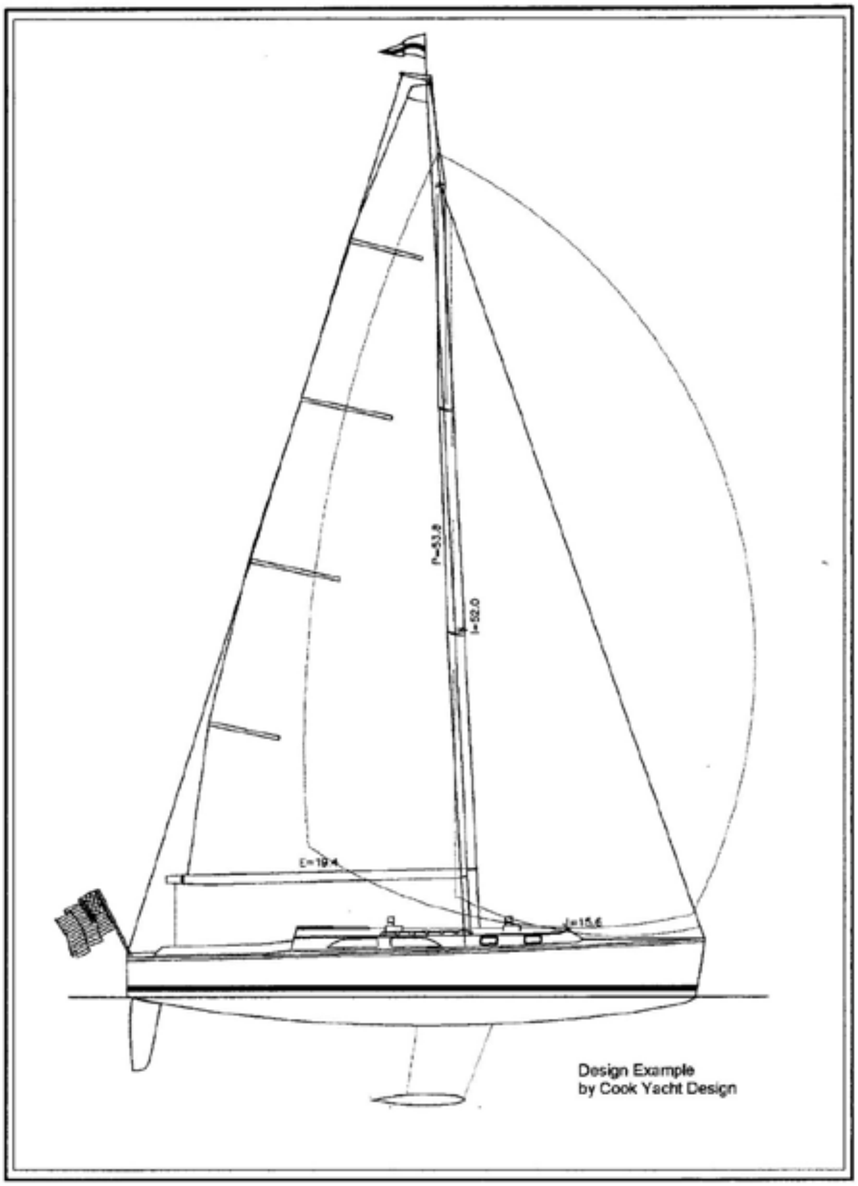
Green Yacht Design Recommendations

Prepared By The

CCA Green Yacht Design Committee

April 15, 2013



Modern and Efficient Yacht for Base to Develop a Green Yacht

Introduction: We have formed a small group of CCA members with a common interest in finding ways to make our yachts more sustainable in this world of ever scarcer and expensive materials, and greater concerns for environmental degradation. Our concerns may be applied to the immediate future but ultimately our interest is for the long term. We want yachting to flourish and to allow others to enjoy the sport as we have. It has been a vital part of our lives. The recommendations of our Committee are presented to promote further discussion and action within our sailing community.

Our objectives have been to evaluate a 40-ft. LOA monohull yacht for coastal and blue water cruising and racing which would have minimum impact on the environment during construction, operation, maintenance, and eventual decommissioning. The design should consider the general outline defined in “Desirable and Undesirable Characteristics of Offshore Yachts” published by the CCA. The design will be distributed to the CCA membership for discussion, and then possibly published to a wider audience. Hopefully the recommendations of our Committee are presented herein to promote further discussion and action. This report addresses two classes of opportunities to employ green considerations: yacht design and equipment.

Such terms as Life Cycle Assessment and Carbon Footprint should be important considerations in future yacht design, but these evaluations are complex processes. We have come up with a way to evaluate the yacht in a simpler fashion. Since a yacht is primarily constructed of a single material, such as wood, glass/ polyester resin, or metal, we have only considered these major construction materials. A typical 40-ft. LOA yacht has 960 Ft^2 of surface area when including the hull and deck. We have used this area in our evaluation and have come up with comparisons between the materials expressed in terms of Embodied Energy. This and other definitions are defined below.

Embodied Energy is the sum of all the energy required to produce goods or services, considered as if that energy was incorporated or “embodied” in the product itself. Our measurement is in Barrels of Petroleum.

