Design of Autonomous Surface Vessels

João Carvalho Vasconcelos

Centre for Marine Technology and Engineering (CENTEC) – University of Lisbon - Instituto Superior Técnico - Av. Rovisco Pais 1049-001, Lisboa, Portugal

The idea of an Autonomous Surface Vessel (ASV) started nearly half a century ago during the WWII and since then this vessels have been following the technology evolution and started to be used not only for military purposes but also for scientific. Nowadays anyone can have an ASV and until now there are no mandatory rules regarding the usage of these drones. Scientist use them to perform a lot of different studies in the waters.

Three vessels were designed: one catamaran, one monohull and one catamaran-SWATH. The catamaran is a small size ASV, designed to operate in very calm waters. The monohull was designed for more rough environments, where currents and waves can be existent, and is equipped with a solar panel to increase its autonomy. The catamaran-SWATH is big sized ASV, a type of ship that seems to be unthinkable for nowadays, because of the risks associated to its operation. Its design was performed in the same way as a manned ship, but the general arrangement and the existing compartments were designed for a unmanned vessel. Although it seems an utopic idea, it is just a question of time until majority of ships are adapted to be autonomous.

Key words: Autonomous Surface Vessel (ASV), composite materials, catamaran, monohull, SWATH.

1. INTRODUCTION

Vessels follow both human and technology evolution, according to their needs and capabilities. A new generation of crafts is starting to get more attention because of its multi-functionality, providing safety and comfort to users, and it can be achieved with low-cost investment. This new generation belongs to the robotic family, where technology allows the operation of a floating machine without human presence on board. This kind of structure is named autonomous/unmanned vessel and can operate underwater or on surface. These autonomous crafts have revolutionized the way to explore the seas. With them it is already possible to explore, with 100% safety, waters that could bring severe health problems to humans and, since these ships are machines they will not need to rest or refuse to do their jobs. The major impulsion given to the development of autonomous vessels was due to the military applications, where safety is the biggest concern, then scientist adopt these vessels to explore waters taking the advantages of technology advances (Romano & Duranti, 2012).

An Autonomous Surface Vessel (ASV) or Unmanned Surface Vessel (USV) is a floating type of platform that has revolutionized the exploitations of waters. The vast versatility of ASVs allows them to operate in a large variety of missions, like oceanographic measurements - bathymetry, water monitoring, salinity, currents, chemistry, earthquake prediction, hydrographic data, ship wreck survey and structure inspection, air and atmosphere measurements - surface winds, air temperature and humidity, sea surface temperature, hurricane path prediction and weather forecasting , military missions - coastal/port surveillance, mine detection and reconnaissance, military training and security , or simply follow an autonomous underwater vehicle (AUV) in order to provide support communications as well as precision location and navigation (Eve et al, 2012).

Scientific purposes are the major cause of an exponential growth in the production of this kind of vessels. Since scientific studies are made in estuaries or lakes, deep water or shallow water conditions, oceans or in a pool, there is a large variety of vessels' sizes and forms - they can be monohull, catamaran, small waterplane area twin hull - SWATH, hydrofoils, trimaran and so on.

Autonomous Surface Vessel is a concept introduced in World War II (WWII), where a small group of remote control vessels were designed for gunnery and missile target systems (Roberts & Sutton, 2006). Other vessels were built by that time for mine and obstacle clearance (Bertram, 2008), being called by "Demolition Rocket Craft". It was possible to see that ASVs were a good way to save human lives and could bring many advantages to military applications.

With the *Global Position System* (GPS) and long range bandwidth wireless data systems evolving and becoming more affordable and efficient, ASVs were given new missions and were quickly inserted in the scientific field, helping scientists to perform their studies (Manley, 2008), reducing the costs related to oceanographic research.

One of the first developers of scientific purpose ASVs was the *Massachusetts Institute of Technology* (MIT) *Sea Grant College Program* (Manley, 1997), where two autonomous crafts were developed, the *ARTEMIS* and *ACES*. *ARTEMIS* was the first platform designed by MIT in 1993 and it was a testing platform, where navigation and control systems were tested. . It was built from a 1/17 scale replica of a fishing trawler, but since it was small sized, it was not suitable for coastal or ocean research because it had limited seakeeping and endurance (Manley, 1997 ; Manley, 2008). It was a monohull with a draft of 0.2 meters and a total autonomy of 4 hours reaching a maximum speed of 2.25 knots with its diesel engine. In order to provide better roll stability and a greater payload capacity, a catamaran hull form was the best solution. *ACES* was the ASV designed in 1996, to fulfill all goals that *ARTEMIS* couldn't achieve, and the final result was a catamaran vessel with a total length of 1.9 meters, 1.3 meters breath and 0.45 meters draft. Both *ARTEMIS* and *ACES* had devices that allowed them to perform bathymetric measurements (Caccia, 2006). The next step was to construct one hull from lighter materials and dismiss gasoline engines. The result was a new ASV built from fiberglass composite material and electric thrusters. *AutoCat* was the name of the vessel and it was constructed in 1999 (Manley et al, 2000). *AutoCat*, *ACES* and *ARTEMIS* had inspired other scientist of the world because of their simplicity, vast applications, low-cost investment and safety.

