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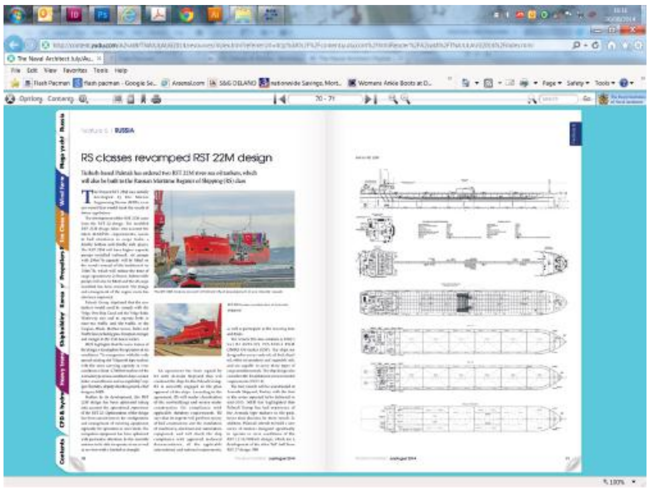

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High fives for solar-powered ferry ops

NavAlt's solar-powered, 75-pax ferry *Aditya* has scored highly when it comes to what her designer, Sandith Thandasherry, highlights as the five core principles of safe, ergonomic, cost-effective, pleasurable and eco-friendly inland passenger vessel design

The following is a truncated version of the paper 'Inland Passenger Ferry Boats', authored by Sandith Thandasherry, CEO of NavAlt Solar and Electric Boats.

Passenger boating is one area where technological modernisation has not penetrated significantly. Many passenger boats are country-built boats, with low safety standards. In many parts of India, water transport is primarily used by the poorer sections of society: since they lack an alternative means of transport, they are forced to travel in such unsafe boats.

This article aims to first define the parameters that can be used to assess the quality of a passenger ferry, and then to compare conventional diesel ferries with modern diesel ferries and solar ferries. In the next section, we'll discuss the choices and trade-offs associated with a good ferry, followed by a case study of *Aditya*, India's first solar ferry.

Aditya has been hailed as India's first solar-powered passenger ferry

Ferry parameters

Five parameters are used to assess the quality of a passenger ferry. These can be presented in various orders, depending on the group who is assessing the parameters: for instance, passengers value safety as the highest priority, followed by comfort, whereas operators and owners tend to place cost-effectiveness as the highest priority. Eco-friendly considerations should definitely be important for governments, due to the effects of pollution in both the short-term (ie, the health and livelihood of locals) and the long-term (ie, the climate change issue).

These five parameters are:
- Safety
- Comfort
- Pleasure
- Cost-effectiveness
- Eco-friendliness

Safety

Adequate boat safety ensures that passengers and crew remain unaffected during the various scenarios that the boat might encounter during the normal course of operation, as well as unlikely scenarios. As such, the boat must be strong and stable, to withstand the payload and external forces. Also, in the unlikely event of an accident like capsizal or fire, onboard lifesaving and firefighting appliances must be sufficient to mitigate the risk and avoid loss of life and property. There are two aspects that ensure higher safety of passenger boats:

1) Building under class

Inland water transport is currently regulated by the respective state governments. This also means that there is no uniformity in standards or compliance. In most states, there aren't enough sufficient surveyors to assess the safety of the boat right from the design / selection of material / construction / testing stages of the process, nor at the lifesaving / firefighting equipment check stages. In this scenario, building the vessel under IACS member supervision would ensure the safety standards are met. The steps involved in the process are explained below:

- *Design approval*: Experienced surveyors check the design of the boat for its strength and compliance to safety regulations;
- *Material selection*: All the critical materials used in construction of the boat, equipment, etc, are type-approved by class;
- *Process monitoring*: Throughout the construction process, surveyors inspect the boat, to ensure the correct process is followed;
- *Boat testing:* After construction of the boat, various systems are checked for functional performance as well as safe operation. Boat stability is also checked by inclining tests and stability analysis;
- *Lifesaving and firefighting*: All lifesaving and firefighting appliances are checked for quality and ability to handle emergency scenarios and fire, respectively.

Hence, until state governments empower the inland registration bodies, such as maritime boards or port authorities, it is advisable to build passenger ferries under IACS member class.

