DESIGN OF A WING SAIL CATAMARAN FOR PASSENGERS TRANSPORT (STRUCTURAL ANALYSIS)

Treball Final de Grau

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Acknowledgements

To Sergio, for the facilities

To my family, for the patience

Abstract

The maritime transport sector has been one of the most traditional ever. Although it is currently in a borderline situation that is accompanied by a new legislative framework on emissions. And it is that the maritime transport is one of the big responsible of the emissions of gases like CO2 and SOX, with all that they suppose for the climate.

The problem requires the application of technologies and systems to improve its efficiency. Among the possible solutions are to adapt innovative measures to develop them and to implement them throughout the entire fleet. And it is that the short sea shipping is being more and more behind, with boats of considerable dimensions making several journeys a day.

This project wants to adapt the wingsail system carried by the America's Cup boats to a multihull that allows its advantages. In addition, a case focused on a region with the need to cover these benefits.

Going through all the stages of design, from the first approximations of the basic dimensions to the design of the hull forms, the estimates of speed and power, all based on a theoretical basis of the fundamental books of the subject, always taking into account all the necessary requirements for the design. The potential that the project can achieve will depend on whether it is interesting as an alternative to conventional ferries and can be expanded in other regions.

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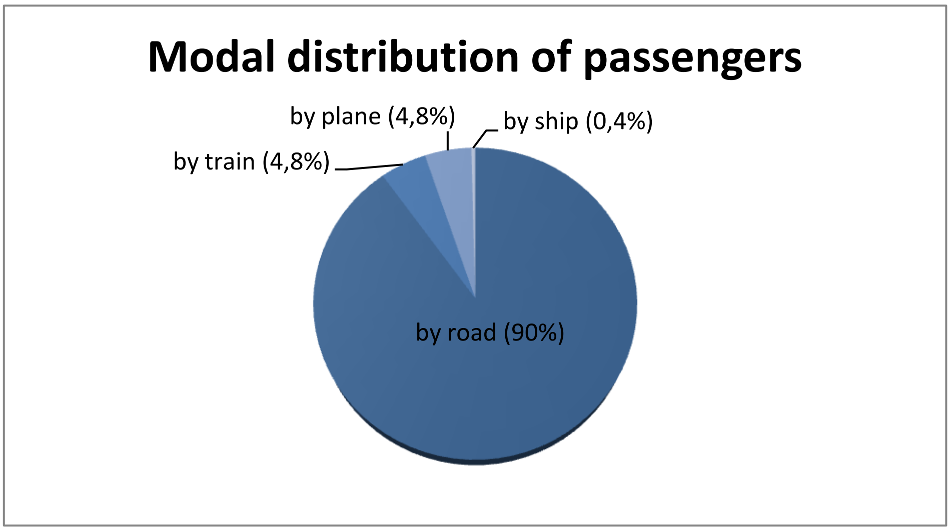
Chapter 1. Introduction

Context

Maritime transport is a sector that has a lot of history, since immemorial times man has used ships to cross the sea, although in recent years there has been a change of trend regarding the purpose of travel. In the beginning, ships were the most used method to transport passengers over long distances, but with the advent of air transport and its speed, it has been focusing on the transport of goods. In fact, for the first time since data is taken, international maritime trade exceeded 10 billion tons transported in one year[1].

Directly, this indicates that there are increasingly larger merchant ships with all the consequences that this entails, from more maritime traffic and more routes to more pollution, since these cargo ships are causing harmful gas emissions, such as sulfur dioxide, besides leaving a clear environmental impact on the water. If all the coastal activity and the great tourist demand are added to these figures, then there is a point of no return in which the environment is being punished by a frenetic activity that does not use measures to mitigate the consequences.

The immediacy of other types of transport means that the airplane is chosen to travel long distances, while years ago everything was moved by boat. Currently passenger ships have been relegated to large cruise ships that make tourist routes and ferries that are responsible for covering short trips.



Graphic 1. Modal distribution of passengers in Spain[1]

This trend shows a fact, and that is that passenger maritime transport has been dedicated to cover medium or short distances, especially in cabotage regime (union of two or more ports that are under the jurisdiction of the same country) and cases of large cruise ships. Ferries are the model most used worldwide to meet the demands of passengers, from seas to navigable rivers. Among its characteristics are its speed and large load capacity, both for passengers and road cargo. On the other hand, their high displacement as well as the big engines are not made by the most efficient boats. Ferries are displacement vessels with a large diesel consumption as well as a high number of gas emissions[2]

The activity of these ferries is focused on coastal areas and between ports in the same country, arriving to travel several times a day like buses. They tend to be large displacement vessels, normally equipped to carry both ro-ro cargoes and passengers (ro-pax) and which connect points in need of a network or infrastructure that allows them to supply areas of difficult or access or of great interest.

Although most of the pollution is caused by large merchant ships, the situation requires measures at all levels. Among the great advantages of the particular nautical one is the sustainability, since they make fewer trips due to their lower activity, there is a part that are still sailboats or using sails for their navigation, they consume less quantities of diesel ... Perhaps the solution would go through expand some measures to certain specific sectors that may benefit from the use.

This project considers that one of the possible applications that could have the rigid sail would be to help traditional sailboats to be more efficient when it comes to moving passengers, in terms of time terms. And is that lately the sailboats are being relegated to punctual departures or particular weekend, a bit more traditional style and is opting for larger ships for regular passenger transport. If it is true that perhaps in terms of number of passengers you can not match a sailboat or catamaran with a big ferry, but the idea should not be wrong: there are sailboats, either multihull or monohull that are capable of carrying a reasonable number of passengers and cover the routes in a more than reasonable time frame. So, why do not you see more sailboats for these purposes?

In part because it depends on the weather conditions, as well as having the efficiency of a large ferry, it makes them relegate. The idea of implementing the rigid candle is to provide them with a point of added value of innovation as well as to achieve that extra performance and thrust that traditional candles do not give in order to compete against the existing ones. Not to be confused, the purpose of the study vessel of this project is none other than to optimize a sailing vessel, rigid in this case, to make it competitive in terms of time and be able to act as a ferry line but offering a more reasonable and sustainable service.

And as far as advantages or added value are concerned, the strong point of the rigid sail is precisely that, the wind factor. In the world of maritime transport, boats are getting bigger and bigger and therefore the propelling equipment is monsters both in size and in consumption and emissions, reaching unattainable levels in the long term.

The objective of the project is to look to implement a new technology, such as rigid sail, in order to achieve a series of benefits such as sustainability, performance, less pollution and apply them to a specific professional framework.

Pollution and environmental care

The current state of the atmosphere warns that the limit is being reached. The transport methods are one of the main responsible for the pollution, in particular the marine transport emits 3% of global carbon dioxide. Emissions are directly proportional to fuel consumption, and with a fleet of merchant ships so large the situation becomes unsustainable. The maritime transport sector accounted for 80% of the world's merchandise trade. It is necessary a change in the sector that favours the measures respectful with the environment as well as sustainable. In addition to their impact on the atmosphere, they also leave a mark on the water, and fuel or oil spills are common. And not only because of carbon dioxide, but also those gases with sulfur particles are dangerous since they favour phenomena. Sulfur is found in fuels due to its fossil origin, and although it represents only 2% of the fuel do not forget the large quantities of fuel used by merchants. In fact, as part of the restrictions on sulfur emissions imposed by the Government of Spain are to mark areas without emissions due to their delicate situation. The footprint in the ecosystem left by sulfur comes from acid rain, a very corrosive phenomenon[3].

A step forward is required both on the part of innovation in solutions and the application of new technologies and on the part of regulatory organizations. The beginnings are difficult and more when there is already a stable infrastructure, but the urgency in terms of alternatives to fuels opens a market opportunity. One of the possible professional fields where to apply the first systems is in the transport of passengers. The boats are usually oversized and with a more adequate design they could become more efficient. This is where the part of the technological innovation comes in from the rigid sail system, until now reserved for high competition. In that sense the appearance of the sail or rigid wing supposes that step forward at the time of being able to implant in boats whose operative needs allow to extract greater performance. This is the case of passenger transport, which has been relegated over the years and which could be the best case to start applying new solutions and technologies. For thousands of years the boats have used the wind for their propulsion, with the increase in the size of the boats, it has not been possible to give sufficient power with the sails and with the fuel rush the big engines became popular. It is about getting profitable in boats of average size the force of the wind like so that it allows them to develop their activities.

Models such as the one presented in the project are aimed at sustainability. From sailing to those moments of motoring, the conditions under which they have been designed make them respectful of the damaged environment. Because also in those areas with great nautical activity the sea suffers, the fact of having electric motors eliminates from the emissions of toxic gases, as well as any noise that they cause and the possible spillages of fuel or oil to the water. It must be said that the areas with the most activity tend to be those with the most natural wealth and a particular ecosystem. It does not hurt that from one of the nautical sectors, such as transport, they begin to be sustainable projects with the environment and take advantage of renewable energies. All these worrisome data become more important when in 2020 the new emissions regulation in force.

Passenger's transport situation

The big competitions is where you usually see the latest advances and technological innovations to be able to squeeze up to the last second of advantage. They are an ideal case to be able to check if the measures are efficient, but always under very specific conditions. Once the results are obtained, it is time to implement these systems in other functions and operations that need it. The success of these solutions lies in adapting to more professional environments as alternatives to obsolete systems. This work not only aims to study the feasibility of rigid sail but also look to achieve its implementation in a sector such as maritime transport, which can benefit from its advantages

Seleccione en el desplegable los años cuyos datos desee visualizar.

Unidad	Tipo de servicio	Año									
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Pasajeros	Cabotaje	10.072.007	9.953.691	9.330.395	9.142.426	9.796.856	9.540.069	10.698.515	11.059.122	11.246.248	11.931.457
	Exterior	4.835.637	4.913.069	4.951.593	4.963.362	4.638.295	4.574.527	4.924.425	5.002.893	5.170.311	5.543.769
	De crucero	4.095.978	4.768.317	4.992.097	5.969.878	6.610.589	6.289.757	6.373.344	6.448.315	7.340.260	7.281.824
	Total	**19.003.622**	**19.635.077**	**19.274.085**	**20.075.666**	**21.045.740**	**20.404.353**	**21.996.284**	**22.510.330**	**23.756.819**	**24.757.050**
Vehículos	Cabotaje	1.891.279	2.133.376	1.935.606	1.647.063	1.673.881	1.830.275	2.112.105	2.065.613	2.122.561	2.242.417
	Exterior	1.169.543	1.163.627	1.229.135	1.275.347	1.206.093	1.172.789	1.243.005	1.167.011	1.187.068	1.322.495
	Total	**3.060.822**	**3.297.003**	**3.164.741**	**2.922.410**	**2.879.974**	**3.003.064**	**3.355.110**	**3.232.624**	**3.309.629**	**3.564.912**

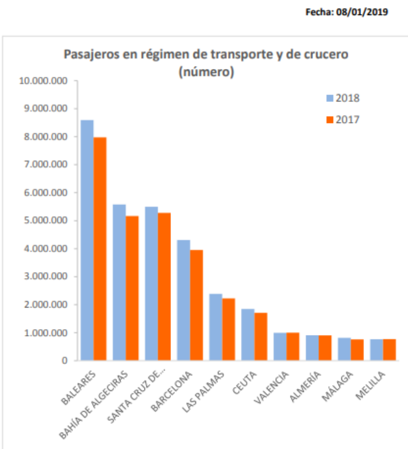
Graphic 2. Passenger transport data in Spain. Source[4]

The majority of passengers who use maritime transport, cruises in part, do so in a short sea shipping transport to move between points in the territory. Especially you can check in the table as those destinations with the busiest and most nautical activity are the most visited, both by citizens of the same country as foreigners[4]

With regard to the most particular nautical or weekend there is still no example or case of a ship that works with rigid sails, since that would not be the purpose of the case or the best example: the departures of individuals in order to Week or summer season with good weather conditions are not the most worrisome cases of pollution, the problem has to be focused on those ships of small or medium size with a great daily or weekly activity, which makes them consume many resources as well as being inefficient operationally speaking. Among these cases are the ferries that cover regularly with several journeys a day between two or more points located relatively close, these are heavy vessels that usually load passengers as well as goods or vehicles or ro-ro cargo. Although they usually cover the trips in a short period of time, many cases without reaching the time of navigation, their function could be ideal for the case of a catamaran driven mainly by rigid sailing. Because to see if the option is economically viable, a ship must be found with a professional activity that is remunerated to be able to match the existing cases, which are large shipping companies

Passenger transport does not represent such high figures in terms of cargo volume in maritime transport, although it is true that there are coastal or inter-island areas that are in great demand in this field. This is the case of short sea shipping transport, which is summarized as the transport between two or more ports of the same country, of great demand in a country like Spain. In Spain there are especially two areas where this type of route is carried out with great frequency, several times a day, such as the Canary and Balearic archipelago. There are two sets of nearby islands where passenger transport is common and frequent, with short and medium distances, usually covering 1h journeys to join two points on different islands. Normally, those responsible for carrying out these tours are ferris-type catamarans, this means that heavy vessels and generally pollutants, which move in a marine environment that is usually quite exploited and punished, in addition to moving in delicate waters and not very deep[5]

Autoridad Portuaria	Mes noviembre		Acumulado desde enero		
	2017	2018	2017	2018	Var. (%)
A CORUÑA	12.851	11.041	174.463	175.961	0,86
ALICANTE	14.740	8.699	216.326	215.126	-0,55
ALMERÍA	37.853	44.504	901.660	910.230	0,95
AVILÉS	701	0	2.207	1.986	-10,01
BAHÍA DE ALGECIRAS	289.519	314.683	5.165.360	5.576.412	7,96
BAHÍA DE CÁDIZ	49.312	46.618	380.520	422.939	11,15
BALEARES	323.788	360.359	7.975.032	8.590.731	7,72
BARCELONA	258.265	275.826	3.950.799	4.309.689	9,08
BILBAO	4.135	10.704	181.848	195.976	7,77
CARTAGENA	18.203	23.545	232.453	216.728	-6,76
CASTELLÓN	0	0	411	568	38,20
CEUTA	122.222	129.513	1.708.402	1.849.302	8,25
FERROL-SAN CIBRAO	698	2.053	20.379	17.534	-13,96
GIJÓN	0	0	21.813	28.771	31,90
HUELVA	2.936	2.581	41.307	46.502	12,58
LAS PALMAS	252.122	241.796	2.225.220	2.385.338	7,20
MÁLAGA	73.201	85.815	763.334	819.127	7,31
MARÍN Y RÍA DE PONTEVEDRA	0	0	143	0	-100,00
MELILLA	43.348	43.875	769.329	763.930	-0,70
MOTRIL	12.741	6.844	327.910	252.427	-23,02
PASAIA	0	4	814	1.394	71,25
SANTA CRUZ DE TENERIFE	511.287	521.363	5.275.894	5.499.509	4,24
SANTANDER	11.439	7.065	228.382	243.954	6,82
SEVILLA	2.506	1.334	23.483	16.728	-28,77
TARRAGONA	654	5.716	51.394	98.139	90,95
VALENCIA	92.843	91.415	1.002.220	994.672	-0,75
VIGO	6.988	5.719	139.024	154.545	11,16
VILAGARCÍA	0	0	1.596	1.158	-27,44
Total	**2.142.352**	**2.241.072**	**31.781.723**	**33.789.376**	**6,32**



Graphic 3. Distribution of passengers depending of the location. Source[4]

That is why, uniting both points, sustainability and passengers, the need to find means or alternative sources that favour and respect the environment begins to be urgent. And this is where the idea of combining a technological measure such as rigid sailing with passenger transport arises, to be able to take advantage of a more efficient push in a boat focused on this solution[6].

As you can see, the project is designed for coastal areas, with large passenger volume and / or activity or need for semi-rapid transport in coastal areas, whether short distances between two points on the same coast as two different islands. It is not so much a matter of competing in the short term with the volume of cargo that passengers move the ferry lines, but rather to be able to offer more sustainable alternatives as well as the added value in navigation that a ferry can not feel so much the motion that provokes sailing[1].

Adapt to the environment

Spain is a country with 3,900 km of peninsular coast and 1,900 km of insular coast, this would indicate that it is a country focused on maritime trade, but the truth is that the infrastructure is not designed or adapted to accommodate or move a larger volume. In fact, passenger transport by sea only accounts for

0.4% of the total number of passengers moving in the country, compared to 10% of freight transport by sea.

The scenario found in coastal or insular areas, in the case of Spain could be considered the Balearic and Canarian areas, makes them favourable to study how beneficial it would be to opt for investing in alternative solutions to favour and improve not only the emission of gases, but also be more careful with the protection of protected natural waters, more respect for the environment and careful with the view set in the coming years, where the situation is already beginning to reach the limits before becoming irreversible.

They are very crowded areas, perhaps of the most of the country during the holiday period, which together with the great use and frequency of trips on boats not particularly respectful with the protected waters, so it is also in an ideal situation and pressing to start endowing your marina with ecological alternatives. As it has been mentioned, these routes are usually carried out by ferries, such as regular bus lines, in which large ships in transit load and in fast journeys connect points in the same area, such as groups of islands (Gran Canaria-Fuerteventura-Lanzarote) . The large volume of passengers using these lines means that it has been taken into account when considering the creation of a more ecological or recreational line, more focused on added value[7].

Because it is true that there is already an infrastructure created around the nautical sector, and it works well, with precision and punctuality, so why would have to change or create another mode of transport? As everything that is obsolete, there comes a time when the responsible authorities have to worry about maintaining the future, so that it is not consumed and because of having respect for the environment, in addition to the conservation of the environment, they must also propose sustainable alternatives in the long-term future. and that is what this project promotes: to provide a ship propelled 100% by sustainable means that can compete with the big ferries. Maybe it is not a quick process or an immediate reality, but it is about starting to operate to polish the weaknesses with respect to the competitors (in terms of time at the time of making the trips) and provide strong points to make the public or consumers or customers for these more ecological alternatives.

It is about providing the best scenario, which would be a good design of the hull of a ship so that when studying the advantages or possible designs of the wing profile it can be as highly efficient as possible, so that the disadvantages with respect to the Ferries can be compensated with other aspects such as added value.

Obviously there are a number of points or aspects that have to be improved or overcome in order to implement rigid sail alone as a natural competitor with respect to combustion engines: after all there are also traditional candles that have always been used for weekend recreational boating or regattas, but which is not exploited in passenger transport (perhaps due to its intermittency or its high dependence on weather conditions), but if it is based on the basis that performance can be extract a rigid sail from a favourable wind (which should be even more favourable for traditional sails) and can push the ship to cover its displacements, it is only necessary that the auxiliary method (if part of the base that the rigid sail will be the first source of propulsion) that will be in this case the engine, can be 100% electric will finally provide a propulsion or push totally clean, it is only achieve that with the optimization of the sail to take advantage of the wind it can maintain or achieve a minimum that ensures the thrust of the ship, as well as in the specific situations that may require more force being able to use the engine.

Normally ferries have large engines with high demands and consumption but in terms of performance or minimum are more than capable to reach cruising speeds more than reasonable to get to reach their destinations in a short time and continue with more trips, and So, more money. But in principle, although perhaps with a wider margin of time, vessel XXX would have to be able to cover these routes with a certain speed and a minimum of guarantees.

