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SOLAR AND WIND POWERED CONCEPT BOATS: THE EXAMPLE OF VOLITAN

Hakan GÜRSU*

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* Department of Industrial Design, METU, Ankara, TURKEY.

INTRODUCTION

As the climate change obliges the reduction of carbon emissions in almost each industry, the use of renewable energies have become more promising as an alternative to oil dependent systems. Within the maritime industry, global transportation emissions are reported as a major carbon dioxide source that releases twice as much as air transportation (Vidal, 2007). The number of hydrocarbon-burning marine engines is more than 10 million only in the US (Price, 2008). As stated in AirClim's report (2011), global greenhouse gas emissions from ships calculated to correspond to 3.3 percent of total global manmade emissions in 2007. Moreover, this global impact is expected to double or even triple by 2050 unless necessary policies are enacted.

Today, boats using solar and wind energy are being developed as alternatives to fossil fuel dependent vehicles. Technologies and materials are advancing in a way that enable high performance yet clean and inexpensive sea vessels. Instead of fossil fuel dependent sailing crafts, eco-friendly water vessels with near zero emissions are being developed, as the pre-industrialized sail boats. Recent experimental projects and research has proved that more sustainable means of transportation is possible in marine design. With a goal of creating an environmentally friendly boat alternative, Volitan is a boat that uses solar and wind power and incorporates composite materials to for an increased performance. The Volitan Project underlines the potential of alternative energy use, and highlights contemporary materials and technologies in sail-vessels design for further exploration.

A Brief Overview of Solar Powered Boats

Though solar boats first appeared in the 1970s, it took a couple of more decades for their commercial use in public transportation. After many projects by various initiatives, boats using solar energy were popularized

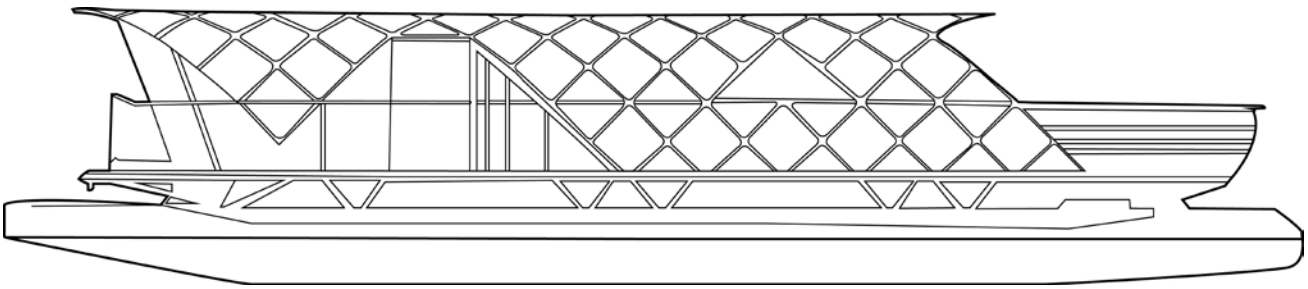


Figure 1. Solar Shuttle Boats by SolarLab.

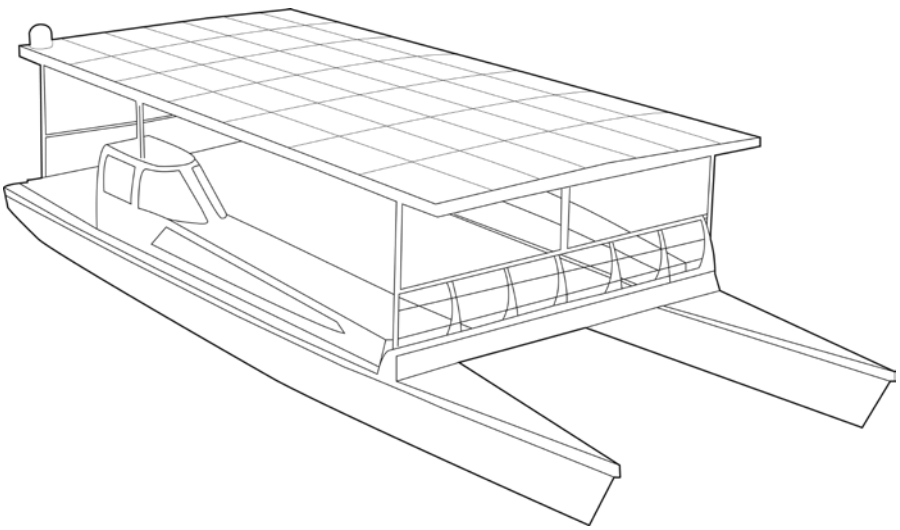


Figure 2. Sun21 Solar Boat by Transatlantic21.

and the concept became more available through several solar powered boats that were built, tested and used. According to Gorter (2010), who covered 105 photovoltaic powered boats worldwide in his study, these can be categorized into three groups according to their purposes as 'people's transportation', 'recreation' and 'private/research' boats. A brief selection of solar powered boats is presented in this section.

The first documented solar powered boat was Solar Craft 1, that made its maiden voyage in 1975 (Electric Boat Association, n.d.). However, the concept of solar powered electric boat actually appeared around 90's. Passenger boats for rivers using electric power from solar cells were among the first commercialized solar boats used in rivers and lakes, where fuel spillages are especially discouraged (Wenham, Green, Watt, Corkish and Sproul, 2013). Built around 1998, Solar Shuttle Boats by SolarLab (**Figure 1**) were among the first public transportation boats that depend completely on solar power.