2) *Building as a catamaran*

The biggest cause of accidents and deaths in inland water is passenger overloading [2],[3]. Given that limiting the number of passengers to a rated capacity per boat is difficult in developing countries – especially during special occasions, like festivals – passenger boats must be designed to take overloading into account.

Single-hulled boats have a very low margin of safety, even when properly designed. Catamarans have a higher margin of stability, especially when handling overcrowding on one side or severe wind, turning or other external effects, like waves. Figure 1 shows the intact stability comparison between different ship types with the same displacement: hence it is recommended that inland passenger ferries should be catamarans [1].

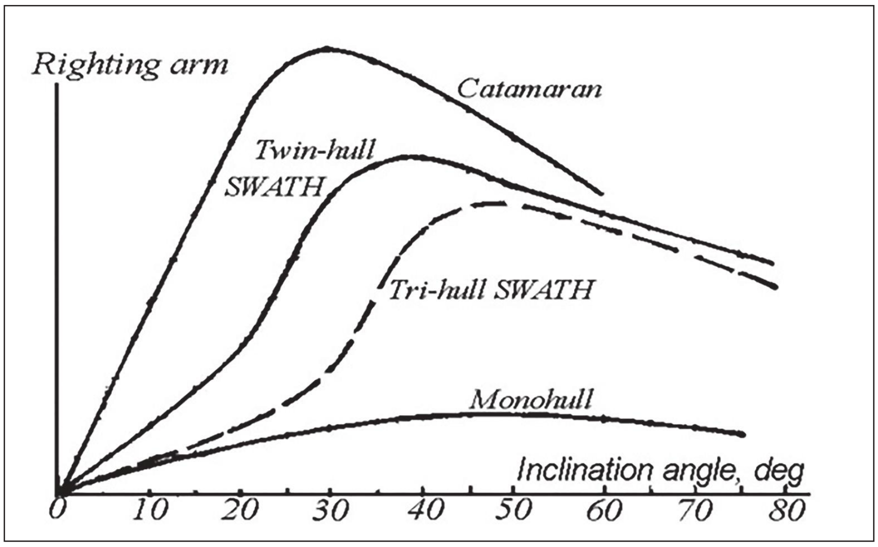


Figure 1: Intact stability comparison (1)

Comfort

The passenger and crew have the basic right to expect to travel and work in a comfortable environment, which can be defined by three aspects:

- *Noise:* Noise pollution is a slow and subtle killer: it may cause hypertension, high stress levels, tinnitus and hearing loss, sleep disturbances and other harmful effects, including a permanent loss of memory or psychiatric disorder [4],[5], [6]. In a passenger ferry, noise primarily comes from the diesel engines (used for main engines) as well as the auxiliary engines (for electric power). For a comfortable journey, a level of below 60dB is recommended;
- *Vibration*: On a passenger ferry, vibrations are caused mainly by diesel engines and propellers. Vibration discomfort is a combined effect of its magnitude, duration, frequency and waveform. Diesel engines inherently have a high level of vibration, which eventually affects passenger and crew comfort. Common health problems related to exposure to vibration over long periods can include back pain, sciatica and digestive disorders;
- *Smell of fuel*: The smell of diesel is another serious passenger comfort-related concern. When you smell diesel- or petroleum-based fuels, you're actually inhaling their fumes, which enter the body, get absorbed in the bloodstream and reach your vital organs, including heart and brain. Your blood ends up containing traces of the fuel, so its oxygen content is reduced – thus your organs don't receive enough oxygen [6], [7]. Breathing petroleum vapours can affect the nervous system (causing headaches, nausea and dizziness) and irritate the respiratory system.

Pleasure

Once a basic level of comfort has been achieved, passengers and crew want a degree of pleasure during travel, related to four main areas:

