts form an 'A' with the sail in between). All other changes are minimal.[8]

[7] A plan can get easily lost and requires special skills to work with. Although in much of the world a soft copy of a plan could perhaps be easily downloaded from the internet if made publicly available in the Marshall Islands access to the internet is more limited and may not be available at all on the remote neighboring islands. For example, research in 2017 found only 39% of the population had access to the internet.(ITU 2017)

[8] In fact, it is possible to use traditional canoe sails of the right size without any changes. The WAM Catamaran could share a sail with a 20 ft (6 m) canoe to cut down costs.

The WAM Catamaran is not designed to win races. The design goal is a safe and comfortable boat for cruising which maintains a decent performance in all conditions. It is designed for effortless sailing and it is not necessary to be a strong master sailor to handle it. This approach is a big step forward in gender equality, as it offers access to transportation for all!

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 the WAM Catamaran in different wind speeds, medium loaded.

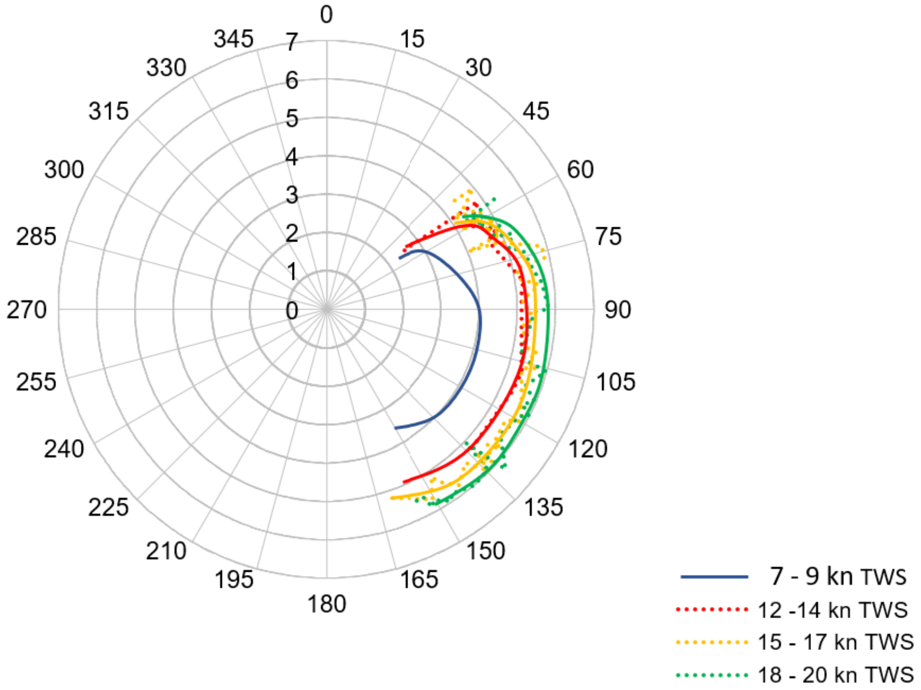


Figure 9: Polar plot of the measured sailing speed of the WAM Catamaran in different true wind speeds, loaded with roughly 700 lbs (approx. 350 kg). Leeway is included. The further away from the centre the coloured lines are, the faster the sailing speed. Each color represents a different wind speed. 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. 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 Catamaran as part of a course.

The WAM Catamaran MkII[9] 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.[10]

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,

[9] The original WAM Catamaran was upgraded, tweaked and fine tuned into the model within this manual. WAM Catamaran Mk II will henceforth be referred to simply as the WAM Catamaran.
[10] SODOTO is widely used to train medical professionals and engineers.

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).

Teaching

Building a catamaran with two 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).

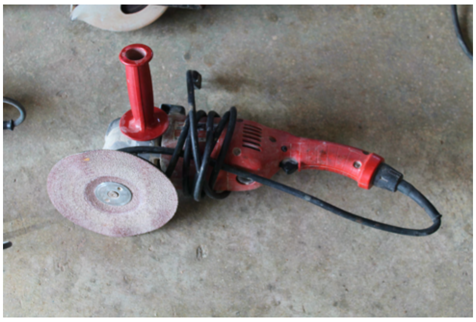
After a couple of weeks, at the latest when beginning the second cat hull, certain project parts should be gradually made the responsibility of individual trainees or groups of trainees. This procedure leads eventually to a widely autonomous organized group of workers at the end of the workshop, who 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 during the three-month training

(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)

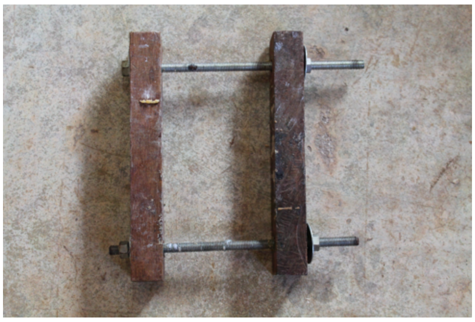
(d) C-clamps (various sizes 15+ pieces)

(e) DIY pipe clamps (30 pieces)

(f) Locking clamps (15 pieces)

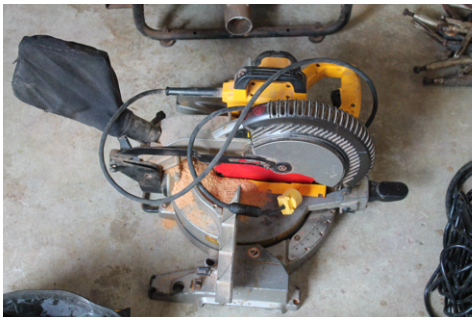
Figure 13: Tools used during the workshop

(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 Catamaran 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	8 sheets	8 sheets	
Lumber	03	Dimensional lumber	1x1 in	25x25 mm	750 ft	250 m	Look for fir, spruce, pine or similar. This is the total amount that need to be obtained. The dimensions don't matter when you go shopping because the lumber will be cut anyway. Quality is more important.
	04	Dimensional lumber	1x2 in	25x50 mm	240 ft	80 m	
	05	Hardwood	2x1 in	50x25 mm	2x6 ft	2x 2 m	
	06	Hardwood	12x12 in	300x300 mm	2x1 ft	2x 0.3 m	
Epoxy	07	Epoxy & slow hardener	30 min.	30 min.	16 gal	60 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).
	08	Baking flour			33 lbs	15 kg	
Fibers	09	Glassfiber cloth	7 oz./sqft	200 g/sqm	538 sqft	50 sqm	Plain or twill both work
Paint	10	Exterior house paint			4 gal	15 l	Water based. If possible use two component marine paint instead
Rigging	11	Dacron sail cloth	6 oz./sqft	170 g/sqm	269 sqft	25 sqm	Polytarp can be used instead
	12	Rope for standing rigging	1/2 in	12 mm	130 ft	40 m	Low stretch
	13	Rope for running rigging	1/2 in	12 mm	100 ft	30 m	Sheet material (soft touch)
	14	Sheet pulley	1/2 in	12 mm	7 pcs	7 pcs	
	15	Trampoline net	1-1.5 in	25-35 mm	45 sqft	5 sqm	Low stretch
	16	Lashing rope	1/8 in	3 mm	656 ft	200 m	Should be very stretchy
Consumables	17	Brush	1 in	25 mm	10 pcs	10 pcs	
	18	Brush	2 in	50 mm	10 pcs	10 pcs	
	19	Velour roller			5 pcs	5 pcs	
	20	Dust mask	N95/FFP2	N95/FFP2	20 pcs	20 pcs	
	21	Mixing cups	8 oz.	200 ml	50 pcs	50 pcs	
	22	Acetone			1 gal	4 l	Tool cleaner
	23	Vinegar			2 gal	7 l	Skin and tool cleaner
	24	Paper cloth			20 rolls	20 rolls	Toilet paper or kitchen wipes
	25	Rubber gloves	size L	size L	300 pcs	300 pcs	
	26	Angel grinder sandpaper disc	40 grit	40 grit	15 pcs	15 pcs	Should fit to the available tool
	27	Orbit grinder sandpaper disc	120 grit	120 grit	30 pcs	30 pcs	Should fit to the available tool
	28	Orbit grinder sandpaper disc	180 grit	180 grit	30 pcs	30 pcs	Should fit to the available tool
	29	Sandpaper	40 grit	40 grit	1 roll	1 roll	
	30	Sandpaper	60 grit	60 grit	1 roll	1 roll	
	31	Sandpaper	120 grit	120 grit	1 roll	1 roll	
	32	Drill bits	0.04-1.2 in	1-13 mm	1 set	1 set	
	33	Forstner drill bits	1 in	25 mm	1 pcs	1 pcs	
	34	Rubber or plastic squeegee	4 in	100 mm	5 pcs	5 pcs	
	35	Jigsaw blades			10 pcs	10 pcs	Should fit to the available tool

Table 4: List of materials for a 20 ft (6 m) WAM Catamaran (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 Catamaran 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 33). The dimension of each batten should be adapted to the original dimension of the lumber to minimize waste.[11] 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 33 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).

[11] 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.[12] 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

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:

[12] 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.[13]

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[14]) and structural adhesives.

[13] To be safe WAM is using marine quality plywood for everything.
[14] 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.[15]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.

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

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

[15] 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.[16]

[16] 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.

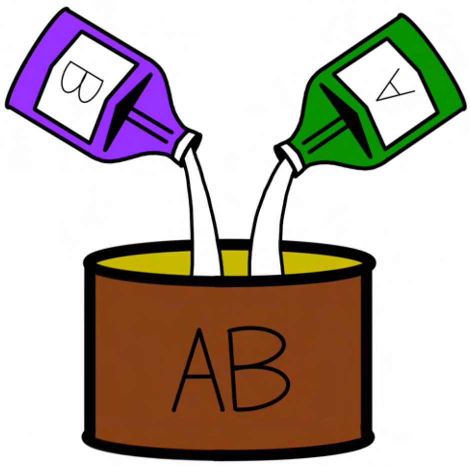


Figure 17: Component 'A' and 'B' are carefully measured and mixed. The mixing ratio is critical and must be correct.

It is important to check whether the ratio is given by volume or by weight.[17] 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).[18]

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[19] 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!

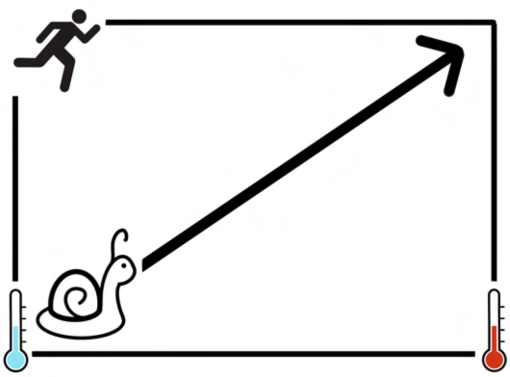


Figure 18: Heat does greatly accelerates the curing of epoxy!

[17]Some manufacturers supply both.
[18]As a reference, most cans of tuna tends to be around that size.
[19]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.[20]

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[21] 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[22] 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.

[20] 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.)
[21] Time to work with the mixed epoxy before it starts to cure.
[22] 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).[23] 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.

[23]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 Catamaran (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 Catamaran 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 33.

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 36, 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 Catamaran). 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 Catamaran 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 33 and 38). 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).

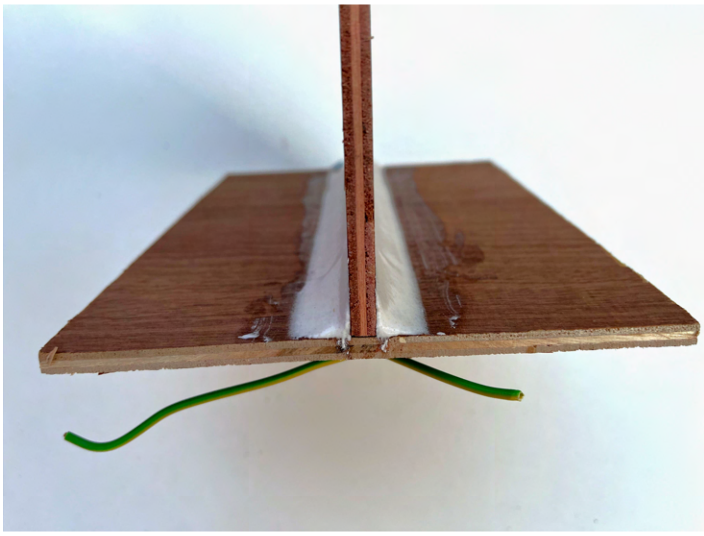


Figure 22: Cross section through a T-joint with a fillet on each side

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.[24]

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.[25] 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.

[24] Gougeon 2005

[25] Colloidal silica and micro balloons are often blended to medium density filler.

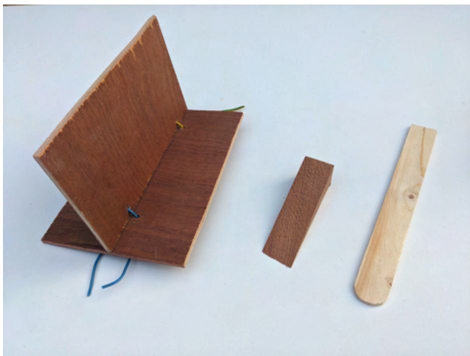
(a) Breaking test of a fillet sample

(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.

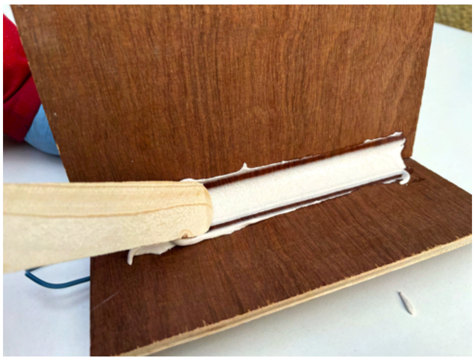
If the sample breaks outside of the joint and keeps the fillet clean and smooth, then the bond exceeds the material strength, so the size and density are strong enough.

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 87). 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 Catamaran. 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.

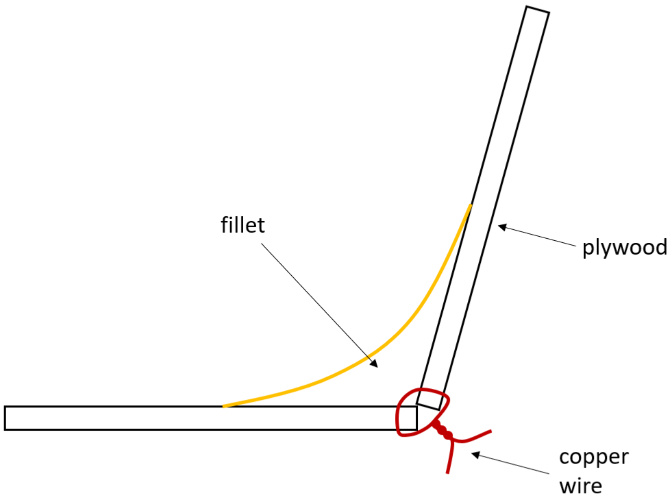


Figure 26: Schematic representation of a stitch-and-glue joint cross section

Construction technique

6.9 Rope hinges

Hinge lashings connect the edges of two panels with a rope in a figure eight style tightened between holes in each panel (see 27 below).[26]

[26] Rope hinges are widely used. For example, they have been used by Wharram for decades on many catamaran rudder designs. They are sometimes used for hatches as well.(Wharram 1999)

Figure 27: Functional model of a hinge lashing

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 28: 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 29 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 29: 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 30. Handle uncured epoxy carefully and avoid skin contact. Always wear personal protective equipment as stated in figure 29 and 30. 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 30: 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 Catamaran 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: Hull side panels

The work on the WAM Catamaran starts with the first hull. Two flat panels from 1/4 in (6 mm) plywood are required for each side of the hull. In line with Marshallese canoe building traditions, the WAM Catamaran has been designed without any drawings or measurements in the form of numbers and units. Instead, measuring and lofting is done with a string and all dimensions are developed through their relation with the hull length. The length can be varied by the builder - between 16 and 26 ft. Based on the standard dimensions of plywood sheets (8 x 4 ft), the easiest way is to make a hull either from 2, 2.5 or 3 sheets of plywood. **2.5 sheets are used for this manual.**

The plywood sheets are placed on the floor (with the smallest piece in the center and the short edges facing out from each other) to form one side panel of a hull. A master string from a stiff material is now cut to the exact length of the plywood sheets for all further lofting (the length of all three pieces of plywood). For 2.5 sheets the master string is exactly 20 ft, see 31.

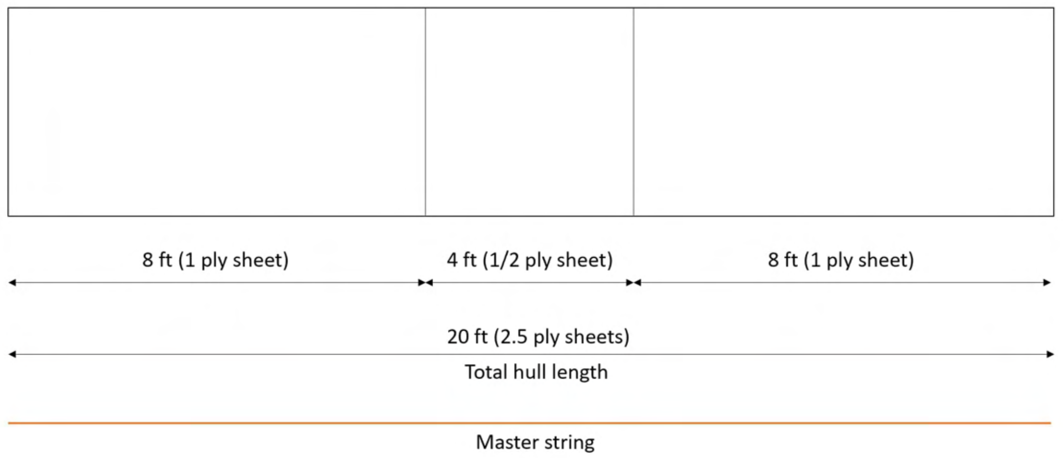


Figure 31: Length of the WAM Catamaran hull (20 ft) derived from the plywood size.

The master string is now folded to six strings of equal length. This length (1/6 of the hull length) will become the height of the side sheets. Based on this measurement, a line is drawn on all plywood sheets, as shown in figure 32 below. The ply sheets are cut to size along these lines using a jigsaw or (hand-held) table saw. The result is shown in figure 34 a) below.

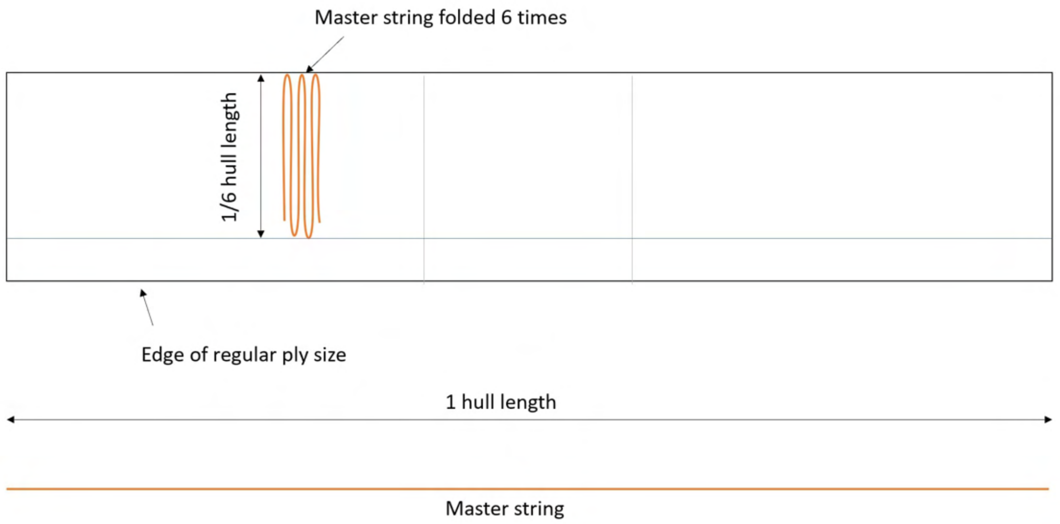


Figure 32: Height of the WAM Catamaran hull set to 1/6 of the total length by folding the master string.

The off-cut plywood strips of about 1 ft (300 mm) width are used to connect the individual plywood sheets to the full-sized side panel. A scarf to join the ply sheets is not necessary, as they are simply connected with a butt-join. The seam is doubled up with the plywood strips (see figure34). The doublets will later be on the inside of the hulls, to leave the outsides flat. Each doublet should end approximately two fingers (1 in, 25 mm) from the plywood sheet's edge to one side (the side where the plywood was not cut yet) and approximately one hand width (4 in, 100 mm) to the other side (where the plywood was already cut in the previous step).

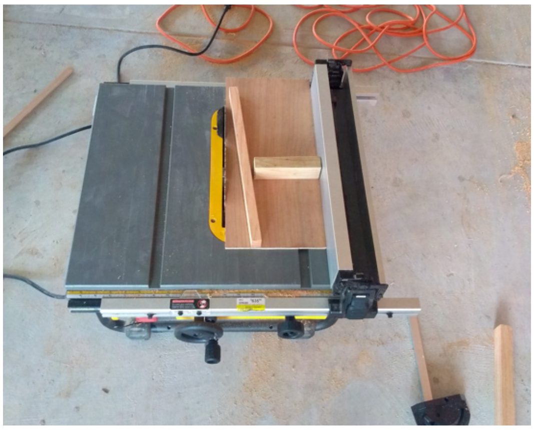
Repeat task 1 four times to produce 4 side panels (2 for each hull).

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

Cut the lumber lengthwise, using a table saw, to the required size of approximately two by two fingers (1 x 1 in, 25 x 25 mm). Slightly larger or smaller is fine, depending on the original size of the procured lumber, as long as the dimensions remain constant throughout the construction. Cut out all knots with the chop saw (very small knots are fine). The battens have to be scarfed to make longer ones. Make a scarfing jig for the table saw (see figure 33 a) below), aim for a scarfing ratio of 1:8 (see 6.3). Cut scarfs into the off-cut battens: produce at least 20 battens (four as shear stringers and 16 for the sail spars) one hand width shorter than the master string (hull length). An additional 22 (1/2 the master string in length) are required for the crossbeams. Another three hull lengths of lumber battens are required for minor reinforcements, but they are not required to be full length (as they will be cut to size when needed). Puzzle them together as shown in figure 33 b) below.



(a) Table saw with DIY jig for scarf cuts.

(b) Cutting scarfs

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

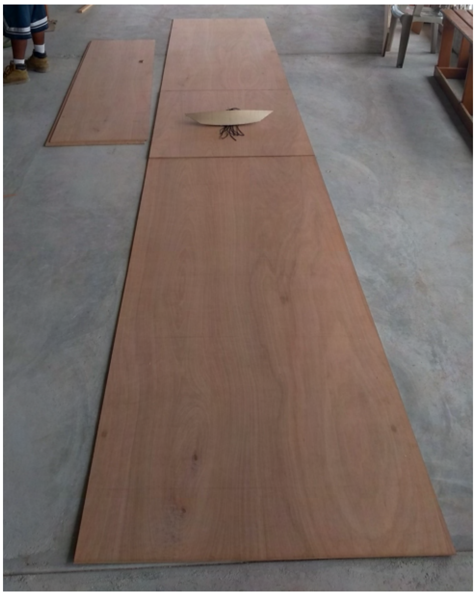
Figure 33: Preparation of the beam lumber.