Offered in various sizes, the length of boats range between 14 to 27 meters and their capacity is around 40 to 120 passengers. For instance, built in 2000, Hamburg Solar Shuttle has 27 meters length with a top speed of 15 km/h and carries 120 passengers, whereas other custom shuttles such as Constance Solar Shuttle provides seating for 60 passengers within a 20 meters body in length. Using photovoltaic panels on their roof, Solar Shuttle Boats take advantage of transparent design that fulfills touristic aims.

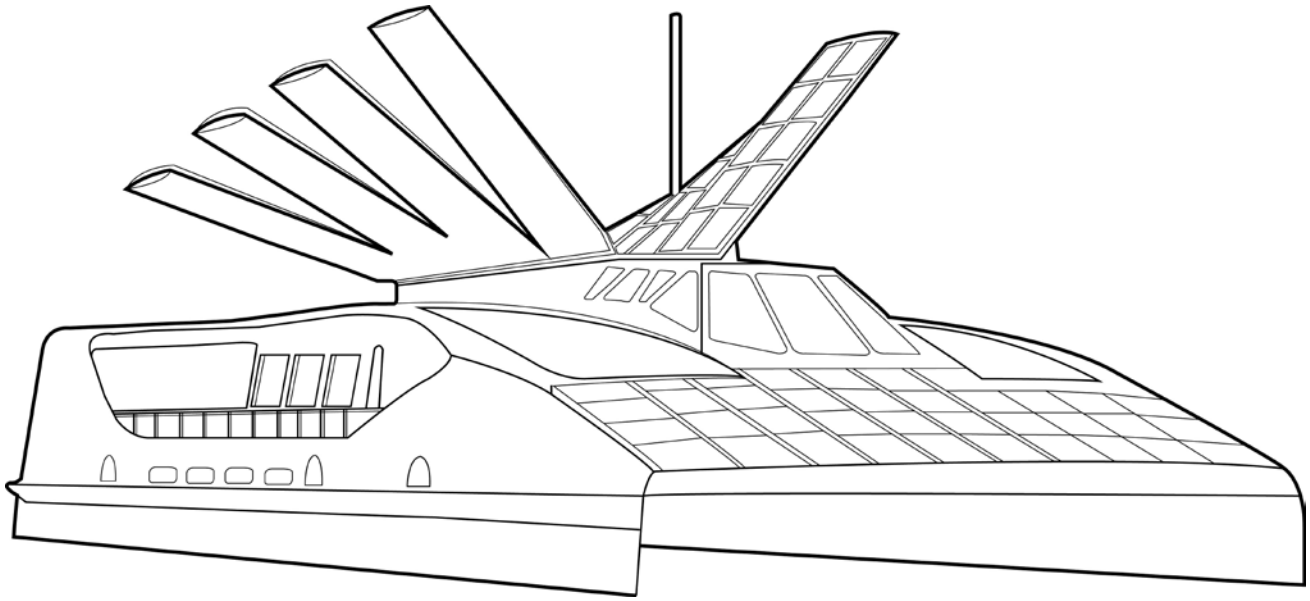
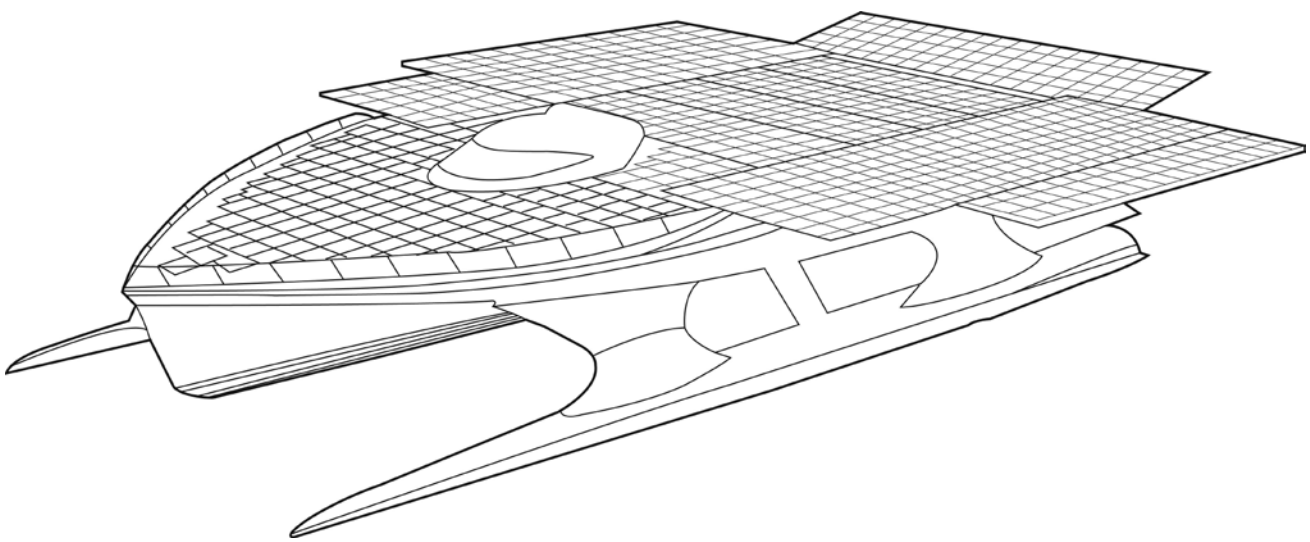


Figure 3. Solar Sailor by Solar Sailor Company.

Another distinctive solar boat is Transatlantic21's solar catamaran Sun21 (**Figure 2**) that aims to promote the potential of solar power technology for ocean navigation (Transatlantic21, n.d.). It holds the record of being the world's first solar powered sea vessel to cross the Atlantic Ocean in 2006-2007. Sun21 completed its 7000 sea miles journey in 29 days by using only solar power. This clean energy powered catamaran is 14 meters long, equipped with solar modules on top, batteries and motors in each hull. The vessel has an average speed of 5-6 knots (10-12 km/h) and carries 5-6 persons. The project is initiated as a response to climate change and still continues to navigate around Europe to increase environmental awareness.