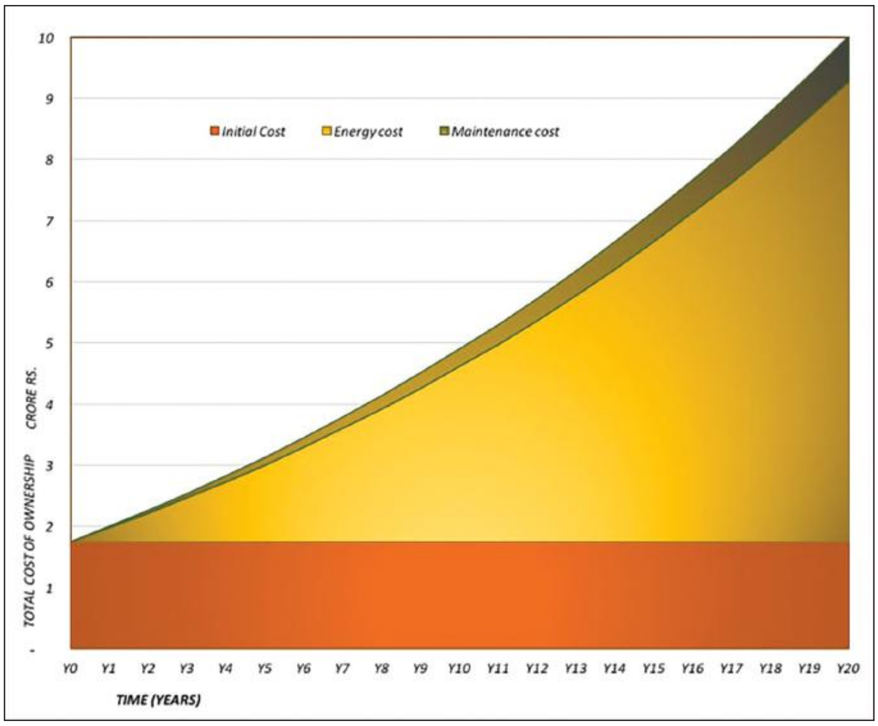


Figure 2: TCO of a 75-pax modern diesel ferry

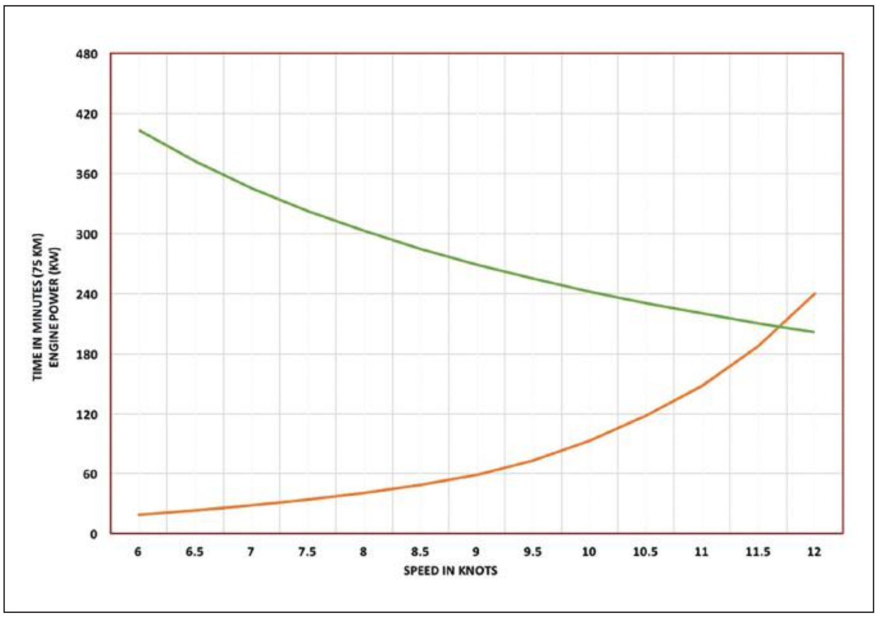
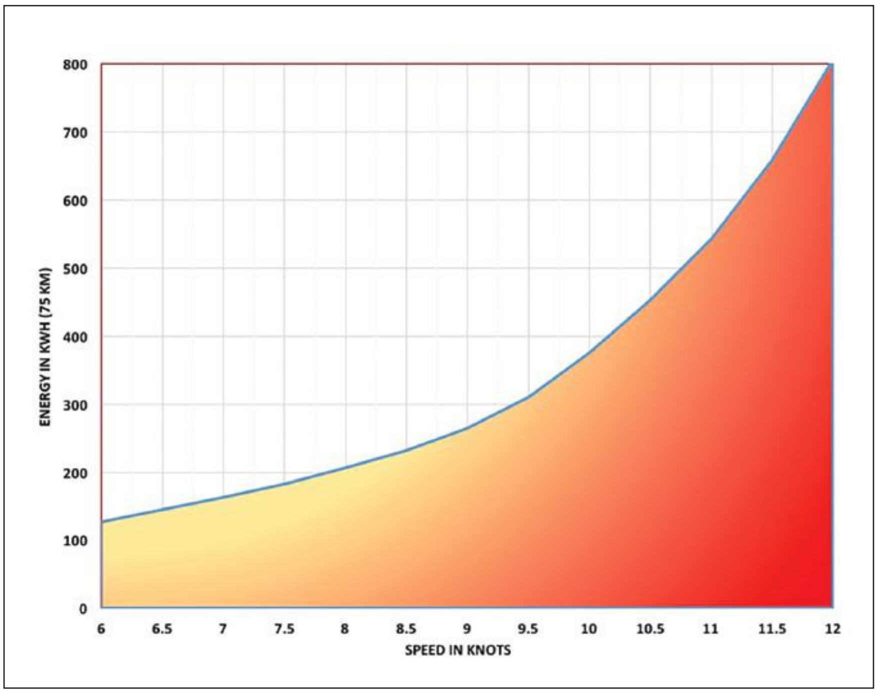