Day 1

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

8.1.4 Task 4: Gluing

Place the plywood sheets prepared for the side panels (Task 1, see 8.1.1) on a flat and even floor as in figure 34 a) below. The doublets are now glued on (see 6 Basic construction techniques, Epoxy as glue) leaving two fingers space on one side and one hand width space on the other. Use wax paper or plastic sheets underneath each seam to prevent the side panels from sticking to the floor. Weight should be applied to ensure a proper bond: glue should squeeze out everywhere, see figure 34 b) below.



(a) Two and a half sheets of plywood are placed flat on the ground. Design the model and master string to be as long as the 2.5 ply sheets.

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

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

Figure 34: Preparation of the hull side sheet for lofting

Day 2

The battens prepared in Task 3 (see 8.1.3) are now scarf joined. 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. Scoop off squeezed out resin and reuse it for other scarf joints.

Allow the glue to cure overnight.

8.2 Day 2

8.2.1 Task 5: Prepare beam plywood

The crossbeams of the WAM Catamaran are rectangular hollow box shapes made from lumber and plywood as shown in figure 35 below.

Figure 35: 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 a sheet of 3/8 in (9 mm) plywood lengthwise into nine strips of 5 in (125 mm) width. Cut three strips in the middle to get six 4 ft long strips. Each full-length strip will be scarfed to one half-length piece to eventually get six 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 36 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 36: Scarf joints of the beam plywood

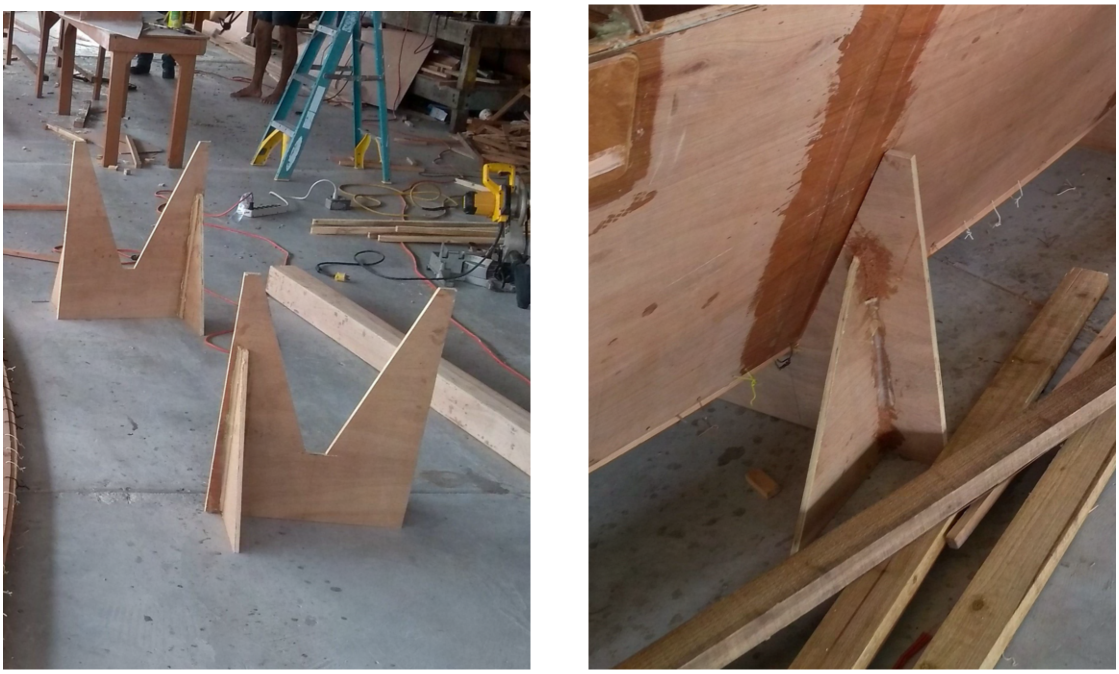
Place all plywood strips on top of each other on a table. Make them look like a stair with every step approximately six fingers (3 in, 75 mm]) long (scarfing ratio of 1:8) and clamp them down. Run an electric planer down the stairs until an even bevel is cut.

8.2.2 Task 6: Clean scarfed battens

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

8.2.3 Task 7: Prepare hull cradles

The V-shaped catamaran hulls need cradles to rest in an upright position. Cut four cradles as shown in figure 37 from thick plywood (e.g. 1 in, 25 mm).



(a) (b)

Figure 37: Cradles for the V-shaped hulls

Take a rectangular piece of thick plywood, approx. 1.5 x 2 ft (450 x 600 mm). Start measuring the cradle by marking the three finger (2 in, 50 mm) wide base of the cutout (the place where the keel will rest). Place two lumber battens (or any other straight thing) of 1/6 hull length (same as the width of the hull side panels) in a V-shape on top of the thick plywood. The battens should intersect the base line on one end each. Measure 1/6 hull length (with the master string) between the other ends of the battens. Make sure the 'V' created is symmetrical. Mark it on the plywood and cut it out with a jigsaw. The cutout triangle is split lengthwise and reused as support (one on each side) as shown in figure 37 above. The support triangles are glued to the cradle with fillets. Keep them close by every time something is glued in the future and use the leftover resin for the fillets. The cradles provide a good opportunity to practice fillets since a nice finish doesn't matter.

8.2.4 Task 8: Reinforce side panels

Flip the hull side panels (task 1, 8.1.1) 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.

8.2.5 Task 9: Glue beam lumber and beam plywood

Glue the scarf joints of the plywood strips (task 1, 8.1.1) 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 8.2.2. Glue four of them side to side to create two 4x1 in (100 x 25 mm) boards as shown in figure 38 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 38: Preparation of the beam lumber

8.3 Day 3

8.3.1 Task 10: 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 11: 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 12: Loft and cut the hull side panels

The outline of the hull side panels is measured according to a semi-traditional measurement system by using the master string. Place one side panel on the floor with the doublets facing up. The height of the hull has already been measured on Day 1 (Task 1, see 8.1.1) by folding the master string to six strings of equal length. By doing so, the hull height was set to 1/6 of the total hull length (in the example with a hull length of 2.5 ply sheets this is roughly 3 ft or 1 m). In the next step, vertical station lines are marked on the side panel as shown in figure 39 below. Figure 40 and 41 below show the process of folding the master string and marking the station lines.

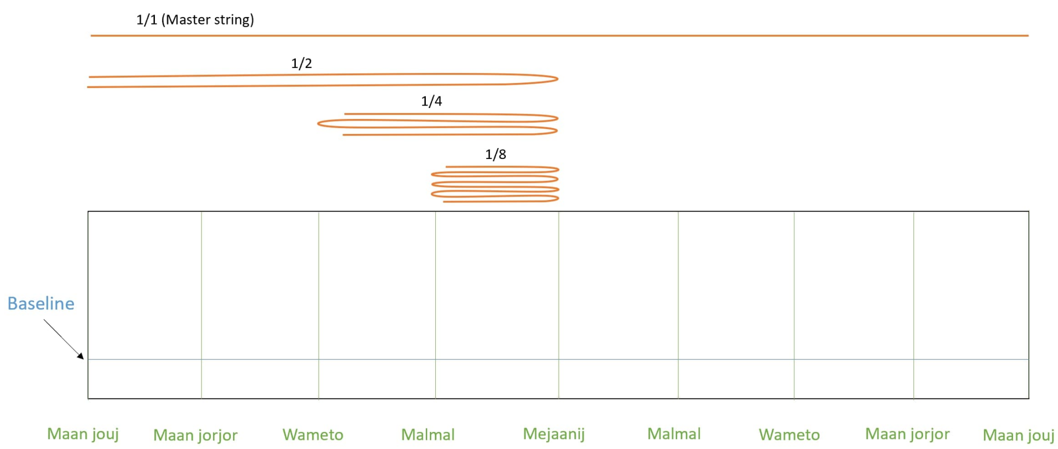


Figure 39: Seven stations dividing the side panel in eight sections are marked on the plywood. The Marshallese names of the stations are given in green according to Alessio[27].

Day 3

Figure 40: Preparation of the master string: It is folded to the required fraction, i.e. 1/2, 1/3, 1/4, 1/6, 1/8 and so on.

[27] Alessio 1989

(a) Station lines are marked on the plywood.

(b) The straight edge of an off-cut plywood sheet is used as long ruler.

(c) The bow line is marked, as measured by the master string.

Figure 41: The lofting process for the hull side sheet

Day 3

Proceed by measuring and marking the bow and stern shape as shown in figure 42. Unlike traditional canoes, bow and stern of the WAM Catamaran are not shaped identically. For hydrodynamic reasons the stern should be more vertical compared to the bow as indicated in 43.

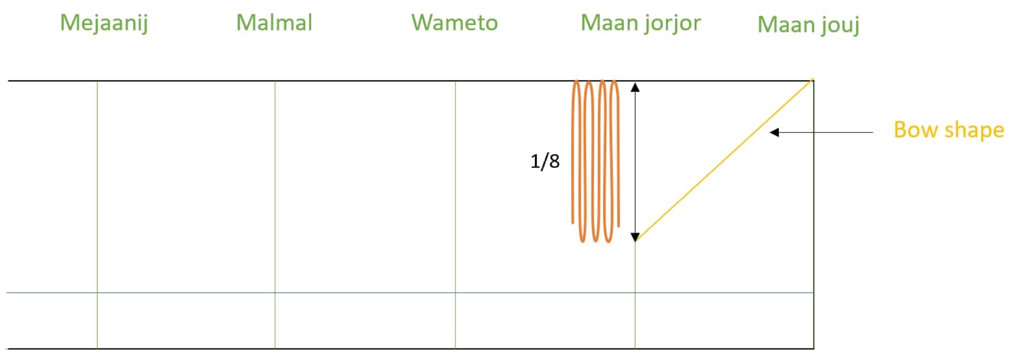


Figure 42: To Establish the bow shape (yellow) measure 1/8 of the hull length down the *maan jorjor* line.

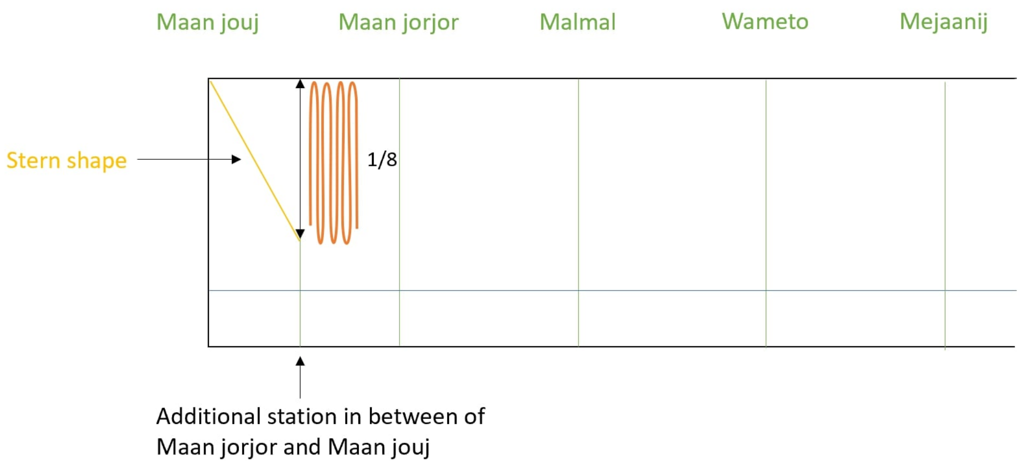


Figure 43: To establishment the stern shape (yellow) measure 1/8 of the hull length down an additional station line halfway between *maan jorjor* and *maan jouj*.

To determine the keel line, draw lines from the lower point of the bow and stern to the intersection of the *malmal* line and the base line as indicated by figure 44.

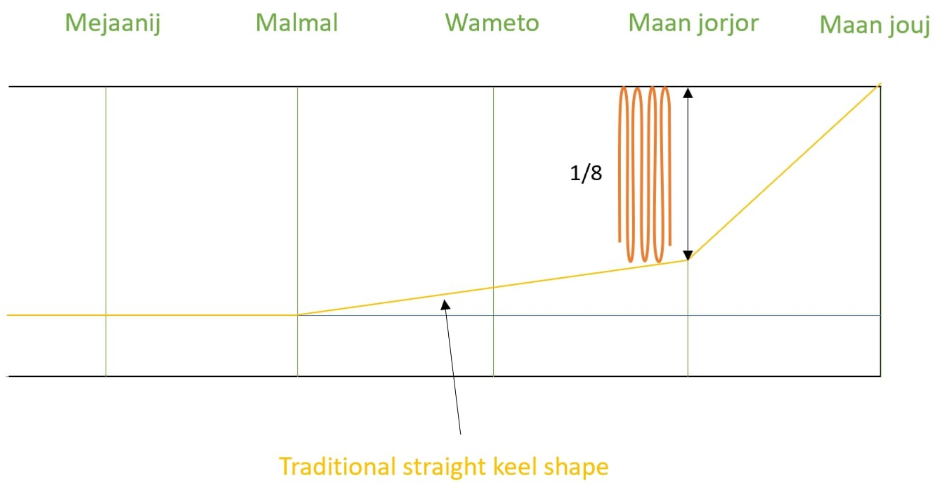


Figure 44: The keel line is developed by simple strait lines between the intersection of *maan jorjor*/bow line, *malmal*/baseline and *mejaanij*/baseline.

An alternative to the easier to build straight keel is a round keel as shown in figure 45 below. Although it is recommended to build the straight keel, the following example photos feature the round keel.

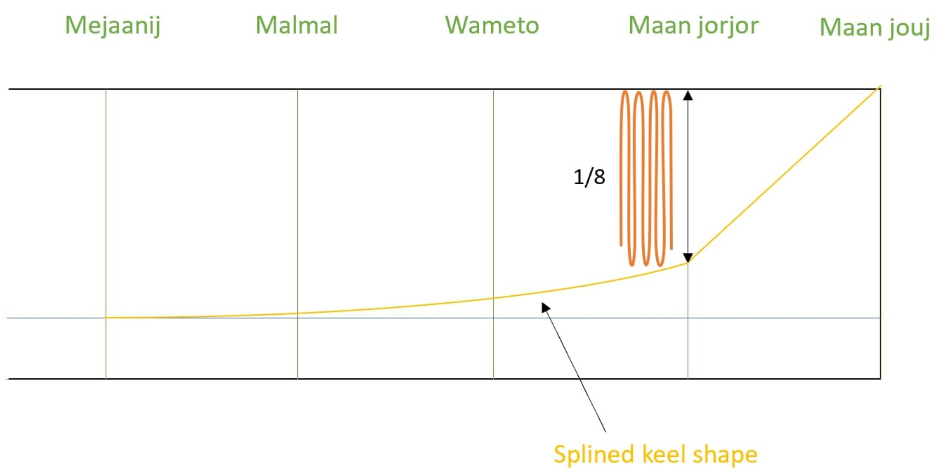


Figure 45: An alternative to the easier to build straight keel is the round keel. It is created by using a 1 in (25 mm) PVC pipe bent into a rounded spline which crosses the intersection of *maan jorjor* and the bow line, an additional station with stern line and *mejaanij* with baseline.

Day 3

With the side panel outline marked, take a jigsaw and cut out the first panel as shown in figure 46 below.

(a) The bow line is marked. It is measured by the master string.

(b) The keel line is marked using a PVC pipe.

(c) The side sheet is cut out using a jigsaw.

(d) The side sheet is ready to have the sheer stringer glued on.

Figure 46: Lofting process of the hull side sheet

It is not necessary to repeat the laborious measurement process for all four panels. Panel 2, 3 and 4 are copied using the first one as template. Before you cut, keep in mind that bow and stern are not identical: You should end up with two pairs of side panels which fit together when their doublets are facing inwards!

8.3.4 Task 13: 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 5, see 8.2.1). Laminate them on with epoxy resin.

8.3.5 Task 14: Glue the sheer stringers

Take the long, scarfed lumber battens. Glue them on the top side of the hull side panels as shown in figure 47 below. They go on the same side as the doublets. The battens should be about one hand width shorter than the hull side panels. Glue them on with an equal offset on both ends. Many clamps are required and pipe clamps may come in handy. Scrape off excess glue. Repeat this process with all the side panels.

(a) (b)

Figure 47: Sheer stringer glued and clamped on the pre-cut side panel

8.3.6 Task 15: 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 38 and explained in 8.2.5. 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.

8.3.7 Task 16: 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 17: 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 18: Prepare the keel lumber

The bow, keel and stern of the hulls are reinforced by lumber. The keel lumber as well as the bow lumber is made from solid 1 x 2 in (25 x 50 mm) lumber. If there is no sufficient lumber of that size, construct it by cutting and scarfing in the same way the 1 x 1 in (25 x 25 mm) battens were made. Unlike the bow and keel, the stern is reinforced by a skeg (see next task).

Place the 1 x 2 in (25 x 50 mm) lumber on top of the hull side panel. Make it overlap the edge of the keel and the stern by 1 in (25 mm). Cut all lumber pieces to size and mark their positions. Gaps should be as small as possible to reduce the glue consumption later. Prepare lumber for both hulls.

8.4.3 Task 19: Loft and cut the skegs

The WAM Catamaran is equipped with a twin rudder system (one rudder on each hull). Each rudder is permanently mounted to the skeg of the hulls canoe stern, see figure below.

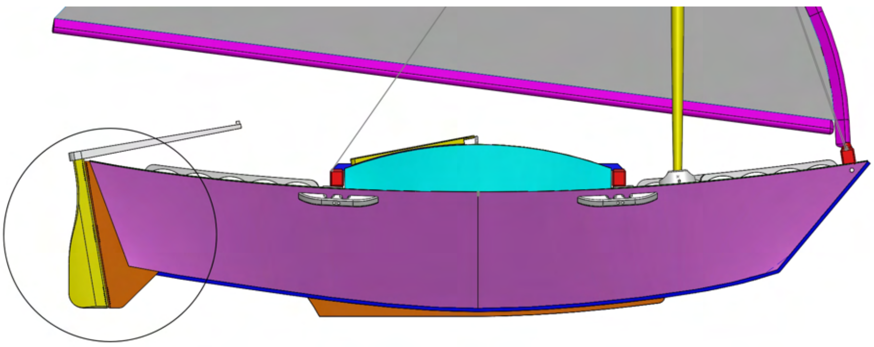


Figure 48: Skeg of the WAM Catamaran (orange encircled part).

The skeg protects the rudder from touching ground when falling dry or beaching. Therefore it extends 1 in (25 mm) deeper than the rudder.

The size of the skeg is determined by the eye of the builder without following any particular rule. As well as common sense, keep following numbers in mind while creating the shape: The trailing edge of the skeg (were the rudder is lashed on) should be more vertical than the stern to allow a horizontal tiller motion. On the top, the skeg should be flush with the deck and extend a minimum width of three fingers (approx. 2 in or 50 mm) past the stern. Another three fingers should extend inside the hull on the full length of the stern to allow a proper bond to the inside. The transition from keel to skeg must be smooth to avoid ropes or seaweed getting caught. The maximum draft of the skeg is chosen slightly less than the deepest point of the keel. The keel should touch the ground first.

The skeg is made from three sheets of plywood, two 3/8 in (9 mm) and one 1/4 in (6 mm) in between for 1 in (25 mm) thickness (the same thickness as the keel lumber). A simple way to determine the final shape of the skeg without wasting plywood is to place a sheet of cardboard under the rear part of the hull side sheet and draw the preferred skeg shape (see figure 49).

(a) The skeg's dimensions are determined by placing a plywood sheet underneath the hull side panel.

(b) The first plywood skeg is used as pattern to cut five more pieces (three for each hull).

Figure 49: Lofting of the skeg

Cut four skegs from 3/8 in (9 mm) plywood and two skegs of 1/4 in (6 mm) plywood according to the developed shape.

8.4.4 Task 20: 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 50 below). The DIY wood clamps (see 14) are especially useful.

(a) (b)

Figure 50: 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 35. 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 50). 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.

8.4.5 Task 21: Glue the beam lumber

Take the remaining eight 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 the same way as previously done (see figure 38).

8.4.6 Task 22: Glue the skegs

Manufacture two skegs (one for each hull) by gluing three of the already cut plywood pieces together as shown in figure 51. Make a sandwich with the two 3/8 in (9 mm) plywood pieces on the outside and the 1/4 in plywood (6 mm) in the middle. This is a good opportunity to use up leftover glue from the previous tasks. Take care that the plies don't slide when pressure (weight or clamps) is applied.

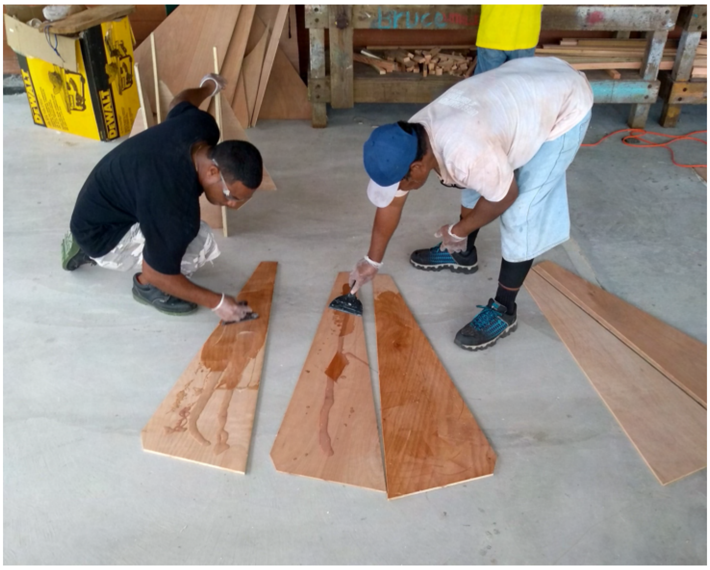


Figure 51: Each skeg is glued from two 3/8 in (9 mm) and one 1/4 in (6 mm) plywood.

8.4.7 Task 23: 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.

If the fillets of the cradles are not finished yet, finish them now.

8.5 Day 5

8.5.1 Task 24: 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 25: Finish the skegs

Take the clamps/weight off the skeg which was glued yesterday. Remove all glue from the outside and grind them smooth with an angle grinder. Taper the trailing edge (the edge that will stick out of the boat) down to 6/8 in (20 mm), this is the same thickness as two 3/8 in (9 mm) plywood sheets.

Figure 52: Skeg with tapered trailing edge

Take a router with a round-over bit (see figure 12 d) and run it along the trailing edge to round it.

8.5.3 Task 26: Prepare the side panels for stitching

To eventually shape the hulls, the hull side panels will be stitched together with copper wire. They will be stitched on top of each other, with the keel lumber and the skeg in between, and spread apart to create the hull shell (see 6.8 for details regarding the 'stitch and glue' technique). In a last preparation step prior to the stitching process, machine a bevel to the keel and stern edges of the side panels on the inside (the side with the doublets and the stringer, see figure 53). The bevel is important, as it allows a smooth transition from keel to plywood and reduces the tension in the seams during the spreading of the hull sheets.

(a) The hull side sheets should be beveled at the edges, which is where they will be joined to the keel, bow and skeg. The bevel is important to allow a smooth join and reduce the tension in the stitch seams when the hull is spread. Around the keel area 45°is sufficient, but the bow and stem require a flatter angle.

(b) An angle grinder is a tool which makes manufacturing a bevel fast.

Figure 53: Preparing the side sheets for stitching

Around the keel area 45° is sufficient. The bow and stem require a flatter angle (imagine how the side panels will meet the keel, bow and stem).

Check whether bow lumber and skeg fit (as they might collide with the sheer stringer).

(a) (b)

Figure 54: Preparation of keel lumber, bow and skeg

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.

8.5.4 Task 27: Loft and cut the center bulkheads

Mark the positions of the bulkheads on the inside (the side with the doublets) of the hull side panels as indicated in 55. Except for bulkhead 3 and 5 all bulkheads are placed on the station which were already marked on the side panels when their shape was lofted. Figure 57 shows the final arrangement of the bulkheads in the WAM Catamaran hull. The shape of the center bulkhead is measured by using the master string as shown in figure 56, 58 and 59. The width of the keel lumber (1 in or 25 mm) must be taken into account (see 58), as well as some cutouts for the sheer stringer.