Life Cycle Assessment is a technique to assess the environmental aspects and potential impacts associated with a product, process, or service, by compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential environmental impacts associated with identified inputs and releases, and interpreting the results to help a yacht owner make a more informed decision.

http://en.wikipedia.org/wiki/Life-cycle_assessment

Carbon Footprint is defined as the total amount of greenhouse gases produced to directly and indirectly support human activities, usually expressed in equivalent tons of carbon dioxide (CO_2).

http://www.boatcarbonfootprint.com/

Green Yacht Design Considerations:

The Value of Petroleum: Let us put our concerns into sharp focus. Petroleum is a treasure. A barrel of oil contains 42 gallons. So let's think about how much energy there is in a barrel of oil.

A barrel of oil contains about six gigajoules of energy. That's six billion joules or 1,667 kilowatt-hours. No, we don't have any idea how much that is, either, so let's think about the equivalent. Sit a reasonably healthy male adult on an exercise bike wired to an efficient generator, and he can produce 100 watts. After he has pedaled an hour, he has produced 100 watt hours of energy, or 1/10 of a kw-hour. It will take a little more than eight 40-hour weeks to produce the energy in a gallon of gasoline. At minimum wage this gives a value of $2,194 / gallon. To produce the energy in a barrel, he would have to peddle for 8.01 years. This would have a value of $109,169.

Construction Materials: This report could go on and on if we detailed these items fully so we have simplified our analyses. The yacht has five major components: Hull, mast, keel, sails, and engine. You will need a keel, sails, and engine in any yacht, so we will not discuss these items. They would be built of conventional materials so we will skip over them for now.

Hull Material: Yacht construction materials can typically be Fiberglass Reinforced Plastic (FRP), Wood, Ferro Cement, or Metal. For metal, we would pick aluminum over steel. It appears to be a superior construction material because it is half the weight of steel, has less corrosion problems, and is very resistant to puncture. Ferro Cement, which is seldom used today, is included to provide an in-depth survey of materials.

For this analysis, we will focus on 1 ft^2 of construction material. For a typical 40-ft. keel yacht, the thickness of these materials would be: FRP = 0.5", Wood = 1.0", Ferro Cement = 1.15", Steel = 0.15", and Aluminum = 0.25". Each of these materials has different cost, strength, and embodied energy, which are reported and computed in rough terms in **Table 1**. Two complicating factors should be noted: First, it must be noted that thinner hull walls will have less stiffness due to the cubic relationship between thickness and section modulus, and so will require more internal structure (ribs and stringers) to produce the same hull shape and stiffness. These equivalencies have not been computed, rather hull thicknesses have been approximated simply based on known examples and general rules of thumb. The effect of internal structure on materials requirements is not quantified here but could be significant compared to the weight differences described. The second complicating factor is that for each of the reinforced materials (FRP and Ferro Cement), the fraction of reinforcement in the matrix strongly influences the embedded energy, as well as the section density, stiffness, and strength. In the case of FRP, because glass has less embodied energy than the resin used as a matrix, more reinforcing glass will reduce the embodied energy. In contrast, in Ferro Cement, the steel reinforcing has more embodied energy than the Portland Cement, and less reinforcing reduces the embodied energy. As with hull thicknesses, generic numbers have been used to represent typical or "rule of thumb" values. A fiber ratio in an FRP laminate where 50% of the volume is glass is very good (very high fiber), results in about 67% of the weight being glass ("fiber") and 33% of the weight being matrix ("plastic").