An alternative energy powered that uses both sun and wind energies was created by Solar Sailor Company in Australia. The design was the first hybrid ferry that became commercially available (**Figure 3**). The 21-meters boat's rigid sails are covered with PV that move and rotate in order to catch the sun and wind, instead of being only a passive energy source. Hybrid

Figure 4. MS Tûranor PlanetSolar.



Solar Boat & Year	Power	Length	Speed	Passengers	Solar Panels	Wind Energy	Motor Power	Batteries
Solar Shuttle Boats by Kopf AG, 1998	Electric	14-27m	12-15 km/h	40-120	Curved modules	None	2x8 kW to 2x18 kW	2x280 Ah, 48 V gel to 2x900 Ah, 80 V, OPZV
Sun21 by Transatlantic21, 2006	Electric	14m	9-13 km/h	5 to 6	65 m^2	None	2x8 kW	520 Ah/C5, 48 V DC lead accumulators in each hull
Solar Sailor, 2001	Hybrid: Electric and Fuel	21m	22-25 km/h	100	168 m^2	Available	2x40 kW electric motors, 1x80 kW diesel generator	80x70 Ah Lead Acid Gel
Turanor PlanetSolar, 2010	Electric	35m	9-26 km/h	12	512 m^2	None	2x60 kW	Lithium Ion

Table 1. An Overview of Alternative Energy Using Boats.

powered catamaran uses electric drives in combination with conventional drive and has a speed of 6 knots with solar and wind energy and 7-14 knots while burning low-sulfur diesel fuel. Carrying 100 passengers, solar ferry reduces carbon emissions by 50 percent. With an aim of creating autonomous and unmanned vehicles for ocean researches, Solar Sailor company makes efficient use of solar-sails with hybrid technology to achieve lower fuel consumption and less greenhouse gas emissions.

So far the largest solar-powered boat, MS Tûranor PlanetSolar (**Figure 4**) was built and launched in 2010 in Germany. 35-meter boat became the first solar powered boat to circumnavigate the world in 2012 after sailing for 548 days (PlanetSolar, n.d.). Designed by LOMOcean Design and built by Kneierim Yachtbau, solar trimaran is covered in 512 square meters of solar panels, has 14 knots (26 km/h) top speed, 5 knots (9.25 km/h) cruising speed and two electric motors placed in each hull that generates a total of 120 kW. According to designers, Planet Solar is so quiet that you could hear the whales breathing. Developed in 8 years, the design aims to create a public awareness on the importance of renewable energies for environmental protection.

Table 1 presents an overall framework regarding the alternative energy using boats and their design specifications. As can be seen, boats in various sizes and capacities are available for different purposes. In addition to the research and developments in this area, several conceptual projects with different purposes and structures are being studied to examine future applications. Advantages of solar boats, such as zero emission, silent navigation and lower operational costs, became clearer with advancements in technology over the years. Increase in energy storage, performance of photovoltaic panels and hybrid systems have made the sun powered sea vessels more favorable and feasible (Kindlimann, n.d.). New types of batteries with increased capacity, lower weight and faster recharging times with longer life cycles are being developed. Moreover, achievements in the photovoltaic technology in terms of the production techniques and solar-tracking mechanisms enabled PV panels to operate with increased cell performances. As Kindlimann states, cell performances of 22 percent that provides an overall 18 percent are generally the present norm. Solar panels are built to withstand impact, high wind and freeze in order to produce power in all types of weather. Generating 80 percent of their potential in cloudy days, they can even produce about 25 percent of their maximum output in the absence of sun at completely cloudy environments (MSEIA, n.d.). In brief, photovoltaic are in demand and there is a great interest in research, development and application of this technology. Apparent correlation between advancements in the area and the design of green sea vessels is expected to increase.

Application of clean and renewable energy use is gaining importance globally due to the climate and energy crises. Several policies and

regulations are being introduced in order to support the development and use of these technologies. With the objective of creating 20 percent of energy consumption from renewables and increasing energy efficiency by 20 percent by 2020, policy framework set by the European Renewable Energy Council puts forward wind and sun power as the most prioritized sources in clean energy collection. The design of transportation vehicles, sea vessels in particular, reflects a similar approach in environmentally friendly energy usage. Developed within this perspective, a boat concept with clean energy use, namely Volitan, is presented in the next part.

AN ECO-CONSCIOUS, SELF-SUSTAINED BOAT CONCEPT: VOLITAN

Volitan was developed as a response to these global issues. At the time of the research, transportation costs were at their highest in the recent years as average oil price was nearly 130 US dollars. With an objective of clean and renewable energy use to decrease pollution, Volitan (**Figure 5**) is developed as a future transportation vehicle powered by sun and wind.