In addition to the added value of sustainability, the fact of being a more recreational model or similar to a yacht, rather than a ferry, could make the balance decant for the public to opt for its use, In addition it could be the object of promotion and aid on the part of the local administration, since they would be interested in promoting sustainable alternatives with their environment, a very exploited medium and punished by a very frequented maritime transport.

As mentioned in one of the previous points, it must be the authority or organizations in charge of the area who decide or favour projects like this, since otherwise the people themselves would continue to take the ferries, as in their cities would continue to drive the most polluting cars or the most polluting buses if aid or benefits are not provided so that these proposals can compete against those plans that have been in place for years. You just have to favour the scenario, as well as the clients tends to tend to or use sustainable methods of transport. As it happened years ago with cars, and as there are still many better ones to be implemented so that people can buy and use the particular electric vehicle, the lack of charging points in the consumer network means that they do not look as many as they are necessary, although it is true that the number of hybrid vehicles increases. Where this use is most seen is in means of transportation of public entities or that move a large volume of passengers on each journey, such as urban buses. For example, in a city like Barcelona the majority of the bus fleet are already at least hybrids, also finding other types such as those powered by natural gas or those that are even 100% electric, but these, without the promotion and assistance of those responsible, would not be competitive against the traditional.

It is not about people deciding on the physical aspect or the beauty of a design (that of a catamaran will be more attractive than that of a large ferry line) but that the added value of this case makes it attractive enough as to be considered an alternative that although with its failures or weaknesses, can face another type of transport. It is about taking a step forward from the Organizations and Governments in favour of ecological alternatives that promote initiatives to improve the problems of pollution. The implementation and expansion of the use of sustainable solutions with the punished environment must be helped

Canary Islands

Moving this situation to a more local level, in Spain there are thousands of kilometers of coastline and with a lot of nautical activity. In particular there are two areas of special interest, such as the Canary Islands and the Balearic Islands. These two communities, due to their geographical needs, require a network of ferries to link their islands, often being the only way to get goods or passengers to all points.

The Canary Islands have a long tradition of maritime transport, there are daily connections between the different ports and it is very much assimilated by society to travel by ferries. In addition, their favourable weather and weather conditions make them a good navigation area for most of the year, with the famous aliseos that allow sailboats to cross the Atlantic from here.

In recent years, the lines responsible for making these trips have been growing, which has allowed them to have more boats, larger and more journeys a day. This factor, added to the great activity and tourist interest that exists in the region, makes the trips by boat are very common. In fact, the Canary Islands are the location chosen every year by sailors and teams to prepare the regattas thanks to its favourable weather conditions. Along with the maritime tradition of the Canarian society for years, they are the main claim for sailing. That is why the local case of the Canary Islands is proposed and studied as a basis for project activity[8]

The transport of passengers in an area such as the Canary archipelago is the order of the day, and more for cases of short sea shipping or movement of passengers between ports in the same country and with navigation within the coasts and waters legislated by it. That is why today there is a large number of companies and ferries working in the area to offer all kinds of trips and activities. From the typical ferry function to link two ports with a regular and fast route to those destined to cruise, ships dedicated to nautical activities or even excursions. Most usually have a common point and is the use of the combustion engine as a driving force, although it is true that for some or even most tasks could be considered alternatives or even sailboats properly, do not usually choose to switch to renewable sources of Energy.

This may be due to the functionality or good performance of the combustion engines, which fail little and allow them to cover and quickly meet the scheduled times and paths and at the end of the day this allows them to make more journeys a day, and So much more income and money. But reaching a certain point of activity and movement reaches the limit of the sustainability that the ecosystem can have to regenerate and grow and follow its development in optimum conditions, and that there are certain moments that, although they are not the most effective solution, must be Decanting the balance in their favour since they will be the only ones that will take care of the environment, and if you do not want to reach a point of no return or natural degeneration, you have to promote new forms or alternatives to traditional transport, as happens with cars. If other sustainable alternatives to large ships are encouraged or promoted, they can eventually reach their numbers, but it is true that at the beginning there is a need for patience and infrastructures to accommodate all the protagonists.

The geographical needs make these ships have to be large to be able to transport merchandise or ro-ro cargo, which implies a large displacement and a large emission of gases due to the great power they need. The alternative to these large ships would pass by lighter ships that by alternative systems to the combustion engines can propel themselves and be able to travel the same routes in a similar time frame, but at the same time being more respectful not only with the emissions of gases but also with the marine environment, which is very delicate.

With the idea of transporting passengers between ports in the same country, that is, short sea shipping transport, this project will study the design stages of a vessel suitable for this mission and that will also combine new solutions and technologies to reduce environmental impact. The idea is to design a catamaran-style boat and provide it with a rigid sail that can provide the power and reliability necessary for the purpose. It is clear that large ferries can exercise this function but sustainability must be promoted, especially in the transport sector, which is usually one of the most polluting.

Illustration 1. Map of the main routes between the Canary Islands. Source[9]

The Canary Islands are composed of a group of 7 islands, some of which are only accessible by sea since they do not have an airport. Some of these islands also have smaller islands very close to them, so the average distances are even short if these distances are considered, as is the case of Fuerteventura-Isla de Lobos or Lanzarote-La Graciosa. As show the Illustration 1 there are routes less than 90 minutes, and as will be demonstrated throughout the work, the catamaran can compete in speed with the ferries, so it is a good alternative

Their great tourist and natural interest make them one of the most concentrated and active points of the entire Spanish coast, as well as their geographical needs and their great tradition in the maritime sector, a great focus of nautical activities. This is how they have a large network of ports connected daily where ferries are responsible for uniting them.

The purpose of the work is to achieve an optimal design of a catamaran to favor the application of a rigid sail and to be propelled by wind energy. Regarding the traditional sail, the rigid wing supposes an improvement of benefits, as well as ease of handling.

While on this map of the Canary Islands you can see the different routes that are covered daily (and some several times) by ferries (to cope with the large volume of passengers and cargo moving between islands), there are still more routes between the main islands and smaller ones that do not appear on the map. As the case of Fuerteventura and the island of Lobos or Lanzarote and La Graciosa, these journeys that do not even reach the middle hour are also covered by ferries of not so big dimensions, being able to be replaced by boats like the one of the project. Other interesting routes that could be covered are those less than one h, such as journeys along La Gomera or between Fuerteventura and Lanzarote[9].

It is true that in terms of speed-efficiency in the displacements and volume of cargo transported, it is not possible to compete against the large ferry lines that operate, but it must be provided with the differential or added value factor of the proposal: to be able to offer an alternative clean and sustainable in these short trips that is respectful with the environment, both with the wind and with the waters, being areas of special interest not only tourist but also natural. New forms of transport have to be opened up that allow that all the exploitation that suffer can be reduced in order to preserve the environment, that after all is the point that is valued and why they attract so many people year after year.

The alternative, although it can not compete one-to-one (against each other), must be able to offer aspects that tip the balance towards this type of responsible consumption with the environment. It must be sought that the added value with which the project is intended to favor its use and be promoted as sustainable consumption

A good engineering project is differentiated by the sustainability that goes with it, both the process and the solution that is applied. This factor is key in the project when it comes to differentiate from existing ones and be able to provide the added value that companies are looking for today. The added value is an inherent characteristic of the product, which gives it an extra value with respect to the competition in such a way as to tip the balance in its favor. In this case, the added value of the project is sustainability and respect for the environment. While currently large vessels cover the routes in a short period of time, their impact both atmospheric and marine is high, reaching limit levels.

That is why, together with the favorable weather conditions of the island, the great tradition in maritime transport and the need to interconnect make it a perfect environment where you can analyze the impact of an eco-friendly solution, and study if the yield would be applicable to more sectors in need

Selection of the boat

Regarding the type of boat (and its hull) it is decided to study the project with a catamaran. Among the reasons that have decided to opt for a catamaran are, in addition to the list of "physical" advantages implicitly brought by catamarans, there is an innovation factor (like rigid sails). And is that in recent years the boom of catamarans is palpable, and not only at the level of recreational and private boating, have also been emerging innovative projects in which they used the catamarans since they considered that they are more efficient or better test bench .

It must be because the great physical conditions and its advantages of the catamarans provide the ideal scenario to test new tools. If only recreational or private boating were taken into account, the situation would be somewhat better, since in addition to emitting less polluting gases, they are usually smaller vessels and even sailboats, so they tend to be more respectful with the environment. But it should not change the focus of the problem, just as it is happening with road transport, both restrictive measures have to be taken to eliminate the main causes of the problem as well as other more technical measures that favour the expansion of the use of alternatives. more sustainable.

It is important to choose the type of boat since it will bring with it a series of advantages and disadvantages associated with the shape of the boat. For this project, a catamaran-type vessel has been chosen for the following reasons[10].

- Stability: important factor when choosing a catamaran. The catamarans present more stability than the monohulls due to the fact of having two helmets, and therefore, a larger sleeve. This means that the transversal stability is much greater, and stability is not only sought for convenience. Being much more stable, the boat can take more advantage of the thrust since it loses less energy, navigation is more comfortable for the passage. Hardly a catamaran heels more than 10º. To achieve the maximum possible stability, the designers try to distance as much as possible the distance between the two helmets. This is important since it has to be built without adding a weight that is excessive or determinant for the structure of the bridge
- Safety: important factor when transporting a large number of passengers. A catamaran has two helmets as well as two engines, that is, they are in duplicate before any failure. Also in case of a waterway in one of the hulls the vessel would not sink, since the other would remain afloat. The catamarans are almost unsinkable, and although a hull has a waterway, its structure is buoyant enough to remain afloat
- Speed: in the comparison between a monohull and a multihull of the same length, the multihull will be faster. The reasons are several, for example that a multihull can have more sail area since it has more beam. Also contrary to what one might think, the interference of the helmets does not slow down, but the tunnel effect occurs. The finer forms of helmets make them more hydrodynamic and faster
- Habitability: for two vessels of the same length the multihull presents more space, not only inside, but also on deck, so a catamaran is ideal for transport. The cover is usually more usable since there is more space
- Draft: generally ships with shallow draft, which makes them ideal for anchoring and navigating in shallow waters.
- Mobility: the fact of having an engine for each helmet, and these separated by the bridge provides them with great maneuverability when maneuvering in confined spaces

If apart from all the advantages that catamarans have, they can be designed in such a way that their virtues are exploited and propelled by sailing, the benefits are extended. The fact of a design adjusted to the needs, both operational and sustainability of the boat, can mean success in adapting the alternative solution

These would be the advantages that catamarans provide only by their typology and forms, but then we must take into account other aspects of these boats, as the large distribution of the main deck makes them ideal for passengers. If you observe the majority of ships used worldwide for the transport of passengers, they are usually catamarans, specifically ferries. In addition lately catamarans have been chosen to try new alternatives thanks to all its advantages which makes them the ideal model to implement new solutions.

Although as a general rule multihulls reach high speeds they also have severe restrictions in order to reach the high speed potential. The most important limitation lies in the load-displacement factor. As a rule to get the maximum possible stability away the hull, with the maximum possible distance that does not imply a significant increase in the weight of the bridge and the structure of the helmet. The typical figures and forms of a catamaran are 50-60% of the beam in relation to the length[10].

The trend of recent years by catamarans has made them ideal to test some of the latest technologies and tools in the market seeking to prove their effectiveness in a more recreational or particular navigation than the high competition environment where they arise. This is how multi-hull models have come out in projects to test the performance of photovoltaic cells and panels and even rigid sails[11].

Similar projects:

This section is dedicated to a series of initiatives and prototypes that show how innovation in the nautical sector is useful to reduce problems. All have in common sustainability and preoccupation with the environment, being alternatives to current methods of maritime transport:

Wind Wing Technologies

Currently there are similar projects, or with a purpose similar to that proposed, studying the feasibility of implementing technological measures (from a rigid wing to solar panels or alternative methods of propulsion) to carry out activities or professional tasks that so far require fossil fuels but that could be covered by more sustainable boats.

This is the case of Wing + Wind Technologies. Located in the bay of San Francisco, this American company designed a prototype catamaran a few years ago focused on passenger transport linking the two ends of the bay. After months of studies sailing in the bay they proved that not only can they compete with the speeds of the ferries, reaching 15-20 kns, but also all the savings and reachability that they achieved saved as much money as emissions to the companies . The first prototype they made had capacity for 40 people but they were already working on a superior model to accommodate 100 passengers. They also showed that in a period of time between 1 and 3 years they were able to amortize the investment, so it is a short period[12].

Illustration 2. Wingsail catamaran. Source: WindWing technologies

Although up to now its purpose was to be the complement to combustion ships for diesel savings, they estimate that the economic amortization period is low (from 1 to 3 years), which can save 40% of costs dedicated to fuel and They also take advantage of a totally renewable and free source like the wind

But speaking coldly of data and savings that can be provided by the prototype alternative that advances the wind wing technologies brand, it can be seen as apart from the substantial savings (of almost half) in emissions and costs related to polluting gases, apart from the use. In the first tests they have carried out, they have concluded that the best option is to first install the sail as a complement to a diesel engine to reduce the effects and benefit from the thrust during sailing. The wind itself is an ideal source for propulsion (it has been sailing for centuries using only the force of the wind to move) as well as the most efficient of all (free-nature). And then there is the point of added value, since all this is done with a view to the future, to the conservation of the climate, of the better state of the waters, of the respect for the environment ... Also one of the points of more emphasis that mention the innovative companies is the fast amortization period

Bound4blue

Another company that is committed to take advantage of the force of the wind, although in this case with a different purpose, is the Spanish company Bound4blue. This company focuses on the use of rigid sails so that large merchant ships can save fuel while they sail. They have received several awards for innovation and implementation of new technologies, reaching savings of 20% fuel thanks to the candles. The scenario they propose is different from that of the project, since these large ships have the equipment of the sails in their large decks, but they still need engines for navigation, although with the data obtained there are already companies that consider implementing their solutions and equip the ships with sails to save on fuel consumption. The possibilities offered by large merchants to install several candles at once as well as the size of these make them the best possible case to show the benefits in terms of fuel savings. Do not forget that for companies with such large ships the cost of fuel consumption is one of the main[13]

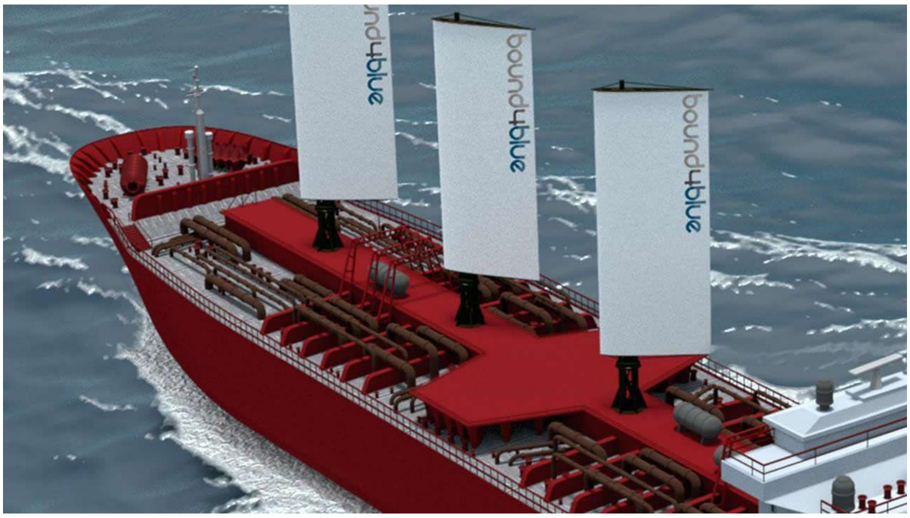


Illustration 3. Wingsail vessel. Source: Bound4blue

Ecocat

The Ecocat is a catamaran sailing along the coasts of Barcelona (at shallow depths) on a route similar to what the Swallows would do (that is, by and for a ride, enjoy a quiet tour) in which it was implemented a series of advances and test benches to test its performance, its implementation on board, its operation, its fusion with the ship and its deck. These advances consisted of a series of solar panels along the deck (which is why it facilitated the choice of a catamaran since these usually have a wider, more usable, more open roof, with more space and habitability) that favored putting a greater number of photovoltaic cells. In addition, the stability with which a catamaran sails makes the performance that can be taken advantage of these systems is greater, and even more is increased when it is done in coastal and quiet areas near the coast

There are large tourist areas where nautical activity is very present and for some time you can find passenger boats powered by electric or gas engines and also use solar energy. They are perfect for areas with many animals because they do not emit noise or waste are very respectful for their ecosystem

Chapter 2. Sizing

As mentioned in the documents of the faculty[14] for the writing of the TFG, the first problem is to define the physical dimensions of the ship, and more when starting from 0. In order to start defining dimensions, certain aspects and operational requirements and classification of the vessel have to be clear

Length

The first dimension, and the most important, is the length. The length limits the speed of the ship, so that the more length the maximum speed that can be reached is higher. Knowing the length allows to make some assumptions about the speed, the load capacity or the power needed to maintain the speed. While the ship is not navigating at the design speed that is assumed, it is navigating in displacement regime. This means that the boat navigates by displacing the water in front of it, so it is not the most optimal point to reach maximum speed. In the end, the speed of the water ends up being the same as the one in which the boat moves. The optimum point is found when both the bow and the stern of the boat are driven by two crests of waves[15]

At low speed, the wave is short and several waves occur in a row. As the boat increases in speed, the wave increases in height and length, until the wave length reaches the stern of the boat. In other words, the wavelength of the wave grows until it reaches the boat's length of flotation. At that moment the boat sails within the maximum wave that has generated and is unable to climb and overcome its own wave, reaching its maximum speed at that time.

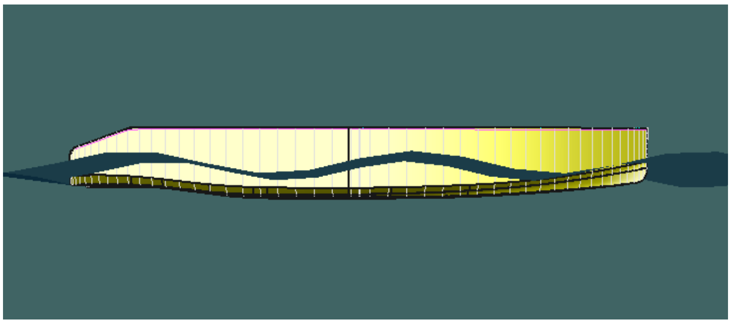


Illustration 4. Several waves along the length. Low speed

Being able to overcome the limit speed does not depend as much on the power as on the ship's forms and its ratios. Normally catamarans are designed so that they can exceed the rated speed. There is a maximum point of speed, that for more installed power that the ship has, it will not be able to overcome.

For operational needs as well as for similar boats, it is decided to determine the length in 24m. It is a capacity more than enough to accommodate an average number of passengers between 50 and 100.

Length: 24m

Displacement

The next parameter that most influences the ship is the displacement. The displacement, which is the weight of the ship depending on the various loading conditions, may vary. Most times the displacement of a ship is provided, this is usually the minimum to give a feeling of lightness and speed. In fact there are times that do not take into account necessary equipment to not increase the weight. The displacement is a factor that relates the load capacity that the boat can carry with the sensation of comfort during navigation.