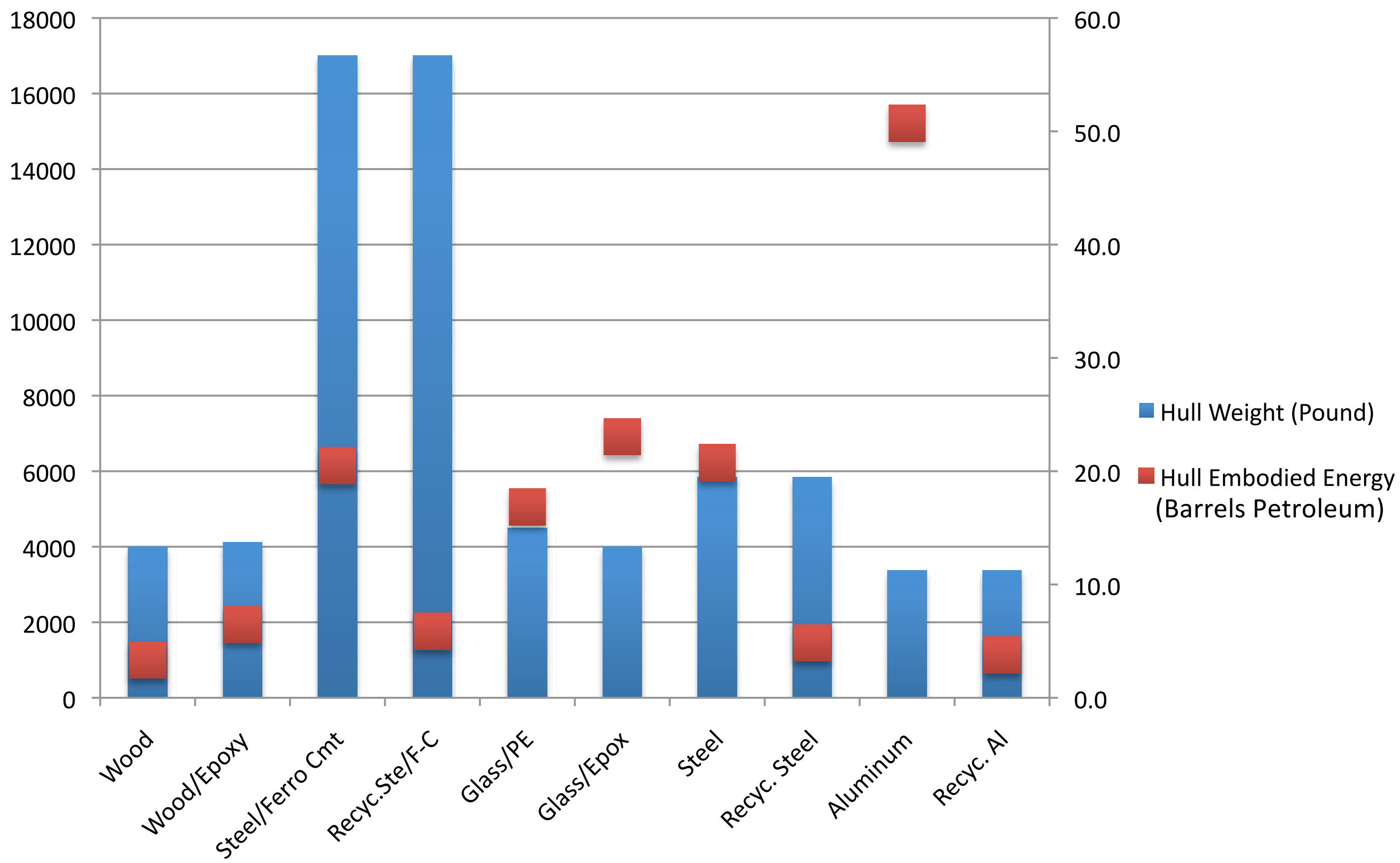
The hull of a 40-ft. monohull has roughly 960 $ft.^2$ of surface area. Total hull weights, while not given in **Table 1**, would be in ascending order: Aluminum 1,300kg, Wood 1,500 kg, 66% Glass/Epoxy 1,500 kg, 55% Glass/PE 1,600 kg, Steel 2,200kg, and Ferro Cement far higher than the others at 6,400kg.

The high weight of Ferro Cement means that certain hull geometries are simply not possible, and stability and motion in a seaway will be different from those of similar hulls made from lighter materials. By converting the embodied energy of each of these materials into a volume of petroleum, they can be compared by a familiar metric. The volume of petroleum equivalent energy to make these hulls, using the 6 GJ per barrel estimate discussed above, is given in the last column of **Table 1**.

Table 1. Embodied Energy of Various Materials in Hull Construction

Building Material	Hull Thickness	Volume % "Fiber"	Hull Weight per ft^2	Embodied Energy of "Fiber"	Embodied Energy of Matrix	Embodied Energy per ft^2	Hull Weight	Petroleum Equivalent in Hull
Units	**Inches**	**%**	**pounds**	**BTU / lb.**	**BTU / lb.**	**BTU**	**pounds**	**Barrels**
Wood	1	0	4.2	0	4,724	19,660	3,995	3.3
Recycled Al	0.25	0	3.5	0	6,356	22,318	3,371	3.8
Wood/Epoxy	1	95	4.3	4,724	57,975	38,281	4,120	6.5
Recycled Steel	0.15	0	6.1	0	6,442	39,208	5,843	6.6
Recycled .Steel/F-C	1.15	12	17.7	6,442	687	44,392	17,000	7.5
Glass/PET	0.5	40	4.7	20,613	22,331	99,730	4,495	16.9
Steel/Ferro Cement	1.15	12	17.7	20,184	687	121,344	17,000	20.5
Steel	0.15	0	6.1	0	20,184	122,852	5,843	20.8
Glass/Epoxy	0.4	50	4.2	20,613	57,975	136,324	3,995	23.0
Aluminum	0.25	0	3.5	0	85,459	300,093	3,371	50.7

Figure 1. Embodied Energy and Hull Weight of Construction Materials



Recycling of yacht construction material is a major concern. Aluminum and steel have proven pathways for recycling. Ferro Cement can be recycled through a smelting process but is seldom done. A major problem exists with glass reinforced materials. There is essentially no available way to recycle the materials. This is one major advantage in the use of aluminum since it is commonly recycled and there are available pathways for its disposal.

http://www.google.com/#hl=en&sclient=psy-ab&q=disposal+of+fiberglass+hulls&oq=disposal+of+fiberglass+hulls&gs_l=hp.12..0i22i30.4739.15919.0.18868.28.19.0.9.9.0.513.2459.8j10j5-1.19.0...0.0...1c.1.9.psy-

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Hull Design: We have considered recommending a specially designed yacht to meet the requirements of our green yacht. There are many very fine designs on the market as production yachts. We do not think we could make a material improvement over some of these yachts. So, instead we have decided to provide you with certain tried and proven hull designs which can be used in selecting a yacht or used as a design base to meet a green criterion. The characteristics of these designs are provided in the U. S. Sailing Performance Handicap data base. Using this data base we have applied design ratios for the yachts which are used in our evaluation. A list of these ratios and typical ranges used are in **Table 2**. The ratio ranges can be considered typical and should not be considered absolute or final. We have used the PHRF data for yachts in the 40-ft. LOA range. This list is shown below in **Table 3**.