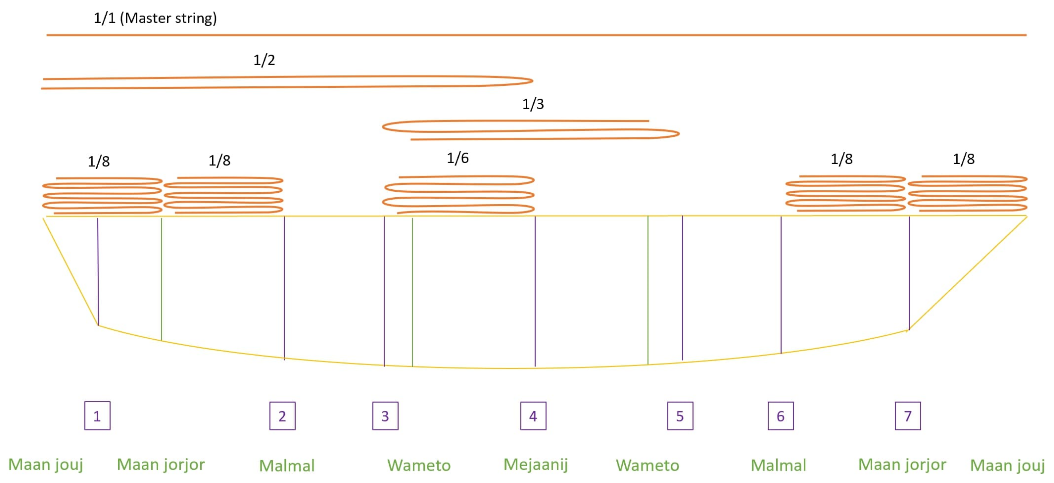


Figure 55: The bulkheads are placed on the station lines. Only the positions of bulkhead 3 and 5 are measured seperately and marked by using the master string.

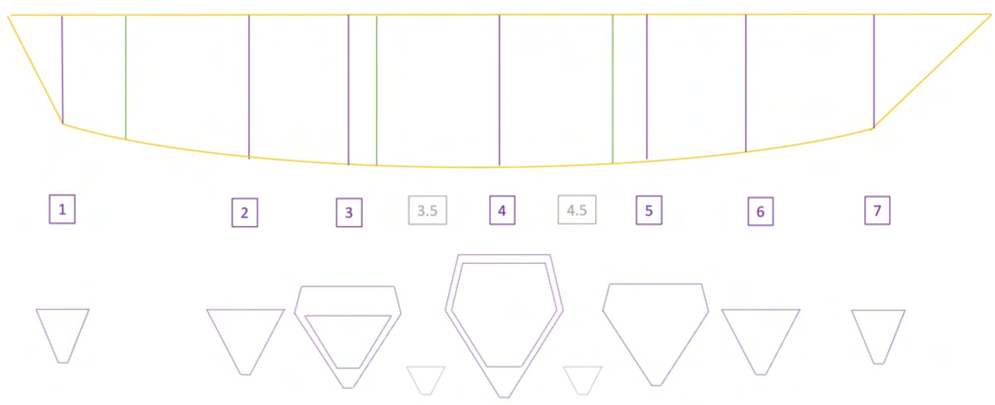


Figure 56: The main bulkheads are marked in purple, and support bulkheads and stiffeners are in grey. The size of the cutouts for the cabin interior (bulkhead 3, 4 and 5) is decided by the builder. A minimum frame width of 2.5 in (65 mm) should remain under all circumstances. Corners should be cut with a large radius (min. 3 in or 75 mm).

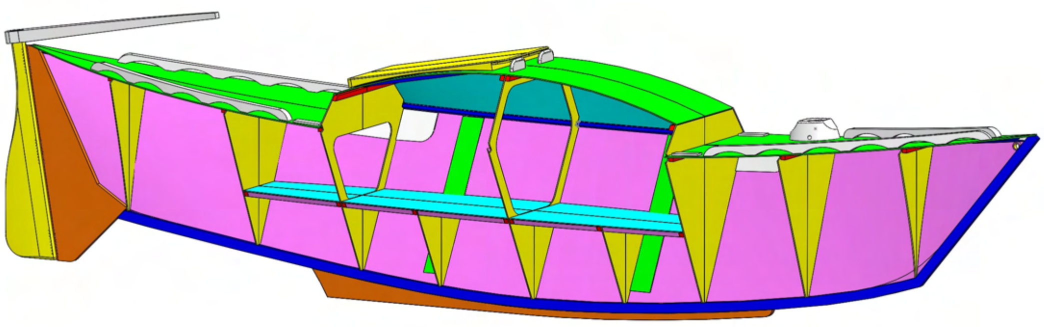


Figure 57: Final arrangement of the bulkheads in the WAM Catamaran hull.

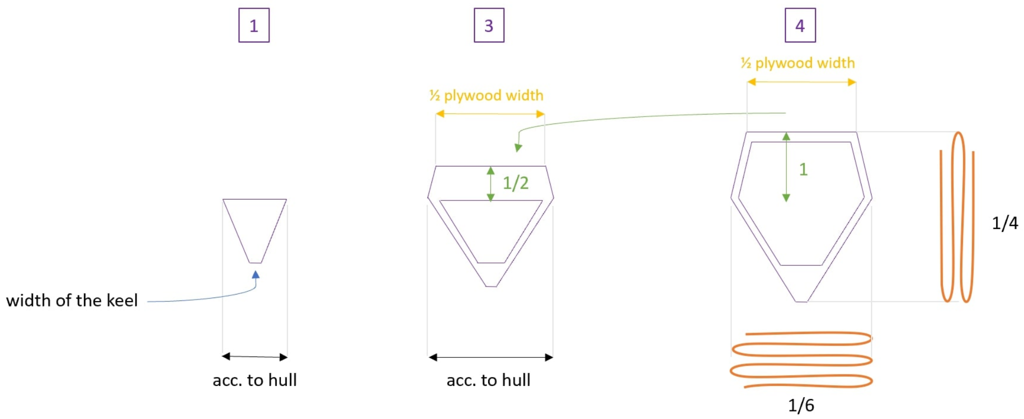


Figure 58: The center bulkhead (number 4) is measured using the master string. All other bulkheads are fit to the height of the hull side panel at their particular position and the spline shape of the sheer after the stitched hull sides are spread. The height of bulkhead 3 is calculated from the center bulkhead 4 (green). The width of the keel plank must be taken into account when the bulkheads are lofted. Bulkhead 3 and 5 are identical except for the cut-out.

The cut-outs should be as round as possible (see figure 59 c and d) and allow a sufficient bunk board width (width of the lower edge of the cut-out). A good approximation was 1/14 of the hull length.

(a)

(b)

(c) A tin can is used to draw the radius of the internal cut-out.

(d) Checking the fit of the center bulkhead at its later position on the side sheet

Figure 59: Lofting the center bulkhead by using the master rope

Cut out two center bulkheads from 3/8 in (9 mm) plywood. Check their fit to the hull side panel as shown in 59 d).

8.5.5 Task 28: 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.

8.5.6 Task 29: Drill and fill the skegs

The rudders will be mounted on the skegs with rope lashings (see 6.9). Drill four sets of lashing holes for the rope hinges (nine holes in each set) close to the rounded trailing edge as shown in figure 60).

(a) The pre-drilled holes in the skeg and the rudder are filled with unthickened epoxy resin.

(b) The bottom of the holes are closed with duct-tape (red) and further sealed by a stick clamped underneath.

(c) The holes are filled with epoxy resin. The plywood will absorb the resin, so the holes will need a couple of refills.

(d) After the resin in the holes has cured they are re-drilled carefully (without cutting into the wood) to the required diameter.

Figure 60: Filling and re-drilling the lashing holes

The inside of any hole must be sealed to be water proof. Therefore, holes are pre-drilled bigger than needed (twice the required diameter) and filled entirely with epoxy resin. Close one side of the pre-drilled holes with masking tape. The tape must sit tight to keep the resin in the hole. Sometimes it is helpful to support the tape by clamping plywood on the bottom of the holes.

The wood will take up lots of resin. Prepare to refill the holes after 30 minutes.

The holes are drilled again - after the epoxy has cured - with the required (smaller) diameter. Make sure not to cut into the wood when drilling the final hole.

8.5.7 Task 30: Glue the second beam

Glue the second beam in the same way as the first one (see 8.4.4).

8.5.8 Task 31: Coat the beam lumber

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.

8.6 Day 6

8.6.1 Task 32: 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 33: Cut rudders

The rudders are measured and shaped in the same way as the skeg, without any specific measurement. Cut them according to the shape in figure 61 below.

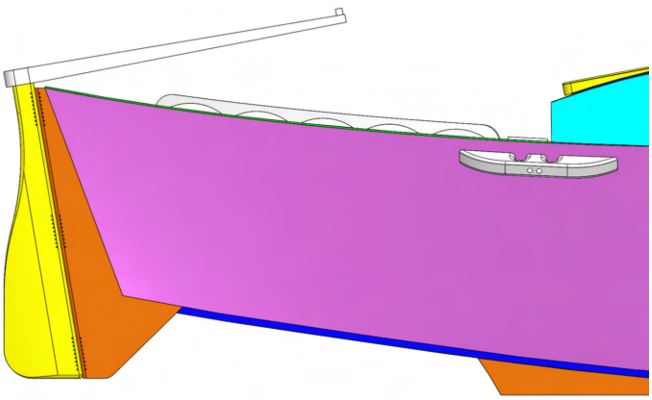
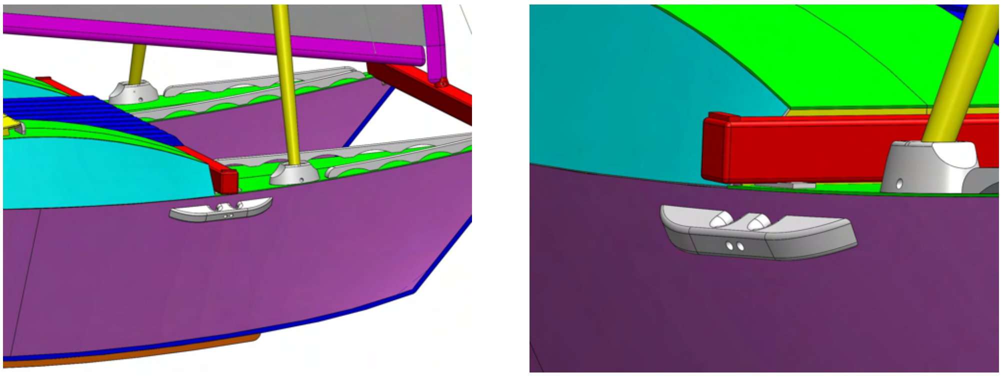


Figure 61: Shape of the rudder.

A good approximation is to make it one foot (300 mm) wide on the bottom and a hand wide (3 in or 75 mm) on the top. Make sure it extends above the deck by min. 3 in (75 mm) for enough space to mount a tiller. Creating a paper template will help create a desirable final shape. Double check its fit on the real hull. The rudders are glued from two 3/8 in (9 mm) pieces of plywood to the same thickness as the tapered edge of the skeg. Cut four pieces for one rudder on each hull.

8.6.3 Task 34: Prepare the beam cleats

The beams will be connected to the hulls by rope lashings. The lashings are tied to beam cleats, which are wooden protrusions on the gunwale. Figure 62 and 63 below show the setup.



(a) (b)

Figure 62: Beam cleats of the WAM Catamaran.

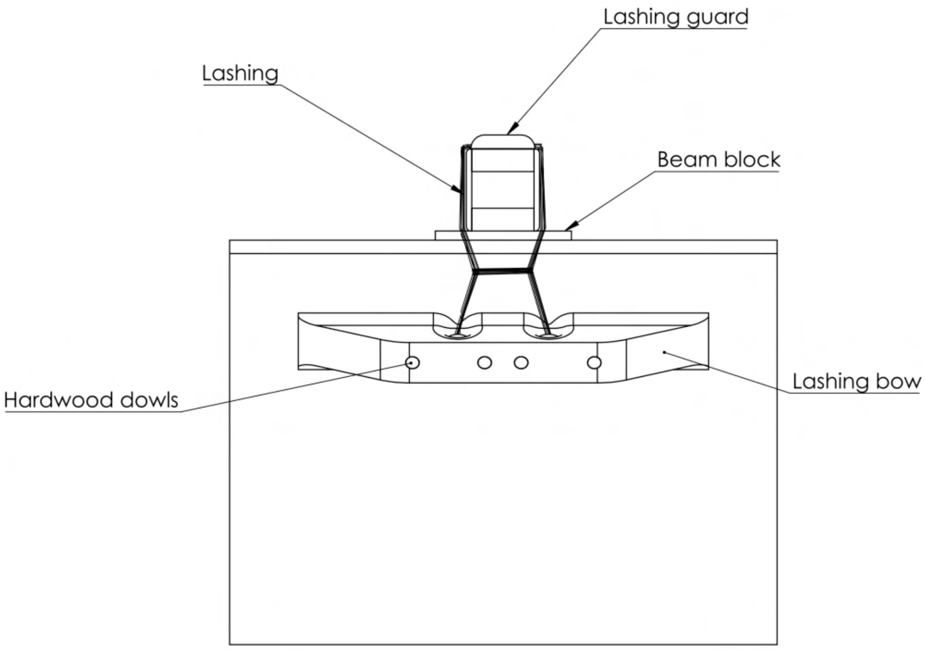


Figure 63: Drawing of the WAM Catamaran beam cleats.

The easiest way to make the cleats (white protrusion of the hull in figure 62 and 63) is to cut them from four individual parts of lumber each. Figure 64 shows the different parts.

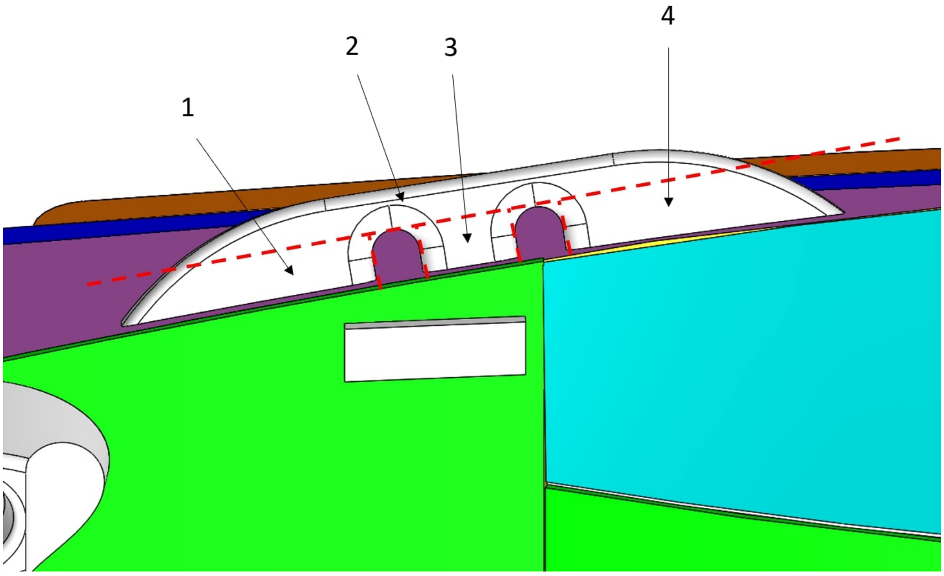


Figure 64: Individual parts of the beam cleats

The beam cleats are important structural parts. The platform is tied to them. If they fail the entire boat fails. Therefore, use only the best lumber for these parts. '3' in figure 64) 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 65.

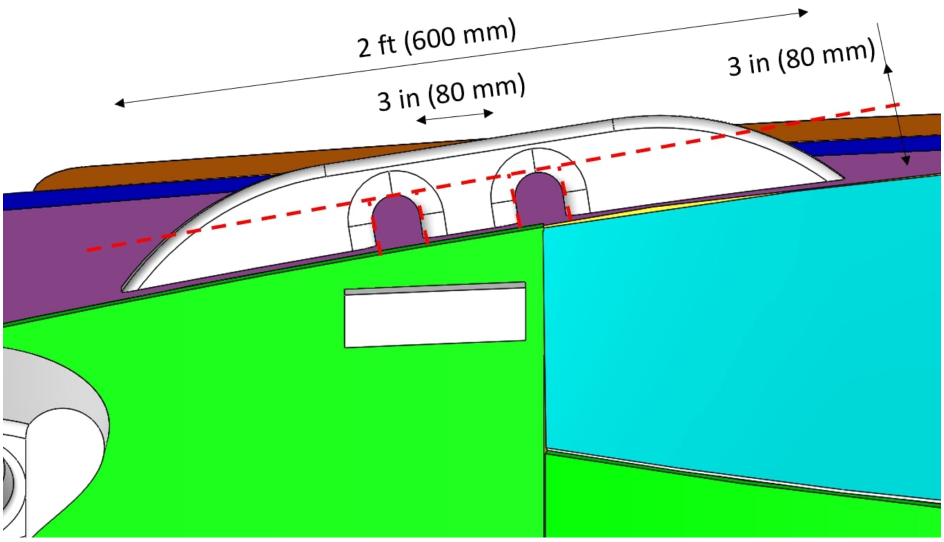


Figure 65: Dimensions of the beam cleats

8.6.4 Task 35: Stitch the first hull

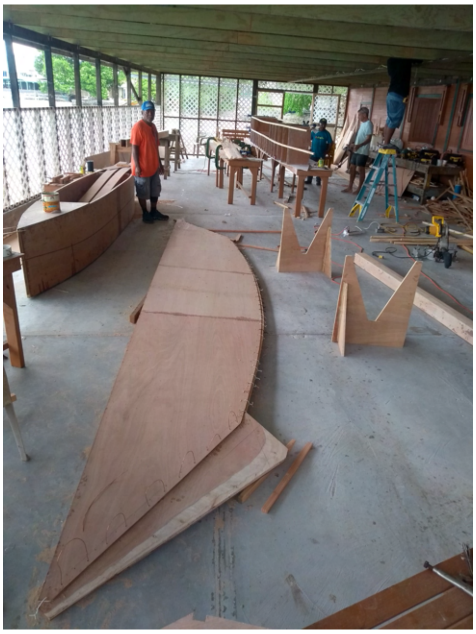
Take a right and a left hull side panel and the keel lumber, bow lumber and skeg which has been fitted to them (see marks). Clamp the two hull side panels on top of each other with the keel lumber, bow lumber and skeg in between them. Make sure the keel lumber, bow lumber and skeg are at their designated position (half in, half outside the hull side panels and parallel to their edges) and fix everything temporarily with clamps (see figure 66 below).

Figure 66: Assembling process of the side panels: Keel, bow and skeg are clamped in between the side panels

Take a drill and drill holes slightly bigger than the already prepared copper wires. The holes should be approximately one hand width apart and one finger width from the plywood's edge through both hull sides and the lumber in between them as shown in figure 67 below. Take the prepared 1 ft (300 mm) long pieces of copper wires. Thread them through the holes and twist them tight as shown in figure 67 below. The skeg may require a different stitching technique as shown below. When the stitching is finished the clamps can be removed.

Day 6

(a) Keel lumber and holes for the copper wire stitch



(b) Hull sides, skeg, keel and bow are stitched together. Clamps are not necessary anymore. The cradles are already prepared (right) to support the hull shell in its upright position.

(c) Stitch of the skeg

(d) Keel stitch

Figure 67: The stitching process

(a) (b)

Figure 68: Integration of the skeg into the hull

8.6.5 Task 36: Open the first hull

Take the stitched side panels and place them upright into the cradles as shown in figure 69. Gently spread the hull sides apart. Do it slowly and frequently check the tension of the stitches. A high tension may rip them out of the plywood. Also make sure that keel lumber, bow lumber and skeg sit symmetrically in between the V-shape of the hull sides. Take the prepared center bulkhead and push it into its position in the hull (marked on the side panels). It is self-locking and should not require additional fasteners. If the center bulkhead doesn't fit perfectly, take it out again and trim it with an angle grinder.

(a) The stitched hull sides are lifted vertically and placed in the cradles.

(b) Ready to spread the hull: The prepared center bulkhead is ready to grab.

(c) The sheer is gently pulled apart to open the hull shell. The center bulkhead is carefully pushed inside. The sheer stringers should snap into the cut-outs of the bulkhead and lock in in place.

(d) The center bulkhead is locked in place. Gaps between the hull and bulkhead should be minimal.

(e) The hull shell with skeg at the stern

Figure 69: Spreading of the hull shell

The flat side panels are transformed into a there-dimensional hull. Figure 70 shows the achievement of this task.

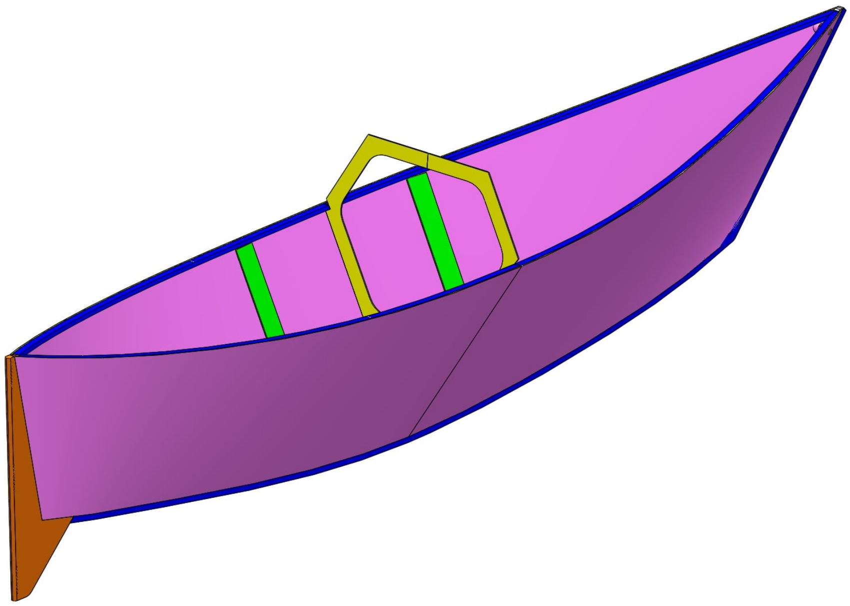


Figure 70: Hull shell with center bulkhead

8.6.6 Task 37: Fit the bulkheads into the hull

Align the hull perfectly before measuring any bulkheads. Pull a string from bow to stern to check for any twist in the hull: The string should intersect the center bulkhead at the hulls center line (half hull width). Correct, if necessary, by pushing wedges under the cradles.

All bulkheads additional to the center bulkhead are not measured to a specific dimension but fitted directly into the hull. Their shape and position is shown out in figures 55, 56 and 58. Make the cabin bulkheads (3 and 5) slightly wider than the sheer would be without them to create a fuller hull shape. All bulkheads are made from 3/8 in (9 mm) plywood. The cutouts of the cabin bulkheads (3 and 5) as well as the bunk support triangles (see figure 71 below) must be leveled to form a flat bunk. Use a straight batten to measure as shown in 71 a). The bunk support triangles should sit right in the corner of the doublets. Make sure all bulkheads fit into the hull without significant gaps (less than 1/8 in or 3 mm) between bulkhead and hull side.

(a) After the center bulkhead is mounted successfully, the bunk board support triangles (bulkhead 3.5) are cut and shaped. They should fit right on the edge of the butt join doublers and allow the bunk boards to sit even on them. The batten in the picture is used to level the upper edges of the three bulkheads.

