Chapter 6
Designing the Best Catamaran

6.1 Introduction

This chapter illustrates use of the Analytic Hierarchy Process in the selection and design of a sailboat. How does one bring together one's ideas when designing a versatile sailing machine? Imagination plays an important role but is full of disconnected thoughts. The AHP was used to first choose the overall sailboat design, and then to select some fundamental hydrodynamic features of the newly designed boat.

There are four basic sailboat designs: sloop, ketch, catamaran and trimaran. The sloop has one hull and one mast. The ketch has one hull with one large mast located at the centerpoint of the yacht's deck, and a smaller mast (mizzenmast) that is usually located behind the helm (where the captain steers). Each vessel uses one mainsail and one jib (triangular shaped foresail), except for the ketch which also uses a mizzensail (mainsail on the mizzenmast).

A catamaran and a trimaran differ in only one major feature. The catamaran is made of two pontoons that are attached by a variety of spar configurations. Usually a tarp stretches between the two pontoons. The trimaran has three pontoons, with the center one being the main body of the vessel. These pontoons are usually connected by a reinforced fiberglass structure. Both the catamaran and the trimaran have one mast, that is located around the centerpoint.

By thoroughly evaluating each type of vessel, the AHP led to the development of a design comprising the best features of both the sloop and the catamaran. This new vessel design is called a Main-Hull-Mono-maran (MHM-maran). The MHM-maran broadly resembles a catamaran. It has two pontoons, but one is much larger than the other. The larger pontoon (major pontoon) is similar to a sloop in both size and appearance. The smaller pontoon (minor pontoon), is approximately 1/3 the length and 1/4 the width of the major pontoon. The minor pontoon is for added sailing performance while the major pontoon provides all living and storage facilities.

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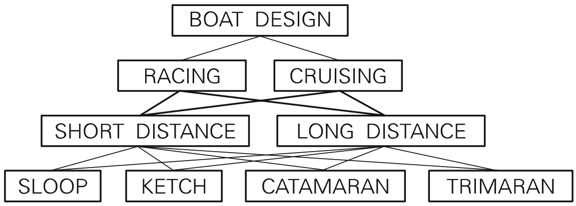


Fig. 6.1 Hierarchy of boat types

6.2 Basic Design

Four criteria were used (see Fig. 6.1) to evaluate the four alternative designs: catamaran, ketch, sloop and trimaran. With respect to sailing performance, both the sloop and the ketch have a greater ability to sail close to the wind (close-hauled position). But the marans are far lighter than their counterparts, thus they sail faster in most "points" of sailing. By points of sailing we mean the direction from which the wind is blowing: a run is with the wind blowing from behind, a reach is with the wind blowing from either side and close-to-the-wind (close-hauled) is with the wind blowing 30–35° off the bow.

The criteria were separated into two distinct categories: cruising and racing. With respect to personal design preferences, long-distance racing was the criterion that carried the greatest weight. Following it was short-distance racing, long-distance cruising and short-distance cruising, in that order. The goal was to design some sort of racing yacht.

Criteria	Weights
1. Short dist. racing	0.231
2. Long dist. racing	0.623
3. Short dist. cruising	0.052
4. Long dist. cruising	0.094

Until recently, the marans did not receive much respect when it came to structural integrity. They were not considered very seaworthy, and in storms the pontoons tended to break apart. But with the development of expensive and strong plastics, vast improvements have been made. Still, many sailors prefer the traditional structural strength of both the sloop and the ketch.

Evaluating each alternative with the above criteria revealed some interesting results. The catamaran, as almost every sailor knows, is superior to all other yachts when it comes to short-distance racing. It is very light and fast but it does not have adequate storage or living facilities, so it is not suitable for long-distance racing. Instead, the sloop was determined to be the best yacht for long-distance racing. It really did not matter which yacht was best for short or long-distance cruising, because neither of these criteria had significant weight to greatly affect the overall outcome. The overall weights of the alternatives are given by:

Alternatives	Weights
1. Sloop	0.379
2. Catamaran	0.348
3. Ketch	0.138
4. Trimaran	0.134

Notice how close the weights of both the sloop and the catamaran are. Up to this point, the results from each hierarchy were used without question, mainly because the final weights clearly marked which was the superior alternative. Before beginning this evaluation it was assumed that the conclusion would be the sloop. But this did not turn out to be the case. It was the catamaran. The catamaran ended up following the sloop by only 0.031. This led to an entirely new conclusion—the development of a sailboat that takes advantage of the distinct characteristics of both the sloop and the catamaran.