Table 2. Green Yacht Design Committee - Yacht Ratio Selections

Desigh Ratio	Typical Ratio Range	
ORR Stability Index Ratio	SI	120 to 150
Displacement/ Length Ratio	D/L	200 to 300
Sail Area/ Displacement Ratio	SA/D	16 to 18
Sail Area/ Wetted Surface Ratio	SA/WS	2.5 to 3.0
Motion Comfort Ratio	MCR	20 to >50
(Ted Brewer Ratio)		

Data are shown for “sailing trim”, with crew and gear on board. Some definitions are:

1. Stability Index (SI) is a US Sailing estimate of resistance to capsize. It starts with the calculated heel angle at which the boat’s righting moment becomes negative, adjusted for: 1. size of the boat (larger boats are more resistant to capsize); 2. the boat’s displacement relative to its beam (beamy boats, though stable at low heel angles, are also more likely to remain inverted after a capsize).

Under US Sailing rules, boats must have a value of 115 degrees for Category 1 races, and 120 degrees for Category 0 races.

2. Displacement to Length Ratio (D/L) is calculated as displacement in long tons divided by the cube of LWL/100; lighter boats will accelerate more easily and will have higher speeds in fast sailing conditions.

3. Sail Area to Displacement (SA/D) is calculated as total sail area divided by displacement in cubic feet to the 2/3 power; higher ratios will indicate quicker response to the wind.

Note: Displacement (D) in paragraphs 1 and 2 above have different definitions for D. The definitions are traditionally used in naval architecture even with this ambiguity.

4. Sail Area to Wetted Surface (SA/WS) is a straight ratio between the two areas; higher numbers will point to boats that tend to sail better in light winds.

5. Motion Comfort Ratio (MCR) is somewhat of an arbitrary calculation. Motion comfort is a personal response to sailing a yacht at sea and varies from person to person. The MCR was introduced by Ted Brewer with tongue in cheek. However, it does help give some perspective in the evaluation. The formula for MCR is:

MCR=Displacement/(0.65*(0.7LWL+0.3LOA)*Beam^1.333)

6. Time on Distance (TOD) is expressed in seconds per mile. It is a General Purpose Handicap (GPH) calculated for a circular random course. It is an available output on the US Sailing PHRF data base. Lower numbers means faster yachts.

7. (SA/D)/(D/L) is a newly derived ratio of ratios introduced by Dan Nowlan at US Sailing. It provides a method to evaluate a yachts speed without actually having a speed rating. More will be said on this ratio of later in this report.

Table 3. PHRF Data for Production Yachts of 40-ft. LOA

Class	LWL	Beam	Draft	Disp.	WS	Sail Area	SI	D/L	SA/D	SA/WS	MCR	TOD GPH	(SA/D)/(D/L)
FARR 400D MH	37.2	13.0	8.7	13453	322.4	1089	126.4	116.6	32.47	3.56	16.7	539	0.278
OPEN 40	40.1	11.3	11.0	12783	316.0	998	115.3	88.6	29.97	3.24	18.2	545	0.338
X-41	37.4	11.9	8.4	18897	361.1	1029	127.1	161.0	23.75	2.92	26.2	579	0.148
J122	37.1	11.9	7.5	18236	352.1	955	118.3	160.0	23.25	2.86	25.5	580	0.145
BENETEAU 407	35.5	12.4	8.1	18260	340.4	889	121.5	182.4	25.46	3.24	25.3	603	0.140
SWAN 40	34.8	12.9	7.3	23407	358.0	893	120.6	248.6	22.03	3.15	30.7	627	0.089
SABRE 402	37.1	13.5	6.7	24544	401.9	933	118.6	214.6	20.93	2.75	29.2	633	0.098
C&C 40	33.5	12.8	7.7	19131	349.1	856	121.6	227.5	23.95	3.07	26.3	635	0.105
J 40	36.1	12.1	6.7	20636	355.8	818	121.0	195.4	21.98	2.90	28.9	642	0.112
NEW YORK 40	32.7	12.7	7.3	20599	341.3	817	124.7	262.1	23.28	3.20	28.8	643	0.089
TARTAN 41	32.9	12.2	7.1	22691	349.3	854	130.5	284.8	21.26	3.05	33.0	651	0.075
JONMERI 40	33.0	12.6	7.7	23984	364.7	814	123.4	298.2	20.64	2.94	34.0	657	0.069
BALTIC 39	31.2	12.5	7.1	20051	326.8	791	122.3	294.7	21.32	3.01	29.7	666	0.072
CAL 40	31.6	10.9	6.0	18279	342.5	768	124.1	259.5	21.93	2.78	32.3	695	0.084
BERMUDA 40	28.7	11.8	4.5	23102	320.4	923	122.4	435.9	22.30	3.53	38.2	700	0.051
CONCORDIA 40	29.1	10.0	5.8	19724	325.8	727	134.5	358.1	19.72	2.76	40.8	735	0.055