(b) All bulkheads are adjusted to fit the size of the actual hull. The goal is to give the sheer a continuous and symmetric spline shape.

(c) All bulkheads are mounted without any gaps between their edges and the hull shell. A string tightened from bow to stern indicates whether the hull is twisted or not.

Figure 71: Preparing and assembling the bulkheads

Bow and stern require diagonal stiffeners. The exact measurements are of little importance as long as they connect keel lumber and bow bulkhead top in a diagonal manner as shown in figure 72 below.

(a) (b)

Figure 72: Diagonal stiffener (symmetric in bow and stern): The exact measurements are of little importance as long as it connects keel lumber and bow bulkhead top in a diagonal manner.

Manufacture a copy of every bulkhead and stiffener for the second hull. Figure 73 shows the achievement of this task.

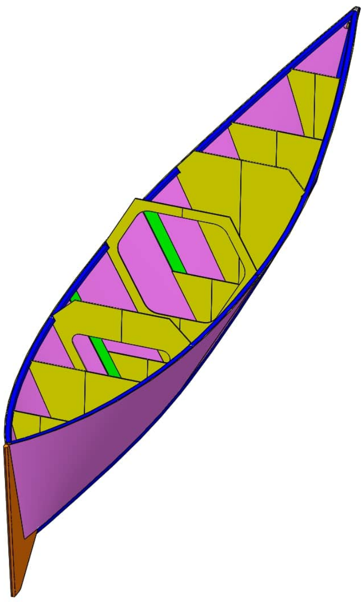


Figure 73: Hull shell with all bulkheads

8.6.7 Task 38: Prepare support battens

The bulkheads of the hulls are reinforced with 1 x 1 in (25 x 25 mm) support battens. They serve as connectors to ensure a proper bond between the deck and cabin roof. For this purpose, they are also required on the top edges of bulkhead 1, 2, 6 and 7 to support the deck. Furthermore, they go on bulkhead 3 and 5, facing bow and stern respectively, at sheer level for the same purpose. Figure 74 shows all support battens in red.

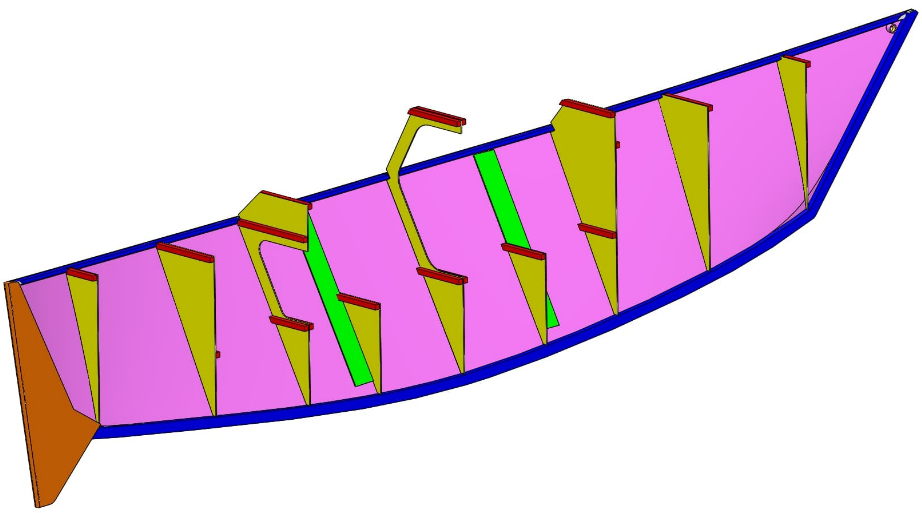


Figure 74: All support battens are shown in red.

To glue on the roof, 1 x 1 in (25 x 25 mm) lumber battens are prepared for the top edges of bulkhead 3 and 5. They go on the side which is facing the center bulkhead or the cabin. The center bulkhead is fitted with two 1 x 1 in (25 x 25 mm) battens on the top edge.

(a) The top edges of all bulkheads are fitted with 1 x 1 in (25 x 25 mm) lumber to increase the bonding surface for a strong joint with the deck and the cabin roof.

(b) The shear and the bulkhead tops are sanded down to allow a smooth fit of the deck panels. A smooth fit is important for a strong bond.

Figure 75: Support lumber on the bow bulkheads

On the bunk level, support battens are used to create the frames to rest the bunk boards on. They go on each side of bulkhead 3, 4 and 5, level with the bottom edge of the cutouts. The bunk support triangles are equipped with one batten on each side for the same purpose. Bulkhead 2 and 6 are equipped only on the side which is facing towards the center bulkhead (the cabin). Their vertical position is determined by a straight batten held across all bottom edges of the cutouts of bulkhead 3, 4, 5 to create a flat bunk (like in figure 76 b) below). To complete the bunk-board frames, support stringers are glued on the hull side (like in figure 76 below). Prepare the support stringers by determining their size and cutting them from 3/8 in (9 mm) plywood, approx. 1x1 in (25 x 25 mm) wide.

(a) Measuring the individual lengths for the support stringers and marking their position on the hull

(b) Leveling the bunk-boards with a straight batten

(c) The bunk-board support stringers are glued in using copper wire to temporarily fix them on the bent hull.

Figure 76: Gluing the bunk-board support stringers into the hull

Figure 77 shows the achievement of this task. The support battens are shown in red, the bunk board support in blue.

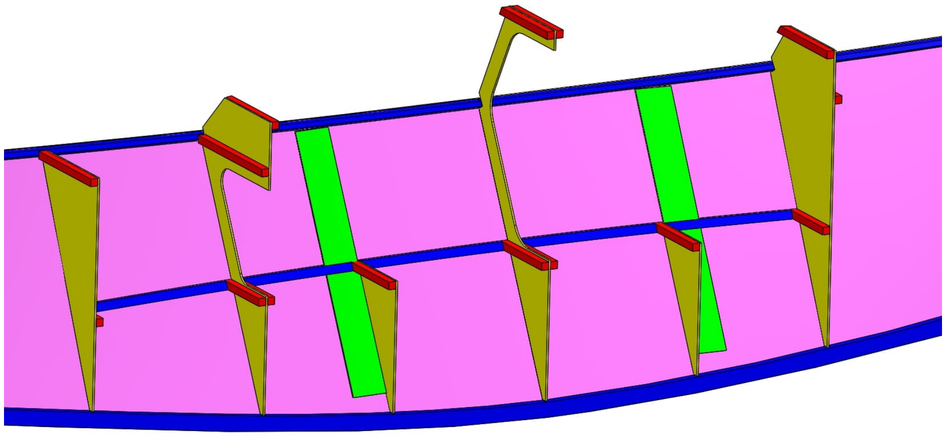


Figure 77: The bunk board supports are shown in blue.

8.6.8 Task 39: Prepare the beam cleat reinforcement

The beams will be connected to the hulls with rope lashings. The lashings are tied to the 'beam cleats', wooden fasteners at the gunwale. To attach the beam cleats, the hull sides are reinforced from the inside by doublets made from 3/8 in (9 mm) plywood. Cut 16 rectangular pieces, approx. 1 x 1 foot (300 x 300 mm), for both hulls. Figure 78 shows how these pieces (white) go into the hull.

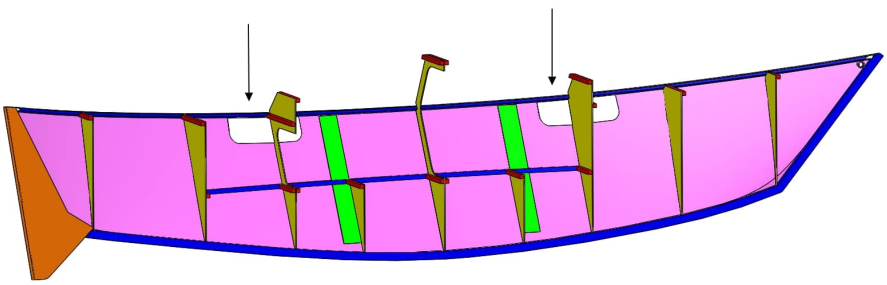


Figure 78: The beam cleat reinforcements (white) in the hull

8.6.9 Task 40: Glue the support battens

Glue on all support battens prepared earlier. The battens for the deck and roof can be mounted by clamps. This works for the bunk support battens of bulkhead 3, 4, 5 and the support triangles as well. The bunk battens of bulkheads 2 and 6 are simply placed into the V-shape of the hull sides with plenty of glue. Take care that all gaps are filled with glue, in particular from below (even though these are difficult to see) and where the battens meet the hull sides. This is important for the longevity of the entire hull.

The support stringers are held in place by copper wire. Simply drill two holes near the center of each stringer and tighten the wire from the outside. Make sure the glue squeezes out the sides and scrape it off. Add more wires if required for a proper bond.

8.6.10 Task 41: Glue the rudders

Glue two pieces of the already prepared rudder plywood on top of each other for the required thickness of 6/8 in (20 mm).

8.6.11 Task 42: Glue the beam cleats

Glue the eight beam cleats for both hulls (four pieces each, see 64 and 65) carefully by clamping the individual parts. Make sure glue squeezes out and there are no voids or gaps. Scrape off the excess glue.

8.6.12 Task 43: Glue the beam cleat reinforcement

Glue on the prepared beam cleat reinforcements. The beam cleat reinforcements go on just before bulkhead 3 and behind bulkhead 6 as shown in figure 78. The inside reinforcements sit right in the corner between bulkhead 3 and 6 and the respective sheer stringers.

8.7 Day 7

8.7.1 Task 44: Shape the rudders

Take off the clamps of the two rudders glued yesterday. Clean the rudders with an angle grinder. Use an electric planer to create a straight leading edge. The trailing edge of each rudder is tapered down to 1/8 in (3 mm) to create a tear drop shape (front round, back pointy, see figure 79 a and b). Start the taper about 3 in (75 mm) from the leading edge. Take an angle grinder for the initial rough work and switch to a sander for a smooth finish. The dark and light-colored lines of the plywood (created by the individual plies) are a good indicator of smoothness. They should be straight and parallel to each other. Round the leading edge with a router (see figure 79 c).

(a) The rudder is glued from two pieces of 9 mm (3/8 in) plywood and tapered at the trailing edge to 3 mm (1/8 in) to create an airfoil shape.

(b) The job is finished fast by using an angle grinder. The parallel lines of the individual veneer layers of the plywood give a good visual feedback on how well the rudder has been shaped.

(c) The leading edge is rounded using a router (see 12 d).

Figure 79: Shaping the rudder blade

8.7.2 Task 45: Drill and fill rudders

Pre-drill four sets of lashing holes for the rope hinges (nine holes in each set) in the rudders (see figure 80 below). Holes should be drilled to twice the required diameter. Make sure the sets match up with those on the skegs.

Fill all holes with epoxy resin (see figures 60 a, b and c) and re-drill them later to the (smaller) size of the lashing rope as explained previously.

(a) Four sets of nine holes for the hinge lashings are pre-drilled with twice the required diameter.

(b) The sets of holes are copied to the skeg.

Figure 80: Pre-drilling of the lashing holes

8.7.3 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.

8.7.4 Task 47: Make fillets (first hull)

Before applying any fillets check the hull again for any twist. To check for a twist, check the top edges of the bulkheads are parallel. Correct, if necessary, by pushing wedges under the cradles.

Apply fillets to all corners between the bulkheads and side panels, bow, keel and stem as explained in 6.5. The fillets stick better if the plywood is brushed with resin first. Off-cut wedges, ground round at the pointy end, work perfectly as application tools. As an alternative the tools shown in the photos 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 and leave a weak joint. It is helpful to make test fillets first and get comfortable with the tools and mixture.

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

(a) Application of a fillet to the joint of the center bulkhead and the hull side. The tool is easily made by a stick of lumber for the handle and a round plastic piece (e.g. cut from a lid).

(b) 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.

Figure 81: Application of fillets

For the keel fillet, tools with long handles and a slightly larger diameter (‘paddles’ like those in figure 82 b) below) are recommended.

The fillet in the keel, bow and stem area should be large enough to cover the entire area leaving no lumber exposed. Work from top to bottom for a clean result. All fillets should be as smooth as possible for proper strength. Scrape off excess fillet mix with a sharp spatula.

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

(a) Keel fillet under construction

(b) Tools with long handles might be helpful for the deep keel fillet.

(c) Application of the keel fillet

Figure 82: Application of fillets

After the fillets are finished, check the alignment of the skeg. The skeg should line up with the hull's center line.

Take care to scrape off all drops and bits of fillet mix, aside from that of the actual fillets, and leave them smooth. Cured resin is hard to remove and any dropped fillet mix will turn into sharp and rough spots which may cause injuries.

8.7.5 Task 48: Glue the third beam

Take the two beam boards which have been coated on one side already and two plywood stripes (which have also been glassed on one side). Glue them together as done for the first two beams (see Task 20, 8.4.4).

Day 8

8.8 Day 8

8.8.1 Task 49: Grind the third 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.

8.8.2 Task 50: Cut the bunk boards

The bunk-boards are a removable floor in the WAM Catamaran hull, see the elements in light blue in figure 83.

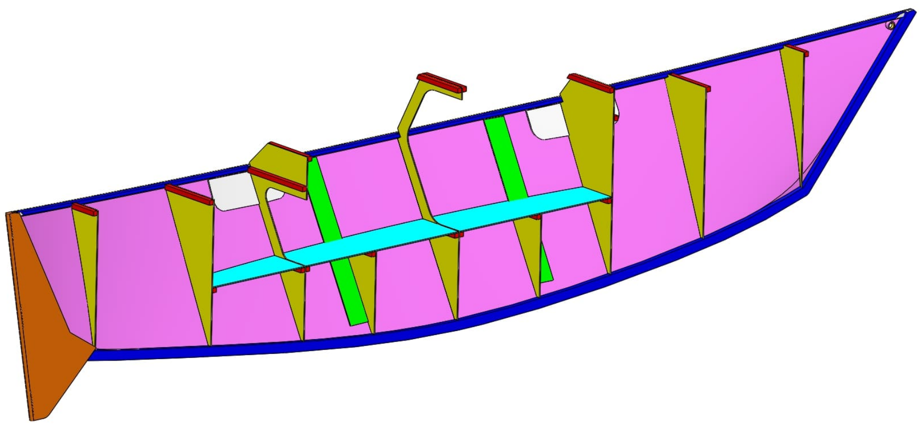


Figure 83: The bunk boards in light blue.

They have to fit perfectly into the frames of support lumber and stringers. To determine their size, push paper (e.g. flipchart paper) in the frames as shown in figure 84. Ask for someone else's help, as an additional pair of hands will help ensure the paper fits tightly to the edges. Mark the outline with a pencil. Use the paper as pattern. Cut the bunk-boards from 1/4 in (6 mm) plywood. Only the boards between bulkhead 4 and 5 should be made from 3/8 in (9 mm) ply. They will be under the hatch and have to handle higher loads, as people will be standing on them. Check their fit in the hull and trim with an angle grinder if necessary.

(a) The shape of each bunk-board is different. A large sheet of paper is used to get the hull dimensions right.

(b) The paper is pressed into the hull the same way as the bunk-board will go in later. A second pair of hands is helpful to keep the paper tight while the outline is marked.

(c) Finished bunk-boards in the hull

(d) The finger hole makes it easy to lift the boards and gain access to the bilge.

Figure 84: Manufacturing of the bunk-boards.

Mark the position of the bunk-boards with a pencil or a sharpy (i.e. numbers from bow to stern), round their edges and drill finger holes to lift them up.

8.8.3 Task 51: Assemble the second hull

To assemble the second hull repeat following steps:

- Stitch the hull: Day 6, Task 35 (8.6.4)
- Open the hull: Day 6, Task 36 (8.6.5)

Fit the bulkheads into the hull (see Day 6, Task 37). The bulkheads are already prepared and should fit at their designated position (marked on the side panels).

Further, repeat:

- Day 6, Task 38 (8.6.7)
- Day 6, Task 40 (8.6.9)
- Day 6, Task 43 (8.6.12)

8.8.4 Task 52: Glue the beam cleats to the hull (1)

Glue the beam cleats to the first hull as shown in figure 62 and 63. Figure 85 shows the current arrangement.

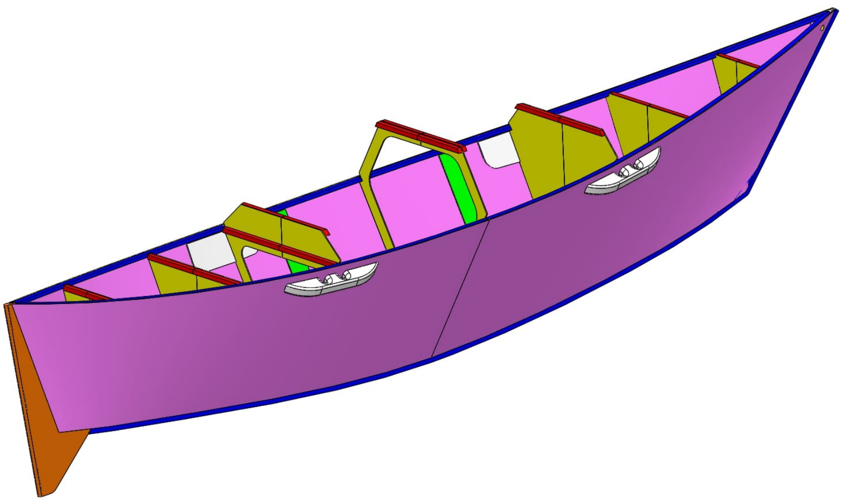


Figure 85: The beam cleats (white) glued to the side of the hull.

8.8.5 Task 53: Glass the rudders (1)

Figure 86: Glass the rudders with 3 layers of 7 oz. (200 g) fiberglass cloth.

8.8.6 Task 54: 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 87. 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 87 a). Wrap it around the beam and wet it out with epoxy. Repeat this process one side at a time until a total of 3 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 87: Beams are glassed and finished

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

8.8.7 Task 55: Glue the beam cleat reinforcement (2)

Glue the prepared beam cleat reinforcements into the second hull in the same way as done for the first one.

8.9 Day 9

8.9.1 Task 56: Carve the rudder handle

The rudders of the WAM Catamaran are controlled by a rudder handle and a cross bar as shown in figure 88 below. To take the Ackermann criteria[28] into account, the handles are designed with a round shape, pointing to the inside. This is resulting in a crossbar substantially shorter than the width of the hull center-lines. The design, according to Ackermann allows steering with reduced drag and more maneuverability.

Figure 88 shows the rudder handles with the curved Ackermann shape (a and b) and the finished arrangement below. Note that the cross-bar connecting the rudder handles is shorter than the distance between the rudders.

[28] Ackermann steering geometry is a geometric arrangement of linkages in the steering of a car or other vehicle designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii. The intention of Ackermann geometry is to avoid the need for tires to slip sideways when following the path around a curve. This can be directly translated into a twin rudder arrangement of a catamaran: The rudder on the inside of a turn needs a larger angle of attack compared to the rudder on the outside. This is achieved by making the linkage between the tillers (tiller crossbar) substantially shorter than the width of the hull center-lines.

(a)

(b)

(c)

Figure 88: Rudder setup.

Carve the rudder handle from naturally curved grown hardwood. Aim for a length of at least 1/6 of the hull length. The end of each handle should bend approx. two hand widths. Carefully carve a mount-hole in the back of the handle which fits to the conical shape of the rudder head. The rudder handle is simply fitted to the top of the rudder and lock in place there due to the shape of the mount-hole.

(a)

(b)

Figure 89: Carving of the tiller

8.9.2 Task 57: Cut the decks

Cut the fore and aft decks for both hulls from 3/8 in (9 mm) plywood. Get the shape by placing plywood sheets on the hull and marking around with a pencil. Cut with a 1 in (25 mm) offset.

(a) The size of each deck panel is derived directly from the hull by placing it at the desired position and drawing a line around the outline.

(b) Preparation of all four deck panels

(c) Cutting a deck panel to size

(d) All four deck panels cut to size

(e) Perfectly aligned deck panels, ready to be glassed on the internal surface.

Figure 90: Preparation of the deck panels

8.9.3 Task 58: Cut the cabins' roof and sides

Split a 3/8 in (9 mm) plywood sheet lengthwise in the middle. Each half is going to be one roof. Determine the size of the cabin sides (clamp on the roof and use a pattern from paper) and cut four cabin sides (two for each hull) from 1/4 in (6 mm) plywood.

(a) The cabin roof is cut to the width of the bulkhead tops and placed at its desired position.

(b) Fixed by clamps, the side panels are cut according to the shape of the roof and the shear.

(c) Cabin sides and roof cut to the right dimensions and placed temporary at the desired positions.

(d) Cabin sides and roof cut to the right dimensions and placed temporarily at the desired positions.

Figure 91: Preparation of the cabin roof and cabin side panels

8.9.4 Task 59: Make fillets for the second hull

Repeat Day 7, task 47 (8.7.4).

8.9.5 Task 60: Glass the rudders (2)

Glass the second side of the rudders with three layers of 7 oz. (200 g) glass fiber cloth.

8.9.6 Task 61: Glass the decks and coat the roof

Glass the later inside of the deck panels with one layer of 6 oz (180 g) fiberglass cloth. Cabin roof and cabin side panels are coated twice (wet in wet) with slightly thickened epoxy resin.

(a) The deck panels are glassed from the inside.

(b) The treatment is for reinforcement and for rot protection.

(c) Cabin sides and roof are coated with 3 layers of epoxy (wet-in-wet) as rot prevention.

Figure 92: Glassing and epoxy treatment as rot prevention measure for the decks, cabin roof and cabin side panels.

8.9.7 Task 62: Glue the beam cleats to the hull (2)

Glue the remaining 4 prepared beam cleats to the second hull in the same way as it was none for the first one. See Day 8, Task 52 (8.8.4).

8.10 Day 10

8.10.1 Task 63: Cut the bunk-boards for the second hull

Check if the bunk-boards of the first hull fit in the second hull. If yes, copy them. If not, repeat Day 8, task 50 (8.8.2).

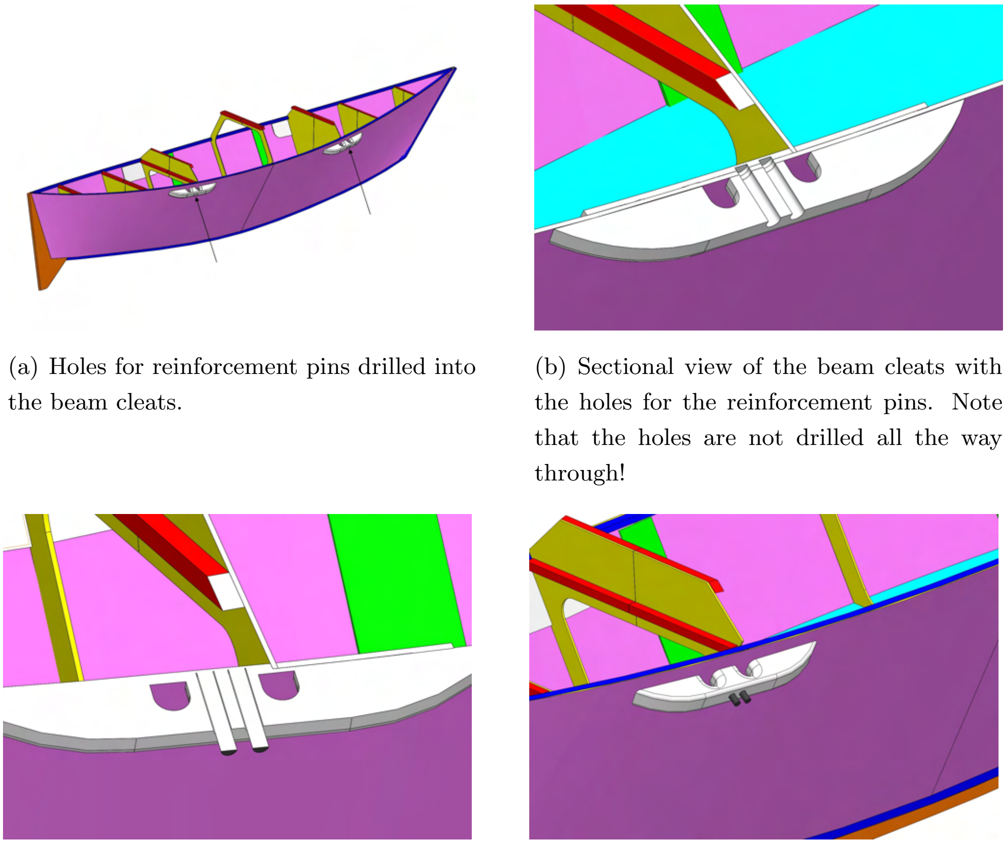
8.10.2 Task 64: Prepare the bulkheads for the roofs and decks

The bent roof of the cabin meets the top of bulkheads 3 and 5 at an angle. Use an electric planer to adapt the bulkheads and the lumber battens glued to their tops to that angle to minimize the gap.