6.3 The Best Combination of Catamaran and Sloop: *A New Alternative*

Since a sloop consists of one large hull, and a catamaran consists of two pontoons, a yacht that combines both characteristics will have to be somewhere in between. Two options are possible—a yacht with one main hull and a single fixed pontoon or a yacht with a variable pontoon. This is where the concept of the Main Hull Mono-maran enters. It is a distinct yacht that has one large hull (main hull) that is shaped much like a sloop's hull. It also has an attached pontoon which provides the vessel with characteristics typically associated with a catamaran. When the sea is rough, one has the option to have the pontoon trail the vessel.

There are only two alternatives in this hierarchy, Yacht A and Yacht B. The only difference between them is that A has a fixed pontoon whereas B has a variable one which can move from the port to the starboard side and vice versa. There are three criteria: Agility (0.558), Stability (0.122) and Anchorability (0.320).

AGILITY is the ability of a design to quickly maneuver under sail. STABILITY is the ability to keep the yacht heeled as upright as possible. Finally, ANCHORABILITY refers to how easy it is to, or not to, anchor or dock the yacht. A fixed pontoon limits docking ability because the dock (slip) needs to be sufficiently wide to accommodate the vessel. The final weights for the two designs are given by:

Alternatives	Weights
Yacht B	0.696
Yacht A	0.304

Thus, in this hierarchy, Yacht B, the model with variable pontoon, is decidedly preferred.

Now that a basic yacht concept has been derived through the process provided by the AHP, the specifics of the MHM-maran, namely, the keel, the rudder, and the sails were designed.

6.4 The Keel

The keel is the most important hydrodynamic feature of any sailboat. A keel is responsible for a boat's stability and prevents it from sliding across the water on certain points of sailing (close-hauled & reach position). Once a keel is chosen, the rudder is relatively easy to design. As the hydrodynamics of the rudder are dependent upon those of the keel: there is a close relationship between keel and rudder.

Since the Australians introduced a winged keel in the 1983 America's Cup, there has been a tremendous amount of research in this area. Many of the keel test results are not available to the public, since it is mainly the very competitive yachting syndicates that perform and sponsor these activities.

When selecting a keel, performance and practicality were considered (see Fig. 6.2). The criteria were: mud, rock, sand and the degree of heel of the yacht. The mud, rock and sand elements were selected, because these are the substances that sailors most often hit when they go aground. A keel provides stability and many other performance factors, but in this case only the degree of heel (leaning to one side) was taken into consideration. The two criteria (performance and practicality) were considered equally important, and within practicality, the three substances the keel can come in contact with are also considered equally relevant.

Thus, we have:

Criteria	Weights
Heel	1/2
Mud	1/6
Rock	1/6
Sand	1/6

Keels are classified into three basic types—winged, torpedo and fin. A deep keel was not considered because such keels have been outdated and are poor performers. Generally speaking, a winged keel provides the least amount of heel because of the lift action that each wing creates as it glides through the water. The wings actually serve as a vertical stabilizer. As the yacht heels (leans on its side), the wings keep the boat a few more degrees upright. The benefit of such a feature is that it allows the vessel to catch as much wind as possible, while minimizing the amount spilled. However, a winged keel is unsuitable for the MHM-maran, because the minor pontoon will serve the same purpose. When the minor pontoon is correctly positioned on the leeward side of the vessel, it will

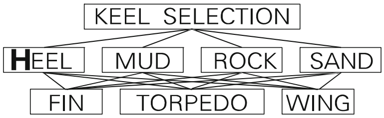


Fig. 6.2 Keel selection

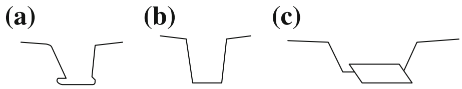


Fig. 6.3 Types of keels. **a** Torpedo keel. **b** Fin keel. **c** Medium oft-sweeping wing keel

effectively reduce the vessel's degree of heel. When evaluating the criteria, the wing was the least favored.

The torpedo keel outperforms the fin keel with the respect to heeling because the torpedo limits the amount of heel. The torpedo keel is given that name because it is a standard fin keel with a torpedo shaped bulb on the bottom (Fig. 6.3a). It is no longer a common type of keel, but at one time it was thought that having much of the lead weight at the base of the keel would act as a stabilizer. Some designers have combined the features of both the winged and torpedo keels.