Common Production Yacht   Ratio Falls Within Typical Range

Table 3 provides information on sixteen yachts of 40-ft. LOA. Yachts in large circulation in the United States have been colored in blue. Yachts which fall within the ratio ranges of **Table 2** are colored in green. All the yachts in the list have been ranked in speed based on TOD with the fastest yachts at the top of the table. By reviewing the table, you can quickly develop a general understanding of the characteristics. The two fastest yachts, the FARR 400D MH and the Open 40 fall are outside of the MCR range and would generally be uncomfortable on a long ocean passage. Several yachts do not meet the SI criteria. This does not mean that they are not safe; however, they would have less tendency to return upright after capsize. D/L ratio indicates yachts which are quite light and those that are heavy. SA/D indicates yachts with excessive sail area. SA/WS indicates yachts which have considerable sail area and, thus, driving power beyond our typical range.

Finally, the last column gives a convenient ratio of ratios computed by (SA/D)/(D/L). This number correlates well with TOD speed calculations. This speed indicator was proposed by Dan Nowlan at US Sailing. **Figure 2** provides a scatter plot of the two quantities. A power curve has been fit to the data. A residual squares statistic indicates a very reasonable fit of the data at 0.8818 to the power curve. A perfect fit would be 1.0000. The reason this graph is presented is that it provides a way to determine speed performance of a yacht without going through the involved procedure of calculating a TOD rating. It is not a perfect predictor; however, it is simple and quick to use. In fact, there are always complaints when using TOD for rating racing yachts. Nothing is perfect in this field.

Figure 2. Graph Showing the Relationship between Time on Distance Versus (SA/D)/(D/L)

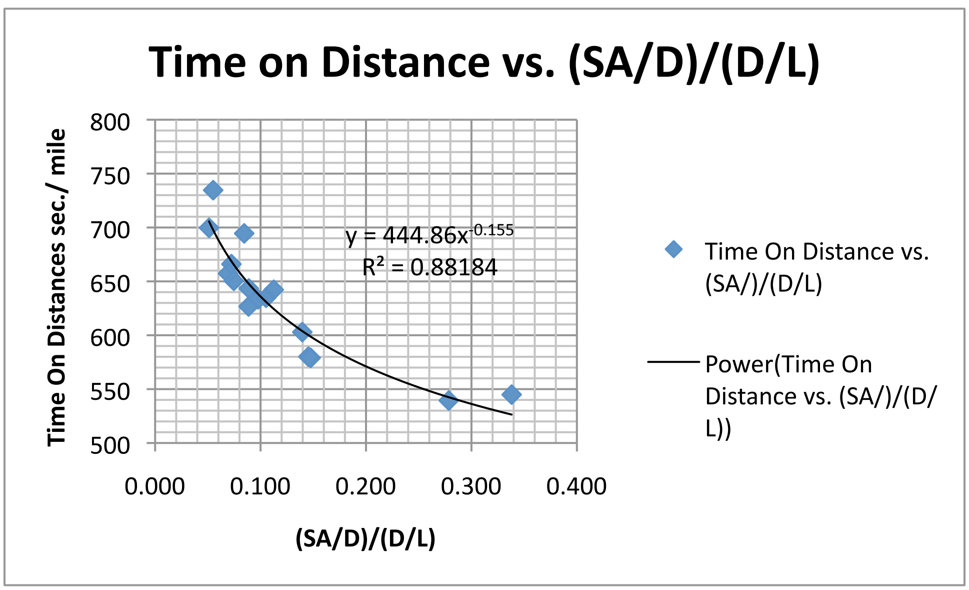

Table 4 provides URLs for the sixteen yachts listed in **Table 3**. It is very instructive to look over this data set. It helps provide a glimpse into the past of modern yacht design and foretells perils and possibilities for the future. When examining **Figure 2**, there is a gap on the power curve between what might be called the tried and proven conventional yachts and the two high-performance yachts in the lower right area of the graph. This gap may be a place where we might expect to see future

ocean-going cruising yachts fit. They would not be extreme designs in terms of very deep keels with heavy ballast deep on the keel, but light in weight and carrying more sail area. Another innovation might be using water ballast to ensure the yacht would be sailing on her lines with maximum comfort for the crew, because the boat would have minimum heel and less pounding in rough conditions. This would also improve the boat's Motion Comfort Ratio.

Our conservative approach to selecting a yacht design is based on realities. We want a yacht which is easy to sail, considering that we will find ourselves out at sea during dark and stormy nights. The unexpected can happen. We want to be able to respond to emergencies with a stable yacht under our feet, and one with predictable responses. We may find ourselves grounded on a rocky shoal pounding in a sea. We want to survive and get out of that dreaded situation. Probably Henry Thoreau summed up a good approach to modern life of his times which applies to yacht design, "Simplicity, Simplicity, and Simplicity."