Level the bulkhead tops and the shear of each hull to glue the deck panels on with minimal gap. An electric planer and angle grinder works best.

8.10.3 Task 65: Reinforce the beam cleats

To eliminate the risk the beam cleats peeling off the hull sides, the cleats are further reinforced with hardwood pins, see figure 93.



(a) Holes for reinforcement pins drilled into the beam cleats.

(b) Sectional view of the beam cleats with the holes for the reinforcement pins. Note that the holes are not drilled all the way through!

(c) Sectional view of the beam cleats with the reinforcement pins inside of the holes.

(d) The reinforcement pins inside of the holes.

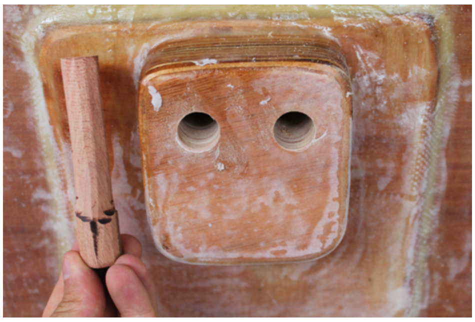
Figure 93: Design of the reinforcement of the beam cleats.

Start by drilling holes through the beam cleats into the hull. The holes, at least 3/4 in (20 mm) in diameter, are drilled into the cleats through the cleat base into the hull side. Be aware, the holes should not be drilled all the way through! The inside must remain sealed! The drill should be stopped 1/8 in (3 mm) before it breaks through to the inside. A mark can be made on the drill bit (e.g. with masking tape) to indicate the maximum depth that should be drilled.

Prepare hardwood pins of the right diameter (they should fit into the holes) and length (they can be longer than necessary) in the next step.

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

(b) Holes (at least 3/4 in or 20 mm) are drilled into the cleats through the cleat base in the hull. Be aware, the holes are not drilled all the way through! The insides must remain closed! The drill should be stopped 1/8 in (3 mm) before it brakes through on the inside. Mark the drill bit so you know the maximum depth this hole should be.



(c) Hardwood pins prepared to fit into the holes.

Figure 94: Reinforcement of the beam cleats to the hull: the photos show an old beam cleat design, which is not recommended anymore, but the principle of the pins is the same.

Prepare 16 hardwood dowels with a thickness of about 3/4 in (20 mm) and a length of 3 in (80 mm).

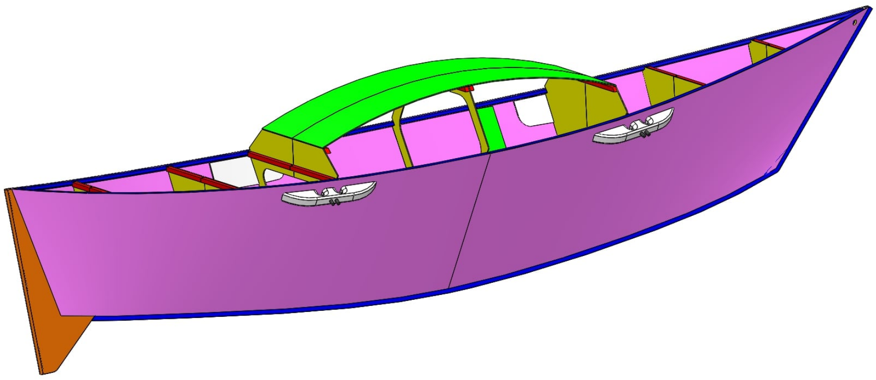


Figure 95: A hardwood dowel is cut using an angle grinder. The end of the dowel will be cut off later anyway, so there is no need to shape it all the way - as long as the diameter is constant over a length of 3 in (80 mm).

8.10.4 Task 66: Coat the bunk-boards

Coat the bunk-boards with slightly thickened epoxy resin three times (wet in wet).

8.10.5 Task 67: Coat the hulls' interior

Apply three layers of slightly thickened epoxy resin (like syrup) on ALL surfaces inside the hulls. It is critical for the longevity of the hull to coat everywhere. Only a perfect coat of epoxy stops moisture from getting into the wood and eventually composting the hull. It works best to put the hull on the ground for better access.

(a) Application of epoxy inside the hull.

(b) It is very important to cover every bit of bare wood with epoxy to keep the hull rot-free.

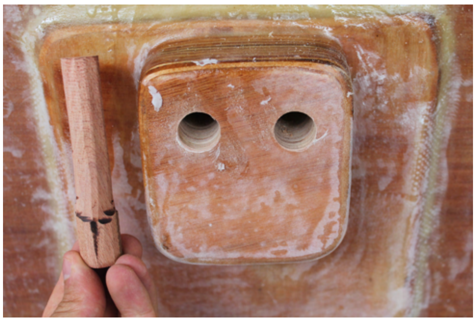
(c) The accessibility proved to be best with the hulls flipped on one side.

(d) Both hulls are treated in parallel with three layers wet in wet. To ensure the job is finished in time, some preparation and planning, and organization of the crew is required.

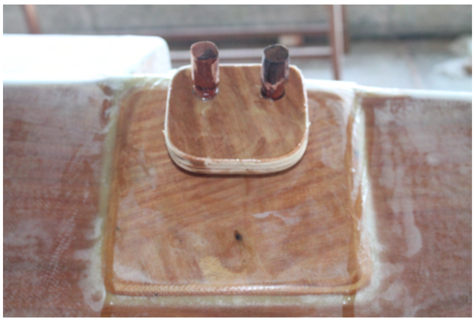
Figure 96: Application of three layers epoxy as rot prevention inside the hulls.

8.10.6 Task 68: Glue the beam cleat pins (1)

Turn the hulls on the side. The holes in the beam cleats should face up. Fill the holes half way up with slightly thickened resin (like thick syrup). Press the pins into the holes and squeeze out most of the resin. Make sure there is no air in the gap between pin and hole. It should all be filled with resin.

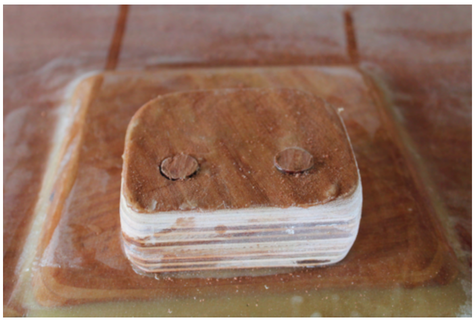


(a) Hardwood pins fitted to the holes



(b) The holes are half filled with slightly thickened resin (like thick syrup). The pins are pressed into the holes, which squeezes out most of the resin.

(c) Squeezing out the resin with the pins, ensures enough resin along the pin and a proper bond.



(d) After the glue is cured the pins are trimmed and sanded.

Figure 97: Bonding and reinforcement of the beam cleats to the hull. The photos show an old beam cleat design, which is not recommended anymore. See figure 93 for the recommended design.

8.11 Day 11

8.11.1 Task 69: Trim the beam cleat pins (1)

Take a hand saw and cut off the hardwood pins glued in yesterday to reinforce the beam cleats as shown in 97 above. Sand them smooth.

8.11.2 Task 70: 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 98 below. Make them at least two fingers high, three fingers wide and slightly longer than the beams' width.

Figure 98: 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 beam's width.

8.11.3 Task 71: Carve the mast feet

Each mast of the WAM Catamaran's A-frame setup sits in a mast-foot (mast base) which is glued to the deck of the hulls.

Carve the mast-foot from hardwood as shown in figure 99 below. The masts will be tied down, drill a lashing hole all the way through (see 99 c). A second hole (not pictured) serves as drainage to avoid rainwater being trapped in the masts' bases. Seal both holes inside with epoxy: Close one end of the hole with your (gloved) finger. Fill the hole with slightly thickened epoxy from the other side. Wait a minute or two, then remove your finger and pour the resin back in your bucket.

(a) The mast bases are carved from large pieces of local hardwood.

(b) The mast bases are planed and sanded smooth.

(c) The masts will be lashed to the bases, so a lashing hole is drilled.

(d) A second hole (not in the picture) serves as drainage to avoid water getting trapped in the mast bases.

(e) Both holes are sealed with epoxy from inside.

(f) Later position of the mast foot on the hull.

Figure 99: Manufacturing of the mast steps.

8.11.4 Task 72: Coat the bunk-boards

Coat the other side of the bunk-boards with slightly thickened epoxy three times (wet in wet).

8.11.5 Task 73: Finish the rudders

Sand the rudder smooth. Redrill the lashing holes at the front of the leading edge without cutting into the wood.

8.11.6 Task 74: Make the tiller crossbar

Take a straight, knot free lumber batten, approx. 10 ft long. Round the edges and pre-drill a lashing hole in one end. Fill the lashing hole with epoxy.

8.11.7 Task 75: Glue on the roofs and cabin sides

Glue the prepared roof panels on the hulls as explained by figure 101 below.

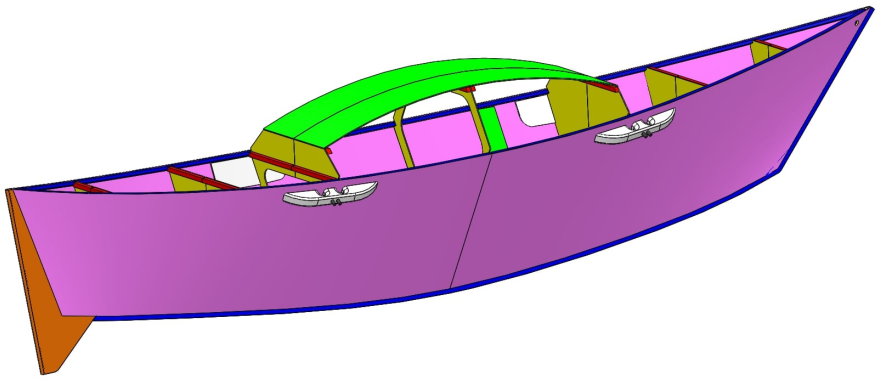


Figure 100: Cabin roof mounted

(a) Cabin sides are sanded at the bonding points

(b) Plenty of glue is spread on the bulkhead tops for a strong bond without any gaps. The glue is should squeeze out as an indicator of a good joint.

(c) The roof is placed on top of the bulkheads.

(d) The roof is bent down to its intended shape and fixed temporarily by clamps going around the bulkhead (not shown in the photo).

(e) Clamps are used to hold the roof down on the cabin bulkheads (not shown).

(f) Scooping off squeezed out glue.

Figure 101: Cabin roof panels glued on the hulls.

Keep the roof in place with clamps as shown in figure 102 below.

(a) The cabin roof is cut to the width of the bulkhead tops and placed at its desired position.

(b) Fixed by clamps, the side panels are cut according to the shape of the roof and the shear.

(c)

(d)

Figure 102: Preparation of the cabin roof and cabin side panels. The cabin sides and roof are cut to the right dimensions and placed temporarily at the desired positions.

Follow figure 103 below and glue on the cabin side sheets. They are held in place by hot melt glue from the outside. Alternatively, the hull can be tilted and weight placed on top of the cabin sides. The inside is still accessible through the open deck, however the entrance is not very spacious. Ask a small person to apply the fillets inside to bond the side sheets permanently into place (see 103 d).

(a) Cabin sides are sanded at the bonding points.

(b) Hulls are prepared with glue and resin.

(c) The cabin sides are held in place by hot meld glue applied from outside. In the next step they will be fixed by fillets from inside permanently.

(d) Finished internal fillets

Figure 103: Cabin sides glued on the hulls

8.11.8 Task 76: Prepare the bow eyelets

To attach the front beam, anchor lines and forestays, the WAM Catamaran hulls are designed with one big lashing hole on each bow. To construct a strong, rope friendly bow eyelet, the holes are reinforced by an insert.

Start preparing the insert by taking 1 ft (300 mm) of a 1 in (25 mm) PVC (thick walled) pipe. Roughen up the outside with an angle grinder (to remove the shiny surface). Next, wet out a 1 x 5 ft (0.3 x 1.7 m) strip of glass fiber cloth. Wrap it around the PVC pipe (tight) and leave it to cure.

Figure 104: PVC pipe for bow eyelet inserts.

8.12 Day 12

8.12.1 Task 77: Drill the bow eyelets

Take the glassed PVC pipe from yesterday. Rough the surface up with an angle grinder and cut it half. Determine the approx. diameter and drill a slightly larger hole (with a hole saw) into each bow. See figure 105 for the approximate position.

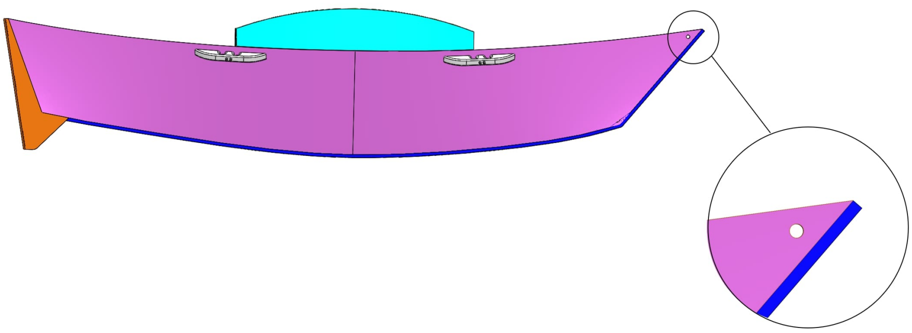
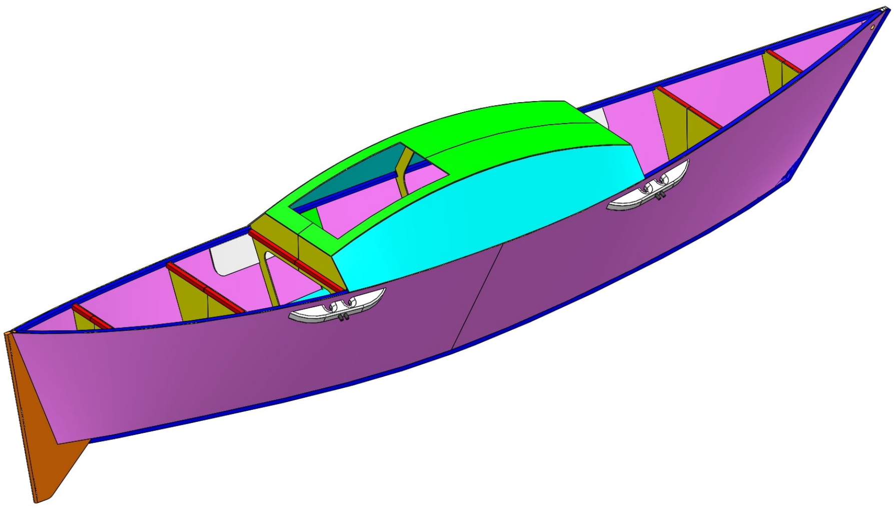


Figure 105: Position of the bow eyelets.

8.12.2 Task 78: Cut the hatch openings

Mark and cut the hatch openings into the cabin roof between bulkhead 4 and 5 as shown in figure 106 below.



(a) The cutout for the hatch in the cabin roof.

(b) The cutout for the hatch is marked on the roof.

(c) The hatch is cut into the roof after the glue has cured.

Figure 106: Cut hatch openings.

Size is not critical. Leave at least a hand width of roof to all four sides.

8.12.3 Task 79: Prepare the hatch lumber

To keep water out of the cabin, the hatch is framed by lumber battens of 1 x 2 in (25 x 50 mm). The battens are simply glued on the roof flush with the cutout. Prepare a frame for each hatch. Adapt the curvature of the roof by shaping the battens.

8.12.4 Task 80: Prepare the toe rails

Prepare toe rails as shown in figure 107 and 108 from 1 x 2 in (25 x 50 mm) lumber. The cutouts are important, as they allow water to be released and the front trampoline to be tied to the toe rails.

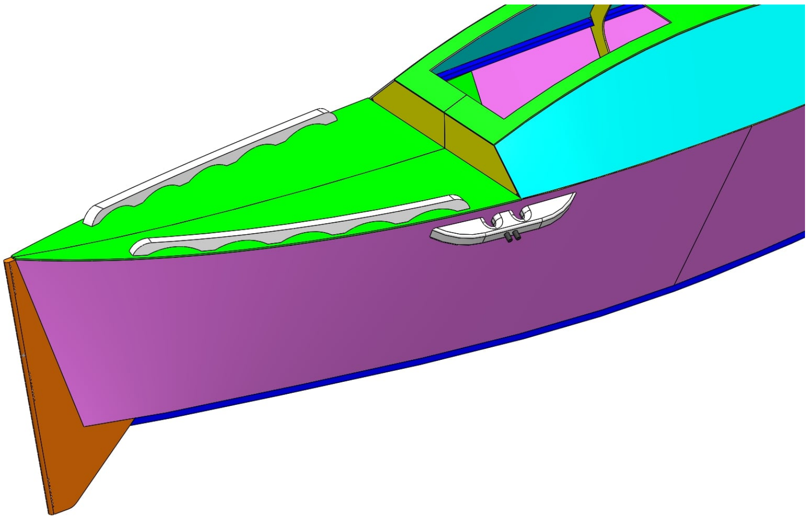


Figure 107: Position and shape of the toe rails.

Day 12

(a) Toe rails on the fore deck

(b) Trampoline attached to the toe rails

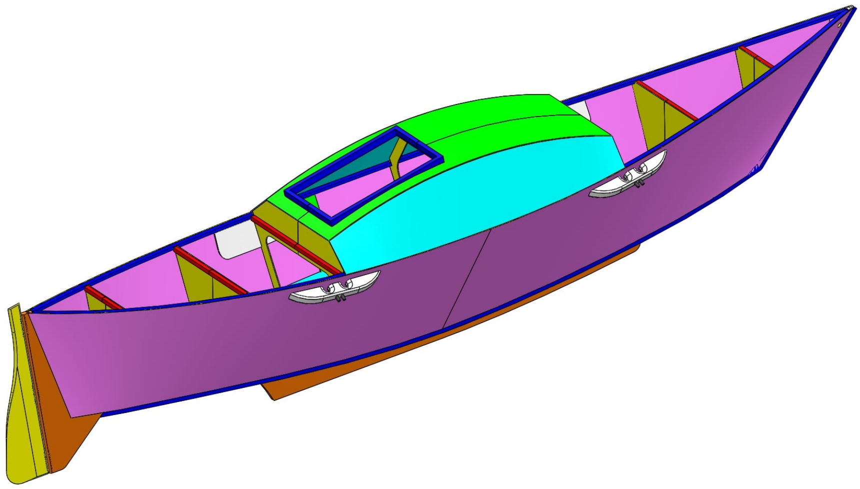
(c) Toe rails on the fore deck

(d) Toe rails on the aft deck

Figure 108: WAM Catamaran toe rails

8.12.5 Task 81: Glue the hatch lumber on

Glue on the prepared hatch frames as shown in figure 109 below.



(a) The hatch frame

(b) The hatch frame is made from 1 x 2 in (25 x 50 mm) lumber. The short pieces (bow and stern) are glued on top of the cabin roof and the long pieces in the hatch opening (touching the cabin roof in a butt-join manner).

(c) The hatch frame is further reinforced with small fillets.

Figure 109: Manufacturing of the hatch frames.

8.12.6 Task 82: Glue the bow eyelets into the hulls

Glue in the prepared inserts. They don't need to be flush, as they will be cut and ground later. Squeeze the glue from outside into the gap between insert and hole for a proper bond.

8.12.7 Task 83: Glue the decks on

Glue on the prepared deck panels as shown in figure 110 and 111 below.

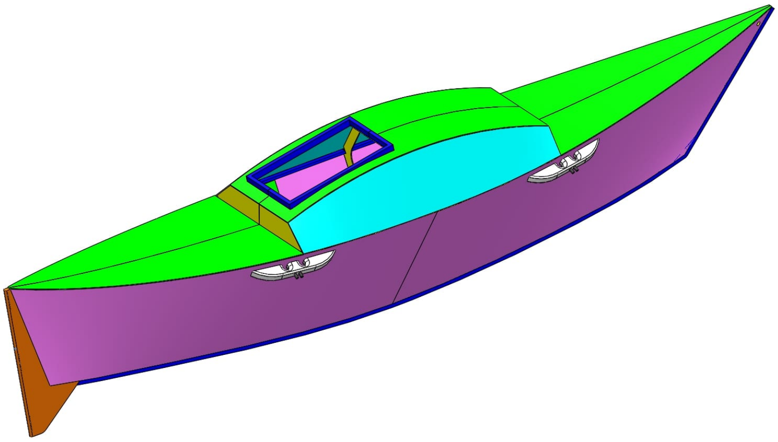
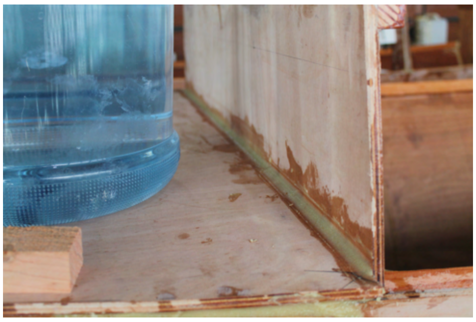


Figure 110: The deck panels on the fore and aft part of the hull.

(a) The deck panels are glued on the shears and the bulkheads with thickened epoxy. Clamps and weights are used to temporarily hold them in place.

(b) It is important to use enough glue (it should squeeze out a little bit everywhere) to create a strong bond without any gaps.



(c) Fillet between deck and cabin bulkhead

Figure 111: Deck panels glued on the hulls

8.13 Day 13

8.13.1 Task 84: Round the sheer and cabin edges

Eventually the entire external surface of the WAM Catamaran will be glassed. It is impossible to apply glass fiber cloth around sharp edges, therefore all edges (shear and cabin) must be rounded, with voids filled and sanded smooth. A good approximation is the roundness of a finger or those of already applied fillets. Follow the instruction of figure 112 below.

(a) A router (see 12 d) is very helpful for the main sanding. A sander is used to achieve the final smoothness.

(b) All edges are rounded and filled with thickened resin (if needed).

(c) The entire deck and cabin surface is sanded in preparation for glassing.

(d) The entire deck and cabin surface is sanded in preparation for glassing.

Figure 112: Preparation of the exterior sheer and cabin edges

8.13.2 Task 85: Finish the hatch frame

Sand the hatch-frames smooth. Round all sharp edges and corners.

8.13.3 Task 86: Finish the bow eyelets

The bow eyelet insert was glued into the hulls yesterday. It was made oversized and sticks out on both sides. Take a handsaw and cut the overlap as close as possible to the hull. Now take an angle grinder and grind it smooth to align with the plywood.