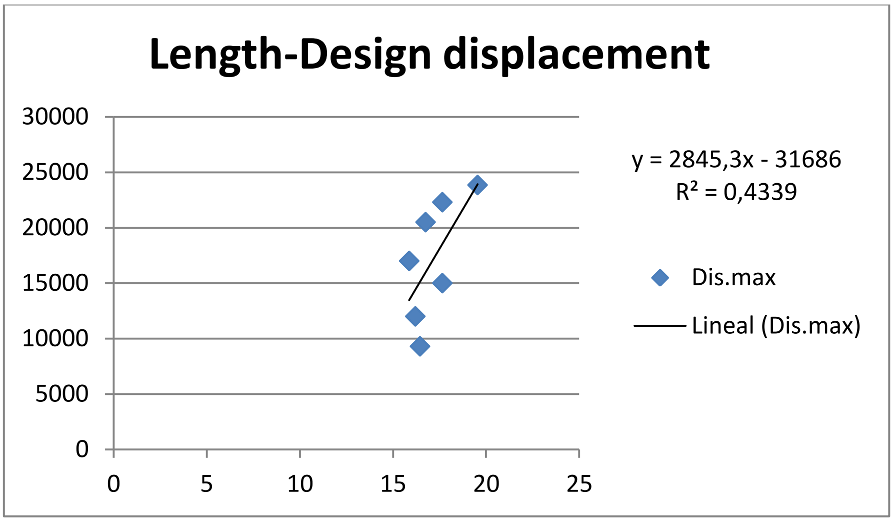
It is known this way thanks to Archimedes, who defined that the weight of an object is equal to the weight of water that it displaces. The volume of the displaced water is also equal to the volume of the submerged object, so this is the reason why a boat floats.

It is not a matter of having a very light ship but of having a displacement according to the operational requirements for which it is designed. A catamaran dedicated to coastal navigation on weekends will not have the same relationship as one that has to spend a long season at sea crossing the ocean. For each type of navigation, the necessary equipment must be available, and this ends up affecting the displacement of the ship. The displacement calculated by Maxsurf for the load conditions of the project (without taking into account the passengers and crew) is:

Displacement: 40 Tn

The weight of a ship can vary considerably according to the load conditions that are estimated or the basic equipment that is considered. In addition to being a passenger ship, we must take into account the extra weight it implies with the maximum capacity of capacity allowed. At an average of 75kg[16] per person and a capacity between 50-80 people, it can reach 4-6 tons more

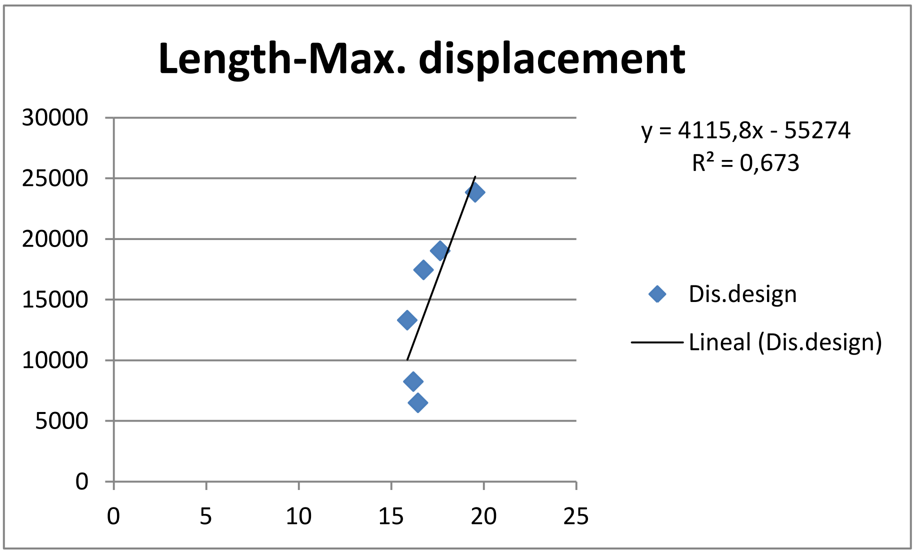
The following linear regressions have been extracted from the tables of the book Sailing Yacht Design (Claughton, Wellicome and Shenoi), and they provide more concrete information about technical data like the coefficients, LCB and LCF positions, rudder's area...



Graphic 4. Linear regression Length-Design displacement. Source [17]

This table obtained provides more in-depth information about the catamarans that appear in it (coefficients, design displacements and maximum ..). The boats in the book table are of a length similar to that of the project, and the truth is that the values are quite similar to those of the catamaran If the unknowns in the equations are replaced by the length of the model, the displacement obtained is:

36.601.2 kg



Graphic 5. Linear regression length-maximum displacement. Source [17]

The maximum displacement obtained for the boat of the project is:

43.505.2 kg

Ratios

Along with the length and displacement the most important parameters are the ratios, as Charles Doane (2010) mentioned in his book (The moden cruising sailboat). The ratios are dimensionless coefficients that relate several characteristics and provide information on the behaviour that can be expected from the vessel. The most used are the displacement-length ratio (D-L) and the speed-length (S-L).

Displacement-length ratio

Based on the values obtained from the ratios, these evaluate and classify the vessels in a range from ultralight to very heavy in terms of motion. A light ship will be easier to exceed the speed than a heavy one, while a heavy ship will have more cargo capacity.

$$D/L = \frac{Displacement}{(0{,}01 * Length)^3} \tag{1}$$

Where:

- Displacement is expressed in Long tons
- Length is expressed in feet

Depending on the load conditions considered, the value of the D / L ratio may vary. For example, if you only take the ship's displacement of 40tn, you get a ratio of 66 (which means ultralight), but for example if you consider the maximum possible passage (100 people) to an average of 75kg per person, it makes the displacement increases by 7500kg, which puts the ratio at 100 (light).

This data is to say that the boat can exceed the speed limit and reach the semi-planning regime. While it is true that it depends on the equipment that has been taken into account for the displacement data, as we add weights the range varies and we can go from light to medium. A more D / L index better capacity of the vessel to transport cargo comfortably

While it is true that it depends on the equipment that has been taken into account for the displacement data, as we add weights the range varies and we can go from light to medium. But depending on the objective of the ship, perhaps a heavier boat is needed if you are looking to cross the ocean, with the weights of the basic equipment. As mentioned in the displacement section, if the information provided is not adequate (if the displacement is less than it should be), the classification scale of the ratios can change. It is important to define the navigation conditions of the ship to equip it with more or less equipment and to know more deeply its behaviour. In the section of speeds(*) will explain more carefully the relation of these ratios for the calculation of the maximum speeds

Speed-Length ratio

On the other hand, the Speed-Length ratio is essential in any kind of vessel's design. It is the coefficient between the vessel's speed divided by the square root of the waterline's length. As can be seen, it is not coincidence that the limit between displacement and semi-displacement is 1.34, since it is considered that the maximum ratio that can be reached S / L. But it is not accurate for multihulls. There are three cases depending on its value:

- Speed/length < 1.34 → Displacement-mode motion. The hull is simply moving the water out of the way as It moves forward.
- 1.34 < Speed/Length < 2.5 → Semi-displacement or semi-planning mode. The vessel is trying to rise up over its own bow wave to get onto plane.
- 2.5 > Speed/Length → The vessel is planning and relies on dynamic lift to raise and hold it out of the water so that it can skim along the surface of the water.

The factor of 1.34 is the physical factor that regulates the behaviour of wave trains. And it is the same value as the nominal hull speed formula.

The project boat will reach the second point at the most (1.34 <S-L ratio <2.5) since the displacement boats do not usually move in a planning regime only. The speed-length ratio of the vessel is 2,09 and this coefficient is more approximate than 1,34. It makes an important difference of almost 50%

$$S/L = \frac{8.26}{D/L^{0.311}} \qquad (2)$$

According to Gerr's formula, this is the maximum S/L ratio a boat can achieve. For this case, it is obtained a S/L ratio of:

2,09

This value falls in the middle of the semi-displacement scale, which together with the other factors studied, places the boat in a position to overcome the helmet speed. The semi-planning regime is more efficient than the displacement, thanks to the design of the stern you can achieve an extra hydrodynamic thrust thanks to its lift. At more speed the waves will be more favourable and prone to be the same length as the boat

Market research:

All design processes usually start with a market table comparing similar vessels. This provides data and regressions that serve to approximate factors such as propulsion to equip the ship.

Boat	Lenght (m)	Beam (m)	Displacement (Tn)	Engine (hp)
Serie 5	15,24	7,8	16,8	110
Leopard 50	15,4	8,04	20	104
Hybrid Cat	15,5	6		50
Flash Cat 52s	15,8	8,6	7,5	80
Lagoon 52s	15,85	8,6	22	115
Catana 53	16,18	8,65	14	150
Aresa 1700	16,5	6,4	24	630
Bali 5.4	16,84	8,74	22	140
Lagoon 560	17,07	9,45		220
Leopard 58	17,56	8,45	28	150
Ipanem	17,8	8,8	23,5	150
Ibiza	17,8	8,8		110
Gunboat 60	18,25	6,52	20	100
Catana 62	18,68	9,49	19,2	220
Doblemar 2	18,8	8		900
Lagoon 620	18,9	10	32	300
Sunreef 62	18,9	9,3	22	250
Lady Joana	19,7	7,2		
Ecocat	20	8	27	100
Contoy 65	20	11	21,6	
Le Providence II	20	8,8	38	600
ODC Marine	20	5,4	26	700
Fountaine Victoria	20,32	9,5	26	300
New 67	20,46	9,84	35	220
Gunboat 68	20,75	9,1	23,8	
Catana 70	20,86	9,49	26,5	300
Picardie II	20,98	8,58	22	
Sunreef 70	21,34	10,4	34	320
Rodman 69	21,45	7,3		

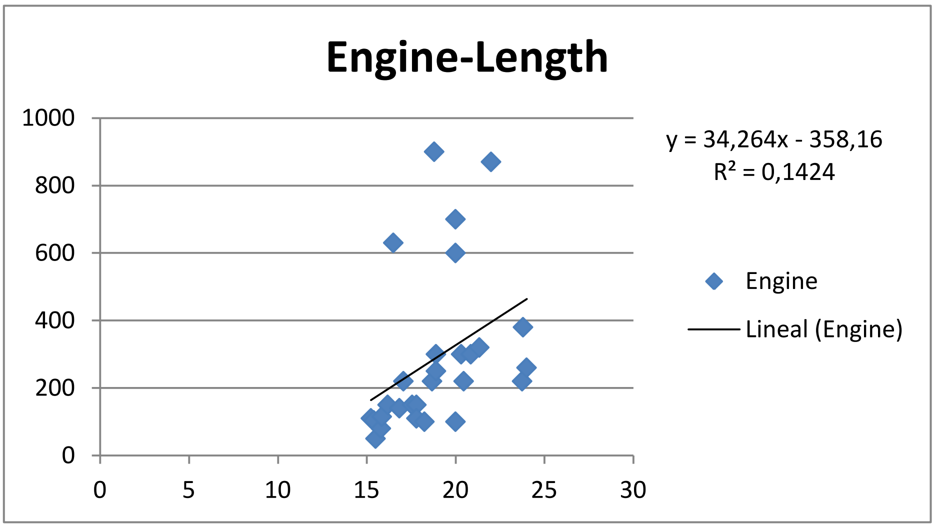
Palma Bay	22	10		
Fly Blue Tres	22	10,7		870
Flash Cat 75	23	10		
Fountaine Pajot	23,75	10,5	22	220
Five Star	23,8	12,5		380
Eco Slim	24	10,5		
Tahiti 75	24	10		260

Graphic 6. Market research

This search and comparative market with similar boats provides a first approximation to the values that can be expected. It also works to see if there is a lot of disparity in the results or characteristics, since it can indicate that there is something that is not well calculated

The first step usually leads to a market search to be able to compare with similar models, and approximate these parameters. It also depends on the needs or activities that the boat has to develop. This market table has been obtained by looking for similar models in terms of dimensions. All boats are catamarans but not all have the same purpose: there are cruising catamarans, other recreational catamarans and even ferries. Mainly looking for boats of similar length and beam, included in a range between 15 and 24m. These linear regressions approximate the power required as a function of the length-displacement dimensions

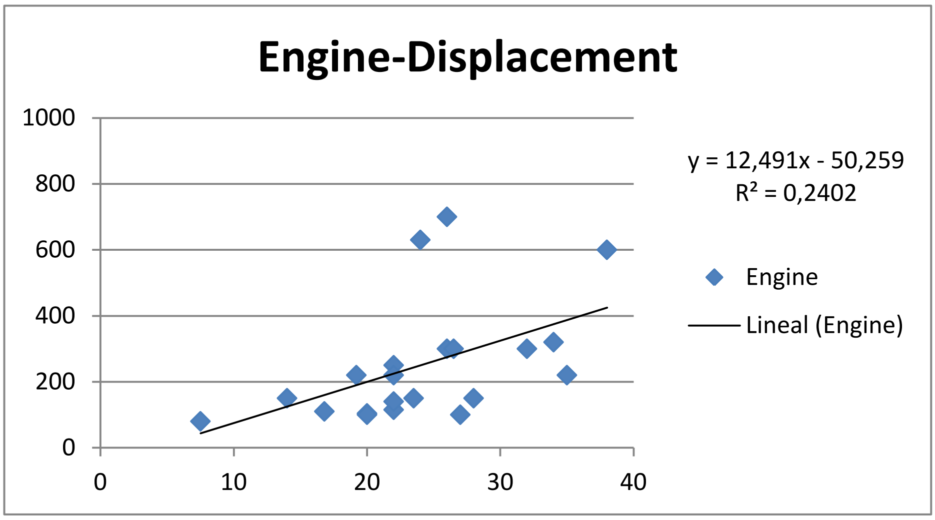
Linear regression:



Graphic 7. Linear regression engine-length

Substituting the value of length (24m) in the equation provided by the graph gives a power for the engine of:

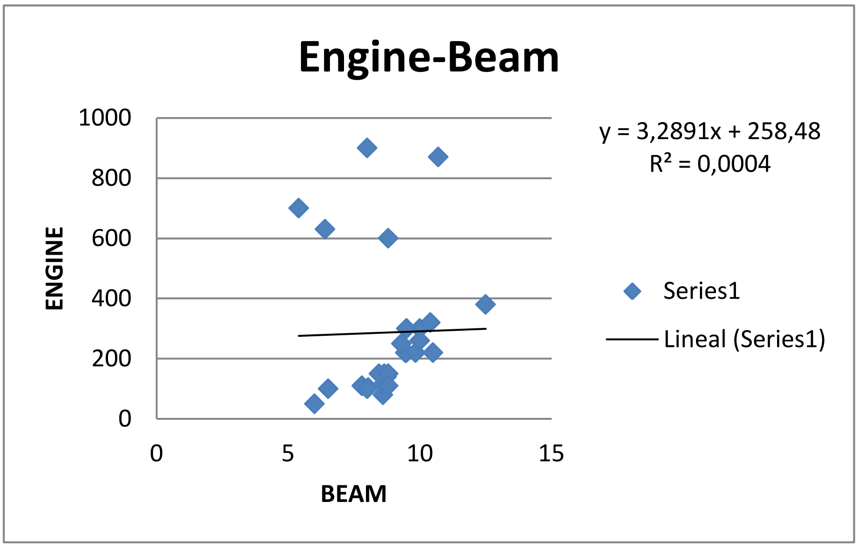
464.15 Hp



Graphic 8. . Linear regression engine-displacement

Substituting the value of the displacement (40 Tn) in the equation provided by the graph, we obtain a power for the engine of:

449.381 hp



Graphic 9. Linear Regression beam-engine

With the equations of the lines you can see how the beam is the least influencing factor when estimating the power To have the most accurate approximations possible, it must take into account those higher R values, in this case 0.004 is almost negligible compared to the other factors. It is a way to see how the beam has little influence when determining the power of the ship, compared to the length or displacement. The factors that will most influence the design of the vessel are those with a higher R coefficient.

Chapter 3. Design Brief

Basic considerations

To be able to start designing the ship, certain prerequisites must be defined. The first is the field of action of the ship: depending on the professional activity to be developed by the ship, the design will have to be adjusted to certain requirements and needs for its tasks. In this case the activity is the transport of passengers, for which one of the aspects that has to prevail has to be the comfort on board. Comfort in the broadest sense: comfort from passengers to navigation, as well as achieving implant that comfort in access and mobility throughout the ship[17].

Catamarans are the most suitable for the function of transporting passengers, in addition to being designed to be propelled by a sail, so that both factors can be combined. In order to choose a helmet design that matches what is needed from the boat, you must first define the operational requirements or the function for which it is designed. This is none other than the transport of passengers in medium and short distances and that can be done by sailing. In terms of length (and speed) will have to compete with ferries: although it is obvious that they may not have the same load capacity, it is to achieve an optimal relationship between number of passengers and speed of the hull as close to a ferry .

- As shown in other chapters, the length should be around 20-24m in order to reach a sufficient average speed. In this range you can compete with the average speeds of the ferries, which are not far away. To be able to cover the routes (medium-short or similar to those covered by the ferries) in a reasonable timeframe
- This length allows to transport an average number of passengers located between 50 and 100. In fact if you look at the market table, there are boats with smaller length and more passenger capacity. It is stipulated in 60-80 the ideal number of passengers
- Not all multihulls have the same length-beam ratio, but for boats with similar purposes to the project, about 50-60% is established.
- The most important ratio is the D / L and the goal is to be as light as possible. The light ships have a ratio between 100 and 200, so you would have to approach more than 100, always taking into account the loading conditions that the ship will have. This index relates the facility to overcome the limit speed.

The energy industry is adapting to the needs that are required from the main sectors. One of them, transportation (whatever the means) already requires electric motors with sufficient power to cover the different types of purposes to which they are intended. It is normal to see how the great innovations of the companies dedicated to the engines, focus their novelties on electrical designs, from small outboard to inboard. This provides an idea of the current trend in terms of transport efficiency and sustainability.