The Challenge

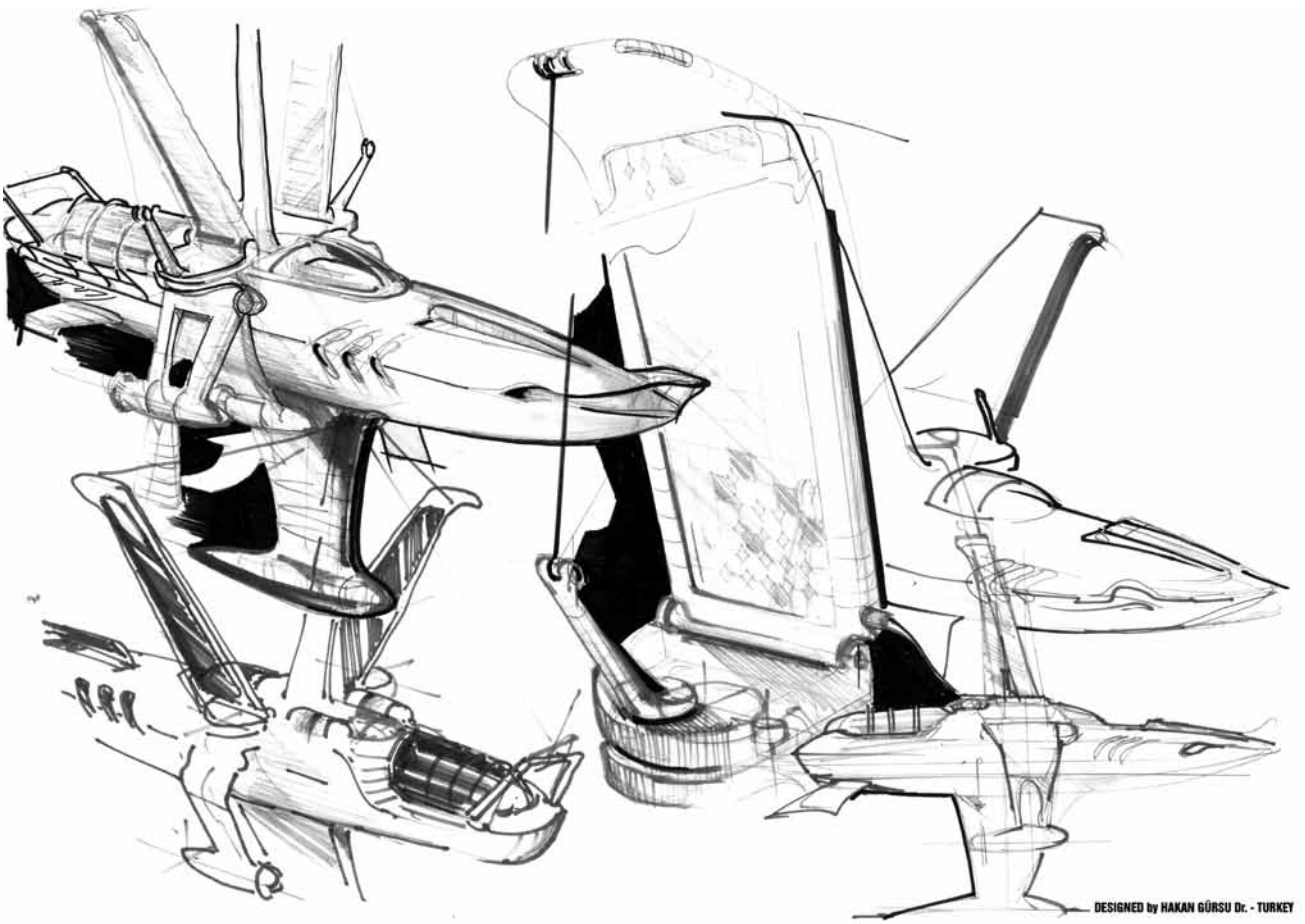
The objective was to create a self-sustained, eco-conscious sailing vessel that would achieve a lightweight system, high sail performance and all-weather navigation capacity with near zero emissions. Additionally, a requirement was the exploration of technologically innovative materials and new construction techniques to minimize aerodynamic and hydrodynamic resistance while maximizing energy efficiency and stability.

Figure 5. Volitan by Dr. Hakan Gürsu.

Examining current possibilities for sustainable energy source use in sea transportation, the design addressed the following challenges:

- How can 'existing technologies and materials' be used in the design of a sailing boat with improved performance and renewable energy use?
- What are the current performance levels and limitations in 'photovoltaic technology' and what efficiency levels are projected to achieve by solar cells in the near future that can be feasible in powering DC electric motors?
- How should solid wings be designed to collect maximum energy through solar panels and wind?
- Solid sail design offers both advantages and disadvantages. Though it holds potential in terms of extending surface area for solar panel coverage, it also presents critical problems such as wind load and flutter. Can solid sails be incorporated in a flexible way to respond to dynamic loads experienced during changing weather conditions?
- How might 'moving and floating-wings' concept with use of rotational stabilizer fins perform in resolving stability problems?
- In what way does efficient use of stored energy to achieve a 'day and night navigation' affect and shape the boat's form?

Figure 6. Sketches by Dr. Hakan Gürsu.



- Instead of the traditional placement of system parts such as the power system, generators and batteries that lead to cumbersome designs, can these parts be reorganized to achieve a more lightweight and dynamic sailboat?

Combining all of these challenges into a new form with dynamic flexibility and visual appeal, Volitan is (**Figure 6**) presented as a futuristic concept boat that emphasizes sustainable resource use in circumnavigation at seas.

Design Solution

Named after the flying fish found in Mediterranean, Volitan is a 32 m. sailing boat that is designed for an efficient use of nature's abundant sources; solar and wind powers. Introduced as a solution to these design challenges, it has several innovative features.

System Design

Volitan harvest sun and wind powers and stores the energy in its batteries to run two DC motors that will assist the sailboat in less favorable conditions and allows her to be propelled day and night. Wing design is specifically shaped to collect maximum energy, while providing an aerodynamic sail structure. Flexible solar-modules on the wings and hull generate energy and create an estimated output of 8-10 kW. Boat is propelled using two electric motors on side wings, which are moving.

Batteries are placed at the end of the centerboard and acts as ballast instead of traditional weight use. All energy requirements on the vessel, including electronic systems, heating and cooling system and water treatment system for desalination of saltwater into fresh water are covered through collected wind and solar power.