The edges of the bow eyelets must be rounded so rope can be run through. Take a router and carefully cut the edge of the PVC pipe round. Do not cut into the glass fiber wrapped around the PVC. Take sandpaper to create a round and smooth edge.

8.13.4 Task 87: Make the hatch covers

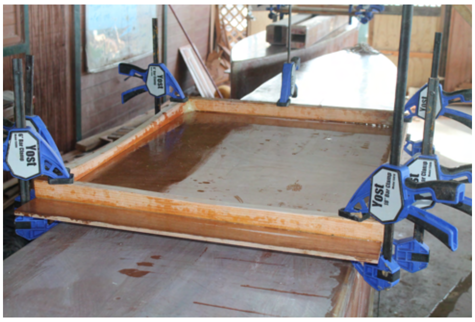
The hatch covers are made from 3/8 in (9 mm) plywood with a lumber frame around the edges. Start by preparing the lumber frame in the same way as for the frame already glued to the roof: Place the lumber of the cover frame one finger width away from the glued on frame. Shape the lumber to meet the curved shape of the roof.

Next, cut a piece of 3/8 in (9 mm) plywood to the size of the prepared frame. Extend the plywood approx. 3 fingers beyond the front lumber as shown in 113 c), d) and e) below. The overlap will provide space for the hatch covers to be mounted to a hinge. Cut a strip of plywood to the size of the overlap.

(a) The hatch frame is made from 1 x 2 in (25 x 50 mm) lumber. The short pieces (bow and stern) are glued on top of the cabin roof, the long ones in the hatch opening (touching the cabin roof in a butt-joint manner.

(b) The hatch frame is further reinforced with small fillets.

(c) The hatch cover is made from 3/8 in (9 mm) plywood and lumber from the same cross section as the hatch frame. The long pieces of lumbers are ground to fit the bent shape of the cabin roof.



(d) The front of the hatch cover plywood extends approx. 3 fingers (2 in/50 mm) beyond the front lumber to allow space for the holes of the rope hinge (see 6.9). The holes are pre-drilled, filled with epoxy and drilled again.

(e) The hatch cover is placed on top of the hatch frame to determine the position for the hinge plates.

Figure 113: Manufacturing of the hatch frame and hatch cover.

Glue all prepared parts as shown in 113 above. The extra strip of plywood will reinforce the overlap to create a strong hinge.

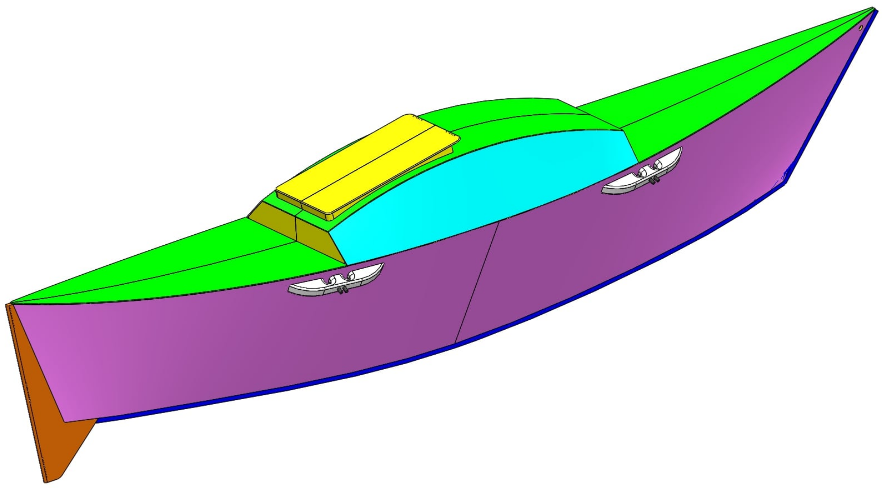
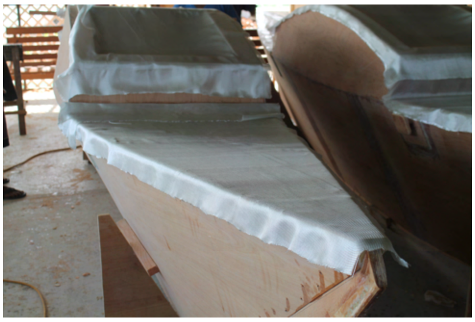


Figure 114: The hatch cover on top of the hull.

8.13.5 Task 88: Glass the top of the hulls

As introduced earlier, the entire external surface of the WAM Catamaran hulls will be glassed. This will be done step by step, beginning with the decks and cabin top. Clean the hulls and remove all dust and debris. Carefully apply two layers of dry glass fiber cloth (7 oz. or 200 g) to the deck and cabin roof: Take the glass fiber roll between two people and walk along the hull. Simply roll the glass fiber over the surfaces. Trim the edges as shown in figure 115 below. Keep the off-cuts. Leave a three fingers wide overlap on all edges. The overlap will double up and result in reinforced edges.

(a) Glass fiber cloth (7 oz. or 180 g) is rolled over the deck and cabin roof.



(b) The glass fiber is cut to the size of the hull with an overlap of three fingers to reinforce the edges.

(c) Additional glass cloth is prepared for the cabin sides

Figure 115: Preparation of the glassing of the cabin and the deck

Wet out the glass fiber following the instructions in figure 117 below. Take the off-cut glass fiber cloth from the bows and apply it to the cabin side (overlapping all edges by 3 fingers). Glue the prepared toe rails on the wet glass as shown in figure 116.

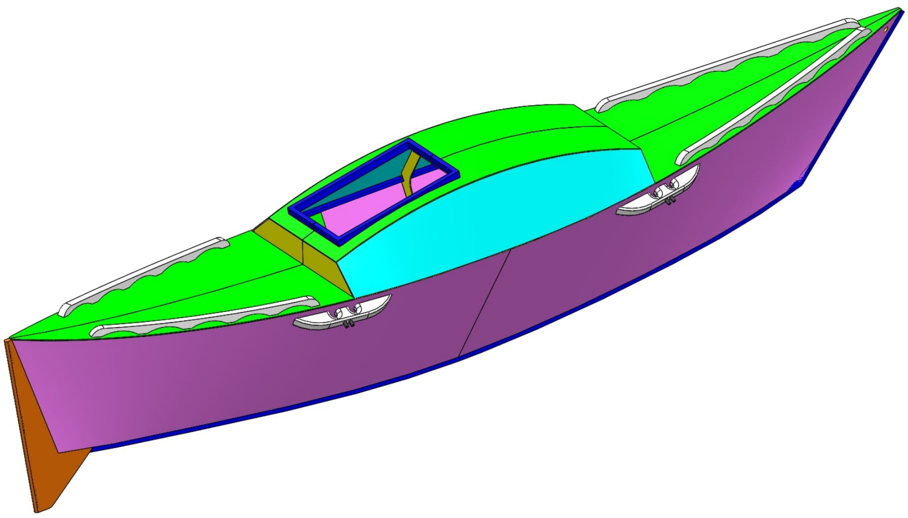


Figure 116: The deck panels on the fore and aft part of the hull.

(a) The epoxy resin is applied directly on top of the glass cloth until it becomes clear (wet out). This is even possible with two dry layers doubled up. The overlap for the edges is wetted out by folding it up on the already wet deck.

(b) The wet overlap is than folded back...

(c) ...and formed into place by hand.

(d) Finished deck laminate. No white spots (air) are (is) left. This means the glass cloth is completely attached to the plywood.

(e) Finished deck laminate. No white spots (air) left, the glass cloth is attached to the plywood.

(f) Reinforcement patches on all corners

Figure 117: Glassing of the cabin and the deck

Apply a flow coat (wet in wet) approx. one hour after the glassing as shown in figure 118 below. Don't forget to coat the toe rails as well.

(a) One hour after glassing another layer is applied wet-in-wet (a ‘flow-coat’) to reinforce the rot-resistant epoxy layer.

(b) The flow coat is clearly visible by the absence of any fiber structure of the glass cloth. The surface is shiny.

(c) Application of the flow-coat.

(d) Shiny flow-coat on the right and fiber structure of the glass cloth laminate on the left.

Figure 118: Application of a flow-coat on the cabin and the deck (the photos do not show the toe rails)

8.13.6 Task 89: Reinforce the bow eyelets

The glued-in bow eyelets are already strong, but they require further reinforcement. (You don’t want to loose the WAM Catamaran because strong waves rip the anchor lines out.) They are reinforced with glass fiber tow (individual strands of glass fiber taken from woven cloth), applied as shown in figure 119 below. Run the wet tow through the eyelets and arrange them like a hand fan to spread the load from the hole across a wide surface (see 119 d).

(a) Prepared glass fiber tow

(b) Tow wet out with epoxy resin

(c) The bow eyelet is reinforced with glass fiber tow. A sheet of wax paper is used to smooth the surface.

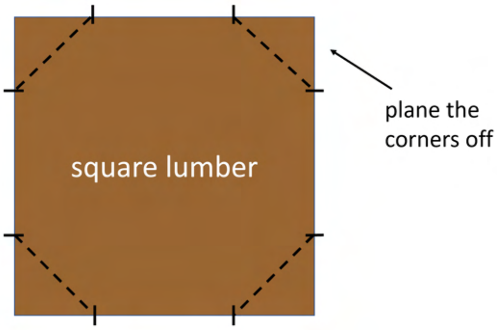
(d) The star shape (to spread the load across a larger surface) of the glass tows is clearly visible after sanding.

Figure 119: Reinforcement of the bow eyelet

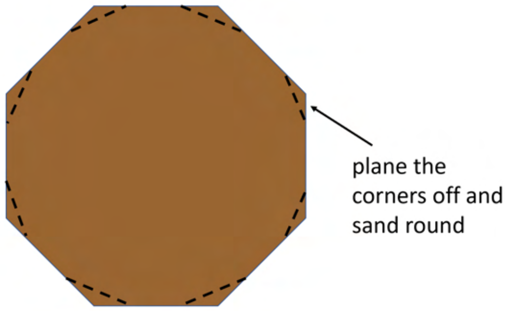
8.13.7 Task 90: Plane the masts

For the masts, two lumbers of 3 x 3 in (75 x 75 mm) and a length of 3/4 master string (15 ft for a hull length of 20 ft) are required. The lumber must be straight grained and without significant knots, cracks or a crown (natural curve).

Start by tapering the ends from 1/3 of the length down to 50 x 50 mm (2 x 2 in). Now plane the edges as shown in figure120 a) below to obtain a shape with eight edges. Continue in the same manner to obtain a shape with 16 edges (see figure 120 a) below). Sand the edges round until the entire mast has a smooth round shape.



(a) Step 1



(b) Step 2

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

Figure 120: The WAM Catamaran masts are shaped from a lumber

8.14 Day 14

8.14.1 Task 91: Prepare the bottom for glassing

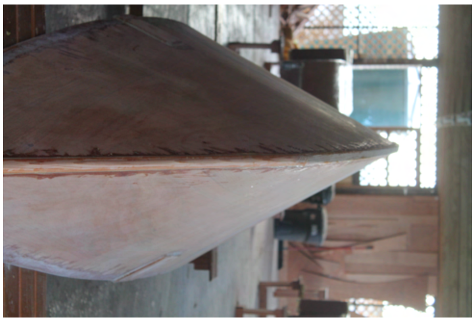
Flip the hulls upside down on saw horses. Remove all stitching wire: Carefully pull out the copper with a pincer as shown in figure 121 a) below. The plastic insulation stays inside (and is easy to grind off).

Now take an angle grinder and shape the bow and keel. While the keel is only rounded slightly (keep the rectangular shape but remove the sharpness of the edges), the bow is rounded for an undisturbed water flow (see figure 121 b) and c) below).

Next, fill all holes (especially those from stitching) and fair the transition from plywood sides to keel/bow lumber (see figure 121 d) and e) below) with fillet mix. The skeg may need some sanding and fairing too.

(a) Hull turned upside down and wires removed

(b) The bow lumber is rounded to make it more streamlined.



(c) The keel lumber is rounded but still rectangular.

(d) All gaps in the transition from hull to keel are filled with thickened epoxy.

(e) All gaps in the transition from hull to keel and all holes from wires are filled with thickened epoxy.

Figure 121: Preparation of the bottom for glassing

8.14.2 Task 92: Glass the first bottom side

Turn the hulls on one side to work on a horizontal surface. Make sure the side where the beam cleats are not reinforced yet faces up. Follow the instruction of figure 122.

(a) Hulls turned on one side to work on a horizontal surface.

(b) Two layers of glass fiber cloth are rolled over the hull side.

(c) Glass fiber cloth wet out with epoxy resin.

(d) Glass fiber cloth is cut to size.

(e) There should be a three finger wide overlap at the keel and bow.

(f) First side is glassed. The second side is glassed in the same way.

Figure 122: Glassing of the hull bottom

8.14.3 Task 93: Reinforce the beam cleats

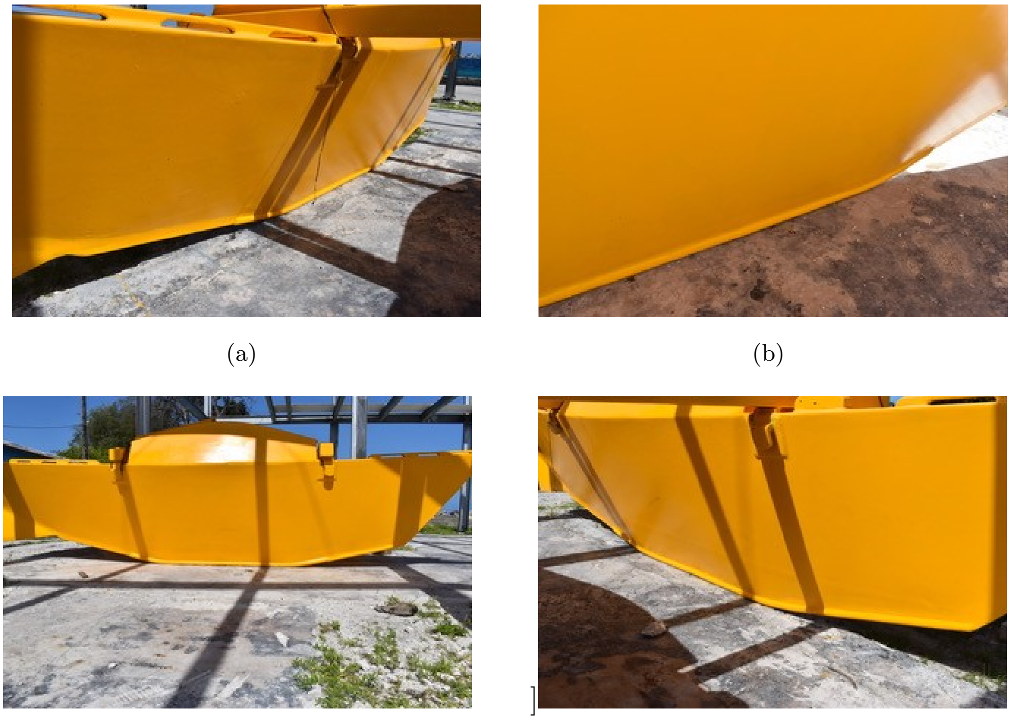
Reinforce the beam cleats the same way as done in Day 10, Task 3 (8.10.3).

8.14.4 Task 94: Drill and fill the keel shoe holes

To protect the keel from grounding, hardwood protective layer will be lashed under the keel. Therefore, three lashing holes are drilled into the keel. As always, they are pre-drilled twice the diameter, filled with epoxy and re-drilled. The holes should be about 2 ft (600 mm) apart from each other. Drill the center hole at the deepest point of the keel. A good size for the finished holes is about 3/8 in (9 mm). Pre-drill with 6/8 in (18 mm) twice the diameter.

Close the holes with masking tape from underneath and clamp a batten under them to support the tape. Fill with slightly thickened resin. Refill after one hour.

Since large pieces of hardwood are not always available an alternative option has been developed: a 2 in (50 mm) PPC pipe[29] is sliced lengthwise, pulled over the keel after the glassing is complete and glued in place. If you want to go with this option Task 94 and 95 can be skipped. The PPC pipe should go on the keel after Task 113. Figure 123 below shows the finished keel with PPC pipe keel shoe.



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

Figure 123: PPC pipe keel shoe

8.14.5 Task 95: Carve the keel shoe

The ‘keel shoe’ (*erer*) is a sacrificial piece of hardwood lashed under the keel.

[29]Plastic pipe commonly used for plumbing.

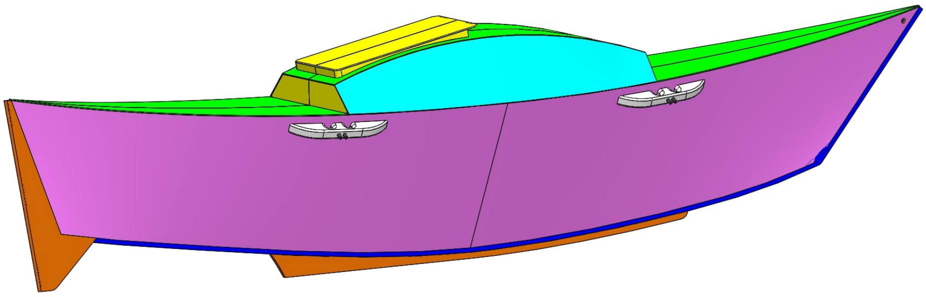


Figure 124: The keel shoe (orange) under the hull. For better sailing performance it is shaped like the back fin of fish.

Cut it to meet the shape of the hulls (simple if the keel is straight) as shown in figure 125 below and drill corresponding lashing holes (no filling needed).

(a) Shaping of the keel shoes, from local hardwood, according to the shape of the keel.

(b) Finished keel shoes

Figure 125: Manufacturing of the keel shoes (*erer*)

8.14.6 Task 96: Sand and drill the hatch covers

Remove the clamps of the hatch covers. Grind them smooth and round all edges (with a router works best). The overlap in the front especially must be perfectly round and smooth for the hinges (see figure 126 below).

Pre-drill one set of lashing holes on each side into the overlap, in the same way as was done for the rudders, and fill the holes with epoxy.

8.14.7 Task 97: Prepare the hatch hinges

The hatch covers will be mounted on hinges (similar to the rudder lashing). So the hinge plate can be glued to the roof cut eight plywood pieces from 3/8 in (9 mm) plywood. Make them long enough to drill the lashing holes in (as shown in figure 126). The correct height depends on your boat: The rounded edge of the hatch should slightly touch the edge of the hinge plate as shown in figure 127. The hinge plates are glued from two pieces each to obtain a thickness of 6/8 in (18 mm), which is the same as the overlap of the hatch cover.

(a) Hinge plate - pre-manufactured and glued on the cabin roof with fillets.

(b) Hinge plate holes match up with the hinge holes of the hatch cover.

(c) The hinge plates and the hatch cover should almost touch each other.

Figure 126: Mounting of the hatch cover hinge plates

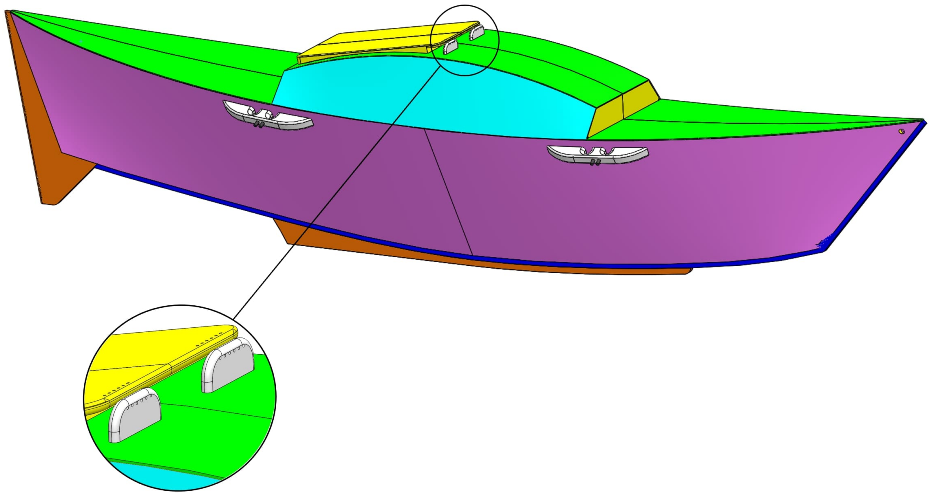


Figure 127: Position and size of the hatch hinges

8.15 Day 15

8.15.1 Task 98: Prepare to glass the second side

The second side of the hulls will be glassed in the same way as the first one, see Day 14, Task 92 (8.14.2). Before any glass fiber is applied, sand the second side smooth (especially where holes or gaps were filled yesterday). Sand all areas of glass fiber overlap too (the bow, parts of the keel and the skeg).

8.15.2 Task 99: Glass the second side

Turn the hulls around to face the other side up. Glass the second side in the same way as the first one, see Day 14, Task 92 (8.14.2).

8.15.3 Task 100: 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 128to cut the upper and lower boom (*rojak maan* and *rojak korra*) from.

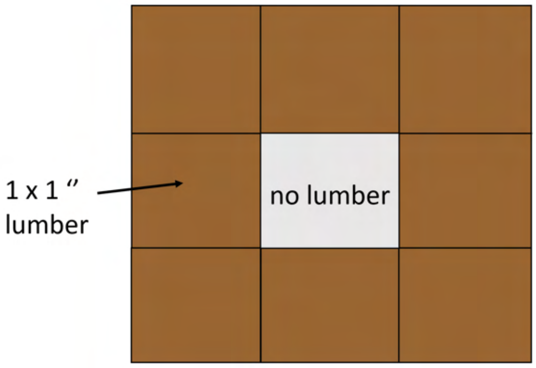


Figure 128: Raw shape of the WAM Catamaran spars: Eight 1 x 1 in (25 x 25 mm) lumber battens are glued into a square. The center is left hollow for weight reduction.

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 101: Shape, drill and fill the hinge plates

Shape the hinge plates as shown in figure 126. Pre-drill lashing holes corresponding to those drilled into the hatch covers. Fill them with resin in the same way as was done with the rudders.

8.15.5 Task 102: Finish Hatch Covers

Re-drill the filled lashing holes. Glass both hatch covers with two layers of glass fiber cloth.

8.15.6 Task 103: Lash the mast heads

Lash the mast heads as shown in figure 129 below.