Operational requirements

If the design of the ship focuses on the transport of passengers there are a number of factors that must be taken into account more concretely:

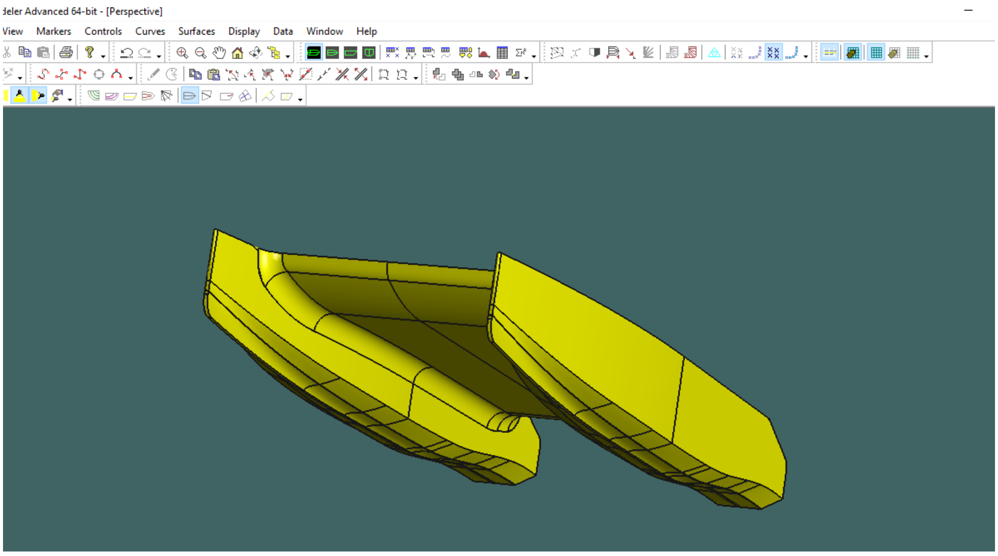


Illustration 5. Perspective view of the rendered hull

- Easy access port-ship: access can be from the side or from the stern, but if a large number of passengers have to go up and down will have to be designed in an efficient way and thinking in the most direct way
- Stern designed to facilitate the access for the steps in one or the two hulls. Also, if the stern is designed with and angle of 15 degrees it will favour the thrust and help to exceed the nominal speed.
- Regular and smooth surfaces along the deck and those areas where the passage moves. Avoid unevenness and irregularities as they not only hinder mobility along the deck, but also can lead to problems.
- As it is a passenger catamaran, where most of the time is spent on the main deck, it will have to be designed to accommodate and seat everyone. Usually there are seats organized in groups and around common areas such as tables, where you can share a space.
- Sufficient clarity on the bridge: this is the space between the two hulls. The more wide, clear and free this space is, the more help. Especially from the point of view of comfort (since the crash of the waves on this surface of the ship is constant and the noise ends up being annoying) as well as the interference of this part on the waves, leading to increase the resistance to the advance. This will reduce also the wave resistance affecting the advance of the boat.
- On the deck seating area install a Bimini cover that protects both the sun and bad weather. Currently there are retractable covers to adjust depending on the needs of the journey.
- In the bow of the boat you can install a hanging network system where the passage can stretch or relax. This system is very common in catamarans and one of the strong points they can offer as a differential factor and a perfect area to enjoy navigation at its best
- Afterwards, it is possible to think about having a bar area or, if a more playful objective is intended, a transparent floor area could be installed to observe the bottom and the ecosystem.

Characteristics of the hull

The book "the sailing boat design" mentions in the section of catamarans the coefficients that have to prevail in the design of the hull forms. The ideal helmet for a catamaran must consist of the following ratios:

- High immersion index (affects the load capacity)
- Low wet surface (affects commuting)
- High prismatic coefficient (affects the resistance to advance)
- Low wave resistance (determines how close the waves may be)

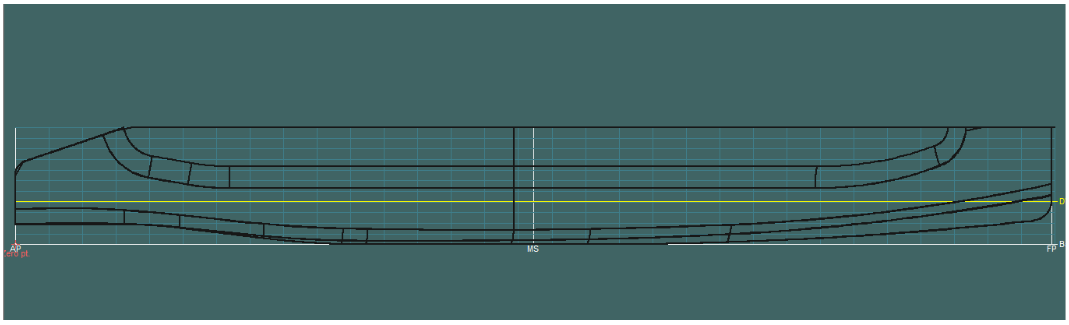


Illustration 6. Profile view of the hull

Normally these basic requirements of the ship are in conflict between them, so it must be the owner or builder who decides which ones should be given more importance. This will depend on how focused you are on the competition. In any case, a high displacement number or load capacity will adversely affect the competition orientation of the vessel.

It will be necessary to consider for each case which aspects of the design sacrifice or enhance for each case. For example, a smaller wet surface will always be better, since the more surface in contact with the water, the greater the resistance that the vessel will have to overcome. Being a passenger ship, cargo capacity matters less, so the immersion index is relative. It is more important that the bridge between hulls be as clear as possible and be distant from the surface of the water to avoid loading more resistance by waves[18]

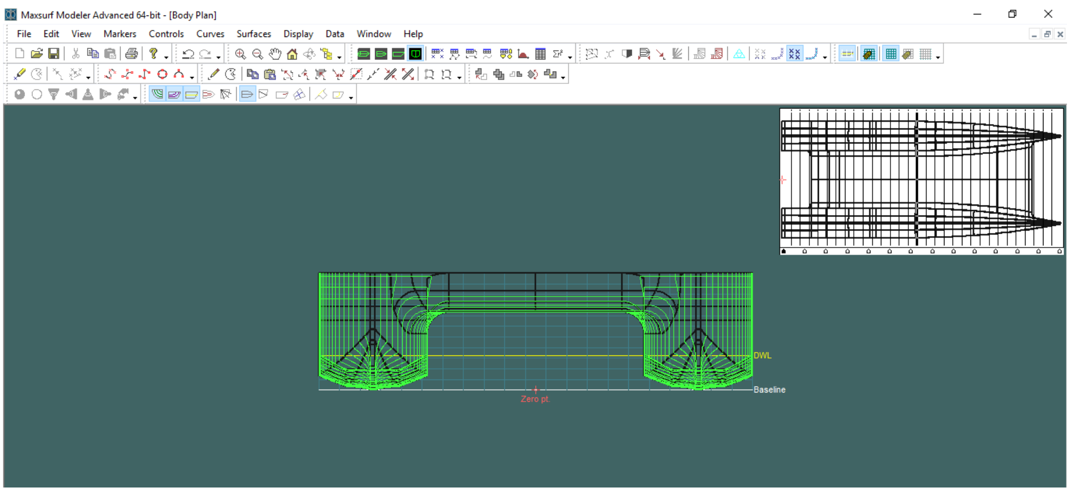


Illustration 7. Frontal view of the hull

Design aspects

As mentioned in sections of the work, however much the type of boat is a multihull, it is not the same depending on the use or purpose for which the boat has to be used. There are catamarans designed for quiet sailing weekend, with good weather conditions, and there are also those who are dedicated to cross the Atlantic and for weeks do not step on a port. Clearly define the aspects for which the vessel will be required will be key to a correct design adapted to the needs. Normally the design brief is the step in which a comparison is made between similar models, either by dimensions or by developed activities, and serves to form the first idea of what will be the design of the vessel (since a passenger ship is not the same as a RO-RO or a gas carrier, or it is not the same a ship that sails through calm waters that one that does it in the open waters of the ocean (blue water cruising).

Another aspect is the area of action: given the success of the Ferries (it is estimated about 2 billion passenger trips per year) especially in coastal areas with difficult connections, they are a perfect alternative (in fact in many areas they would come to be like public transport to move) for the journeys. The basic requirements to compete against ferries are:

- Regime of high speeds to cover the routes. It must be able to compete with speeds similar to ferries
- Sufficient comfort for the passage. It is one of the priorities of boat design
- Good sailing and motor navigation, but always boosting the wind factor. The forms must accompany a good performance for navigation, especially sailing, rather than motor
- Attractive design (eye catching) to boost the popularity of the design, together with good materials and finishes.
- Easy handling for no more than two people. At this point helps the fact of rigid sail, since thanks to its automatic control can be easily controlled by a short crew, in addition to being able to guide it always in the most effective way automatically.
- Look for a source of 100% ecological propulsion, in addition to sailing, using electric motors for those situations that need motor navigation

It is about optimizing the hull so that the rigid sail can give all its performance to the maximum. If these points are successfully merged, the ship would have to be able to cover existing routes between islands or coastal areas more or less quickly (speed) and with a significant reduction in air pollution and fuel costs.

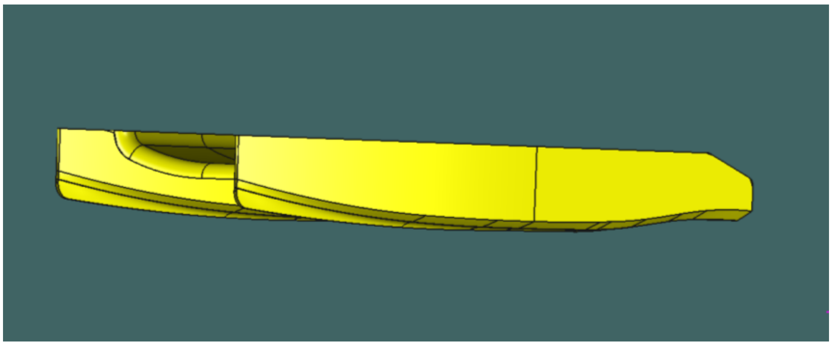


Illustration 8. Rendered view of the hull

Added Value:

The added value: today is a very frequent term that refers to those implicit (non-physical) characteristics that new products or designs bring with them. Normally this factor is related to innovation, technologies, sustainability, development ... And the objective is that these values help to compete against traditional methods. In the case of the boat, the great added value is respect for the environment as well as the sustainability of the project that has to match forces against established companies such as the Ferris.

The project and the design must be endowed with implicit factors to differentiate them from the existing ones. In this case, sustainability is the factor to promote, since it would be a revolutionary model to promote renewable and clean energy, this factor should be present on the ship. In a way it is patent with the rigid sail, which is the great advance of the ship, but it would make sense that the motorization was electric to favor the fact that it is clean. In addition, this alar profile enhances the image linked to the environment of added value. Since the sail has been the main source of propulsion of the boats during all the history, to return a little to the origins in a sector where every time the boats and the motors are bigger, this is not more than an attempt to return to enhance systems that have worked so well. Because most, if not all, companies that are dedicated to transport passengers do so with oversized boats in terms of power and size to be able to ensure a minimum of time.

With the strong competition existing in the market, and with most companies already established, the success of the project lies in 3 points: the first is the attractive design that can be provided to the ship. Today most charter companies are successful thanks to a design that attracts attention, so aesthetically has to capture. In second place is the personality of the project, the added value. The added value is a factor that brings the project, and is what makes it differentiate from the competition. The added value must be able to show those values that are intrinsic to the project, those factors that it wants to promote. And third is the fact of getting the support of organizations and entities responsible for transport on the island, so they can be interested in the project and empower it so that the first steps can be with their support. The transport sector currently has an obsolete image and does not evolve, since the boats are the same ferries as a general rule. This point can be a favourable factor to sail catamaran to be able to renew the image

These factors are what help to promote the use, and tend to be linked to new companies that want to differentiate themselves from the established and propose innovative solutions. It is important to provide added value projects that can make them attractive or interesting to the general public, expanding their use. If a new company or business does not offer anything different from the existing offer, they will hardly be able to compete against an already established infrastructure. They have to innovate measures that favor the propagation of renewable energies as well as achieve integration within the professional sector so that in this way they can be popularized

Aspects of construction

At the time of the process of construction and manufacture of the helmet there are a number of aspects that can involve large savings not only economic but also in terms of ease and time[15]

- Use of the maximum possible symmetry in order to reduce costs
- Optimize cover lines to optimize in only one
- Simple construction methods to avoid confusion
- Optimization of laminates for a more effective-economic solution

Among the factors that can determine the success of a ship are points such as:

When starting to design the ship's hull, many designers start by making a comparison or comparative table between existing ships similar to the idea they want to make, and among the most important data are the block coefficients and prismatic, in addition to the LCB and the LCF. What this does is help define the hull lines with sufficient volume as well as correctly position the LCB and LCF.

One of the most critical points that multihulls have is the relationship between load-displacement capacity, and thinking about this, they focus a lot on obtaining the maximum possible stability, especially transversally (sleeve stability), and this happens by placing the helmets as far as possible. Typically the relationship between the length-beam is 50-60% of the total length.[19]

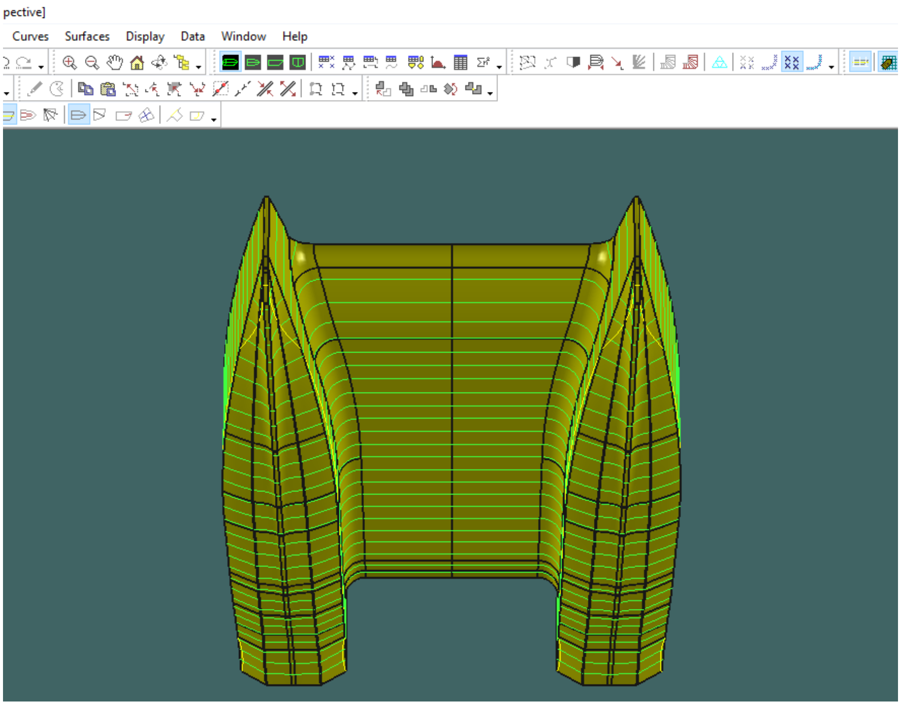


Illustration 9. View from below the helmet

Methodology

The methodology that has been followed is in certain aspects similar to the design spiral.

- Analyze the state of the current maritime transport sector in search of a problem
- Study the impact of the problem and its scope
- Analyze the different alternatives that can mitigate the problem
- Study the implementation of new technologies that are aimed at improving the situation
- Take stock of the solutions according to their viability and sustainability
- Achieve implementation in a case of a particular activity of the sector
- Evaluate the results according to whether the impact of the problem is reduced

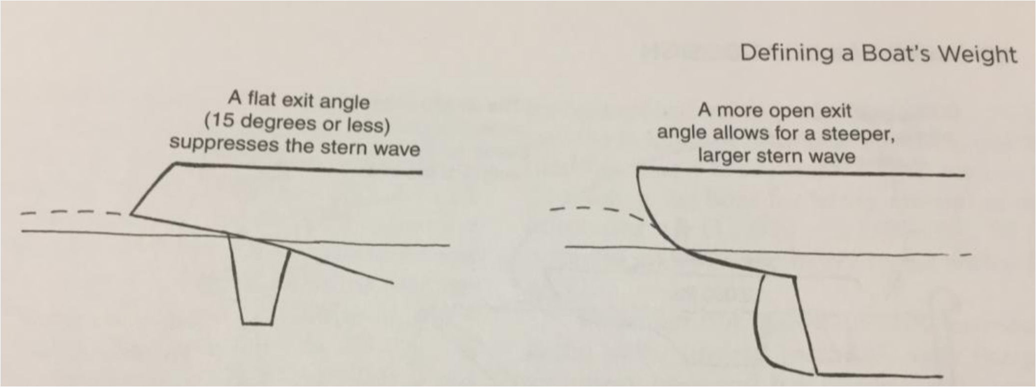


Illustration 10. Optim stern design (15º). Source[15]

Chapter 4. Speed

A displacement ship is one that navigates by displacing the water around it. This generates a wave that starts at the bow of the boat and moves along the length. For low speeds there are several waves at once, while the optimum point is at that speed that generates a wave of length equal to the length. Hence, the formulas of the waves can be related to those of the length or speed of the vessel, since being of the same length allow to know the speed of the other. When there is only one wave period what happens is that both the bow and the stern of the boat are driven by wave crests, so the speed is higher.

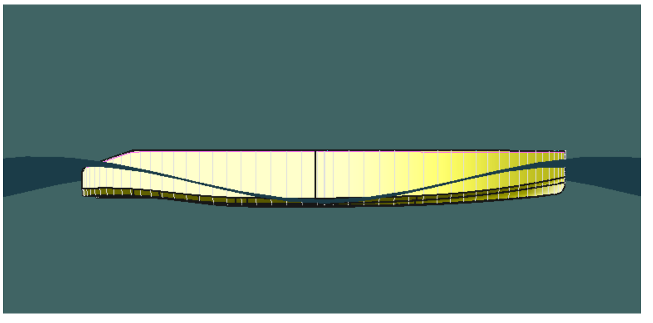


Illustration 11. Optimal speed point. One wavelength

There are two formulas that estimate the hull speed that the boat can reach, but they are not the same. Depending on the type of boat you can reach higher margins (always taking into account that the speed is designed to be reached by the strength of the engine). As mentioned in the previous chapter, there is a direct relationship between the length of a boat and its speed. As a general rule, the more length more speed can reach the boat. Multihulls are not usually the most reliable to perform speed calculations, because due to their configuration allows them to reach higher limits. Among the reasons that can explain the disparity of results are the sleeve, the tunnel effect that occurs between the helmets, the calculation of the wet surface area

Hull speed

The nominal speed of the hull is closely related to the length of the boat. Not only because of its physical limitation, but also because formula relates the speed of the boat with that of the waves it generates. At a low speed of the ship several wave periods are formed in its length, as the speed increases the wave trains become larger and eventually there is a wave of the same length as the boat. The reason is because the water ends up moving at the same speed as the boat, reaching the optimal point of speed that is obtained when the bow and the stern of the boat are each driven by a wave crest. The factor of 1.34 (which does not stop being an S / L ratio) is due to the fact that for physics reasons it is the maximum speed relation that exists between wave trains generated. In fact it would be possible to calculate the speed at which the ship moves knowing the distance between the peaks of the waves.

$$HS = 1{,}34 * \sqrt{LWL} \quad (3)$$

Nominal Hull speed: 11.8 kn

The only negative aspect of this formula is that it does not take into account certain aspects of the catamarans, so the results are not as accurate as they should be. To approximate the speed of the multihulls it is necessary to use the formula of Gerr. The speed of the hull can be exceeded due to two factors: one is that as a boat increases its speed in turn it increases its length since it sinks more; the other is due to the design, and that is that it is possible to design the stern of the boat so that it can eliminate the stern wave and thus get an extra push.

Gerr Formula

Compared with the helmet speed formula, which considers that 1.34 is the maximum S / L ratio that can be obtained for a ship, the Gerr formula considers more variables. After all, the possibility that a boat reaches its semi-gliding regime, that is, that it exceeds the ratio of 1.34, depends on some factors that must be taken into account.

These factors are the D / L ratio of the boat and also the design of its shapes, since the stern of the boat can be designed to support all the hydrodynamic thrust when the boat starts to plan. It will not have the same facility to overcome the nominal speed of a boat with a light ratio than a medium or heavy one, always taking into account a reasonable displacement of these.