DC electric motors, in contrast to engines, provide good maneuverability and offer extra storage space with their smaller size. Batteries specified for concept are Gel type that provide a large number of charge / discharge cycles. Also being sealed, they prevent acid leakage and therefore more environmentally friendly.

Wing Design

Built to collect optimum energy from the sun and the wind, Volitan's characteristic sail design that is accompanied by counter lower wings creates an X-shape in diagonal position. This enables to achieve a dynamic stability, where upper and lower parts move in accordance with weather dynamics. Charged by solar panels, batteries power the twin electric motors that drive the side propellers. Flexible solar panels that are placed on the foredeck also add up to energy generation by solar wings.

As it is indicated in the OECD's publication on renewable energy, the innovation here does not lie in the PV panels, but in the efficient and feasible integration of them into the structure of the boat (OECD, 2012). Covered with 300 meter-square solar panels on two sides as active and passive collectors, solid sails enable harnessing both the sun and the wind energies with an airfoil section. With a 150 meter-square surface area, they correspond to 240-meter square conventional textile sail as well. Therefore wings move in two axes; shifting vertically to catch wind and rotating horizontally for a maximum solar exposure. This dual movement capability allows adjusting both the direction and the angle of the wings. Analyzing trends in PV powered boats; studies by Gorter, Voerman, Joore, Reinders and Van Houten (2010) indicate a high tendency to roof placement of PV

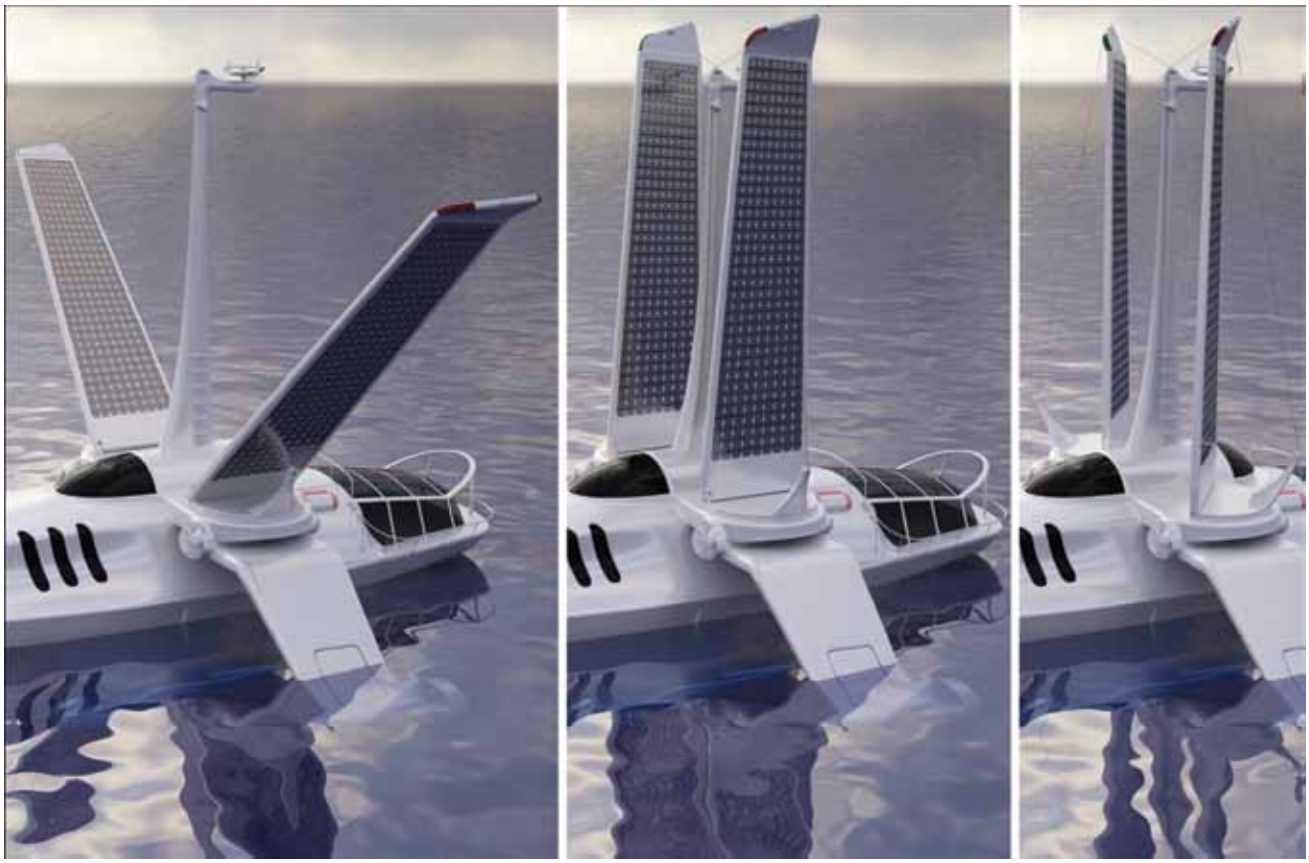


Figure 7. Solar Wing Movement Capabilities.

panels with 61 percent, whereas only 8 percent of solar powered boats have adjustable PV modules. Volitan's unique wing design (**Figure 7**) is shaped around energy collection and presents a flexible system. Sails are activated by servomotors and hydraulic system that are placed in wings and connected to the solar-electrical drive. Tracking system is controlled by computer and enables automatic optimization.