Table 5. 40-Ft. LOA URLs

BALTIC 40	http://sailboatdata.com/viewrecord.asp?class_id=3327
BENETEAU	http://sailboatdata.com/viewrecord.asp?class_id=3158
BERMUDA 40	http://sailboatdata.com/viewrecord.asp?class_id=1650
C&C 40	http://sailboatdata.com/viewrecord.asp?class_id=2501
Cal 40	http://sailboatdata.com/viewrecord.asp?class_id=1977
CONCORDIA 40	http://en.wikipedia.org/wiki/Concordia_yawls
FARR 40	http://www.farr40.org/specifications.html
J 122	http://www.jboats.com/j122
J 40	http://sailboatdata.com/viewrecord.asp?class_id=2292

JONMERI 40 http://sailboatdata.com/viewrecord.asp?class_id=2536

NEW YORK 40 http://sailboatdata.com/viewrecord.asp?class_id=2514

OPEN 40 http://www.owenclarkedesign.com/Class40OpenRacingYacht

SABRE 40 http://sailboatdata.com/viewrecord.asp?class_id=3397

SWAN 40 http://sailboatdata.com/viewrecord.asp?class_id=2222

TARTA 41 http://sailboatdata.com/viewrecord.asp?class_id=3354

X-41 http://www.x-yachts.com/seeems/11884.asphttp://dan.pfeiffer.net/boat/ratios.htm

http://offshore.ussailing.org/Page1130.aspx

Green Equipment Recommendations:

We have reviewed suitable materials for a green yacht and how to select an optimum design from the vast array of production yachts. There is no single design item which can provide a great leap forward in providing an acceptable green yacht. As in the case with the development of a fuel efficient hybrid automobile, the result is the combination of many small improvements. Now we will suggest some steps you can take to make the use of your yacht as green as possible.

Sails: The sail plan must be designed to ensure ease of use of your yacht so you will rely on your sails and not your engine. Single line reefing is probably the simplest method for taking quick reefs with the minimum of confusion. However, care should be taken to run the single line through sheaves with minimum friction, such as Harken ball bearing sheaves, and use a low friction track on your mast.

Roller furling head sails are essential and much safer than having to handle head sails in rough conditions on a heaving wet deck. An inner head stay with a staysail is both ideal in heavy weather and for use on maneuvering in close conditions. In fact, you will probably develop the technique of landing at floats with no power since you can easily roll up the staysail as you approach the float to reduce speed and even manually backwind the staysail to put the yacht into reverse.

To minimize your use of petroleum based materials, limit your sail inventory to a main, jib, staysail, spinnaker, and one special sail: a roller furling drifter. This is a light weight head sail designed to roll up on its luff rope. The sail should be made of a strong, light weight and low surface friction material such as Mylar. This sail might have a J dimension of 100% for easy handling. Use one of the continuous line furlers made by Karver Systems or other manufacturers. This sail can be easily hoisted and left in place for most conditions out ahead of the genoa roller furler. During heavy weather or on the mooring for extended periods, the sail can be dropped and conveniently stored because it is light and rolls into a coil shape. The magic of this sail is its ability to make your yacht move in the lightest of wind conditions. You will be fooled when you use it in light air conditions. From an apparently calm condition, you will pick up a zephyr and the yacht will accelerate giving you the impression that the wind has come up. Be careful. You may follow the new wind and head ever higher. Then suddenly a luff will appear on the sail and your great sailing experience will come to an end as you slow and come back to reality. This sail is especially important while motor sailing. It will allow you to throttle back on your engine and save energy. This is especially important when you are using electric power for propulsion.

Our encouragement to minimize your sail inventory is based on several factors. Sails are made of petroleum based materials. Many extra sails sit in the sail locker and hardly ever get used. They also add weight to the yacht. We suggest that you have well cut sails and spend time learning to use them in all conditions. Sail shape can be easily controlled using the modern rig to adjust to most conditions. Many sailors lose time on their yachts changing sails and then having to adjust them for the conditions. This time would be saved by adjusting what you have in your simple inventory.

Bottom Paint: Hydrodynamic drag on your yacht is a serious concern for fuel efficiency under power, as well as speed and gratification under sail. International Paint LLC has developed a bottom paint for large commercial ships which is now available for recreational yachting. The paint is called “Intersleek 900.” It is a fluoropolymer coating. It deters slime and weed due to its very slippery, non-stick surface. It is designed for vessels moving at 10 knots or higher, but can be used on a yacht with periodic cleaning with a soft sponge or rag. It does not contain any biocides or copper. Instead, it releases fouling once the yacht gets underway where water flow can do the cleaning. The up-front costs for the initial application are higher than conventional paints, but the surface will last 3-5 years. The installation of the painted surface must be done by trained personnel.

The measured fuel consumption and savings are 9%. This is a major improvement! This is a new product and not yet tested in the yachting industry. We have not had verification of its effectiveness in the yachting industry. However, improvements of this type are important, and we hope test results are very positive.

Low Ballast: An ever prominent task is to reduce yacht weight which saves materials and requires less fuel to drive the yacht. Most keels have considerable lead in the upper portion of the keel where it adds little to providing stiffness for the yacht. The objective is to have low positioned ballast. For this reason, the evaluation of the keel design is imperative. Reducing weight in the upper section of the keel and lowering the weight to the bottom of the keel can save 25-35% in keel weight and provide a yacht with the same stiffness with correspondingly lower displacement, and make the yacht cruise more easily and save fuel. In terms of embodied energy, lead comes in at about 35 MJ/kg, so removing a ton of lead by itself represents slightly more than half a barrel of petroleum equivalent saved.