There are many cases where the displacement measure varies, or not all express it with the same conditions, and everything is designed to favor the image of a fast, lightweight ship, but the objective for which the ships are designed must be respected. . A ship for coastal navigation and under places of shelter is not as well equipped that the one who has to cross the ocean with weeks on the high seas, will not have the same speed limits either. This influences when calculating the D / L ratio, since a low displacement will always result in a lighter ratio, and therefore, a better ratio. In addition, as mentioned, the nominal speed is not designed for multihulls, a factor that is present in Gerr's formula[15].

$$Gerr = 2{,}09 * \sqrt{LWL} \quad (4)$$

Gerr Speed for multihulls: 18,2 kn

At the end of the day you can see how the formulas are the same, because of the square root of the length, what varies is the factor that precedes it. While 1.34 is the maximum for the nominal speed, with the Gerr formula, values around 2 are reached, which means a substantial increase. In the case of catamarans or multihulls, the factor of 1.34 can be substituted for the one obtained in the S / L. In this case it goes from 1.34 to 2.09 and it makes sense because catamarans can reach higher speeds (The increase is important when going from 1.34 to 2.09)

Maxsurf program

These two formulas can be used knowing the dimensions of the ship, without having to design it and provide a first impression of the ship. Then there is the possibility of using design programs to simulate the behavior of the ship. For this it is necessary to have the boat already designed in a format accepted by the program, and start to perform the different analyzes and simulations. In the case of Maxsurf, a program that consists of several parts, has precisely a section to analyze the boat speeds. It is an exhaustive analysis since the same program is able to calculate the necessary coefficients to make an approximate simulation, besides being able to modify a series of conditions that influence at the time of calculations, such as the state of the sea, the methods used to do the calculations ... Going a little more in detail, when making the analysis of the speed with the program have to determine which methods are the most valid or acceptable for the boat. This is achieved by observing the graphs, since you can see how there are methods that do not have coherence or do not follow the same pattern of the majority, as well as knowing what type of graph should be found. Once only valid methods remain, you can know the desired graphics and also the relationship of these with the Froude number. As a last step, the program simulates the waves or wake that the ship is leaving behind while sailing at a certain speed.

In addition and since the work wants to argue that a catamaran is more efficient than a ferry, heat simulations of both types of ship (with the same dimensions) are compared, as well as the Froude number and the speed limits.

Froude number

The Froude number is important for the calculation of speeds. The number of Froude does not stop being tied with the speed, with what the change in function of that value is chosen is noted. With the speed of the Gerr formula you get a better Froude number, in fact there is a difference of 0.39 to 0.62. This makes the Froude move from the semi-planning to the displacement regime, with all that it entails. All the ratios calculated so far suggest that the boat could reach the semi-glide, and the Froude only confirms it[20].

$$Fr = \frac{V}{\sqrt{g * L}} \qquad (5)$$

Froude (Hull speed): 0,39
Froude (Gerr): 0,62

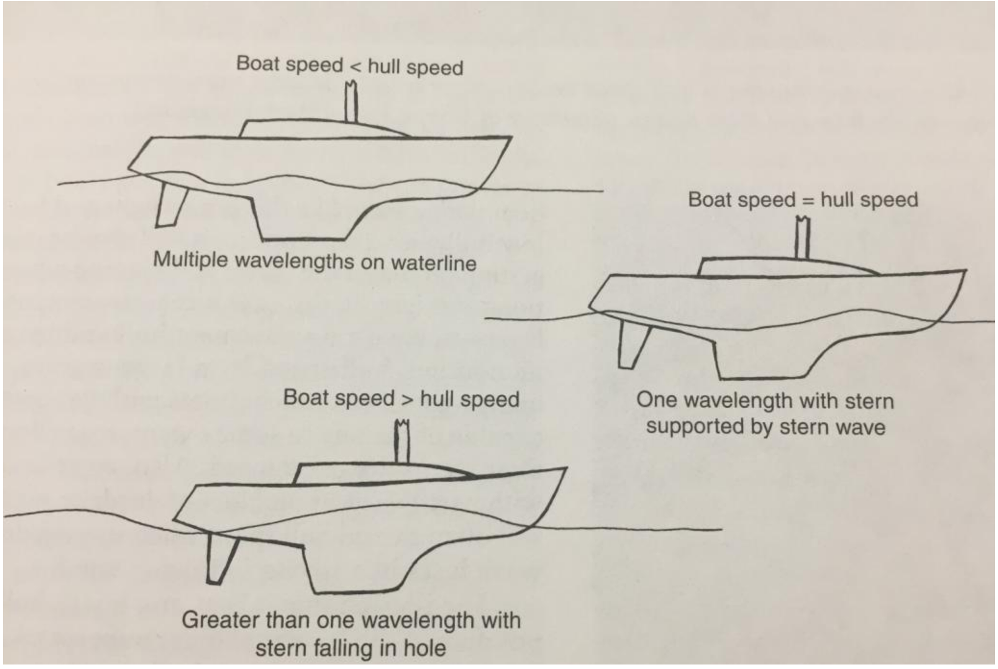


Illustration 12. Different behaviors according to the speed

Speed (kn)	Froude Lwl	Froude Vol
4,000	0,135	0,344
4,400	0,148	0,378
4,800	0,162	0,413
5,200	0,175	0,447
5,600	0,188	0,481
6,000	0,202	0,516
6,400	0,215	0,550
6,800	0,229	0,584
7,200	0,242	0,619
7,600	0,256	0,653
8,000	0,269	0,688
8,400	0,283	0,722
8,800	0,296	0,756
9,200	0,310	0,791
9,600	0,323	0,825
10,000	0,336	0,859

10,400	0,350	0,894
10,800	0,363	0,928
11,200	0,377	0,963
11,600	0,390	0,997
12,000	0,404	1,031
12,400	0,417	1,066
12,800	0,431	1,100
13,200	0,444	1,134
13,600	0,458	1,169
14,000	0,471	1,203
14,400	0,485	1,238
14,800	0,498	1,272
15,200	0,511	1,306
15,600	0,525	1,341
16,000	0,538	1,375
16,400	0,552	1,410
16,800	0,565	1,444
17,200	0,579	1,478
17,600	0,592	1,513
18,000	0,606	1,547
18,400	0,619	1,581
18,800	0,633	1,616
19,200	0,646	1,650
19,600	0,660	1,685
20,000	0,673	1,719

Graphic 10. Maxsurf Froude number table

In Graphic 10 you can see the difference in speeds according to the number of Froude (Lwl), as with the value of 0.39 the speed limit is 12kn while with 0.62 the 18kn are reached. This is one of the differences depending the methods

At low speeds, the most influential factor in terms of resistance is resistance by friction, and this is linked to the wet surface of the boat, being normally larger in a catamaran than in a monocoque. But between the hulls, the bridge area, a tunnel effect is produced that favors speed and creates synergies that drive the boat

The Froude number relates the speed of the boat to the regime in which it navigates. Normally the displacement boats, which are those that navigate better through the water than on the waves, have a Froude number between 0 and 0.6.

When calculating the Froude number depending on the chosen speed, it will vary. If the nominal helmet speed is taken, the Froude number is low (0.39) while with the closest approximate speed of the Gerr formula, it reaches 0.62, placing the number in the limit between the displacement regime and semi-displacement. When treating Gerr's formula of a more approximate speed, it is understood that the ship will be able to sail in semi-planning since the characteristics and calculations make it think so: light ship, in addition multicasco, and with a number of Fn that exceeds the limit of the displacement boats

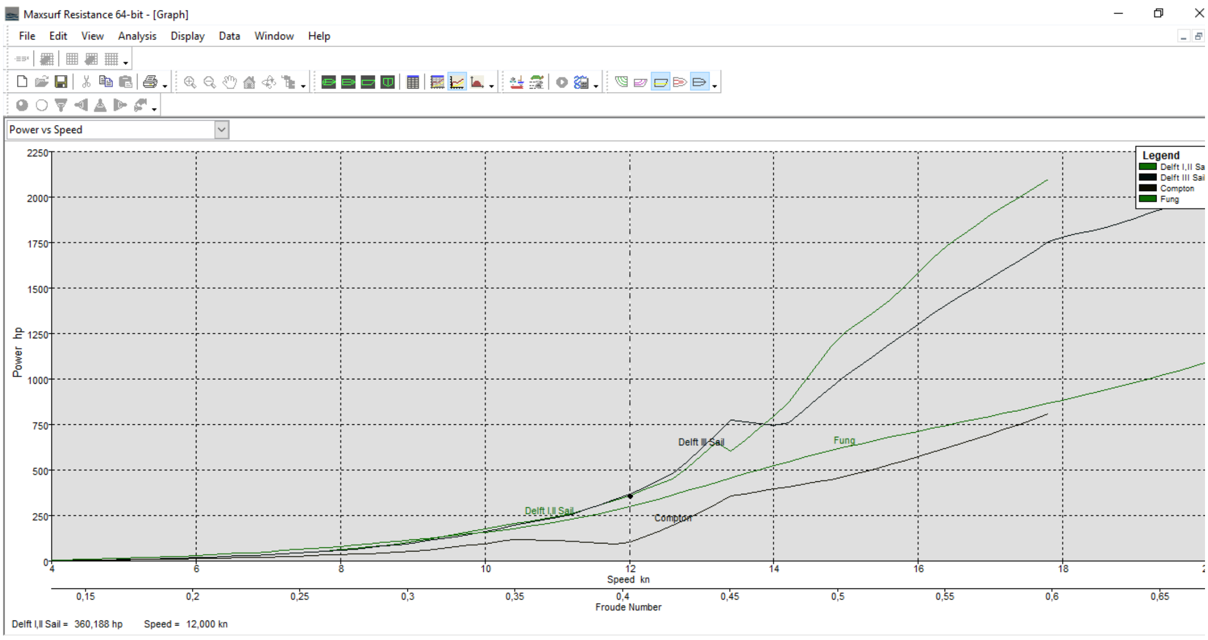


Illustration 13. Power-speed graphic

Observing the Illustration 13 it can be understood how the power increase is proportional up to the critical point located at 14kns. From this speed the increase is almost exponential, which is why it is not logical to continue increasing the power of the engine since the relationship will not be sustainable. Also keep in mind that the graph shows the power to get the speed through the strength of the engine, only by the action of the engine. And in this case the performance of the engine is reserved for specific moments in which a minimum thrust is required and situations in which only engine propulsion is required.

The program also takes into account the performance of the engine, at lower performance more power will be needed to reach the same speed. Assuming that the performance of the electric motor is superior to that of diesel, it can be concluded that less power will be needed than that expressed by the graph

The key point of this chapter is to understand the relationship that exists between the length of the boat and the speed it will allow to reach as well as the influence of the ratios. Especially in a model that is designed from 0, of which there are no samples or tests in test channels, the ratios provide an idea of the behavior of the boat. They also allow the option to corroborate if the purposes for which the ship has been designed are achievable. The critical power point is found at:

Power required (85% efficiency): 400hp
Power required (70% efficiency): 500 hp

From this point it does not make sense to keep increasing the power of the engine to achieve some more speed since the increase will be minimal for the entire investment in horsepower

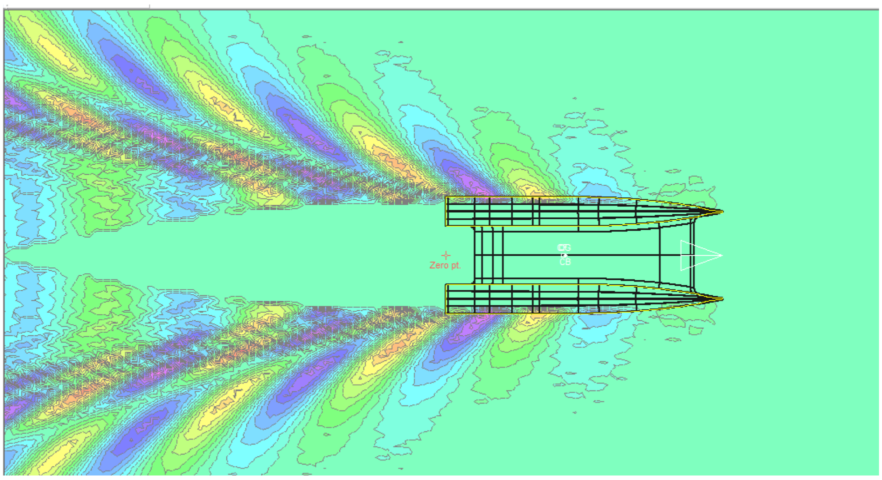


Illustration 14. Analysis of the wake (9kn)

In the Illustration 14 and Illustration 15 it is appreciated that as the speed advances the waves that form the prow of the boat are increasingly longer. In addition to being speeds below the nominal speed of the hull these have a wave length less than the length of the hull, and it is seen as the waves that most involve the boat are those that are in contact with the stern. For 9kns the critical Froude number is still not reached to move to the semi-gliding regime, so at low speeds the ship navigates in displacement mode. These speeds usually cause the engines to work at a non optimal rate, and in this way they still emit more gases and have higher consumption demand

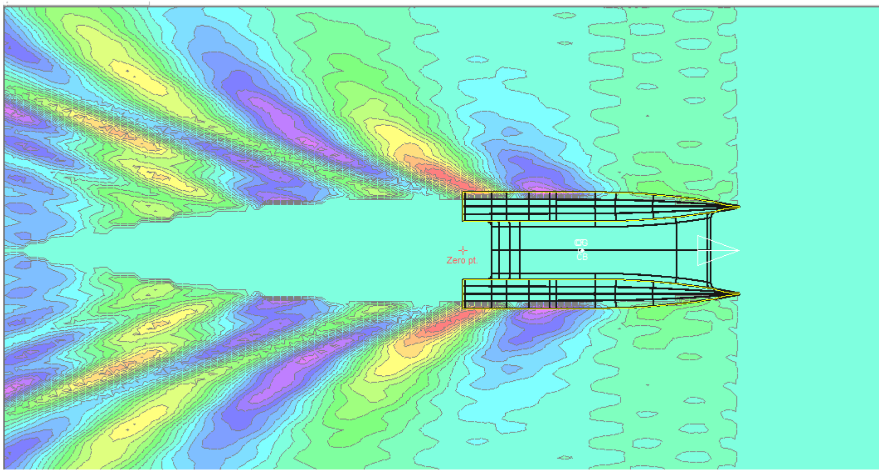


Illustration 15. Analysis of the wake (12kn)

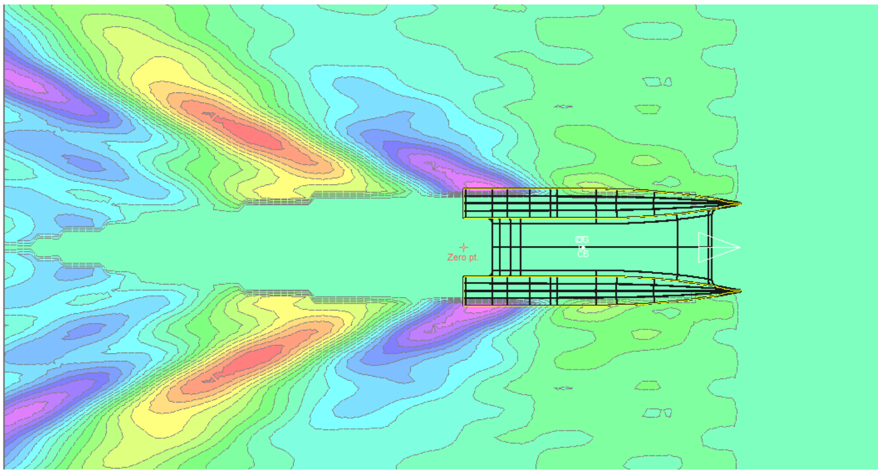


Illustration 16. Analysis of the wake (16kn)

If you analyze the illustrations on the behaviour of the wake and the waves on the ship's hull (for 9, 12 and 16kn respectively) you can see how the resistance of the waves increases (less speed prevails friction resistance), as the hot colours indicate. Also, as the speed increases, you see how the waves also get bigger (result of the relationship explained in the Hull speed). For low speeds in addition to more wave trains generated by the boat there is more friction resistance, especially in the case of catamarans.

In the comparison between the Illustration 15 and Illustration 17 (both at 12kns) between the ferry and the hull of the catamaran, it can be seen how the ferry leaves a wake of much greater waves, in terms of length and resistance (as shown by the warm and red colours). This is consistent with the fact that current ferries have very large engines, in order to overcome wave resistance, as well as to reach reasonable speeds. Thus, the catamaran needs less power to overcome the resistance and to reach the nominal speed

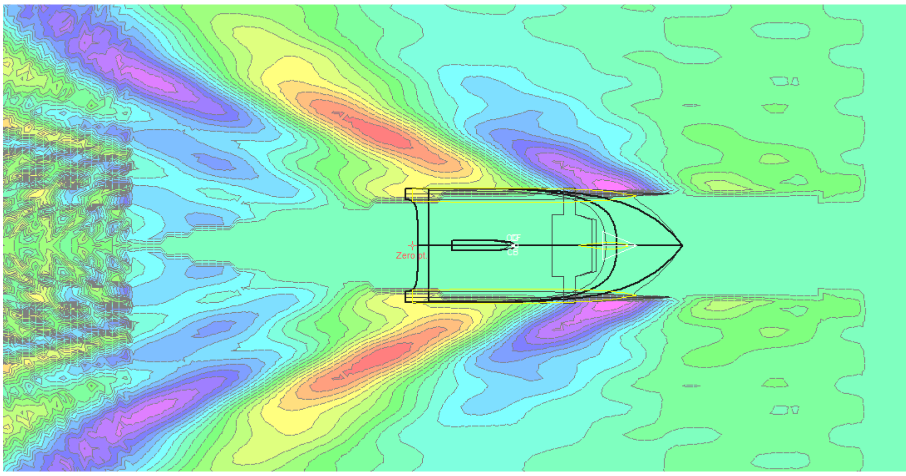


Illustration 17. Analysis of the waves in a ferry model (12kn)

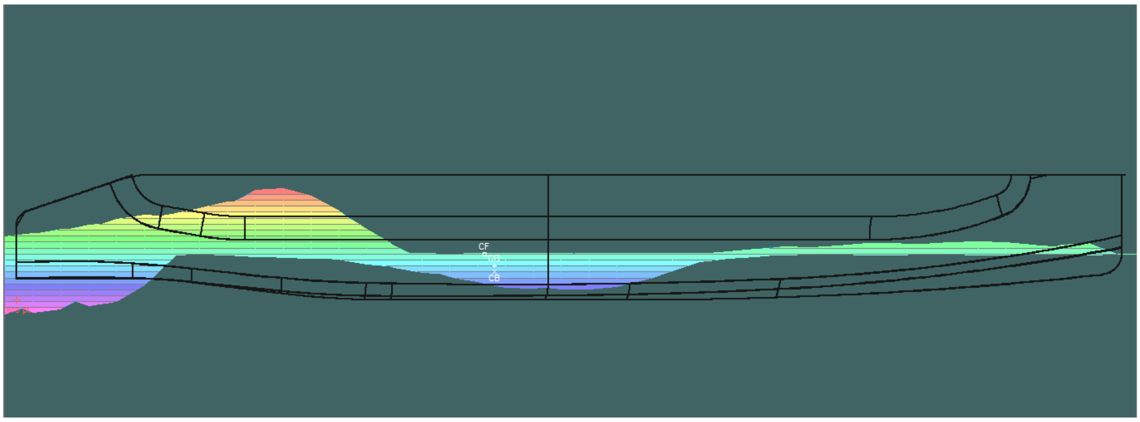


Illustration 18. Profile wake form (10kns)