Figure 3: Power and time (75km) versus speed

- *Spacious interiors*: pleasurable boat journeys are enhanced by wide spaces in the passageways and between the rows of seats. Catamaran ferries have larger deck area than single-hull boats, and can thereby provide spacious interiors;
- *Seating*: The width, cushioning and ergonomics of seats reduces tiredness and adds to the pleasurable nature of the journey;
- *Entertainment*: This is mostly relevant when noise and vibrations are already low, and includes music, TV, WiFi connectivity, etc;
- *Aesthetics*: Usability and aesthetics are the two most important factors in assessing the overall user experience for an application. Hence a well-designed interior can improve the pleasurable nature of a journey.

Figure 4: Total energy (75km) versus speed



Total cost of ownership

This is the real cost of owning the passenger ferry. Many people only consider the initial cost of purchase and overlook running and maintenance costs. When comparing different kinds of ferries, the operating costs that are common to all types of boat, like crew wages, are not considered. This is relevant when one has to study the feasibility of operating the ferry in a particular location and factoring in revenues. The three key considerations are:

- *Initial cost*: The cost of purchase of the boat. For instance, taking a 75-pax modern diesel ferry as an example, the initial cost is about 180 lakh rupees (US$277,000);
- *Energy cost*: The cost of fuel for running the boat and its systems. In a diesel ferry, energy cost is the dominant cost in its total cost of ownership (TCO). On a long-term basis, the diesel cost is usually projected to increase by 5% annually. If our example 75-pax ferry has twin 37kW engines and consumes 100 litres for 10 hours of daily operation at 6knots, this equals 35,000litres per year (for 350 operational days), translating to 22.8 lakh rupees (US$35,000) in the first year;
- *Maintenance cost*: This includes all other non-fuel costs of running the boat, like lube oils, filters, engine overhauls, etc. It is approximately 10% of the energy cost, annually: so, for our example ferry, 2.3 lakh rupees (US$3,500) in the first year (see Figure 2).

It is imperative to discuss the impact of speed on TCO as this affects the energy cost profoundly, as well as initial and maintenance costs (see Figure 3). For propelling a boat in water, the speed-power curve grows exponentially: at lower speeds of 6knots, the exponent is clearer to 2.5, whereas at higher speeds of 12knots this reaches close to 4. So, when speed doubles from 6-12knots, the engine power increases from 16-200kW, more than 10 times multiple. The travel time for the same distance is only halved.

What this means is that the energy needed for the same distance also increases rapidly. In this example for a daily range of 75km, when the speed changes from 6knots to 12knots, the total energy grows from 125kWh to 800kWh, more than six times multiple (see Figure 4). The total energy translates to total fuel consumption (for diesel boats) and grid charge (for solar boats) which drives the energy cost. Hence it is imperative to choose the right speed to ensure the transport system is sustainable.

Eco-friendliness: air

The environmental impact of a passenger ferry is an important parameter to assess. A diesel ferry causes both air and water pollution.

Carbon dioxide (CO_2) is the primary product of petroleum fuel combustion. The warming effects of CO_2 as a greenhouse gas have been known for a long time. A typical diesel ferry that consumes 100litres per day emits 94tonnes of CO_2 yearly. One litre of diesel produces 2.68kg of CO_2 [12].