Solar: Solar energy is here to stay. It is light in weight and relatively efficient is size for delivering energy. Rigid panels give more power output per unit area as compared to flexible panels but are about twice the weight. The panels make no noise and are very reliable. They can be mounted where space is available such as on top of the cabin, dodger, or on a Bimini. Typically in the New England area, four rigid panels mounted on top of a Bimini can provide the power to continuously power a small and efficient electrical refrigeration system and other minor equipment on a yacht. The control systems are readily available for solar power systems and there are a number of panel manufacturers, so availability of components is good. We strongly recommend solar panels**.**

Wind Turbine: A wind turbine is a good alternative power source when used with solar cells. If one system is down due to clouds, low wind, night, etc., the other source may well be able to deliver valuable power. There are at least four creditable suppliers of wind turbines. The usual location for mounting the turbine is at the stern. There is a source of vibration from the turbines which might be annoying to some and should be considered in designing the mounting for the wind turbine. If noise is a problem, they can be shut down when not needed. But, they provide a very efficient source of power relative to their weight and size.

http://www.windenergy.com/sites/www.windenergy.com/files/Yachting-Monthly.pdf

BREEZING UP …W. Bradford Willauer

Installation of Renewable Energy Solar and Wind Devices

Water Turbine: Generating electrical power by extracting energy from the water flowing past the yacht is a very reliable method to obtain energy. The technique has been used for decades with success. There have been many system designs ranging from using a belt drive from the propeller shaft to a generator, to a generator mounted on the stern rail being driven through a long length of rope from a propeller in the water, or a stern mounted strut with the generator and propeller.

However, these systems generally reduce the yacht speed by a half knot, so you don't get something for nothing.

Typical designs are shown below:

http://www.wattandsea.com/en/cruising-hydrogenerator

http://www.ampair.com/yacht-generators/aquair-100

Lighting: Light Emitting Diodes (LED) provide a significant opportunity to conserve electrical power aboard a yacht. Typically they consume one tenth the power while providing the same light illumination as tungsten filament bulbs and thy have typically ten times the operating life.

http://www.torqeedo.com/us/

Electrical Propulsion-Power Estimates: To achieve 5 knots in calm water, a moderate-displacement 40-footer requires about 5kw of input to the motor or 7 horsepower. This assumes an overall efficiency of 50% for the motor, drive train, and screw propeller. For one hour of operation solely on battery power, and 50% discharge of batteries, 10 kilowatt hours (Kwh) of battery capacity are required. For 12 hours operation 120 Kwh is required. A 10 Kwh pack of conventional sealed batteries will weigh 400 Kg (880 pounds), require 154 liters volume (5.4 cubic feet), and cost $1,600. For twelve hours of propulsion, these estimates increase to 10,560 pounds, 65 cubic feet, and $19,200, which is impractical.

Weight appears to be the most important limitation. A creative designer might try to replace the ballast with batteries, but then volume becomes the limiting factor. A volume of 65 cubic feet might be achievable in the bilge, but not within the keel without a severe drag penalty. Thus, one would have to choose between more drag (requiring more power) or less stability (not acceptable). One could think of various improvements, ranging from higher-efficiency propellers (larger diameter, slower turning) to high-tech batteries.

Lithium-Ion (LiIon) batteries may be the most promising development in the near future, especially with active development for automobile applications. LiIon system cost is three times that of lead-acid batteries, LiIon will have 28% of the weight and 50% of the volume in comparison to lead-acid, and LiIon will require a more sophisticated design and additional battery management electronics. Thus, ignoring the extra cost, Lithium-Ion batteries should give between two and four times the range under power compared to conventional lead-acid batteries with the same volume or weight. In conclusion, it may be practical to design an electric system to give 1 hour at 5 knots with conventional batteries, or 2-4 hours with Lithium-Ion batteries. The requirement of 12 hours under power can only be met with a conventional or hybrid propulsion system, using an internal-combustion engine to power the propeller directly or via a generator.

There are safety issues with LiIon battery technology. In time these safety issues should be solved with better battery chemistry and charge regulation. However, they should not be omitted in your evaluation of batteries due to their light weight and power density. This is a rapidly changing field.

Hybrid Drive System: The hybrid propulsion system consists of a small size conventional diesel marine engine. The engine drives a motor generator which, in turn, drives the propeller. When operating under electric propulsion, the electric motor is decoupled from the diesel and drives the propeller directly. When the diesel engine is used for propulsion, the diesel drives the propeller through the electric motor. In this condition, the electric motor can act as a generator. When only battery charging is required, the electric motor is decoupled from the propeller and acts as a generator. By having the electric motor in the system, the motor can be used to supply power to start the diesel and can eliminate the alternator on the diesel engine. This saves weight and simplifies the diesel.

An alternative combination of components is a diesel engine directly driving a generator and the resulting electric power driving an electric motor. This combination eliminates clutches. It is not as efficient as the direct drive of the propeller by the diesel, but the system does have the advantage of having the engine run at a constant speed which should provide some efficiencies.