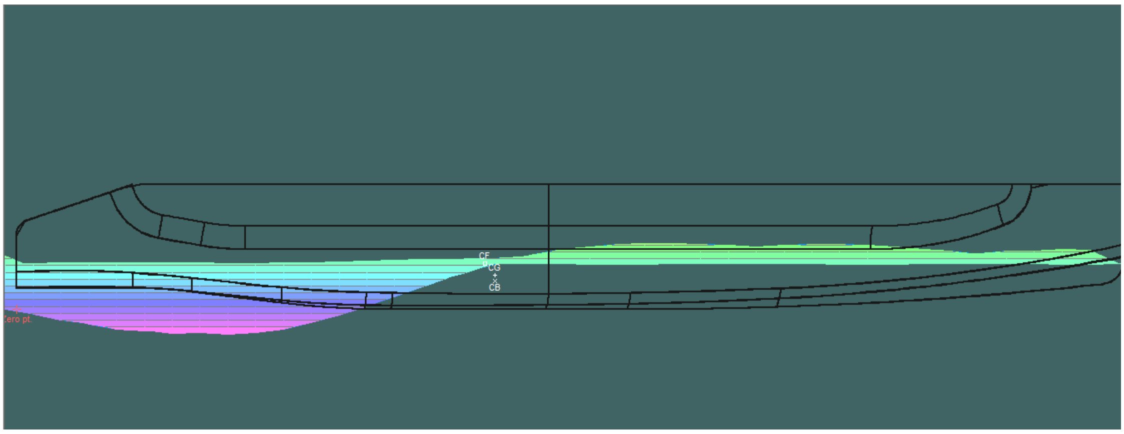


Illustration 19. Profile wake form (14kns)

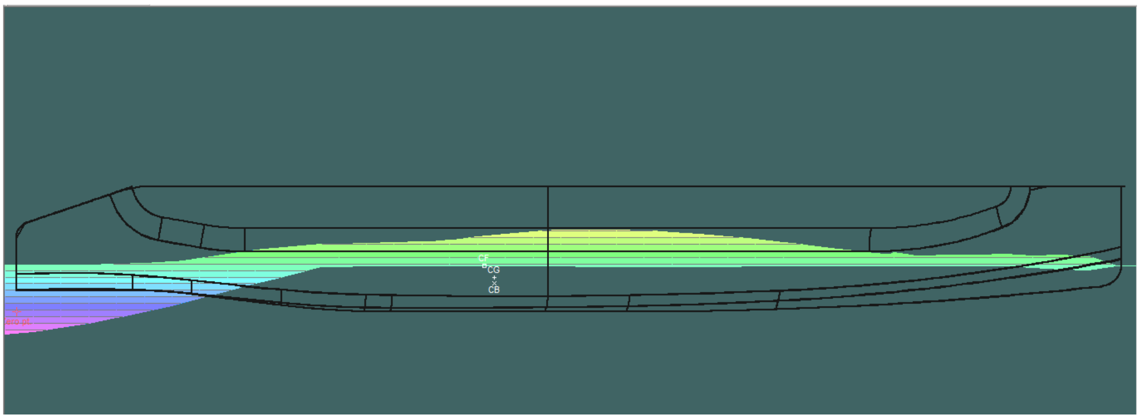


Illustration 20. Profile wave form (18kns)

Comparing the images in the profile view of the shape of the wave, it can be seen that when the boat sails below the nominal speed (and the Froude) the impact of the wave is greater than when the 18 knots are reached. This is because the semi-planning has been reached and the boat sails at a more optimal point, as the stern is supported by the hydrodynamic thrust of the stern wave. At low speeds it can be seen how several wave periods are distributed along the length. This limits the browsing performance since it causes a lot of interference. In addition it is observed as at more speed the wave has less height, favouring the push

Chapter 5. Power

The boat has been designed following the requirements of sailboats, since it is intended to be propelled by the rigid sail system. Starting from the base that wants to promote the forms to be the most suitable for this purpose, it must be installed in any way an engine system for certain situations.

When it comes to sizing the vessel's power, it is necessary to keep in mind the objectives as well as the operational requirements to estimate adequate power. The primary source of propulsion is the wind and it has to be maximized thanks to the support of the rigid sail along with the hull forms to reach the optimum point during navigation. The objective is to achieve maximum thrust thanks to the wind. Otherwise, and for safety reasons, an engine must be installed on the ship for those situations in which the port enters or exits or due to the bad weather conditions that require the engine to govern the ship.

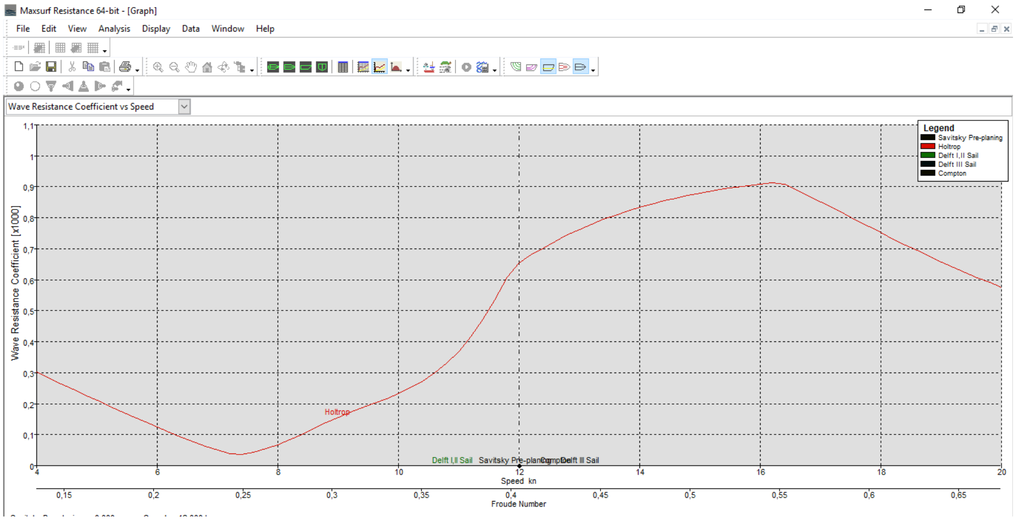


Illustration 21. Wave resistance-speed graphic

When estimating the performance of a naval engine it is very useful to read the power-speed graph to observe the phenomenon that occurs. As a function of speed, the graph increases proportionally until it reaches a limit point where the progression becomes almost exponential. This indicates how much power that is installed on the ship will not always be possible to continue increasing the speed, at least in a sustainable manner[21]

Catamarans have two engines, one per hull, and it is one of the characteristics that make them special. On the one hand for a security issue, since at the point that one of the engines would fail, the other one would still be working. The other is a matter of maneuverability, and is that having two engines separated by the bridge (more separation plus maneuverability) makes it easier to maneuver and to make more precise movements over reduced distances

Normally the estimation of the power is an important process of the boat due to the great dependence it has on the engine. Not only that, but also we must grant a margin superior to the approximate for those situations that still require more push. On the other hand, sailboats usually have small engines in relation to their dimensions, and thanks to the sail that provides the necessary thrust, the engine is relegated to specific moments of maximum demand..

In line with the purposes of the work, the idea of installing an electric motor system that does not produce gas emissions or fuel consumption is valued. In addition, there are currently systems that take advantage of solar or wind energy to recharge the batteries and thus not depend so much on port connections. It is a perfect system for the boat since while sailing, the engine system will use the energy of the wind to act as a generator and charge the batteries, ready to use when necessary.

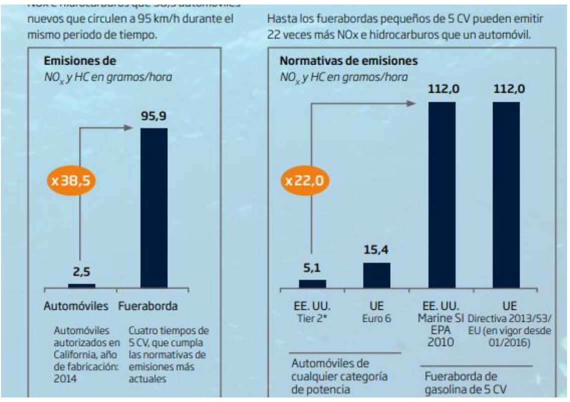


Illustration 22. Pollution comparative engine car-outboard engine. Source: Torqeedo

Although the boats are more efficient in terms of power output, the fact is that large merchants produce the same pollution as 5000 cars. On a smaller scale, you can see how an outboard motor working at full speed generates the same amount of emissions in one hour as 38.5 cars at 95km / h during the same time. That is why although marine engines are more efficient they have to adapt to the needs of the environment and start to be more ecological[22].

To estimate the power of the engine that the ship will carry, a series of previous calculations must be carried out. These calculations are done by knowing the main dimensions of the ship, as well as a series of coefficients and tables. The coefficients are important when calculating the resistance that the boat will have to overcome in its advance, and they are influenced by factors such as the shape of the ship, the speed regime in which it moves, the number of Froude and Reynolds ...

Normally the engines are oversized so that there is no lack of power situation. But if certain aspects of saling are clear, such as sailing basically, you can adjust the capacity much more. In this case the functions that will be required of the engine could be considered auxiliary, except for the times that due to the lack of wind it is necessary to cover the route.

Since the objective of the project does not stop being to find an alternative solution to combustion engines, the idea that is shuffled for the engine is an electric type. Electric motors are more efficient than traditional motors, generally because they suffer less mechanical losses. A diesel engine that does not work at its optimum margin is less effective. In addition, electricity that does not consume the engine can be used to distribute to the rest of the ship's services. That is why, in line with the work, the vessel will be equipped with electric motors. Also today, the greatest expense that shipping companies have is the consumption of diesel needed by fleets, in addition to being the most polluting factor.

Factors that influence the power

Among the important factors that determine the choice of the engine are wet surface area, type and navigation area, coefficients of resistance, type of boat ... Catamarans have the advantage that being so stable allows them to take advantage of the push more efficiently.

The area of wet area is a determining factor when estimating the power of the boat. The more surface of the boat is in contact with the water, the more power it will need to move it. There are formulas that approximate the wet surface, just as the Maxsurf program provides this information. Comparing the results it is verified how the wet area is around 100 square meters.

Another factor that influences when calculating the power is the Froude number, as can be seen in the section on speeds. For low speeds (at a low Froude number) the behaviour of a catamaran is worse than that of a monohull because of the larger wet surface, and therefore more resistance. In addition, the wider the bridge that connects the two hulls, the lower the resistance will support the ship. Resistance is another factor that directly influences the power. To begin with, at low speeds, the great part of resistance is friction, you have to open the way by moving the water in front of you. Once a higher speed is achieved, the resistance component that most affects the boat is wave formation[20].

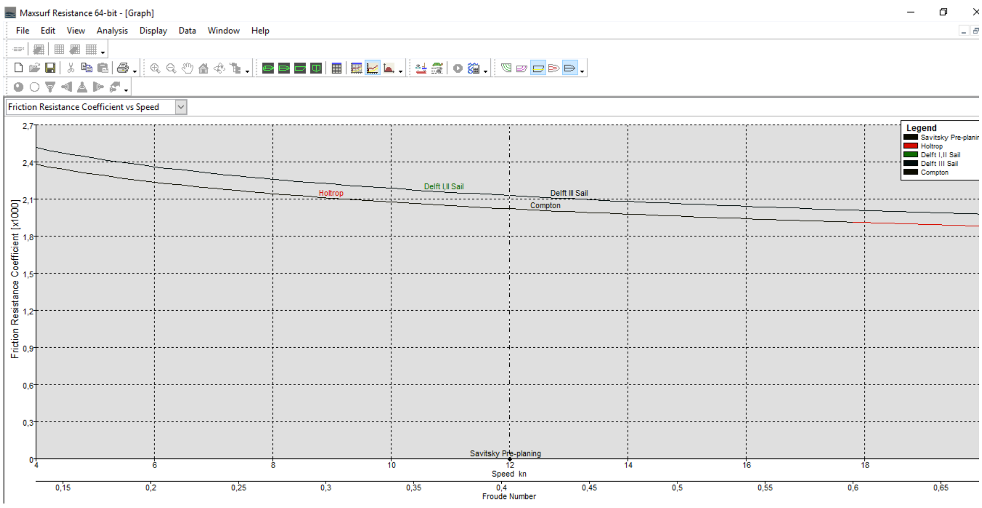


Illustration 23. Friction resistance coefficient-speed graphic

When travelling at low speeds through static water, the waves generated by the hull of the boat have a very small amplitude, meaning that wave-resistance is practically negligible and total resistance of the vessel is mainly caused by viscous resistance. As speed is increased, period, amplitude, height and length do so as well, and wave-making resistance starts playing its roll. As the speeds increase, and with them the Froude, more resistance by wave formation but less interferences of the wave systems. Also reached this point is generated a dynamic lift, which together with two symmetrical helmets help create this lift

For catamarans of a certain size certain formulas, such as power, are somewhat short. And is that there is not yet a detailed explanation of why catamarans get such fast speeds if they have more wet surface area, and the currents that occur between the hulls instead of limiting potentiate the tunnel effect

It must be said that marine diesel engines are more efficient when they are travelling at low speeds. In fact, one of the possible situations that arise to reduce pollution of ships is to reduce speed. Although one thing is that they are more efficient at low speeds and another that they do not have to endure more resistance.

The greater slenderness as a general rule of the hulls of a catamaran causes the formation of waves at high speeds to be reduced, which makes it easier to reach. If the ship has to operate at low speeds the catamarans have the handicap of high resistance due to the high wet surface area, but then it is to be understood that a multihull is not chosen for its hydrodynamics but for its physical characteristics

Calculations

Through the equations of the regressions a preliminary power of 450hp is obtained. This would be the power needed to navigate all the time driven by the engine at a cruising speed. In this case the motor has a more complementary function, so it is not necessary to reach this data. Following the purpose of the project to use and depend on the minimum of the engine, and counting that the characteristics are favoured for the best performance, lower power will be required

While the estimation of the power can be done by means of formulas, previous knowledge of certain coefficients and data, for boats of a certain size it begins to be complicated. There is another method and it is to use the graphics provided by the simulation programs to know what the demands will be. These graphs are more complete than the formulas because they indicate at all times the power or resistance ratio that the vessel will have for each speed. They also provide a more complete idea of what the behaviour of the engine will be since evolution is shown.

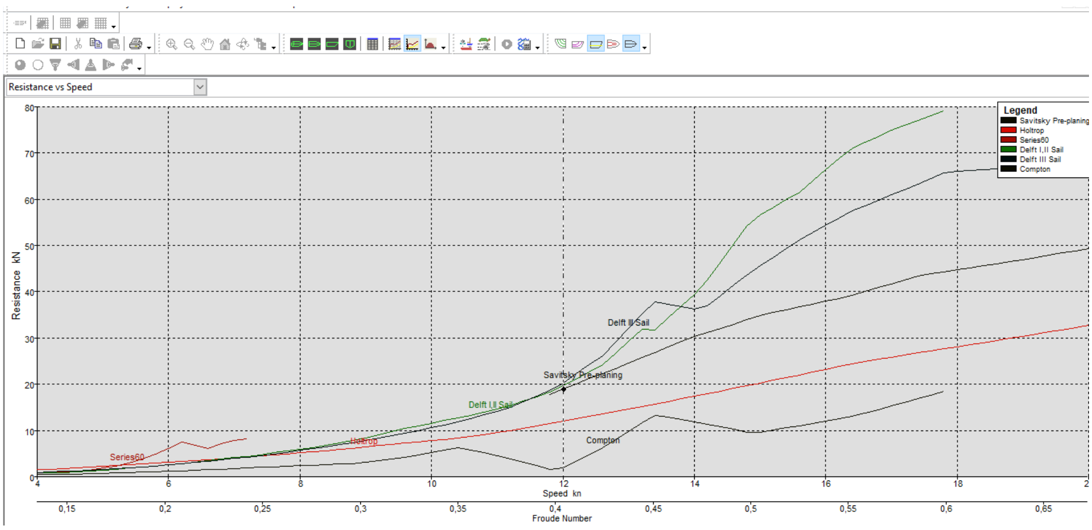


Illustration 24. Resistance-speed graphic

For all the aforementioned points it has been determined to adjust the necessary power and not to fall into oversizing that has to lead to the installation of a hybrid model. With the needs of the project is more than justified the electric motor, in this case two for being a catamaran, to be a complement to the sail system. Since the sail is the main source of energy, the dependence of the engine becomes smaller, so that the sizing can be adjusted.

$$P = Rt * V \quad (6)$$

Power required (at 12kn): 210 hp
Power required (at Gerr's speed): 330 hp

In the graph you can see how the limit point is placed at 12 kn, being from this the exponential and unsustainable increase. For the calculation of the power it is necessary to multiply the nominal speed by the total resistance. The graph shows how the reasonable limit of the resistance is over 35KN, so the product of the power is 210hp (quite similar to what the power-speed graph reports). As the speed increases, an increase is more and more difficult to sustain by the engine, so that with the maximum speed obtained for multihulls, of 9.57kn the required power would be 332hp

That is why it is important to know the limitations of the boat as well as its operational requirements to estimate the power in the most approximate way. Most of the cases the motors are oversized to ensure the operation, but if the goal is to be as efficient as possible, along with the factor of the rigid sail, it has been proven how the power can be adjusted.

Engine selection

Torqeedo is one of the leading companies in the marine sector in terms of engines. In fact, many of their models are currently electric. They started out as small outboard electric motors for small boats or boats but in the latest catalogs there are already options for large inboard engines with very efficient technological systems that allow them to be installed on boats with high professional activity, such as ferries[23].

As a general rule, electric motors are more efficient than traditional combustion engines. This is due to several factors, but the fact that there are no explosions contributes to fewer losses, along with the other advantages that make them bet heavily on them. The electric motors are silent since there are no moving parts or explosions, they are also more respectful since they do not produce gases or possible leaks of fuel or oil

The Deep Blue system of Torqeedo is designed for large sailboats up to 80 feet in length as well as boats for professional use. In the case of sailboats the system takes advantage of hydraulic generation. The electric propulsion system can be used as an electricity generator in sailing routes. The fact of being a system that has batteries that are charged makes it ideal for this purpose, since as not all the journey will be made by motor will be loaded as necessary.

In addition to the benefits of the electric motor also brings a number of advantages such as comfort, since it produces no noise, sustainability to emit much less emissions, much more efficient ...

For all these reasons, together with the studies and calculations of the speeds so for the purpose that has been defined to the boat has been decided by a Deep Blue engine that is consistent with the line of action and added value.

In addition the operational requirements of the boat can be supplied and supplied from an electric motor, which together with its respect for the environment, makes it the ideal choice. The size of the boat, the professional activity it develops, the area of navigation and autonomy that it needs and all the fields lead to the installation of the electric motor have been valued.