Suspended (floating) wings extend below waterline and are equipped with a 200 horsepower electric motor on each side that propels the boat. Floating wings tilt and enable maneuvering. Rotational movement of these lower wings increases overall stability, flexibility and performance. Motors placed at the end of the wings are vertically shifting and enable "u-turn" by backward and forward drive, so as to turn around a point. Rotational "stabilizer fins" on the edge serve for balance as well. Floating wings are retracted in well sailing conditions to lower resistance and decrease profile in docking. On the contrary, in harsh weather lower wings extend whereas upper sail wings are folded up for increased stability. In overall, Volitan is engineered to operate in 60 knots of wind safely.

Structural Design Considerations

Wing design presents an optimization since the structural parameters such as hydrostatic resistance and high durability require critical considerations in the design of the sea vessels. One tall solar wing could lead to an unstable boat with a stretched mast/hull length ratio. By dividing the solar panel coverage to dual side wings, the concept reduces aerodynamic friction profile and increases performance for both sailing and solar collection (**Figure 8**). Furthermore, floating wings increase overall stability

Figure 8. Upper View.

and are used to achieve high sail optimization in conjunction with a new computer navigation system. Additionally, rotational and reflection angles of solid wings are intercepted and coordinated with floating wings below. Solid sails are connected to keel with steel tension cables for structural stiffness.

Hull design, as a critical factor in overall boat performance, holds considerable potential for improvement. Weight/strength optimization is required in order to decrease heaviness while at the same time keeping internal hull structure stiff. Through structural analysis, use of technologically advanced materials will enable to achieve a high strength/weight ratio and a well-engineered hull.

Volitan concept has highly non-linear dynamics that vary considerably with vessel's forward velocity. Design introduces couplings between vertical and horizontal movements that are performed in relation with sun and wind. This interrelation, which has largely been ignored in classical boat designs, results in a complex multivariable problem. Thus control systems design has significant physical and operational elements associated.

The project was developed using 3D computer software, after initial sketches were made. Various CAD programs were incorporated into the modeling of Volitan, including Rhinoceros 3D, which is used in marine industry. The design's hydrodynamic and aerodynamic characteristics were assessed using a variety of design parameters in digital environment.

The Selection of the Materials

Optimization of structural specifications such as boat weight and speed relationship requires a careful evaluation of materials in order to have an efficient design. Advantageously, building materials and techniques are projected to get stronger, lighter and cheaper, allowing sea crafts with increased performance through technology (Tarjan, 2009).

Using contemporary materials and technologies to the design's benefit; materials used in the design of the Volitan are selected both for their performance and environmental characteristics. The hull shell is made from a composite of double layer carbon fiber and epoxy resin and covered in carbon-foam lamination to create a carbon symmetric sandwich panel. This method enables to achieve a lightweight yet stiff and durable composite body structure that is well suited to intended organic forms. An epoxy primer coat is used in body finishing, with additional ultra-violet resistant coating above the waterline. Reflective and transparent parts on the body will be fabricated from high impact resistance polycarbonate panels. Double layer solar cell panels (high performance flexible photo-voltaics) are placed within a carbon fiber structure on both sides of the solid sails. The outer surface of the panel is protected by special tempered glass to provide high transmittance of sunrays.

Designed for durability and long lasting, selected materials will maintain their strength for in excess of 80 years. Flexible solar panels are expected to serve for more than 20 years under normal conditions, yet the photovoltaic cells may last much longer. Maintenance requirement for the panels is limited to an occasional surface cleaning to ensure maximum optical transmission through the cell array. For electric motors and hydraulic system parts, a regular periodic maintenance will be effective such as cleaning, lubrication and replacement of worn parts.

Aesthetic Considerations

Designed in accordance with hydrodynamic and aerodynamic principles, Volitan's sleek form was referred to as 'sexy' and 'swank' by several reviewers (Price, 2008). An appealing and distinctive form is intended in order to differ the concept from classic boat line and highlight its innovative features. She accomplishes this with smooth main body curves without pronounced edges and with dynamic wings that enable both physical and visual stability. Technologically superior construction techniques allow a seamless body within an organic form. Concept is stylized in a way to leave an impression of amazement and create an emotion of desire.

Environmental Considerations

Sailing, in a traditional sense, is already an activity that uses clean energy and has no adverse effect on the environment. Aiming to revive that spirit, Volitan navigates using renewable sources and consumes the energy it generates. It eliminates pollution, noise and fuel bill. Exploiting the potential of the solar and wind energies, the design eliminates the use of fossil fuel. On a yearly basis, Volitan will approximately save 5300 lbs. of carbon dioxide compared with a conventional diesel vessel of similar size.

General Specifications

Volitan (**Figure 9**) is 105'3" ft. long, 24'8" tall (max.) and is 92'7" in width with solar wings (45 degrees max.), 24'9" wide at the low body (min.).

Figure 9. System Parts & Components.