Nitrogen oxides (NOx) are generated from nitrogen and oxygen under the high pressure and temperature conditions in the engine cylinder. NOx mostly comprises nitric oxide (NO) and a small fraction of the very toxic nitrogen dioxide (NO_2). NOx emissions play a role in the formation of smog. The diesel ferry mentioned above would annually produce 1.3tonnes of NOx (1litre of diesel =37g of NOx).

Sulphur oxides (SOx), mainly sulphur dioxide (SO_2), are generated from the sulphur present in diesel fuel and comprise a colourless, toxic gas with an irritating odour. Sulphur oxides are the major cause of acid rain. The aforementioned diesel ferry would produce 285kg of SOx annually (1litre of diesel = 8g of SOx).

Particulate matter (PM) is generated in diesel engines. The same ferry would annually produce 52kg of PM (1litre of diesel = 1g of PM).

Carbon monoxide (CO), hydrocarbons (HC) and aldehydes are generated in the exhaust as the result of incomplete combustion of fuel. A significant portion of exhaust HC is also derived from the engine lube oil. When engines operate in enclosed spaces, CO can accumulate in the ambient atmosphere and cause headaches, dizziness and lethargy. HC are also an important component of smog.

Parameter	Conventional ferry	Modern ferry
Safety	Low	High
Comfort	Low	Low-Medium
Pleasure	Low	High
TCO	Low	Low-Medium
Eco-friendliness	Low	Low-Medium

Table 1: Conventional vs. modern ferry, using the five parameters

Higher-efficient engines and cleaner fuels are known to reduce the adverse impact of pollution.

Eco-friendliness: water

There are two ways in which water is polluted by the boat's fuel and oil. Firstly, the unburned fuel from the engine to the exhaust line is released into the water. Secondly, oil often leaks from engine/machinery spaces or as a result of engine maintenance activities and mixes with water in the bilge, and this is discharged into the water.

Oil, gasoline and by-products from the biological breakdown of petroleum products can harm fish and wildlife and threaten human health if ingested. Even in minute concentrations, oil can kill fish or have various sub-lethal, chronic effects. Bilge water may also contain solid wastes and pollutants containing high levels of oxygen-demanding material, oil and other chemicals [8].

Conventional vs. modern diesel ferries

Conventional ferries are single-hulled, made of wood or steel, not built under IACS classification and feature diesel engines; they put less focus on pleasure/entertainment. Modern diesel ferries are a few steps ahead: they are IACS-compliant catamarans, made of GRP (mostly) or aluminium, with high-efficient diesel propulsion and satisfying parameters related to pleasure/entertainment.

The monohull form and lack of IACS member involvement mean conventional ferries score low when it comes to safety. Conventional ferries are also noisy and