(a) Recess for the lashing

(b) Lashing fastened in a figure-eight motion

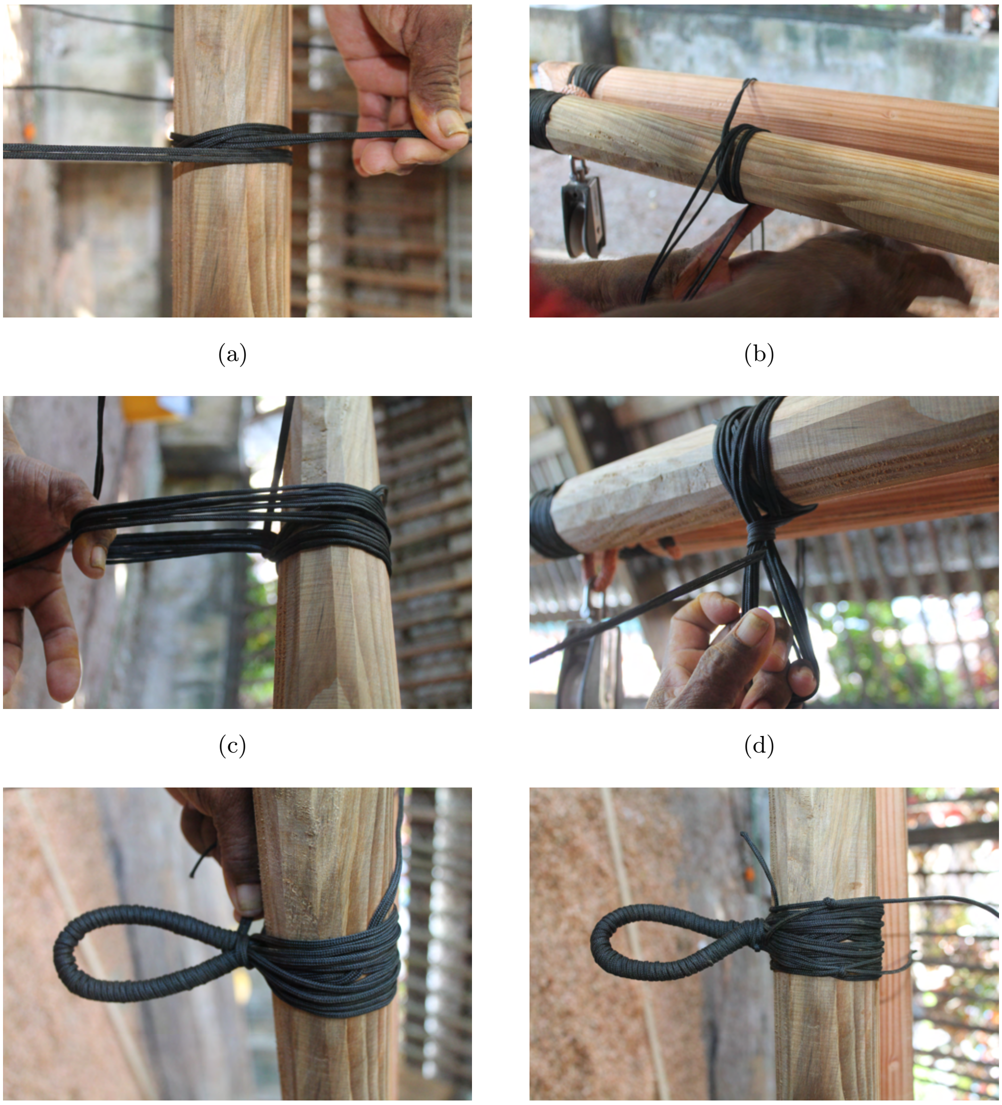
(c) Lashing finished and locked. To further tighten the lashing, the rope is now wrapped around the cross point of the figure-eight lashing.

(d) Finished mast head lashing with halyard pulley

Figure 129: Masthead lashing

8.15.7 Task 104: Fore- and backstay lashings

Each mast is supported by a fore- and a backstay close to the mast head. The stays are attached to special lashings. They are tied to the bare pole without any holes or bolsters as shown in figure 130 below.



(a) (b) (c) (d) (e) (f)

Figure 130: Lashing as for- and backstay attachment.

Day 15

8.15.8 Task 105: 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 foots as shown in figure 131 below. Lash one clamp on each mast.

(a) Preparing the cleat from hardwood

(b) Lashed on cleat at the mast

Figure 131: Halyard and spilling line cleats

8.16 Day 16

8.16.1 Task 106: Glass the bottoms

Turn the hulls upside down. Sand both hull sides of the hulls. Apply glass fiber cloth (7 oz. or 200 g - use off-cuts) on the bow, keel and lower part of the skeg. Make sure all remaining plywood is glassed with three layers while keeping an overlap of at least three fingers to the previous glassed areas. For further reinforcement in case of grounding, reinforce bow, keel and the lower part of the skeg with one an additional wide cloth stripe. A total number of at least seven layers should be applied.

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

Figure 132: Keel, bow and skeg are covered by seven Layers of 7 oz. (200 g) cloth as reinforcement in case of ground contact.

8.16.2 Task 107: 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 128. 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.

8.16.3 Task 108: Close the beam ends

The open ends of the beams expose the end grain of the beam lumber and plywood (see 35). 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.

8.16.4 Task 109: Prepare the deck

The space between the beams and the hulls of the WAM Catamaran is either covered by a trampoline made from net or by a solid slat deck between the hulls and beams. WAM Catamarans shorter than 20 ft should go for the net trampoline to save weight, whereas larger versions above 20 ft are more comfortable with a slat deck. The 20 ft version performs with both options. If cargo/passenger transport, fishing and other work is the main objective, the slat deck is strongly recommended.

Trampoline The trampoline can be made from any type of strong net. A mesh size below 1.5 in (38 mm) is desirable for comfortable walking. Nets from a low stretch material work better as they result in a much tighter trampoline. The net is simply lashed and tightened between the beams. Cut a piece to the size of the space between hulls and beams and lash it on. Pull it as tight as possible. It may be required to re-tighten the trampoline occasionally. The trampoline doesn't require any preparation and is assembled together with the rest of the platform. If you choose the trampoline option, skip the next section and go to Day 17. A trampoline between the fore and central beam will be installed anyway.

Slat Deck The solid slat deck is shown in figure 133 and 134 below. Cut the slats from 2 x 4 in (50 x 100 mm) lumber 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. Cut as many slats as required to fill the space between the hulls, keeping a distance of approx. two fingers between the slats. The slats are held in place by three cross beams made from 2 x 4 in (50 x 100 mm) lumber. One cross beam is placed on each end to lock in between the beams, the third one reinforces the center. All connections are made by rope lashings.

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

Figure 133: Pre-lashed deck slats treated with boiled linseed oil

The entire deck complex is treated with boiled linseed oil for preservation and rot prevention. 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

Day 16

for the deck, as a damage to the epoxy coat is very likely to happen (lots of edges and people walk on it) and a damaged epoxy coat accelerates the rot process.

(a)

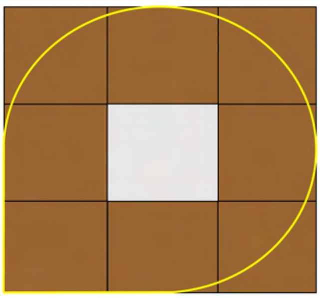
(b)

Figure 134: Slat deck mounted between hulls and beams

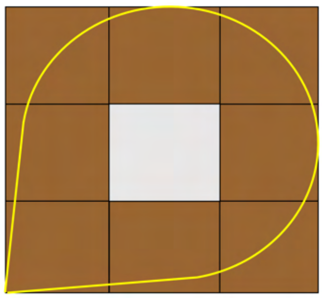
8.17 Day 17

8.17.1 Task 110: Plane and shape the spars

Plane the spars glued yesterday according to figure 135 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 135: Teardrop shape of the WAM Catamaran spars

8.17.2 Task 111: Drill the spars

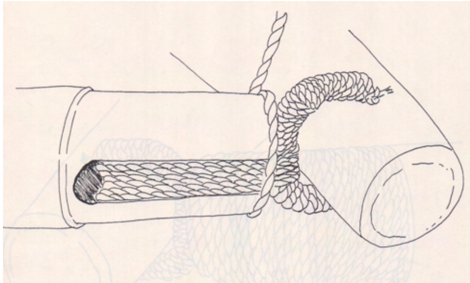
The sail is lashed to the spars. Therefore, drill lashing holes into the pointy side of the spar. The sail will be lashed on with 30-lb fishing line, the lashing holes can be small. Place them approx. one hand width apart from each other.

Figure 136: Lashing holes for the sail

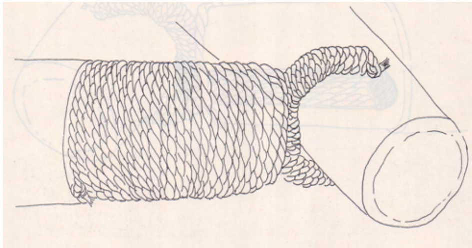
8.17.3 Task 112: Lash the spars

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 137 and 138 below.

Figure 137: Lashing of the spar front ends (*kapelpel*)



(a)



(b)

Figure 138: *Kapelpel* lashing as documented by Denis Alessio[30]

8.17.4 Task 113: Sand everything

Sand the entire surface of both hulls in preparation for painting. Rudders, tillers and hatch covers are already sanded. Do not sand through the glass fiber. Just rough it (make the shiny surface disappear) by using 180 grid sand-paper.[31]

8.17.5 Task 114: Glue the hatch hinges on

Glue the hatch hinge plates on (with a fillet) as shown in figure 126.

8.17.6 Task 115: Glue the mast foots and beam blocks on

Glue the mast foots and beam blocks on the hulls as shown in figure 139.

[30] Alessio 1989

[31] If you build the PPC pipe keel protection instead of the hardwood keel-shoe this would be the time to glue the PPC pipes on. See Task 94 for details.

(a) Eight hardwood blocks of the same size are cut as support for the cross-beams

(b) The blocks are glued at the position of the beams - right in front of the cabin bulkheads and above the beam cleats. The mast feet are placed right on top of the second bulkhead. The exact position of the bulkhead is determined by knocking on the deck and listening for the change of sound of the knocks (you will hear the sound of where it is less hollow above the bulkhead).

(c) The blocks should not touch the cabin bulkheads to allow water to drain.

(d) The mast feet are placed on what will later be the outsides (right and left) of the catamaran, so on one hull the mast foot is on the right side, and on the other one the left.

(e) Direct contact between deck and beams would create a narrow gap which would be difficult to maintain and always wet.

Figure 139: Manufacturing and mounting of the beam support blocks

The mast foot should be placed on top of the bulkhead as shown in figure 140.

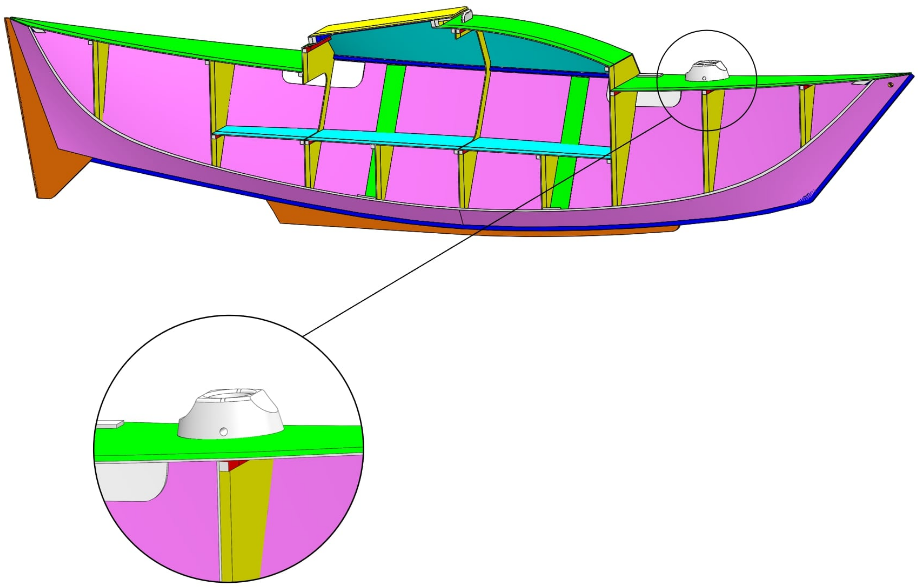


Figure 140: Beam blocks and mast foot glued on top of the decks

Figure 141 shows how the hull looks like after this task.

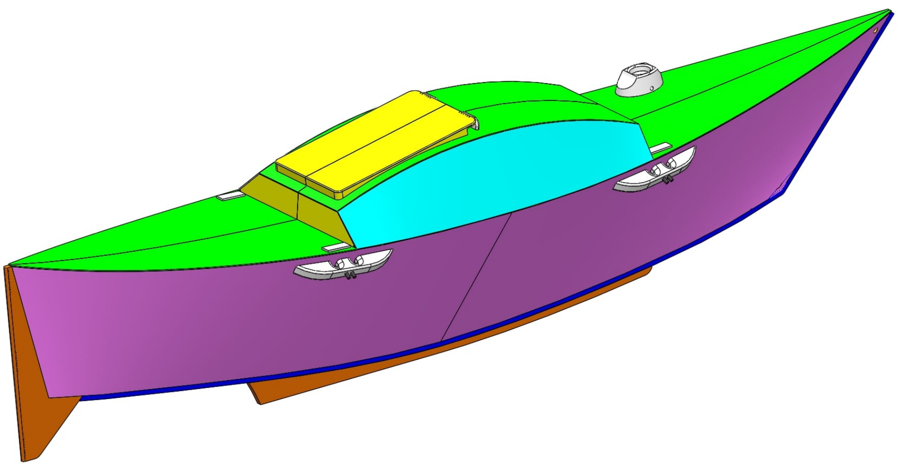


Figure 141: Beam blocks and mast foot glued on top of the decks

8.17.7 Task 116: Finish the beams

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 three layers of glass fiber cloth.

The three bare beams are finished by adding further location specific parts: All beams are equipped with end blocks on each side on the top ends (see figure 142 a) below). The end blocks keep the beam lashings from sliding off the beam ends. The end blocks should be made from hard wood.

Other features of the beam to be added are the alignment blocks on the bottom of the center and rear beam. They are shaped like the end blocks, but positioned in such 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. The contact area of beam and beam blocks is further reinforced with glass fiber cloth as rot prevention.

The aft beam is further equipped with hardwood cleats for the backstays. The cleats should be mounted as shown in figure 142 a) below. They are designed to cleat a knot o the backstay rope into them. To release the backstay, even under tension, it is enough to pull the loose end up.

The fore beam is equipped with three sail steps (*depakaak*) from hardwood as shown in figure 143. Shape them and glue them on with epoxy glue.

(a) Hardwood backstay cleat (rear beam only) and end block

(b) Hardwood backstay cleat (rear beam only)

(c) Alignment blocks on the bottom of the beam: The contact area between the beam and hull is reinforced with additional glass.

Figure 142: Modifications of the bare beams for the WAM Catamaran

(a) (b)

Figure 143: Depakaak (tack mounts) on the front beam.

8.17.8 Task 117: Oil the spars and masts

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 118: Clean and paint the hulls

Sand all parts glued and coated yesterday. Clean both hulls, beams and hatch covers with soap and fresh water. Wash the soap water and the last remaining dust off with fresh water. Apply paint to the dried hull as recommended by the paint manufacturer. Simple exterior house paint is fine.

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

(b) Brushes are used for detail work only

(c) The edges are carefully finished with a paint brush

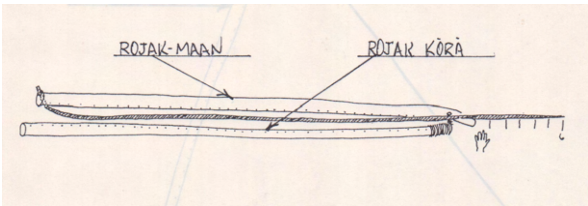
(d) The main surface is painted using rollers

Figure 144: Painting the hulls

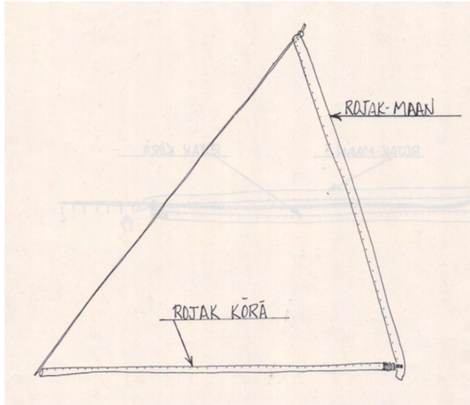
8.18.2 Task 119: Measure and cut the sail

Cut the sail cloth[32] according to figure 145 below.

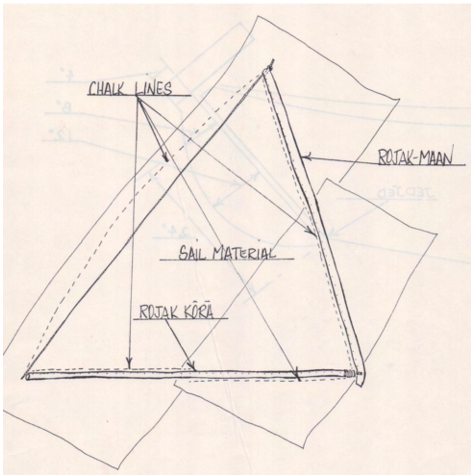
[32] For this manual it is assumed that dacron (polyesther sail cloth) is used. Alternatively polytarp or canvas can be used for the sail.



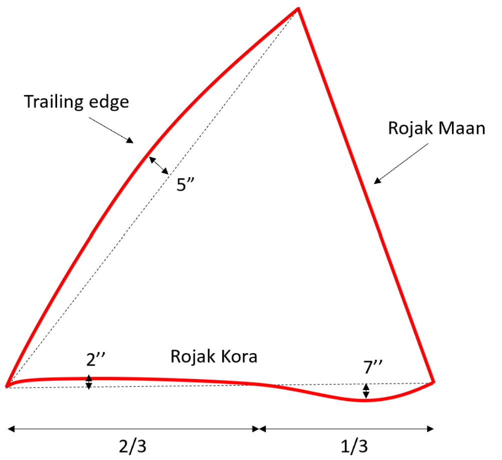
(a) Attach a string to the top end of *rojak maan* (upper spar), measure it six hand spans longer than the *rojak maan*. Attach the loose end to the tip of *roja kora* (lower spar or boom).



(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 145: Measure and cut the sail cloth.[33]

Cut the sail cloth panels along the lines drawn in figure 145 with an offset of three fingers (2 in, 50 mm) to the outside (cut the panels larger than measured).

8.18.3 Task 120: 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.

[33] 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 145 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.

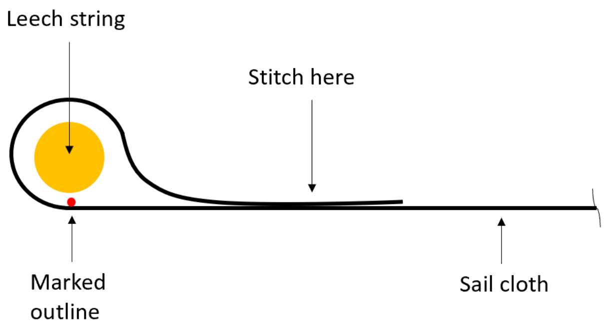


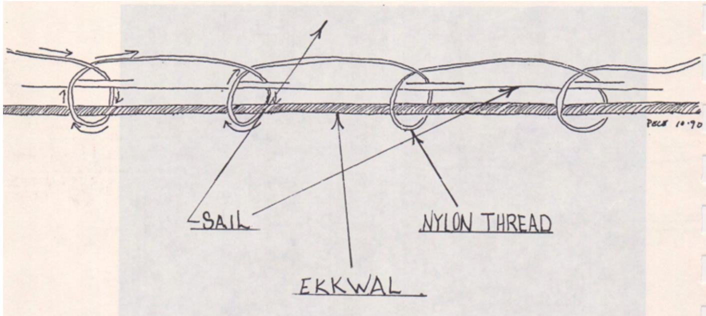
Figure 146: The edges of the sail are reinforced by leach strings.

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.

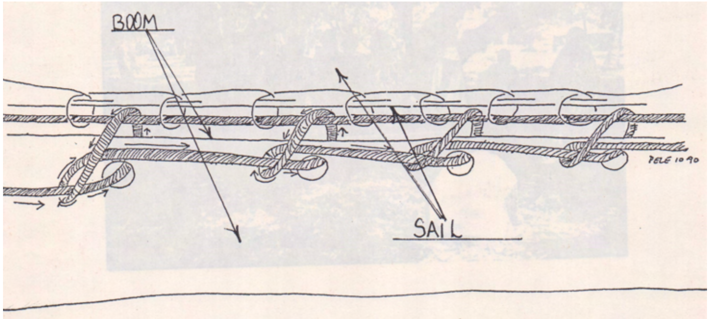
8.18.4 Task 121: Stitch the sail to the spars

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 147. The nylon thread (fishing line) is wrapped around the sewn-in leech string and the external connector string (in figure 147 from *ekkwal*[34] but any other material can be used as well).

[34]Traditional coconut fiber rope.



(a)



(b)

Figure 147: The way the sail is stitched to the spars as documented by Denis Alessio.Alessio 1989

The external leech lines are now sewn to the spars as shown in figure 147 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.

(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 148: Stitching the sail to the spars and setting up the trailing edge leech line

Assemble sail and masts as shown in figure 149 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 149: Indoor test of the rig

8.19 Day 19

8.19.1 Task 122: 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 150 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.

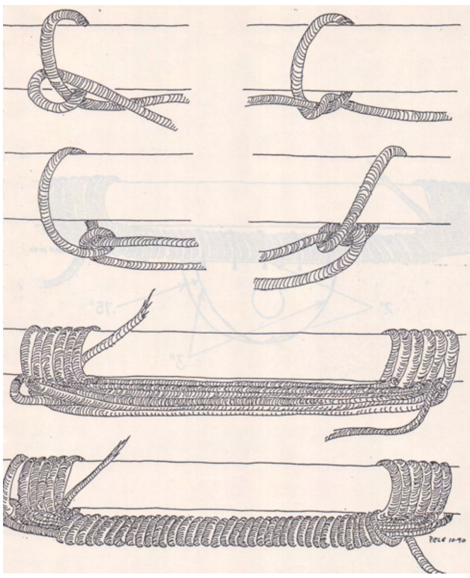


Figure 150: Main sheet (*iep*) bridle

8.19.2 Task 123: Lash the tiliej loops

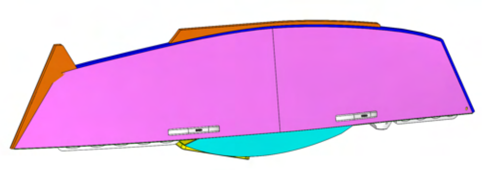
The *tiliej* or spilling lines are used to depower the sail and catch the upper spar when the sail is lowered (like lazy-jacks). Lash attachment loops to the lower spar in the center of the main sheet bridle the same way as it was done for the shroud loops (see figure 130).

Figure 151: *Tiliej* loops in the center of the sheet bridle

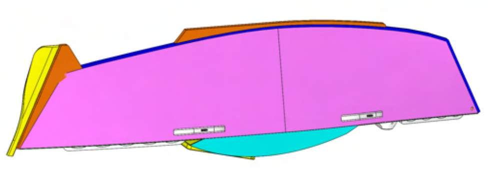
8.20 Day 20

8.20.1 Task 124: Assemble and launch the WAM Catamaran

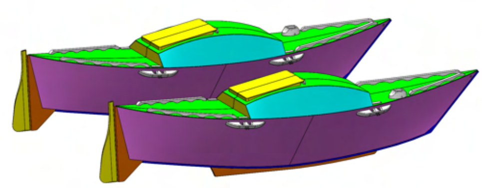
The assembly process of the WAM Catamaran is shown in figure 152 and 152. A detailed description follows below.



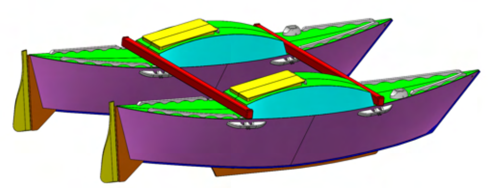
(a) Flip the hulls upside down and lash the keel shoe to the keel



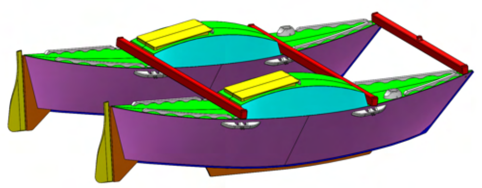
(b) Lash the rudder to the skeg



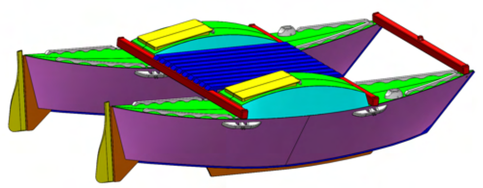
(c) Place the hulls next to each other on an even ground



(d) Lash the main and aft beam on the hulls

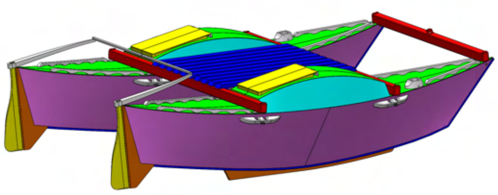


(e) Lash the fore beam on the bows

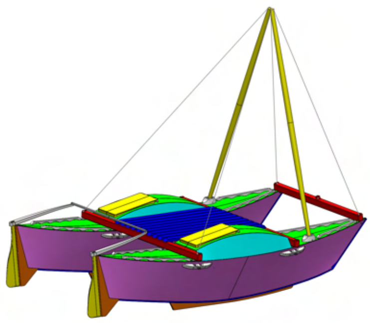


(f) Take the pre-lashed slat deck and place it between the main and the aft beam. Alternatively mount a trampoline net.