The most powerful electric model available in Torqeedo is a system known as Deep Blue. With an equivalence of up to 160hp, it is designed for sailboats up to 120 feet in length and those that have professional functions, such as ferries, so the project meets the requirements. The fact of being designed for sailboats is because during sailing, the system uses wind energy to supply the generator and thus the rest of the equipment that needs it. It adapts not only to the needs of the ship but also provides an extra boost that in this case is ideal for the type of navigation. It also has other advantages such as more efficiency than a diesel engine, without any contamination (neither environmental nor acoustic, nor fuel or oil).

2 engine systems Deep Blue: 100kW (270hp)

Power graphics

Technical data

Inboards	Deep Blue 25i	Deep Blue 50i	Deep Blue 100i 900
RPM propeller (maximum)	1,400 rpm	1,400 rpm	900 rpm
Output (peak)	33 kW	60 kW	110 kW
Output (continuous)	25 kW	50 kW	100 kW
Torque	350 Nm	350 Nm	1070 Nm
Weight (incl. electronics)	85 kg	85 kg	450 kg

Saildrive	Deep Blue 25 SD
Max. propeller speed	1,360 rpm
Output (peak)	33 kW
Output (continuous)	25 kW
Torque	180 Nm
Weight (incl. electronics)	125 kg

100kW

New for 2019

Deep Blue 100i 900

Suitable for yachts up to 120 feet long, this robust direct-drive motor delivers the low rotational speeds necessary to efficiently power large sailing yachts and other heavy displacement vessels. This new addition to the Deep Blue family delivers 100 kW of continuous, emission-free power, ultimate torque, low maintenance and is powered by high-capacity batteries with technology by BMW i.

Illustration 25. Engines comparation. Source: Torqeedo

Following the purpose of the project to use and depend on the minimum of the engine, and counting that the characteristics are favoured for the best performance, lower power will be required. Another requirement of the project is to become 100% ecological and renewable, so electric motors will be proposed.

Torqeedo is one of the leaders in the field of electric motors. While the vast majority of their models were small capacity for small boats, they already have a couple of models for more displacement boats. The Deep Blue system is the most suitable for the functions that are required. This system not only has a powerful electric motor but also has all the parts integrated in an optimal way. There are two versions of the Deep Blue system: a 100% electric and the other hybrid version. Obviously, the characteristics are not the same and you will have to choose according to the needs that best suit you. The hybrid version, with a diesel engine, is more durable both in terms of speed and autonomy has more capacity. While the electric version has less autonomy for high speeds, if you sail, the system uses wind power to charge the generator and supply electricity for the on-board equipment. This plays a big point in favor of the project.

While both models are quite efficient, at least more than a combustion engine, the hybrid system emits gases and needs diesel to supply the generator, so it is not 100% respectful with the environment. In addition to the sustainability and efficiency of electric motors in general, for the project the Deep Blue 100 model is chosen, designed for sailboats of up to 120 feet in length and boats for professional activities. The torque is low since it is designed precisely for displacement boats, and the continuous power of 100Kw per engine is estimated more than enough for specific situations .Electric motors not only pollute in terms of emission of gases, they also have less impact in terms of spillage of fuel or oil from engines to water. They are also more acoustically respectful with the environment, so they are more favourable and comfortable factors.

Torqeedo also manufactures several similar models but that adapt to the different needs that they may have. Whether inboard or outboard, depending on the type of boat and how it moves there are variations in the torque, so that the displacement boats have a lower torque, while the glide boats reach 2400 rpm. For the displacement boats the best option is an engine with a low torque, since these engines are designed for the purpose of not reaching very high speeds. On the other hand, for the glide boats, it would take more revolutions

The only difference is in the power supply of the generator, being able to be through a diesel engine (with fuel) or from renewable energies. This solar or wind energy is used during navigation to recharge the batteries and supplying the necessary electricity to the equipment on board. For the case studied, it is an ideal system since during all the time you are sailing, you will be providing power to the generator. Although the hybrid version uses very little amount of fuel it can always be improved and be 100% electric

The hybrid system consumes fossil fuels but in small quantities, so even if it is not 100% clean it is more sustainable than traditional engines. The advantage of the hybrid system is in the autonomy it provides to the boat, being able to travel more miles while maintaining a higher speed.

Among the challenges facing electric motors are their propagation and use for boats of a certain weight or length. Up to now they were small boats that could be equipped with an electric motor for their propulsion, especially boats, because the power and autonomy of these did not allow them to be extended to larger ships. In recent Torqeedo has made an effort to present alternative solutions to be applied to boats such as sailboats or boats with professional activities such as ferries or water taxi. The latest version of 2019 already has 100kW engines ready to solve the current demands in terms of pollution and sustainability. In addition to the great results obtained and the variety of engines depending on length, power, torque, autonomy makes it easy to choose the most suitable type of engine for each case.

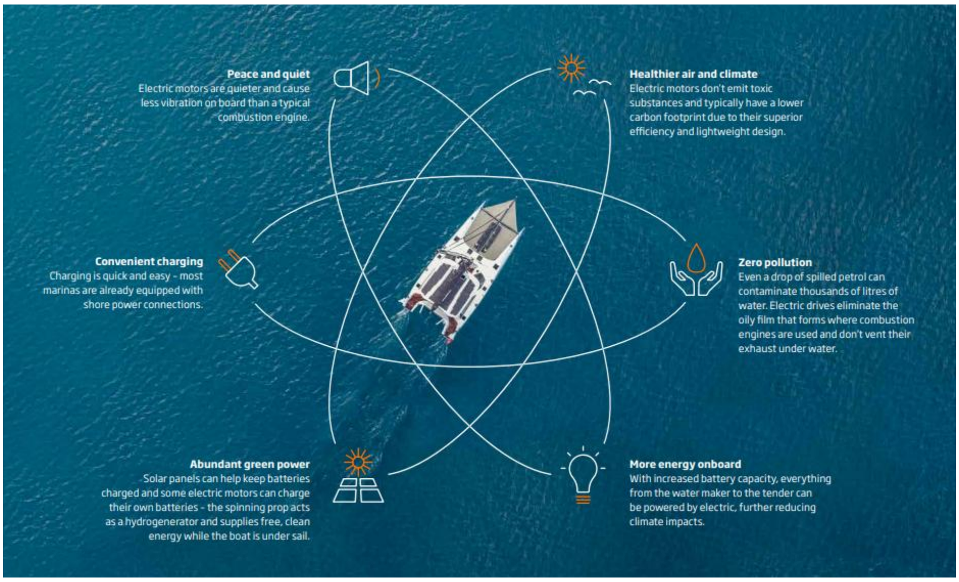


Illustration 26. Benefits of the electrical engines. Source: Torqeedo

Chapter 6. Wingsail design

Definition

A wingsail is a variable-camber aerodynamic structure that is fitted to a marine vessel in place of conventional sails. Wingsails are analogous to airplane wings, except that they are designed to provide lift on either side to allow the vessel tack and navigate on both tacks. Whereas wings adjust camber with flaps, wingsails adjust camber with a flexible or jointed structure. Wingsails are typically mounted on a rigid spar, often made of carbon fibre for lightness and strength. The geometry of wingsails provides more lift and a better lift-to-drag ratio than traditional sails but makes them more complex and expensive than conventional sails[24].

Wingsails change their camber (the asymmetry between the top and the bottom surfaces of the aerofoil) depending on tack and wind speed. A wingsail becomes more efficient with greater curvature along the downwind side; since the windward side changes with each tack, sail curvature must change too. This happens passively on a conventional sail, as it fills in with wind on each tack, but on a wingsail a change in camber requires a mechanism. Wingsails can also change camber to adjust for windspeed.

On an aircraft flaps increase the camber or curvature of the wing, raising the maximum lift coefficient at lower speeds of air passing over it. A wingsail has the same need for camber adjustment, as windspeed changes (a straighter camber curvature as windspeed increases, more curved as it decreases).

Mechanisms for camber adjustment are employ independent leading and trailing airfoil segments that are adjusted independently for camber. More sophisticated rigs allow for variable adjustment of camber with height above the water to account for increased windspeed.

Advantages selection

Compared to conventional “soft” sails, a wingsail is much more complex, providing lift with variable camber, controlled by a flexible or jointed structure. The wingsails offer greater aerodynamic efficiency compared to the canonical sails and better performance

These wingsails are difficult to control and the research on their stability in multiple scenarios is still evolving. Finding a stable setting in all navigation conditions for these wing sails is challenging and there have already been catamarans “flipping” or “falling over” due to this instability. As in the aerodynamic stall of an airplane wing, these wing sails can stall during operation and it is crucial for designers to understand their stall behaviour under different wind conditions.

There are three main reasons to use a wing instead of a sail: efficiency, less actuation force required, and self-trimming.

The first and most obvious is that a rigid wing is far more efficient than a cloth sail, although some attention needs to be given to Reynolds number effects and the coefficient of lift, CL. Also, the Lift/Drag (L/D) ratio of wingsails can achieve rangeof more than 100, whhile the L/D of the conventional sail is in the 3 - 5 range. Further, a cloth sail suffers from aeroelastic collapse when pointed high into the wind (the sail is said to be luffing). This causes a great deal of drag when sailing closehauled and effectively limits how high the boat can point into the wind. The rigid wing, by contrast, suffers no aeroelastic problems; it can point straight into the wind with very little drag, no flapping, no whipping about, and no noise, while effectively reefing the wing. In fact, the feathered wing-tail combination has much less drag than the bare mast. The ability to reef a sail (or reduce the area of the sail) is moot when using a rigid wing because the wing has far less aerodynamic load on it than the bare mast itself.

The second main reason to use a wingsail for propulsion is less force is required to actuate the wing itself. A cloth sail is fixed to the mast, and trimmed from the boom. Since the center of pressure of the sail is aft of the leading edge, the trim force must overcome a portion of the lift of the sail. Inspection of a conventional sailboat shows a large block and tackle with eight or more loops of line attached to the boom is required to trim the main sail. With a winch, an additional 8:1 mechanical advantage is required to hold the boom in. To control this effectively in an automatic manner, a very large and fast-acting actuator is required. These types of actuators quickly become very expensive and a typical one would cost more than the entire budget for the project. By contrast, the wing can be designed to pivot near the center of pressure of the wing itself. The wingsail is turned to an angle of attack either directly or through an auxiliary trimming surface. In either case, this is accomplished with a small DC motor and can be actuated quickly and inexpensively. The cost effectiveness of this design is the main reason it was used for this project.

The third main advantage of the wingsail over the conventional sail is the ability to make the wingsail self-trimming. The benefit of this is that the wing will absorb gusts without transmitting the force of the gusts through to the guidance system. By decoupling the propulsion system from the guidance system through passive stability (self-trimming), the control system design is greatly simplified. Through proper arrangement of the flying surfaces, the wingsail will readjust automatically to a change in either wind speed or wind direction, with no intervention from pilot or control system.

The self-trimming capability makes the wingsail ideal for an autonomous sailboat because it eliminates the requirement for a very large and fast acting actuator to constantly retrim the sails. The only time that direct intervention into the trim control of the wing is required is when the wing crosses the longitudinal centerline of the boat. During this maneuver, the flap and tail are reversed from their previous positions. Note that in a conventional sense this corresponds to tacking (when the wind is from the front of the boat) and jibing (when the wind is from the stern of the boat). The maneuvers using the wingsail are very gentle and controlled because the bearings allow the sail to rotate 360 degrees about the mast without interference and the wing can point straight into the wind with no ill effects[25].

Conventional sails have one serious advantage: due to their sharp leading edge, they tend to be insensitive to Reynolds number variation. This alone may explain why they have persisted on modern designs even after the preponderance of evidence has demonstrated that wings are vastly superior. The other advantage that cloth sails may have over rigid wings is weight: for sails below a certain size, a rigid wing will almost certainly be heavier. This is due to the square-cubed law with respect to the strength of structures. Above a mast height of approximately 20 meters, the structure of the mast could just as easily be incorporated into the spar of a wing. Winged catamarans have superior aerodynamic thrust on all points of sail and superior aerodynamics at higher wind speeds, but the difference of weight requires more wind at lower speeds and produces greater drags on the hulls due to the extra displacement of water.

The applications of the wingsail range from competition catamarans participating in races like the America Cup to large merchant ships with long decks where they can install a set for fuel savings. But until now it has not been possible to find a profitable activity for its specific function[26]

Airfoil selection

An airfoil section can be made either symmetrical or asymmetrical. An asymmetrical section can always achieve a higher maximum lift coefficient and a higher lift/drag ratio than a symmetric section. Symmetric sections have the advantage of identical lift characteristics with both positive and negative angles of attack. Symmetry arguments become important in sailing vessels because a sailboat is required to sail equally well on both port and starboard tacks and thus the section must be symmetrical.

Using modern airfoil design techniques and a simple plain flap, one can achieve very close to the maximum CL of an asymmetrical section. Thus, the increased weight, complexity, drag, and loss of the ability to self-trim in an asymmetrical design seem hardly worth the effort. Indeed, the ease of handling a symmetric section which does not pivot horizontally about the mast allows an increase in wing area, thus making up for the lower maximum lift coefficient.

Taking this into account, NACA 00xx series seem the best option to simplify the design and manufacturing without sacrificing performance. As some wingsail catamarans of similar sizes, like some participating in America's Cup, NACA 0006 airfoil has been chosen for the preliminary design. With the maximum thickness (6%) at 30% of the chord, the main specifications are showed below:

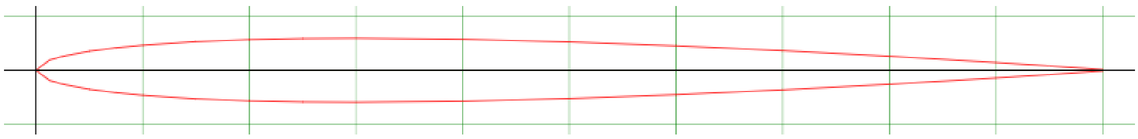
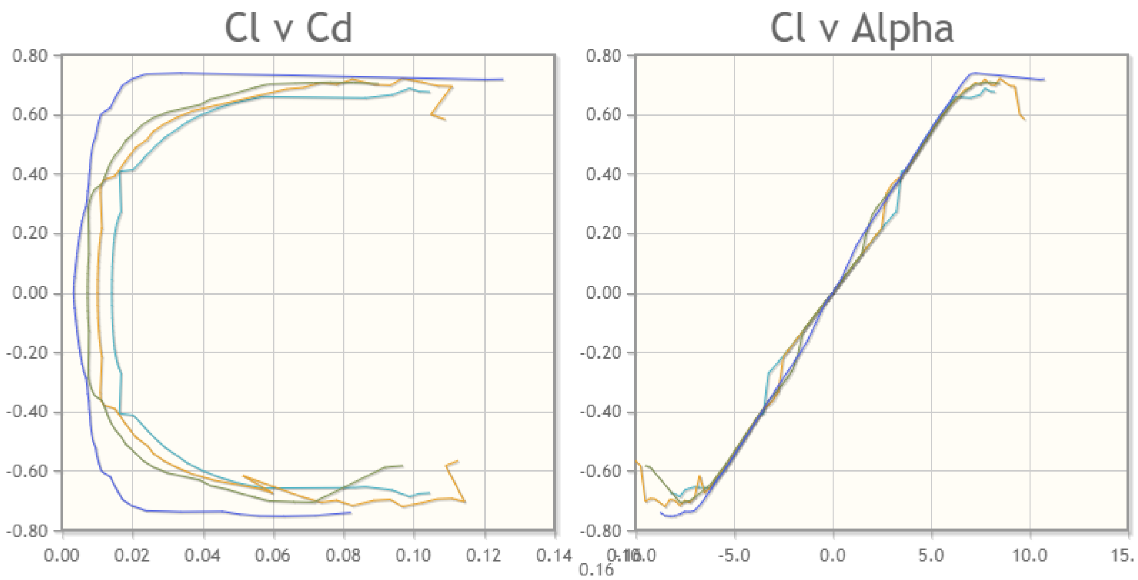
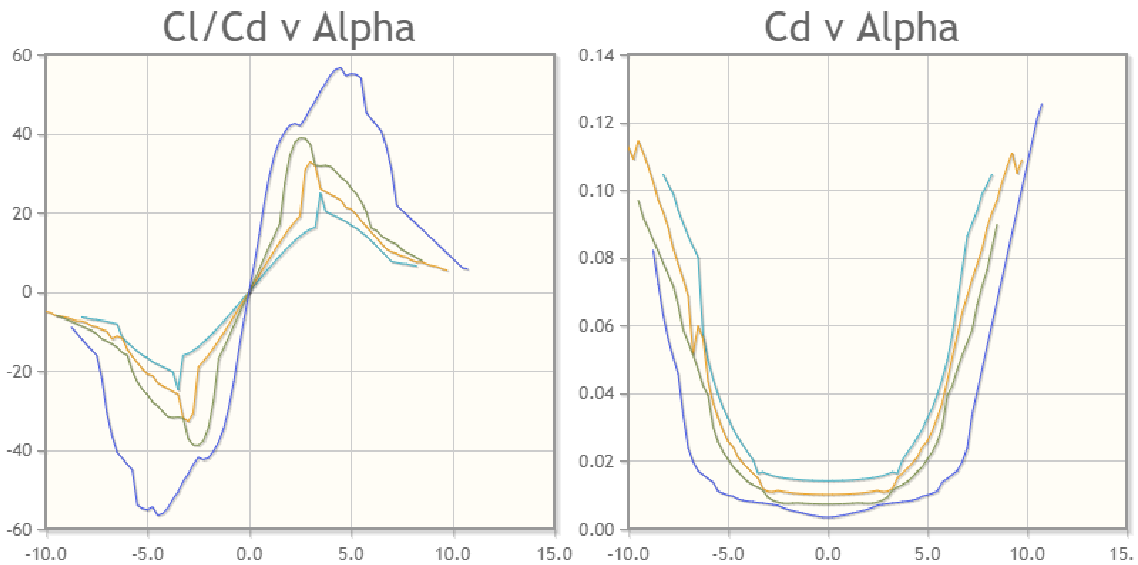


Illustration 27. Wingsail profile NACA



Graphic 11. Coefficient graphics from the wingsail



Graphic 12. Coefficiente graphics from the wingsail

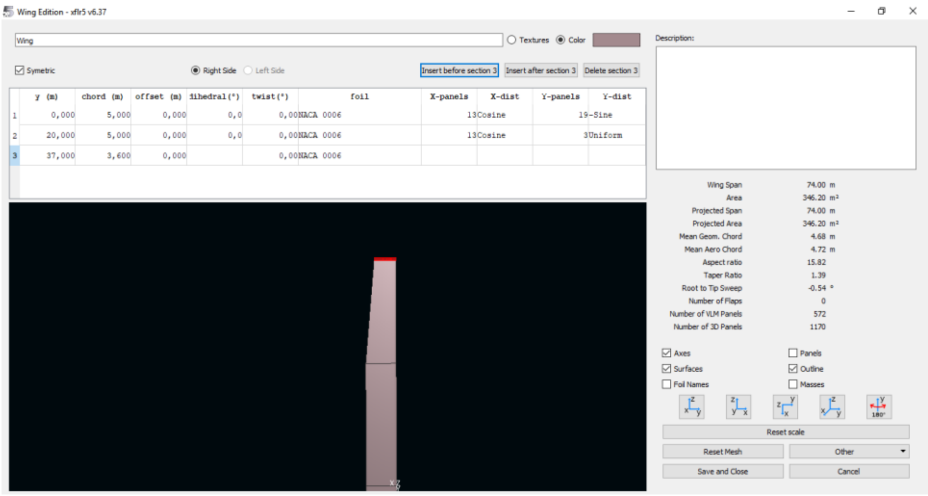


Illustration 28. Lateral view from the wingsail

Wing structure

Wingsails are of two basic constructions that create an airfoil, "soft" (fabric-shaped) and "hard" (rigid-surfaced). Due to the size of the designed vessel, a hard structure is considered necessary.