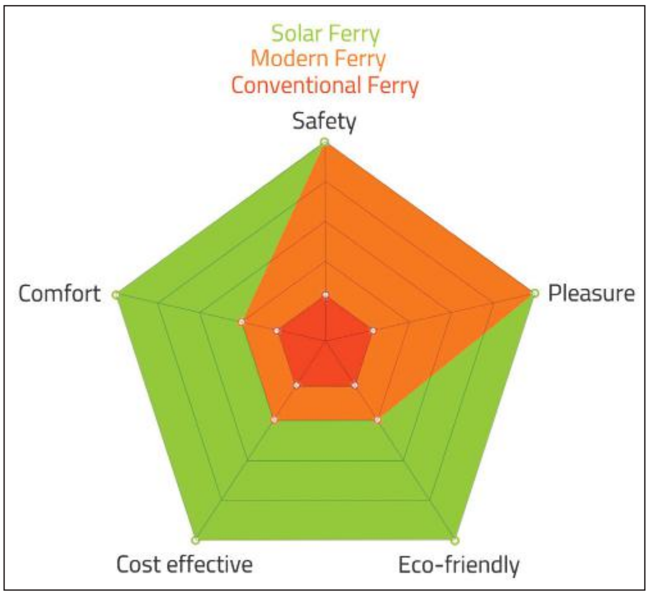


Figure 5: Comparison of ferry types

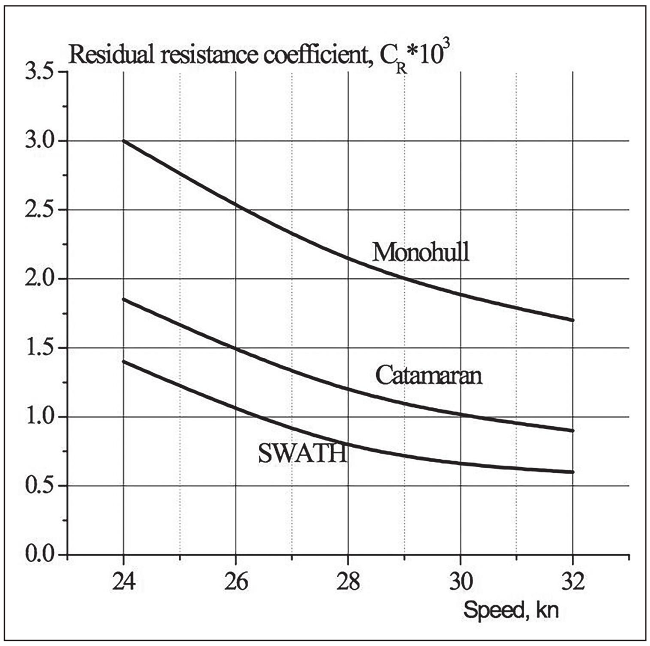


Figure 6: Comparison of residuary resistance (1)

have high vibrations and an intense smell of fuel. Hence, they also score low in the parameter of comfort. Modern diesel ferries manage to slightly improve on noise/vibrations by dampening its creation from the machineries and isolating it in the machinery space. The diesel smell is marginally lower, since the machinery exhaust is isolated from passengers and crew. Thereby, modern diesel ferries rate low-to-medium in the parameter of comfort.

Conventional ferries rate lower than modern models in pleasure, as their interiors are crammed and the seats provide bare minimum comfort: similarly, they lack entertainment facilities and have little or no aesthetics when it comes to interior design.

Both boats, being powered by diesel engines, rate low in TCO since the energy cost of diesel is high. In conventional ferries, although initial cost is lower (since quality is low), the energy cost is higher than modern ferry boats as such heavier boats with higher drag require more power for propulsion. Since energy cost is the dominant cost, the TCO of conventional boats is higher than that of modern ferries.

Since both boats are powered by diesel engines, both cause air and water pollution. However, the use of an efficient hull form and lighter materials reduce the powering needs and thereby engine size and fuel consumption of the modern ferry. Also, the engines in the modern ferry are more efficient, with lower emissions.The two boat types can be compared using the five parameters as shown in Table 1 (page 22).

Aditya: a case study

Aditya is a 75-pax solar ferry boat, built under Indian Register of Shipping (IR) class, featuring a GRP hull and aluminium superstructure, electric propulsion and no fuel on board (see *Ship & Boat International*, September/October 2016, pages 55-56). Inaugurated in January 2017, she takes 22 trips daily, each of 2.5km – a total of 55km – from 7.00 to 19.00, with breaks in between. Each trip is a 13-15 minute journey at an average speed of 6knots and she carries approximately 1,500 passengers daily.

A conventional diesel ferry operating in the same location burns 100litres of diesel daily, giving a daily energy cost of 6,500Rs (65Rs./litre). Adding lube oil cost, filter replacement cost and engine overhaul, the average daily cost is about 7,000Rs [11].

In comparison, *Aditya*'s daily energy cost is 163Rs (22kWh grid power @7.4Rs./kWh). This difference in daily cost means that, in a year (350 days' operation), *Aditya* saves 35,000litres of diesel, 94tonnes of CO_2 and 22 lakh rupees in energy cost. If one were to assess *Aditya* with the above five parameters, she would score 'high' in each category:

- *Safety*: *Aditya* is built under IACS class and is a catamaran;
- *Comfort: Aditya* is propelled by electric motors and hence very silent. There are very low vibrations and, since there is no fuel, no smell of diesel;
- *Pleasure*: As a catamaran, she is very spacious, and has cushioned seats which are ergonomically designed. The interiors are well-designed and she has a music system and TV;
- *TCO*: As shown above, *Aditya*'s yearly savings amount to 22 lakh Rs – so, within less than two years, she will break even, compared to a modern diesel ferry. In her lifetime of 20 years, including battery replacement in years 7 and 14, *Aditya* would save enough money to build three more solar boats [9];
- *Eco-friendliness*: As a solar ferry with no fuel on board, there is no air or water pollution. Hence she rates highly in the eco-friendliness parameter.