The most common keel is the fin keel (Fig. 6.3b). It goes straight down deep and tends to draw much water. Variations of the fin keel exist, such as a shoal draft keel which draws less water, but is thicker and longer. The shoal draft keel was not considered because it is not a good hydrodynamic performer. The fin keel was favored and after placing it on the major pontoon, it was found to be an excellent choice. When sailing in a close-hauled or reach position, the fin keel would reduce the MHM-marans sliding effect across the water.

The winged keel presents a problem in mud (Fig. 6.3c). If one runs into mud, there is a good chance of getting stuck. The wings tend to anchor themselves into the mud, making it difficult to break away. The torpedo keel is no worse than the fin keel, but the bulb base can also stick into the mud.

Rocks are a problem for all keels. Sailing in shallow waters with a rocky bottom is hazardous. A winged keel does not fare well when it hits rock—structurally it can crack, or a wing can break off if the impact is sufficiently strong. A torpedo keel is better in rock than a winged keel but no better than a fin keel. A fin keel usually receives the least damage when its base hits rock. If the forward middle part of a keel is hit by rock, it could suffer chips and cracks.

When a boat hits sand, it goes "thump, thump" a sensation sometimes associated with engine problems. Fin and torpedo keels do about the same thing when hitting sand, causing the boat to skid across. With a winged keel, one needs to be concerned as to whether or not enough thump is due to one of the wings, which could break off. We have:

Alternatives	Weights
Fin	0.391
Torpedo	0.352
Wing	0.257

We determined that the fin keel is the best suited for our purposes. Earlier, we spoke of its hydrodynamic advantages. With respect to the environment, the fin keel is the least affected by different bottom surfaces. It is relatively easy to get out of the mud, and it is least damaged when coming into contact with hard surfaces.

6.5 The Rudder

There is a definite relationship between a keel and a rudder and once the keel type is selected, the rudder more or less falls into place. What had to be considered was the rudder work coefficient (CWR) and the angle of deflection. These became the criteria. There are three basic alternatives—an attached rudder, a skeg type and a spade rudder (see Fig. 6.4).

The attached rudder is connected to the keel with hinges (Fig. 6.5a). At one time, this type of rudder was widely used, especially when the yacht had a deep keel (a keel that began shortly after the bow and went all the way back to the aft). Neither deep keels nor attached rudders are in much use nowadays.

The skeg rudder is made in a variety of shapes and sizes (Fig. 6.5b). It is not attached to the keel. Rather, it is attached to a skeg that extends from the base of the hull. The theory behind such a design is that it is more streamlined and allows water to pass slightly faster by the rudder, thus making the rudder's movements more effective.

The spade rudder is the sailing industry's most commonly used rudder (Fig. 6.5c). It is attached to a rudder post which in turn is connected to the helm (steering wheel) by a pulley assembly mechanism. It is also made in a variety of shapes and sizes. Some go deep, but never deeper than the deepest point of the keel, while others tend to be less rectangular. This type tends to be the number one choice among yacht manufacturers today, mostly because it is easy to configure hydrodynamically with specific keel characteristics. Thus, it was not surprising that the spade rudder was the most favored. Spade rudders are commonly used in conjunction with fin keels.

Criteria	Weights	Alternatives	Weights
Rudder work coefficient	0.556	Spade	0.470
Angle of deflection	0.444	Skeg	0.319
		Attached	0.211

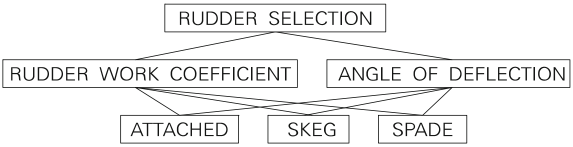


Fig. 6.4 Rudder selection

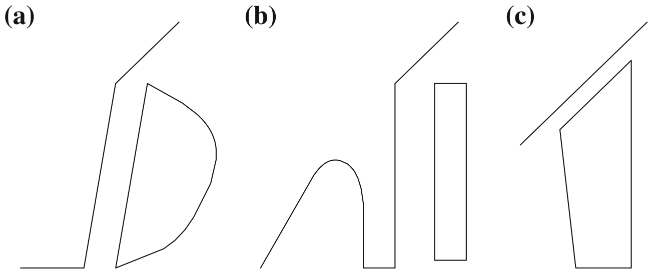


Fig. 6.5 Types of rudders **a** Deep keel with an attached rudder. **b** Skeg type rudder. **c** Spade rudder

6.6 The Overall Mhm-Maran Structure

So far we have selected the major underwater hydrodynamic features and the basic overall design (see Fig. 6.6). Now it is time to take a closer look. The big design problem is connecting the pontoons together. There are only two choices at this stage: one solid piece, or two poles (see Fig. 6.7).