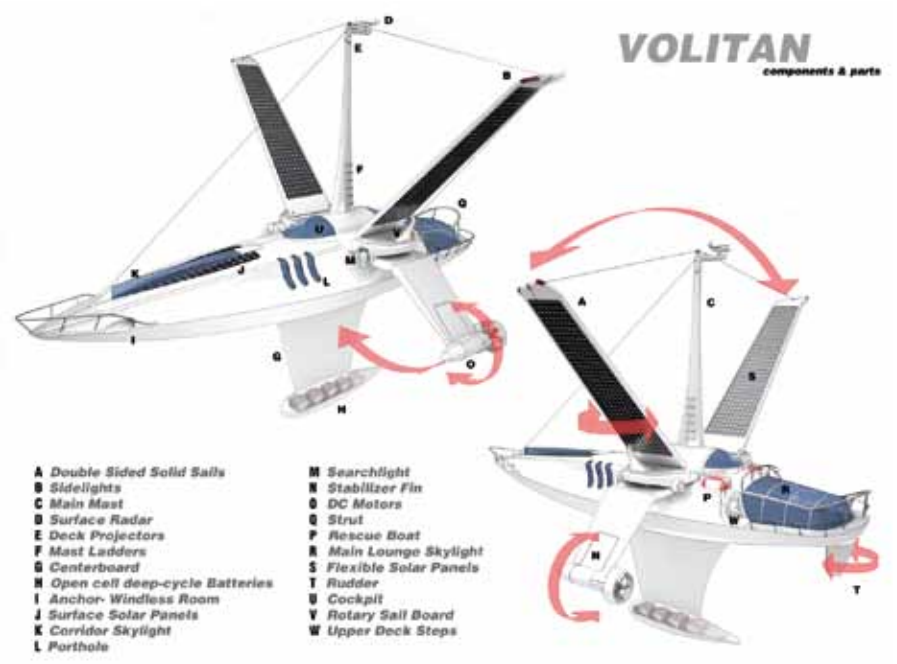
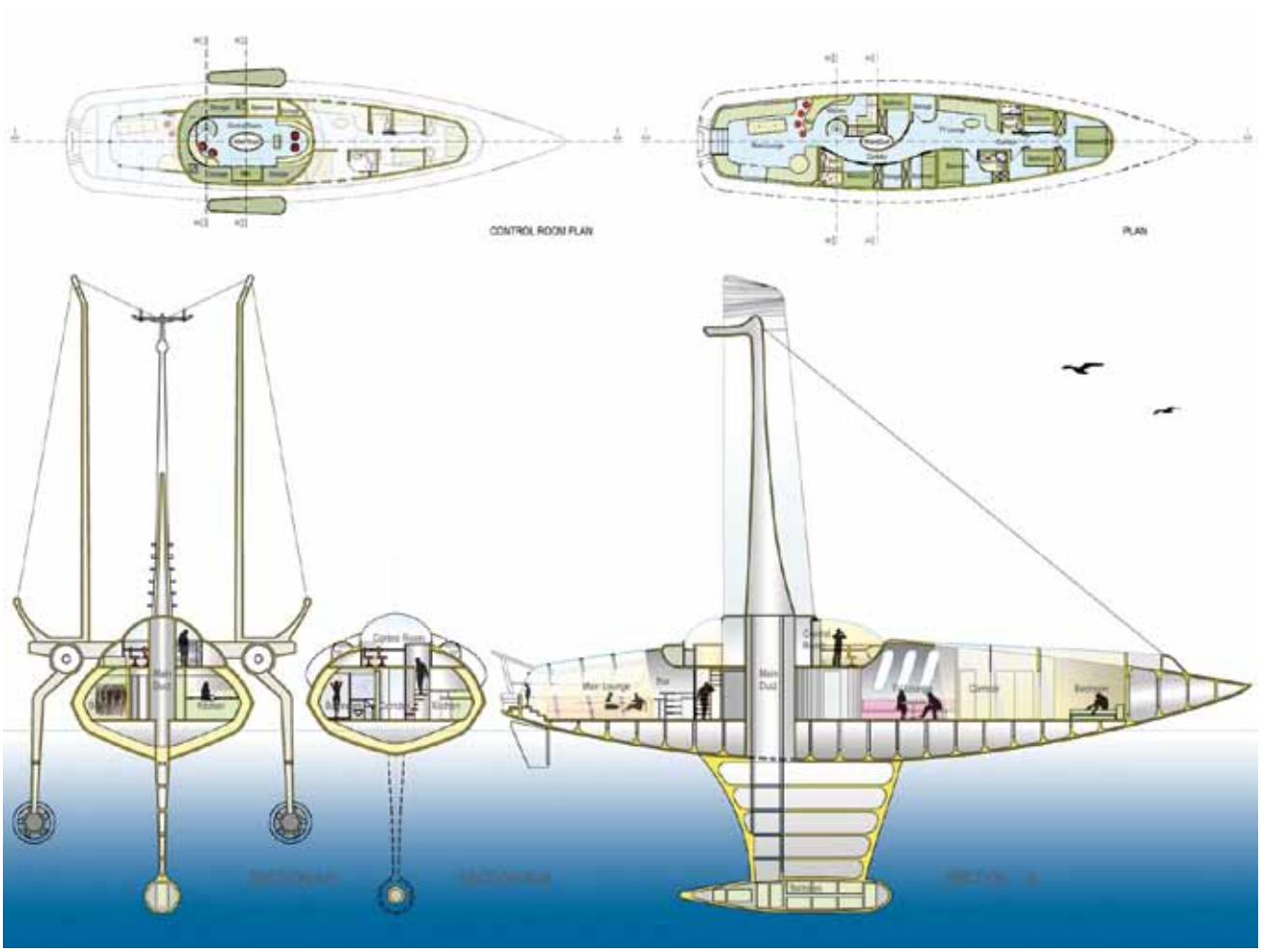


Figure 10. Section Views.



Speeding forward as its name suggests literally, Volitan has an average speed of 12-14 knots per hour, whereas it has a top speed of 18 knots in convenient weather conditions. Material selection for design is advantageous in terms of lower weight and therefore easy of acceleration.

Volitan's (**Figure 10**) interior design includes a control room, bedrooms & storage spaces and a bathroom at upper deck. The main deck has bedrooms for crew and passengers, a kitchen, the main lounge and a TV lounge. Accommodating 10-12 persons, its interiors are designed with a minimalist approach.