There is an ever-growing list of suppliers of hybrid components including electric motors-generators, couplings, and electrical controllers. The list is ever-changing and not given here.

http://threesheetsnw.com/blog/2012/02/nigel-calder-peeks-into-the-future-of-your-boats-engine-and-you-may-be-surprised-what-he-sees/

http://www.lemcoltd.com/

http://www.oceanvolt.com/

Diesel Engines: Yachting diesel engines give very similar performance in each class of engine. There are many similarities in their designs. Engines manufactured by Yanmar, Westerbeke, and Beta all consume about 1 liter/ hr. at 16 HP. There is no engine advertising more efficiency than the others. However, we feel that an increase in efficiency could be obtained if the market demanded more efficiency. We hope you will encourage the industry to design for more efficiency. This could result in a major savings in the energy consumed by yachting.

Propeller: There are several ways to improve on propeller design, ranging from its mounting, drive shaft placement, to the actual shape of the propeller. The commonly used propeller shaft which protrudes through the hull and is suspended from a strut introduces drag, and the off angle of the shaft loses thrust. The sail drive, a vertical strut which protrudes below the hull, minimizes these effects; however, there is a frictional loss in the right angle bevel gears. The hydrodynamic drag of the sail drive can be further reduced by mounting it at the trailing edge of the keel. The efficiency of the sail drive can be further increased by using a high aspect ratio propeller. This would give about a 5% increase in thrust. We would like to encourage the yachting industry to develop these types of changes.

Electric Outboard: The use of an electrically powered outboard is a very practical way to reduce fossil fuel consumption and increase safety aboard a yacht. Currently the German Torqueedo electric outboard represents the most advanced system on the market. It uses LiIon batteries and has been optimized for efficiency and convenience. This type of outboard may be a valuable addition for your yacht.

Propane fueled outboards are now available which run cleaner than gasoline outboards. However, they use a fossil which is explosive in nature. These facts make them less desirable than the electric outboard.

http://www.google.com/#q=torqeedo&hl=en&source=univ&tbm=shop&tbo=u&sa=X&ei=FhZoUdbnIq3B4AO08oCICg&sqi=2&ved=0CEkQsxg&bav=on.2,or.r_qf.&bvm=bv.45175338,d.dmg&fp=cbbd6afc3d1368e3&biw=1093&bih=517

Alcohol Stove: Methyl alcohol (Wood Alcohol) is a renewable fuel which burns cleanly. It does not burn releasing as much energy as commonly used propane gas, and is quite safe to use. A methyl alcohol fire can be extinguished using water to dilute the fuel. An accidental release of propane gas can lead to a serious explosion.

Propane fueled stoves heat up more quickly than alcohol stoves but this is a minor limitation considering the advantages in using a renewable fuel for cooking.

There have been many alcohol stove designs for yachts over the years. Currently, the Origo stove is the most popular. It is small and easy to use, except the fuel must be added to the stove by hand. If the manufacturer of this stove were to have a continuous fuel feed system, the stove could be quite ideal for a green yacht.

http://www.defender.com/product.jsp?path=-1%7C406%7C694%7C319792&id=60353

Cordage: The modern yacht uses considerable synthetic rope cordage. These typically are nylon, Dacron, and some newer high strength materials. These are all made from a petroleum base. It would be difficult to conceive of a yacht using other materials due to their strength, wear resistance, and rot-free nature. However, consider your disposal of these materials. Often they are just discarded to the dump. Make an effort to recycle your used cordage. It has many recyclable applications.

Renewable Energy Philosophy: With today's technology, it is impossible to power a yacht solely with renewable energy. The renewable sources cannot provide the power needed due to the severe space limitations on a yacht. However, a relatively small energy collection system can provide considerable energy because a typical yacht sits at a dock or on a mooring most of the time. This is especially true for weekend sailors. For this reason, a limited sized energy collection system can charge batteries to full charge during the week so there should be a good reserve of power for use during the weekend. LiIon batteries increase the energy storage potential of the batteries to be even more practical. For the foreseeable future, renewable energy will greatly help to reduce one's carbon footprint. The energy conscientious sailor may be able to operate almost entirely using renewable energy and, thus, feel the constant challenge and the rewards of trying to stay in energy balance with nature. Certainly using an efficient sailing yacht with modern energy collection systems can be very rewarding!

Conclusion: We have evaluated construction materials for future green yachts and suggest that aluminum is the better choice because it is recyclable. We have concluded that there are many fine designs already available which can be modified to be suitable as a green yacht. These changes would take care of the owner's personal needs, and in making the yacht lighter and adaptable for green systems such as LiIon batteries and renewable energy solar and wind collection systems, or others which may be available in the future. These recommendations may not seem earth-shaking; however, if adopted, they can lead to significant reductions in the use of fossil fuels and, thus, continued degradation of our environment. It is a series of small steps which can help to balance our place in nature and, we hope, guarantee the continuation of our great sport… sailing!

Acknowledgements: We wish to acknowledge the assistance in preparing this document by Jim Teeters of US Sailing Association in PHRF data analysis, and Nat Pearre who assisted in the materials analysis.

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Extra Reading:

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Loibner, Dieter; "Sustainable Sailing"; Sheridan House Inc., 2009

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