Each choice had to be flexible enough, so that it would move with the pontoon to the other side of the vessel. A solid connection, that leaves no visible gap between both pontoons, raises the question of seaworthiness. Such a structure could get swamped by a wave and break. Also, a solid structure would weigh more than two poles, thus adding to the overall weight of the vessel.

By comparing both alternatives with respect to the criteria: the poles were most favored except on strength. Using poles is not only less expensive, but easier to design. On the main pontoon, a dual track assembly would follow the rear perimeter on which the ends of the poles would be attached. On the minor pontoon, two curved tracks would travel along the centerline where the poles would also connect (Fig. 6.8).

Criteria	Weights	Alternatives	Weights
Ease	0.637	Poles	0.528
Strength	0.258	Solid	0.472
Weight	0.105		

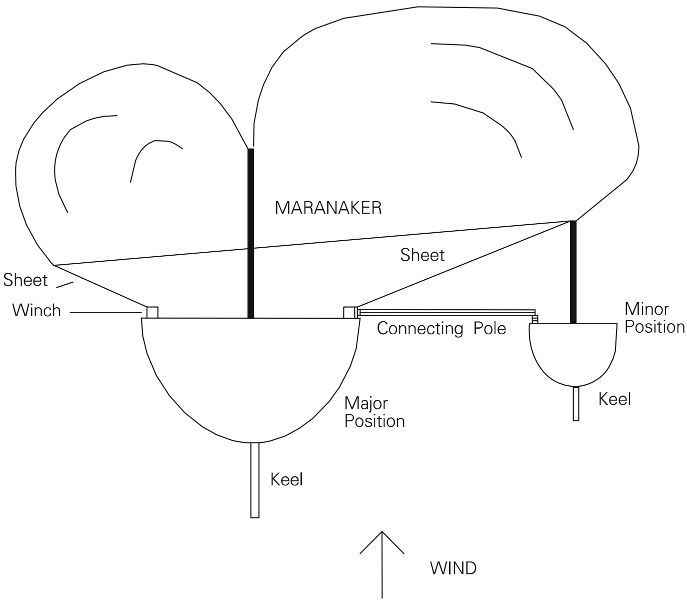
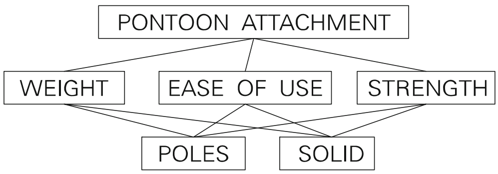


Fig. 6.6 MHM-maran on a run position

Fig. 6.7 Pontoon attachment



This design connects the two poles, and the tracks serve to provide the poles with movement, allowing the minor pontoon to swing around the main hull (Figs. 6.9 and 6.10).

The poles are strong, present no problem with respect to seaworthiness, and would be much lighter than a solid structure. Poles can also extend and retract, thus they are most suitable for the necessary pontoon swings.

Next we selected the material from which the pontoons would be built (see Fig. 6.11). The possibilities are fiberglass, aluminum, titanium and stainless steel. These materials happened to be the most resistant to rust. Titanium is light, strong but also very expensive and difficult to work with. Yet, it is a popular metal among the yacht racing community, because of its lightness and strength. Aluminum alloys are much cheaper than titanium and are sufficiently strong for most yachting needs. Aluminum is light, but much heavier than titanium. Fiberglass is good for salt water, but it is also heavy. It cannot undergo much direct stress. Stainless steel is relatively expensive and heavy, yet it is very strong.