Acknowledgments and Further Implications of the Project

Volitan is developed within a framework of using the technology for the benefit of people and environment. It supports protection of life, health, prosperity and global environment and aims to contribute to an efficient and sustainable marine transportation system. Introducing a self-sustainable vessel with innovative and eco-friendly features, the project creates opportunities in increasing environmental awareness by drawing attention to naval pollution and promotion of sustainable approaches in marine industry. The project includes a study of the following subjects that can be further explored;

Structural analysis and material selection for lightweight hull structure,

Performance/Weight relationship,

Design of ship-steering dynamic positioning systems for small vessels,

Design of floating wing and fin stabilizer control systems,

Design and performance study of solar panel covered solid sails,

Propulsion control design,

Track-keeping controller design.

Featured in global media and press, Volitan is referred by several prestigious publications including Popular Science and BusinessWeek magazines. Honored by various design competitions as well, it holds the first prizes in both Transportation and Nautical/Boats categories in the International Design Awards 2007. Volitan is also the winner of Green Dot Awards 2008 first prize in Transportation Design category.

Gregor Tarjan reviewed Volitan in his book Catamarans: Tomorrow's Superyachts in 'Future Perspectives' chapter as an innovative concept that signs future perspectives and trends:

> "The "Volitan" is a fantastic concept boat with impeccable green credentials. Using sails, wind and solar power to get around it stores energy in its batteries. The secret to the "Volitan" which can operate in 60-knot winds is the way its four wings react to weather conditions" (Tarjan, 2009).

In 2013, Volitan was invited to 'Think Ahead' exhibition in Museum Victoria in Australia that explores past, present and forecasted representation of future through several themes, including transportation. Design is showcased in transport timeline of exhibition, which will be open for 10 years.

CONCLUSION

Advancements in the technology and materials coupled with sustainability challenge aroused by environmental concerns made renewable energy

powered vehicles prominent. Use of nature's sources to achieve pollution-free sailing vessels became possible through harnessing sun and wind power and several projects are carried out around the world to tap into the potential of clean energy use at seas. Circumnavigation with using only solar power is already achieved; nonetheless several challenges are yet to be met.

Designed to address the sustainability and efficiency concerns along with structural, aesthetical and stability considerations, the Volitan concept is an exploration of future possibilities for the sea vessels. Introducing innovative features as its X-shaped solid sails and fins, and the way the system parts are organized, the design achieves a lightweight yet stabilized sailboat with an overall quality. Apart from providing an emission-free navigation solution, Volitan has an aim of raising awareness on global warming and alternative energy use as an iconic symbol navigating at the seas.

The project results show that possibilities offered by (i) technologies that enable renewable resource use in sea vessels and (ii) materials with increased efficiency are of importance in future sea craft design. Considerations and characteristics present unique parameters that can be evaluated and compared in further studies. To conclude, further examination and research in mentioned areas reveals a great potential in designing of an eco-conscious and sustainable sea transportation vehicles.

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Anahtar Sözcükler: Güneş enerjili tekne; solar yelkenli; geleceğin ulaşımı; yat tasarımı; sürdürülebilir deniz araçları.

GÜNEŞ VE RÜZGAR ENERJİSİ KULLANAN KAVRAMSAL TEKNELER: VOLİTAN ÖRNEĞİ

Küresel ısınmanın etkileri, toplam küresel sera gazı salınımının %3,3'üne neden olan deniz ulaşımında alternatif enerji arayışlarını artırıyor. Geçtiğimiz on yıl içerisinde güneş ve rüzgâr enerjisi kullanan ve verimliliği giderek artan tekneler geliştirildi ve fosil yakıt bağımlısı araçlar yerine, sıfır salınıma yakın deniz araçları hedefleniyor. Deneysel proje ve araştırmalar doğrultusunda güneş enerjili deniz ulaşımında bazı kilometre taşlarına ulaşıldı, ancak bu gelişmeler deniz teknolojilerinde sürdürülebilir ve verimli yöntemlerin keşfinin yalnızca başlangıcına işaret ediyor.

Bu yazı deniz araçlarında güneş ve rüzgâr enerjisi özelinde seçenek enerji kullanımına dair bir zemin oluşturmakta ve güneş enerjisiyle çalışan teknelere kısa bir genel bakış içermektedir. Bu bakış açısı doğrultusunda yeni bir tekne yaklaşımı ana fikir olarak sunuluyor ve teknenin tasarımında aşılması hedeflenen problemler ve göz önünde bulundurulan ölçütler, tasarım sürecinin belgelenmesiyle tartışılıyor. Yat tasarımında temiz enerji kaynakları ve *kompozit* malzemelerin sunduğu olanakların keşfi için geliştirilen Volitan, fosil yakıt kullanan teknelere karşı sürdürülebilir bir seçenek olarak öneriliyor. Proje yaklaşık sıfır karbon salınımı ile aralıksız seyir yapabilecek, kendine yeterli kişisel bir yelkenli için güneş ve rüzgâr enerjilerini kullanıyor. Makale, olası çalışmalarda yararlanılmak üzere çevreci bir tekne kavramının tasarımında yer alan konu ve parametreleri derliyor. Son olarak, çalışma (i) yenilenebilir ve çevreyi kirletmeyen alternatif enerjiler ile (ii) güncel malzeme ve teknolojilerin, hafif ancak sağlam, düşük maliyetli ve verimliliği yüksek tekneler elde etmek üzere deniz araçları tasarımında kullanımının potansiyelini işaret ediyor.

HAKAN GÜRSU; B.ID., M.Sc., Ph.D.
Received B.ID in Industrial Design in 1984, MSc in Architecture from METU in 1987 and PhD. degree in city planning from METU in 1996. Currently instructor in the Department of Industrial Design at METU, Ankara; and Founder and CED of Designnobis Design Company based in METU Technopolis. Along with his academic career, worked as a design professional in several sectors for over thirty years. His interests are industrial design practice, innovation and sustainability. gursu@metu.edu.tr