Plotting the five parameters for the three ferry types, one can see the benefits of the solar ferry (Figure 5). The next section aims to describe the type of solar ferry, depending on the application.

Solar ferry types

There are three key requirements to make solar passenger ferries possible: drastic reduction in weight; drastic reduction in drag; and a reliable power train. This section aims to specify the details of the type of solar ferry with trade-offs discussed in detail.

As described earlier, it is advisable to build under class to ensure vessel safety. This also ensures that the critical components of a solar boat – ie, battery, motor, propulsion, steering, safety and materials used for boat construction – are approved by class. For a higher stability margin against overloading, overcrowding and external effects (wind, turning, waves, etc), it is recommended that the solar ferry is built as a catamaran. Catamarans have larger deck area, which means larger coach roof area, to ensure a larger area is available for the placement of solar panels. A 75m passenger ferry of 20m in length and 7m in breadth can accommodate 20kW solar panels that can provide 80-90% of total energy (the rest being sourced from the grid). Catamarans also have lower resistance than monohulls (see Figure 6).

The catamaran design provides higher manoeuvrability with twin propulsion compared to a monohull with engine, and requires a lower draught compared to monohulls – and, hence, can operate in more locations. Catamarans also roll less when the boat is in berth, increasing passenger comfort.

One key requirement is to reduce the boat's weight, so the total propulsion power can be reduced. A typical 75-pax steel or wooden ferry is about 45-50tonnes in weight. A GRP or aluminium ferry of the same capacity would be around 30-35tonnes. This has to be less than 20tonnes to make it as a solar ferry. To do this, apart from using lighter materials like GRP and aluminium, the structural design has to be optimised for the lowest weight. Additionally, designers should eliminate every item in the solar ferry that is not needed.

GRP and aluminium should be used for the hull, deck and superstructure: steel and wood would make the boat very heavy. Between the two, GRP is a clear favourite for inland passenger ferries as it would be cheaper, and produce less drag. The cost for GRP is higher when making a few boats, since the mould cost is significant: however, when there are more than five boats in the order, GRP would be cheaper. Also, GRP manufacture and repair involve simpler processes compared to complex TIG welding in the case of aluminium newbuilds. Drag is lower for GRP since it can be moulded to any shape and thereby create a hull with an optimum shape. In contrast, there is a limit as to how far aluminium can be bent to form complex shapes. As such, GRP boats have sleeker designs and deeper and softer chines.

Aluminium wins when it comes to seagoing boats, as it can withstand impact much better than can GRP.

Power requirements

A conventional 75-pax ferry needs about 50kW in shaft power to propel the boat at 6knots. In comparison, modern ferry boats need about 30-40kW shaft power for the same function. For a solar ferry, this shaft power has to be reduced to less than 20kW to make it work. To make this possible, the underwater shape must be well optimised.

The propulsion battery is the most important part of a solar boat. The type of battery is crucial: while many types are available, one of the most reliable is lithium, and particularly lithium-iron-phosphate chemistry, since it is very safe with low risk of generating sparks / causing fires. Lithium batteries need good battery management systems to ensure long life and performance. The battery must meet the highest standards for application in marine propulsion: for this, it has to pass a lot of tests and be certified by a member of IACS.

The motors used in the ferry (inboard or outboard) must be highly efficient, reliable and rugged, and meet marine standards. Suitable controllers must be used to control the speed of the motor – and, thereby, that of the boat. For efficient use of power, a highly efficient propeller, with as large a diameter as possible, is very important. Use of well-designed propeller pockets can increase the propeller diameter.

Other aspects that affect propulsion power need to be addressed – proper flow to propeller, adequate clearances, shaft bearing, rudder design, etc.

Since the area available to place solar panels on the coach roof is limited, the highest-efficient solar panels are used. These panels must be low-degradation and feature a performance guarantee of at least 20 years, and must meet marine environment salt water protection requirements (IEC 61701). Charge controllers must be high-quality and operate using the Maximum Point Power Tracking {MPPT} algorithm for highest output. ***SBI***

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