Most of the existing wingsail structures are quite similar to aircraft wings, with the mast acting like a stringer and multiple ribs with the airfoil shape:

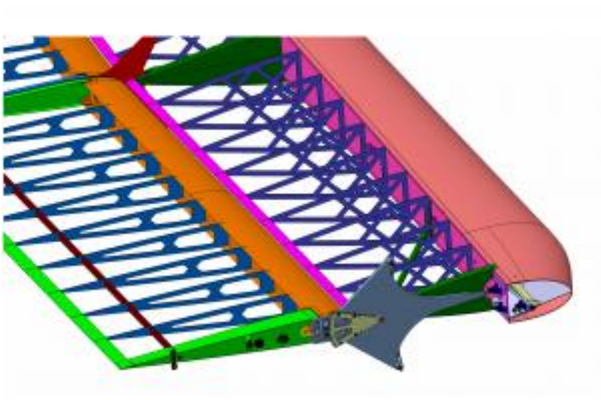


Illustration 29. Interior structure of the wingsail

Regarding the mechanism to move the flap, several options have been tested. The best option to accomplish all the requirements in this particular case must be studied individually, as there are not so much passenger wingsail catamarans[27].

Calculation

The wingsail propulsion system works like a conventional sail, which generates force from the wind to produce the boat's speed, Vx. Like all traditional sailboats, the maximum boat speed is a function of the relative angle between the boat and the wind. As wingsails do not suffer from aeroelastic collapse (and can thus point higher into the wind), they still cannot generate forces to propel the boat directly upwind. Wing lift (L) can be calculated; with values of Cl up to 0,65 and the wing configuration, a total lift coefficient (CL) between 1,8 and 2 is hoped to be obtained:

$$L = 0{,}5 * \rho * S * CL * |v|^2 \quad (7)$$

Lift: 32kN

$$D = 0{,}5 * \rho * S * CD * |v|^2 \quad (8)$$

Drag: 10 kN

With air density of 1,225kg/m3, apparent wind velocity of 22kt and a surface of 170m2.

In the resistance-velocity graph, it can be observed how the force exerted by the resistance for a speed of 14 knots is stipulated in 29kN for the simulation.

The sail area of a ship like the characteristics proposed in the project is between 130-170m2. Assuming a wingsail of the same dimensions, counting that they provide 20-50% more thrust, are values of 32kN wing lift force. Among the factors that determine wing efficiency are the aerodynamic lift coefficients and the resistance coefficient (CD) and the apparent wind speed. The CL factor is adapted thanks to the symmetry of the flap to optimize, so that the best angle of the wind can be directed.

These graphs relate these coefficients with the profile of the wingsail.

The force of sustentation of the sails takes into account the apparent wind, which would be conformed by the sum of the real wind plus the speed of the boat, so that as the ship acquires more speed, more lift.

The Drag coefficient corresponds to the aerodynamic drag, which will be less than the better wing design.

The situation would require a first start to motor to be able to reach the 8kns, until being able to reach the fullness of the candle. As the boat sails thanks to the propulsion system, it uses the force of the wind to power the generator. In the Canaries, the mean average wind speed is at 16 knots, so the forecasts are optimistic in terms of reaching sailing.

Summary of the propulsive characteristics of the systems

	Diesel system (ferri)	Hybrid + wingsail	Electric+wingsail
Power (engine)	400 hp	320hp (engine)	260hp (engine)
Lift (wing)	-	+25/40%	+25/40%
Autonomy (electric)	-	Up to 50 miles	Between 6-10h
Speed	15-20kn	14-18kn	12-16kn
Pollution	CO2, SOX, oil	Few quantity	0

Graphic 13. Propulsion systems comparative

Depending on the priorities and operational requirements, there are several factors when choosing the propulsion system.

The combustion engine provides some advantages known as autonomy and high speeds. On the other hand, one of the objectives of the project is the use of renewable energies, so it is discarded as an option.

The hybrid system could be the most appropriate if the use of the vessel is directed to the transport of passengers. They reach distances of 50 miles without the need to pull the generator, and the quantities of fuel are quite small compared to a diesel engine. There is the possibility of navigating in a renewable way and always brings something more autonomy than the electrical system. Always counting on the push of the wingsail, which depending on the conditions reaches values between 20-40% of the extra thrust.

Finally, the electric version is the most risky, since it will always depend in most of the climatic conditions to extend the autonomy and maintain the high speeds. Electric motors offer sufficient autonomy for a low speed range, so it will be essential to achieve a good sailing regime so as not to exhaust the capacity of the batteries. The autonomy of the electrical system will be prolonged more to a range of low speedsWhile the ship is sailing, the generator will be fed with wind energy, prolonging the power of the engines.

Tasks to be developed during the wing project

Once the main characteristics of wingsails have been studied, the following tasks may be developed to fully design an operative wingsail:

- Completely define the wing form through CFD analysis
- Choose the suitable structure and its materials to get the necessary lift without affecting the vessel's stability
- Perform a brief approach to the automatic control of the wingsail
- Study the economical viability of the project

Chapter 7. Regulation

For the development of the activity and classification as a passenger ship, there is a series of regulations that the project must comply with. The regulations are regulated by the International Maritime Organization[28] and in the chapters of the SOLAS[29] agreement aspects such as safety, equipment on board, gas emissions are treated ...

Passenger ships of 24m in length and above sailing through Spanish ports will have to abide by the Solas agreement and Royal Decree 1247/1999. The SOLAS defines as ship of passage all that boat with capacity for more than 12 people. It also establishes a limit of passenger boats in the 24m (smaller and equal or higher). In addition, the regulations in force establish the minimum space for passengers as well as an average weight for the calculation of their cargo.

The maritime navigation zone of the ship is class A (in passenger transport boats), whose navigation is short sea shipping between Spanish ports reaching more than 20 miles from the coast. Also for the sailing conditions the boat's class will be B. Most trips between the Canary Islands already represent a classification of maritime zone A, with B or C being the closest connections such as Tenerife-Gomera or Fuerteventura-Lanzarote

This space is 1 square meter for every 4 passengers and the average weight of 75kg[16]. New passenger ships must undergo several inspections: one prior to the start-up or start of the activity, a periodical survey every twelve months and then punctual inspections in case of stranding, accident or any modification. In addition all passenger ships must be provided with the safety certificate in navigation once the initial inspection has been completed.

The aspects of regulation can be divided into three blocks according to the field, be it pollution, safety and design and equipment.

Pollution: as of January 1, 2020, the new regulations in regard to gas emissions come into force, and more specifically, limiting those that contain sulfur particles. With the new regulation on emissions of sulfur SOX particles ships will have to go from 3.5% parts mass / mass to 0.5%, both for use in main engines, auxiliary and boilers. The regulations regarding gas emissions are extensive and have restrictions for the most harmful models, but it is not an issue that influences the project. The main purpose of this project was to achieve a sustainable design as well as to eliminate the environmental impact and the ecological footprint. It is a model that is expected to work in a 100% ecological and sustainable regime, without producing emissions or other impacts caused by the use of fuel. The wind as a source of primary propulsion taking advantage of sailing to supply the generator and equipment[30].

Safety: basic activity moves a large volume of passengers, so security measures have to be extreme. From on-board devices, distribution of inputs and outputs, on-board signaling and equipment layout. As part of the safety is the design itself of the ship, placing collision bulkheads as well as help systems to open all sliding doors, providing watertight spaces, bilge pumps, collectors ...

- Two independent motor-driven systems to start the steering system.
- 3 bilge pumps

- Evacuation: safe escape routes will be available and free of obstacles. These routes will have to be helped with clear brands and guides.
- The doors of the escape routes will open in the same direction as the direction of traffic.
- All ships will have two breathing apparatus for evacuations.
- In ships of less than 1000 tons of tonnage, the administration allows only one evacuation route
- Means needed to ensure the safe passage of the dock on board
- For ships with more than 36 passengers they will have to have thermal boundary bulkheads in the entire superstructure and hull. These bulkheads will be of class A60.
- All the openings, except for exceptions, will have a closing system and will be as resistant to fire as the enclosures that limit them
- The fire doors, as well as the sliding ones have a margin of time for their closure, both minimum and maximum, and it must be possible to close them from a remote point in a room. The doors must be able to close under a system failure , and also have to withstand a temperature of 200º for 60 minutes.
- The openings and vents will be the minimum possible number to maintain the safety of ventilation on board.
- Ventilation ducts that pass spaces classified as A must be of non-combustible material
- Boats of less than 1000 tons will have a fire pump by automatic start-up or from the command post
- The diameter of the collector will be sufficient for the flow of two simultaneous pumps to circulate.
- The number of hoses or jets will be at least 2, which allows reaching any part of the ship and can provide water from two different pumps. The pressure in this case will be 0.3N / mm2
- Except fuel pumps, all the rest can be used as fire pumps. Minimum two pumps on board.
- The length of the hoses will not be less than 10m nor more than 15/20 depending on the area. 15m for the engine room, 20 for the covers
- Portable fire extinguishers will be installed in the accommodation and service spaces, one of which will be next to the entrance. In closed spaces, fire extinguishers will be available at a maximum of 10m.
- In addition, a valve for each hose or jet will be available so that it can be closed when necessary.
- Passenger ships must have a system of at least two water nebulizers.
- ships carrying more than 36 passengers should develop a maintenance plan for low-altitude lighting systems and public address systems
- There will be a fixed fire detection and alarm system. Among the elements necessary for fire-fighting equipment are: detection and alarm system, extinguishing system, sprinklers, manifolds, butterfly valve pumps, portable fire extinguishers, hoses, jet, fire doors, service interruption system ...
- In addition, passenger ships will have a book on fire prevention and action.
- The ventilation of the pump room will have a minimum of 20 aspirations per hour.
- Smoke detectors will be installed in all accommodation areas, passage areas and staircases as well as escape routes and in all engine rooms. In addition to manual actuators that will not exceed 20m.
- Passenger ships of more than 36 passengers will have all centralized fire detection alarms in a room.

- The openings made in the watertight bulkheads will be as few as possible, and the tightness of the spaces must be maintained
- Do not allow automatic sliding doors to be closed with a heel higher than 15º. In addition all of them may be closed from the checkpoint
- They will be provided with an alarm that warns of their telematic closure, as well as a minimum and maximum speed in their movement. In addition there will be the possibility of manually and individually closing the doors.
- For the bilge system, a minimum of 3 pumps will be installed in the system. In addition to suction ducts on the sides and scuppers that do not allow the free circulation of water through those non-watertight spaces.
- The main and auxiliary steering apparatus are arranged so that failure of one does not impede the other.

Design and equipment: designed to transport passengers, the ship must have a control bridge from which to control all maneuvers as well as having a clear view of the course of the ship. In addition to the installation of a series of equipment for telecommunications, to calculate the losses and routes, radar to help during navigation ...

- 9 GHz radar transponder to detect objects near the boat. A NAVTEX receiver.
- A portable bi-directional radiotelephone equipment of VHF.
- Have an electronic method to measure depth
- Velocity and distance meter
- Course transmitting device
- Automatic identification system (SIA)
- As the objective is to cover routes between all the islands, and there are distances that exceed 20 miles from the coast, the classification of the ship will be A.
- In a ship lacking a closed runway, the float length at any point can be determined considering a supposed line of continuous margin that in none of its points is less than 76 mm below the top face of the deck (on the side) to which the bulkheads are kept watertight.
- The passengers will be arranged on the decks, on one side achieving the most unfavourable heeling moment.
- A forepeak bulkhead shall be installed no further than 5% of the length of the ship and no more than 3m.
- There will be a double bottom from the forepeak to the stern
- A watertight door allows the authorized passage of passengers or crew and closes immediately afterwards.
- All vessels will have draft marks on the side of the hull

Chapter 8. Conclusions

Once finished the first part of this project, which corresponds to the design of the helmet as well as the theoretical introduction throughout the process can be concluded that:

The main objective was to design an efficient and sustainable boat that will not contaminate the environment, and to focus it on a professional sector for its development. The project has been divided into two parts, one focused on the theoretical part and the design of the hull, and the other on the design of the sail.

The process of designing a ship from 0 entails making many decisions, and among the most difficult steps, you have to start defining specific parameters of the ship. The dimensions of the ship are very important and affect the behaviour and potential that may have, so you have to be clear about the purposes. These purposes must be clear, since the success of the design depends on its adaptation to operational requirements, regulations, type of navigation ...Normally the market comparison is a good starting point to get an idea of how similar models are.

Another conclusion is that although the wingsail mechanism is relatively new, its success in the future will depend on its adaptation to professional functions. While currently the mechanism is for racing, competitions and large boats, there was not yet any system designed for the transport of passengers.

In addition, these developments will help the transport sector to change the image of the outdated sector. The ships that carry out passenger transport have not innovated or dedicated their efforts to improving both their image and their performance, and this leads to a transport of passengers that is relegated to very specific situations and with a fleet of outdated ships. The added value is much sought after today, and a boat is no exception. The project is designed to be different and original from the first moment, from the design of the hull to the wingsail system through the choice of the engine, the factor of sustainability is very present.

In global terms it is difficult to compete against large ferries established in areas of high demand, but it has been observed as the estimates of speed and time of the project and the ferries are similar, it will be necessary to check later if all the assumptions are met. The main objective was to bet on renewable energy systems to achieve the propulsion of the ship. Passenger maritime transport in short sea shipping is lagging behind and is losing importance in the overall volume of journeys. New technologies can be an improvement not only in terms of efficiency but also in attracting more passengers thanks to sustainability.

Although it seemed unthinkable that a boat dedicated to a professional activity could not depend on fuel, and the project offers the possibility of being 100% electric and sustainable. It is true that the electrical system may be somewhat right in terms of power and autonomy (and this could lead to the hybrid version) but you have to take risks and consider that the rest of the conditions are favourable to enhance sailing.

It is being checked how the current measures are aimed at limiting the most polluting transport vehicles. For a few years it has been in force in road transport and in cities, as of January 1, 2020 it will also reach ships. But the limitation of emissions must not be the reason to change the sources of propulsion, factors of conservation of the environment must prevail, take care of the ecosystems and more delicate areas ...

The new framework that enters into force in 2020 is not only focused on reducing emissions to the environment, but goes further when talking about issues such as sustainability in the sector. The goal of sustainability, not only in terms of ship propulsion, but throughout the entire manufacturing process

The wingsail not only gives greater thrust than the traditional soft sails, but also its system: it can be controlled automatically to detect the best angle of attack and guide the structure at all times, it can be equipped with solar panels for energy capture solar, even nanotechnology in the panels of the sail allows the capture of thousands of data at all times for analysis, easily manageable ...

One of the big decisions is to opt for the hybrid Deep Blue or electric system. Due to the needs of the project as well as the objective of transporting passengers as an alternative to ferries, the most realistic and safest option would be the hybrid propulsion: it ensures more distance, power and speed although it is true that it also continues to use fossil fuels that pollute, although with a small amount. The boat can travel more than 50 miles without having to activate the generator

The risky and 100% electric option is a bit short in terms of capacity of autonomy at high speeds, which ends up depending in most of the favorable weather conditions for the extra push of the wingsail. This option could be valid for short 30 'trips, in which short distances would favor the electric motor in this case. What is certain is that the Torqeedo propulsion system has a great efficiency, both hybrid and electric version, and that during sailing, take advantage of the wind generator to recharge thanks to wind power

In Spain, a country with a lot of tourist activity especially in the coastal area, there is not much tradition of nautical transport as well as alternatives for mobility in these regions. The necessary infrastructure is only present in the Balearic and Canary Islands, so they are ideal areas for both their characteristics and the volume of passengers, to propose this system as an alternative to ferry lines. Normally they have a very delicate ecosystem, so respectful navigation is necessary, as well as the support from the Administrations. The study of a close and concrete case has been made to move from a local to a global scope by expanding the solution

As a last point to comment, they have tried to implement the skills acquired throughout the career: from the use of specific programs for calculations and sizing, the use of the third language, a teamwork, good references and bibliography.

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Annexed documents:

I Caculations

HYDROSTATICS			Nominal Hull speec	11,8890551	kns	6,11625836	m/s	Cf	0,00114673	Standard value		
LENGTH	24	m	Multihull max spee	11,9045201	kns	6,12421425	m/s	Cr	0,29268293	(75% of volum)		
BEAM	10	m	Max. Hull speed	18,6135546	kns	9,57563975	m/s					
DRAFT	0,8	m	Gerr Formula					Ct	0,29382966			
DISPLACEME	40	TN										
VOL.	39,02439024	M^3						Total resistance	470130,81	n	470,13081	Kn
			#Reynolds	122242210					1152345,38	n	1152,34538	kn
WSA	45,2376	m^2										
WSA	83,456	m^2	Previous caculus	8,08722118								
				65,4031465				Engine power	2875441,5	kW	3906,84987	hp
D/L ratio	81,99827856	(light)							11034444,3	kW	14992,4515	hp
	0,7872	0,48781512	#Froude	0,62438023	(Gerr)	(<0,57 displacement boat)						
	78,72	(ft)		0,39881103	(nominal)	(standard displ.boat froude number						
				Froude Proje	0,37166888							
S/L ratio	2,097909621	More accurated for multihulls										
Theorical relation displacement-power												
	160	Kw	#Froude	0,39881103								
Speed for m	11,90452015	kn										
	(Propellers project formula)			D/L ratio (with 100 passenger)								
				47,5	(weight)	97,3729558						
	6,124214255	m/s										
	(with some l	5,7										
Froude Proje	0,371668878											

II Model comparative from "*The yacht sailing design*"

Vessel	LOA	DWL	BMAX	BWL	CP	CB	WS	TMAX	Dis.design	Dis.max	RA
Le Tigre	16,45	15	8,2	1,1	0,5755	0,41455	39,1	1,4	6500	9300	0,52
J Bells 2	16,2	15,2	8,6	1,07	0,5591	0,4378	35,5	1,1	8250	12000	0,7
Sunset 65	19,54	17,2	9,33	1,85	0,578	0,455	72,2	1,58	23850	23850	1,153
Tigresse	17,65	16,2	9,2	1,73	0,569	0,421	59,5	1,5	19031	15000	0,718
Fourcats 52	15,87	14	8,82	1,55	0,571	0,446	46,3	1,35	13314	17000	0,708
Sunset 55	16,75	14,8	8,42	1,75	0,579	0,456	53,4	1,55	17458	20500	0,719
Table Bay 58	17,65	16,48	902	1,82	0,571	0,424	63,7	1,55	19031	22300	0,718