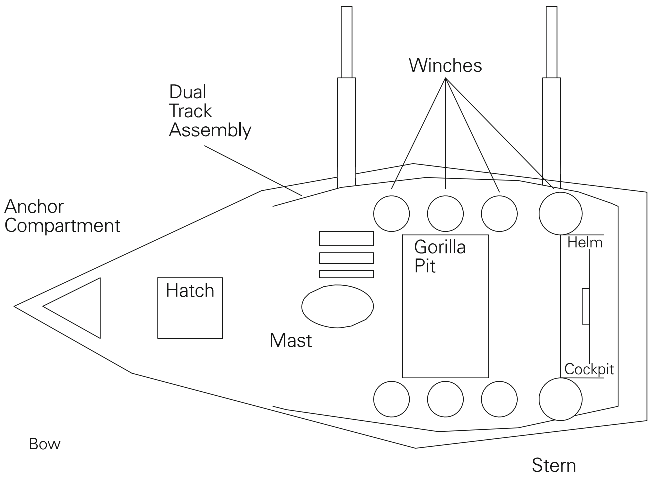


Fig. 6.8 Main hull

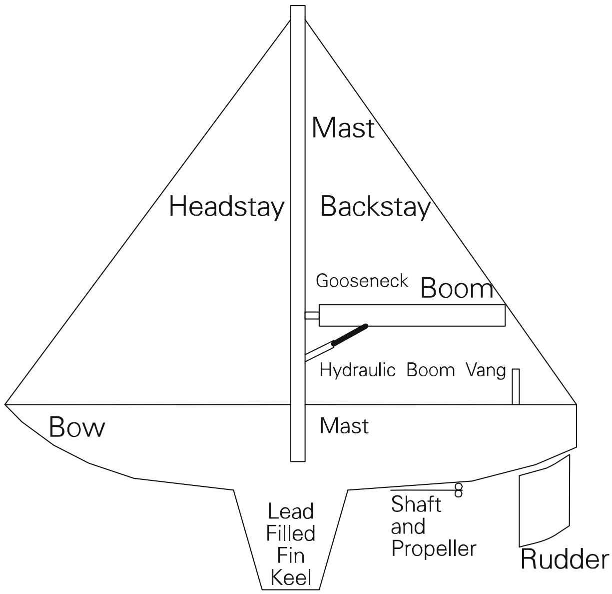


Fig. 6.9 Main hull side view

By having a dual track assembly follow the aft half of the major pontoon's toe rail (see Fig. 6.12) the minor pontoon would be mobile. It would be able to swing around to the leeward side (the side where the wind exits the surface of the boat) to minimize the MHM-maran degree of heel. On the run position, it would not matter which side the minor pontoon is positioned, since the wind is blowing from

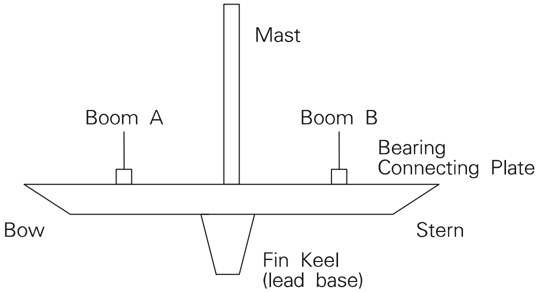


Fig. 6.10 Pontoon side view

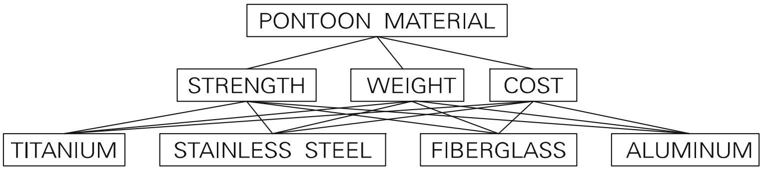


Fig. 6.11 Pontoon material selection

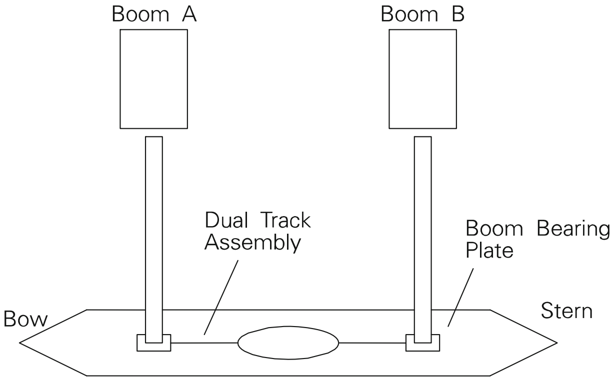


Fig. 6.12 Pontoon top view

behind. The evaluation of all materials with respect to strength, cost and weight gave rise to titanium as the most favored. This guarantees that a strong, and flexible connection would be made between both pontoons.

Criteria	Weights	Alternatives	Weights
Strength	0.648	Titanium	0.564
Weight	0.230	Stainless Steel	0.161
Cost	0.122	Fiberglass	0.063
		Aluminum	0.212

6.7 Conclusion

The hierarchic conceptualization of sailboat design yielded the unique MHM-maran structure. With one large and one small pontoon (connected by two poles made of titanium), a fin keel, spade rudder and a never before seen sail (maranaker), it offers many performance benefits to the sailor and it is being considered by a contemporary sailboat manufacturer. However, it may be expensive for the average sailor.

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