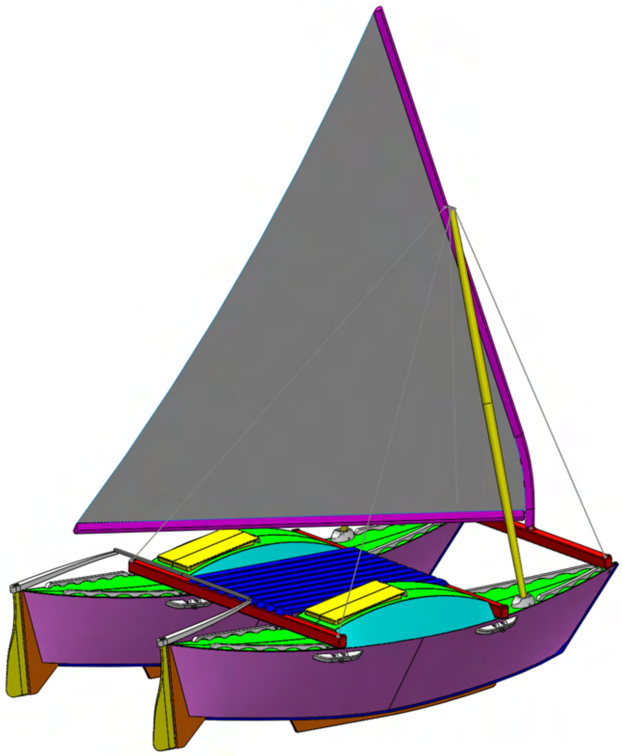
Figure 152: The assembly process of the WAM Catamaran (1 of 2)



(a) Mount the rudder handles and install the cross bar. The rudders should be parallel to each other, toe-in or toe-out is not necessary.



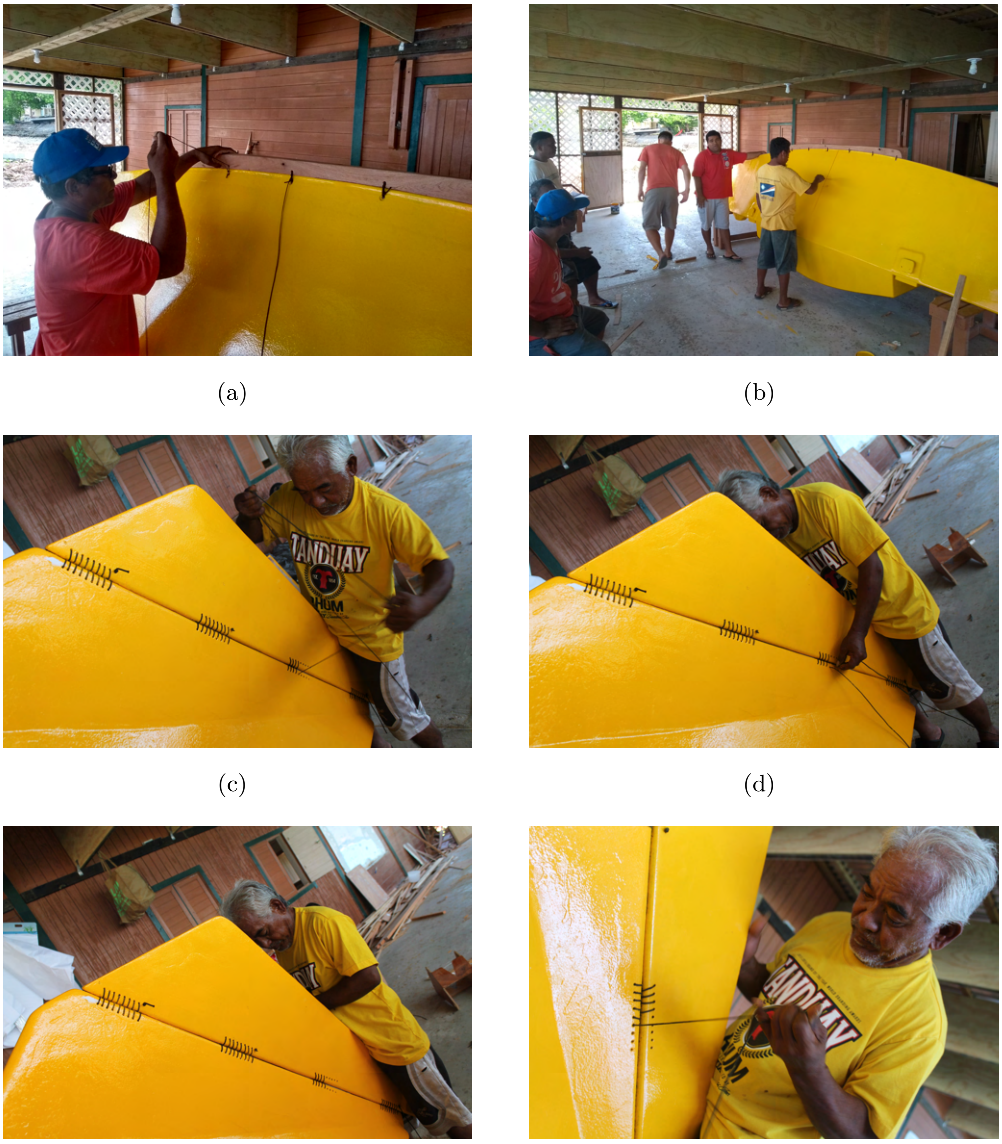
(b) Install the halyard and the spilling lines. Step the masts and lash them to the mast feet.



(c) Install the sail

Figure 153: The assembly process of the WAM Catamaran (2 of 2)

Start by lashing the rudders and the keel shoes on as shown in figure 154 below. The lashings must be pulled as tight as possible for a safe connection.



(a) (b)

(c) (d)

(e) (f)

Figure 154: Lashing of the keel-shoe (a-b) and the rudder (c-f)

Place the hulls on an even ground (ideally on the beach at low tide) in the cradles. Place the beams at their desired positions. The alignment blocks on the bottom of the beams should fit right in between the beam blocks on the deck. Temporarily lash the beams loosely in place. Measure the lineup of the hulls: The hulls must be parallel, otherwise the drag of the catamaran may be significantly increased. The parallelism of the hulls is simply measured with a string: The bows and the sterns should be apart by the same distance. Adjust the position of the hulls if required.

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

Start the beam lashings with a double overhand knot (stopper knot) as a 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 155 b). 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.

The front beam is simply lashed to the bow eyelets hence no beam cleats were glued on the bow area.

(a) The first hull placed in cradles in front of the slip way

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

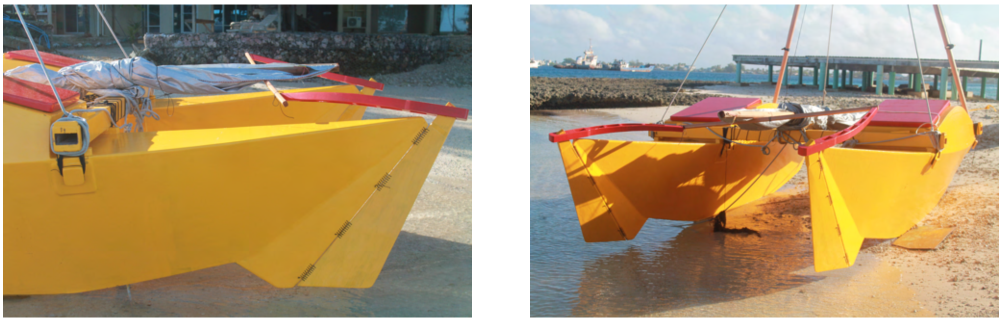
(c) Finish the lashing by wrapping the rope around the loops.

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

Figure 155: Lashing of beams and hulls. Note that the photos show a different type of beam cleat but the lashing is the same.

Next, the rudders are set up and adjusted. Start by mounting the rudder handles on the rudder heads. The handles simply slide on the tapered top of the rudder and lock in place with gravity.

Take the prepared rudder crossbar. It was already manufactured with a filled and re- drilled lashing hole on one end. Lash this hole to one of the tiller ends (both have lashing holes at the ends). Temporarily mount the bare end of the tiller crossbar to the other tiller handle by using a clamp. Now measure the parallelism of the rudders. The process is similar to the measurement of the parallelism of the hulls explained earlier: Use a string to compare the distance between the leading edge and the trailing edge of the rudders. Adjust the position of the tiller crossbar (clamp) until the distance between leading and trailing edge is equalized. Mark the position of the tiller handle on the tiller cross bar and drill a lashing hole. Lash the tiller crossbar to the lashing hole of the tiller. The tiller crossbar must be disassembled after the launch to seal (fill and re-drill) the just drilled lashing hole with epoxy.



(a) (b)

Figure 156: Rudder and tiller setup

Take the already lashed and oiled deck segment. Place it in between the center beams as shown in figure 157 and secure it in place with lashings. Cover the space between deck and front beam with a trampoline net. Lash it tightly between the toe rails and the beams.

(a) (b)

Figure 157: Slat deck and bow trampoline

The A-frame mast is raised in a final step before launching. Place the masts (already lashed together at the top) on the deck of the catamaran, with the mast feet facing to the front. Attach pulleys, for the halyard and the spilling lines, directly to the mast top lashing (see figure 129 d). Then, attach lines for the fore- and back-stays to the lashed-on loops close to the mast head. Pull the halyard and the spilling lines through the pulleys and cleat them at their designated clamps on the lower section of the masts. Attach another pair of pulleys (or stainless steel rings) for the running back-stays to the outside lashings of the aft beam.

The mast bases (glued to the deck) have lashing holes. Drill a corresponding lashing hole in the mast ends and lash them to the mast feet. Raise the mast by pulling the fore stays and lifting up the mast head. Secure the back-stays to keep the masts from falling over to the front.

Adjust the mast rake to a vertical position (fine-tuning is possible later) and lash the fore-stays to the bow eyelets. The back-stays are cleat into the wooden hooks on the rear beam and secured with a stopper knot.

Mount the tack (*kapelpel*) of the sail in the central *depakaak* on the front beam. Attach the halyard to the halyard loop of the upper spar and the spilling lines (*tiliej*) to the loops on the lower spar. Attach the sheet (*iep*) to the large sheet bridle on the lower boom. Install a 3:1 purchase from pulleys to reduce the sheet load. The lower pulley of the sheet is connected to the center of the rear beam.

Remove the cradles and attach an anchor or mooring to a V-shaped bridle (the anchor line splits in two and is tied to each bow eyelet). Wait for the tide to lift the WAM Catamaran up (if it was assembled on the beach at low tide) or get ten people and carry it carefully into the water. Read the next section and enjoy sailing.

(a) Spilling lines attached to the lower boom.

(b)

(c)

(d)

(e)

(f)

Figure 158: The final setup

9 Sailing and maintenance

9.1 Setting up

Set up the rig as described above. For optimal upwind performance the upper spar of the sail should be almost vertical. Mount the rudder handles if they were taken off. Make sure the halyard is ready to hoist the sail and the spars are not tied together anymore. You are ready to go.

9.2 Launching

The WAM Catamaran is best launched down a beach or a ramp. It can be pull over the ground, the keel shoes protect the hulls. Make sure not to hit coral or rocks with the hulls.

9.3 Sailing

Unlike traditional Marshallese canoes, the WAM Catamaran does not have a distinctive windward and leeward side. It can face the wind with both sides equally well and changes the direction of travel by turning around like a car (see section Tacking and jibing below).

To start sailing 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. This is done while the catamaran is facing the wind. The spilling lines (*tiliej*) should be loose, the ends tied to the second mast cleat. To get going pull the sheet (*iep*) firmly and pull the rudder handle to windward to bear away. 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).

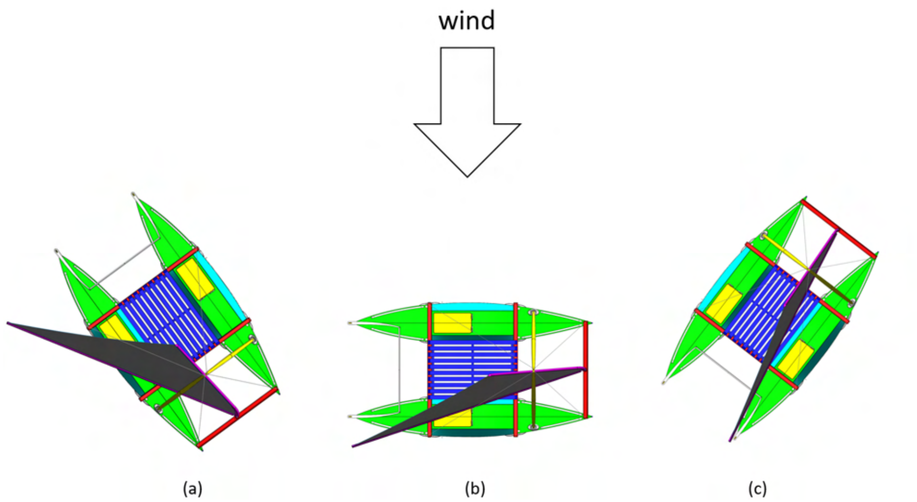


Figure 159: Sailing ownwind with the wind from behind (a), reaching with the wind from the side (b) and upwind with the wind ahead (c).

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

The course of the WAM Catamaran is controlled with the double rudder system. Simply pull the rudder handle right to turn left and the other way around.

The force of the wind in the sail always try to tip the WAM Catamaran over to leeward (capsize). The windward hull and the platform work as a counterweight to keep the WAM

Catamaran 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 Catamaran can capsize very quickly and the crew has only limited time to react. In this situation dump the main sheet (release it all the way) as quickly as possible to depower the sail and turn into the wind. To stop the windward hull from becoming airborne make it more heavy. Place cargo or people over there to be on the safe side. The WAM Catamaran is very safe and forgiving in strong winds. So far no capsizing has been reported.

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.

The leeward backstay cuts into the sail in a similar way as soon as the sheet is furled for sailing downwind. For a more effective sail shape the leeward backstay should be set loose, as it is not required to support the mast. Just don't forget to pull it tight again before tacking or jibing!

Like all sailing craft, the WAM Catamaran cannot sail directly against the wind. To reach a destination upwind zig-zag on a course close to the wind as shown in figure 160. Although it is possible to sail with the wind right behind, it is not recommended for safety reason. A small change of the wind direction or a slight turn of the WAM Catamaran might cause the wind to catch the sail from the wrong side and the boom to swing over. In this scenario the spars will likely brake and the crew might get injured.

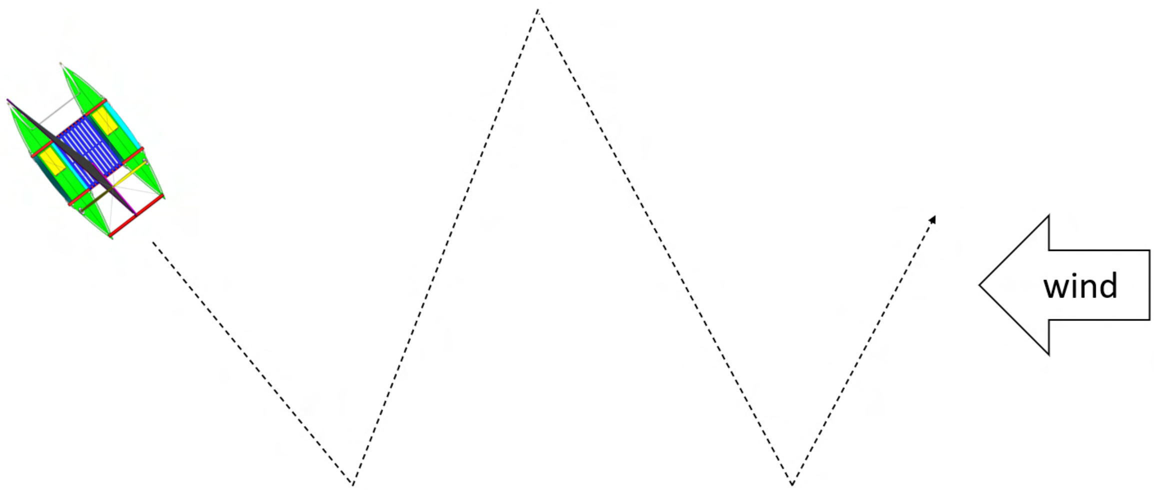


Figure 160: Sailing to a destination upwind in a zig-zag pattern.

9.4 Tacking and jibing

To come about, or in other words to turn around to face the wind with the other side, the WAM Catamaran has two options: It is possible to either turn into the wind or away from it. Turning into the wind and sailing through it is called tacking, turning away of it until the wind is blowing from the other side is called jibing.

9.4.1 Tacking

Tacking is a very simple and safe maneuver. Just make sure the catamaran has some speed, turn into the wind and wait for the cat to slowly turn through the wind until the sail catches the wind from the other side as shown in figure 161. Make sure the leeward backstay is tight before turning into the wind.

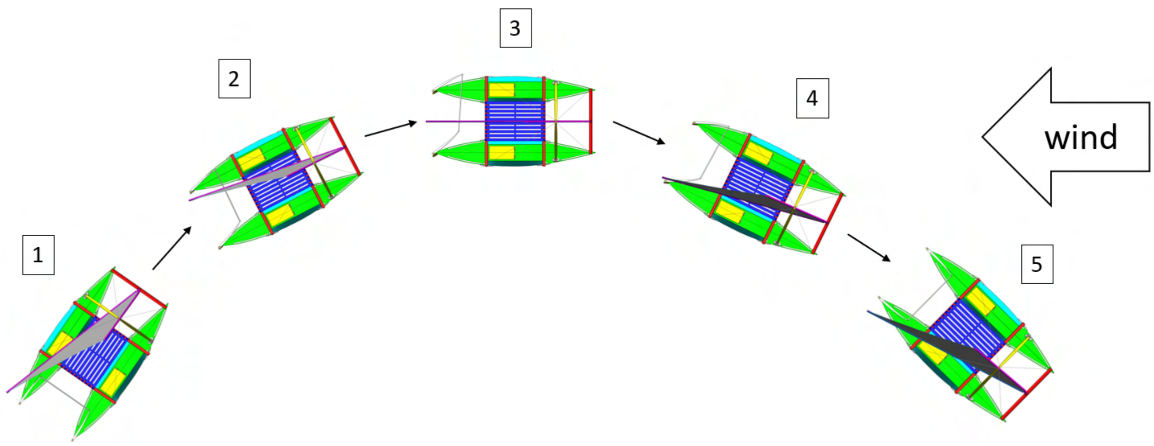


Figure 161: Tacking the WAM Catamaran.

In very choppy conditions or in strong wind it might happen that the catamaran gets stuck in a tack and starts to drift backwards. Most of the time the tack can be saved by turning the rudders into the opposite direction and backing up backwards. In case it doesn't work try another tack with more speed or jibe.

9.4.2 Jibing

Jibing works similar as tacking. Instead of turning into the wind the catamaran is steered downwind until the wind almost blows from behind as shown in figure 162. The boom is brought over the deck by pulling in the sheet and the leeward backstay is pulled tight (2 in figure 162). Now the catamaran is steered more downwind until the wind catches the sail from the other side and the boom swings over (2-3 in figure 162). Keep your head low, as the boom is very powerful, especially in strong wind. It is very important to pull the sheet tight before the boom swings around to limit the distance and therefore its swinging speed. Jibing with a loose sheet is very dangerous and can result in broken spars and serious injuries or death!

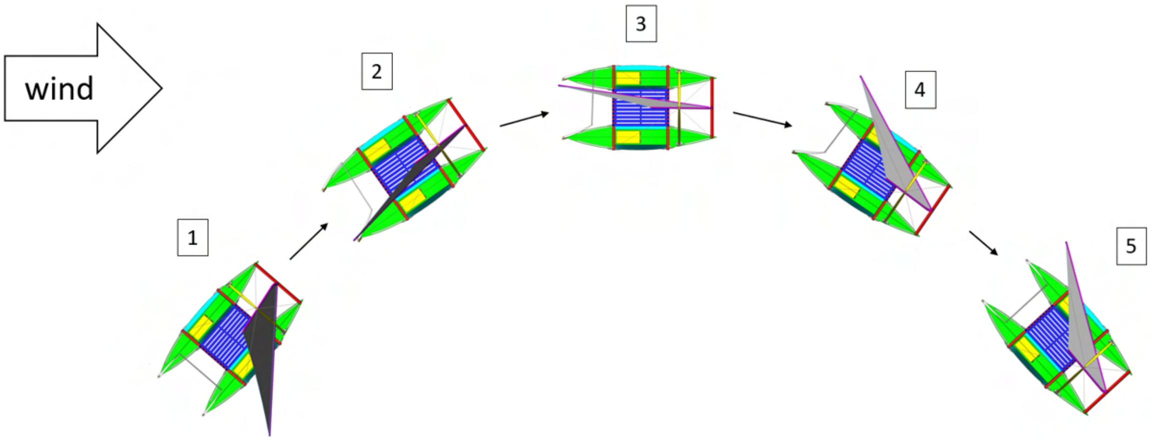


Figure 162: Jibing the WAM Catamaran.

9.5 Maintenance

A craft built the way the WAM Catamaran is built can last a very long time of up to 50 years and more. To get such a long lifetime out of your catamaran, constant care and maintenance is required. Since the catamaran 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 Catamaran 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, 47

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

butt-join A joint made by fastening the parts together end-to-end without overlap and often with reinforcement. 32, 46

capsizing To tip a boat over while sailing. 6

catamaran A water craft with two parallel hulls of equal size. 6, 8

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. 8

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

double hulled-canoe See catamaran. 3, 6

doublet An additional piece of lumber or plywood to reinforce a butt-join by overlapping the seam where both parts meet. 47

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. 9, 21, 22, 27, 29–32, 35–39, 43, 44

exothermic A chemical reaction that produces heat, such as the curing of epoxy. 25, 43

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). 9, 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

gunwale The top edge of the hull of a ship. 73

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

jibe Manoeuvre of a sail boat. The direction of travel is changed by sailing slightly off the wind until the boat faces the wind on the other side. 6

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

keel shoe Piece of hardwood lashed under the keel to protect it from getting scratched. 9

Light ship weight Weight of the empty watercraft. 8

lofting Lofting is a drafting technique to transfer lines from a plan to the full size material. It is used to draw lines on plywood sheets to cut them to the desired shape. 9, 45

Max. loading capacity Maximum weight that can safely be put on the watercraft. 8

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. 44

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, 10

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

rocker-line The rocker-line refers to the bend of the keel viewed from the side. 9

rudder Adjustable flap on the back of a boat used for steering. 6

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

single-handed To sail alone, operate a boat without crew. 6

skeg A fixed fin mounted on the back of a hull, often used to mount the rudder. 61, 63, 64

spline A continuous curve with a natural curvature. A spline can be designed by bending a batten or any other flexible straight object around a couple of fixed points. 58

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

tack Manoeuvre of a sail boat, wich allows the direction of travel to be changed by sailing into the wind until the boat is facing the wind with the other side. 6

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

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

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