In Germany during the period of 1998-2000 the *MESSIN* project was developed (Roberts & Sutton, 2006 ; Caccia, 2006), consisting on the design of a fully autonomous surface vessel capable of high accuracy of positioning and track guidance and, as a carrier of measuring devices in shallow waters. The project was named *Measuring Dolphin.* A catamaran hull was built from fiber glass composite material.

In the same period of time (1997-2000), *Europe Union* founded the project named *Advanced System Integration for Managing the Coordinated Operation of Robotic Ocean Vehicles* (ASIMOV) (Caccia, 2006 ; Oliveira et al., 2000), where the objective was to develop a number of ASVs that could supply direct acoustic communication link with AUVs, improving the navigation and positioning of the vehicle. In this project the Portuguese institution from University of Lisbon - *Instituto Superior Técnico* (IST) had developed an ASV named *DELFIM* to support the AUV *INFANTE*, ensuring fast data communication between both vehicles (Alves et al., 2006). *DELFIM* operated near Azores islands in the Atlantic Ocean, so the vessel had to be robust to navigate in ocean waters without endangering its stability and availability, resulting in a bigger craft with better seakeeping properties. The designers choose the catamaran hull type for better roll and pitch motion. Equipped with a *Differential Global Position System* (DGPS) and a *Doppler unit* for transmissions the ASV had a total communication range of 80 km. Other components like sonars and scanning devices allowed the ASV to perform bathymetric measurements and communications with the submerged ASV.

Another country that entered in the history book on the development of ASVs was Italy, by developing the *Sea Surface Autonomous Modular Unit* (*SESAMO*) ASV (Caccia, 2006 ; Caccia & Bono, 2005). The work was done by the robotics group of *CNR-ISSIA* with cooperation of the *National Program of Research in Antarctica* (*PNRA*), between 2002 and 2004, and the main objective was sea surface micro layer sampling in Antarctica. The vessel was designed to be able to achieve high cruise speeds to go and come back from the sampling area, and needed to have the ability to collect up to 35 liters of sea water. It was equipped with devices that would perform onboard measurements of the water samples, in order to evaluate if it was a good or a bad sampling. This vessel was going to operate in open waters and therefore good stability was needed. Once again the catamaran hull type was chosen and the autonomy ranged around 4 to 6 hours.

In 2004, the *MIT* developed a new concept for the usage of ASVs, with the project *Surface Craft for Oceanographic and Undersea Testing* (*SCOUT*) program (Curcio, 2005), consisting in the fabrication of four vessels. The design objectives were simplicity, robustness, versatility and improved utility. Easiness in deployment and recovery were one of the main constrains of the project. The *SCOUTs* were built from existing kayak hull and were programmed to work together in their research tests for a period of time of 8 hours at a maximum working speed of 3 knots (Manley, 2008).

From 2004 to nowadays, the ASVs suffered a big jump in their production. Scientists yielded to these robots and with the growth on the production and technology, new systems were developed and better crafts were constructed.

In the end of 2004 a new revolutionary vessel was developed, in the USA, by the *National Oceanic and Atmosphere Administration* (*NOAA*) in cooperation with *National Aeronautics and Space Administration* (*NASA*) (Higinbotham et al., 2006). This vessel was called *Ocean Atmosphere Sensor Integration System* (*OASIS*) and its main task was to collect in-situ, ocean and atmosphere measurements. *OASIS* was designed to be a low-cost, low-speed, reusable and long duration platform to operate in open ocean waters. Equipped with sensors to obtain biogeochemical and air-sea measurements, it could quantify the air-sea CO_2 fluxes and gas transfer velocity. *OASIS* may also be used for mapping dynamic features like oil spills and harmful algal blooms, but the major innovation were the solar panels to automatically recharge its batteries and increase significantly the autonomy of the vessel between 36 to 72 days (2160 – 4320 hours).

In Portugal two new ASVs were being developed by *Instituto Superior de Engenharia do Porto* (*ISEP*). Both ASVs were designed to support an AUV in its missions. The first ASV produced was named *ROAZ* and it could not only support the AUV but also perform bathymetry of riverbeds, estuaries, dam basins and harbors (Ferreira et al, 2006).

Later, in 2013 the *MIT* developed a new kind of ASVs for high speed purposes and called them as the second generation of ASVs (Brizzolara & Chryssostomidis, 2013). The project consisted in the design of two high speed vessels, one respecting the conventional SWATH hull type and the other with a hybrid Hydrofoil-SWATH hull type, both designed to minimize the advance resistance and obtain favorable propulsive power at relatively high speeds.

New hull shapes and concepts are always being developed, not only because the improvement of the ship efficiency, but also in the demand of the safety onboard. New hull concepts like the catamaran-SWATH are starting to show themselves as really good solutions, when a single vessel needs either speed or static behavior in the water. This concept has to be really well studied and designed, because the ship must be provided with really large ballast tanks that can submerge the pontoons to a draft where the ship enters in SWATH mode. Nowadays SWATHs are starting to become a more used concept for passenger ships, because of the extreme comfort they provide. A SWATH has a small waterplane area and because of that, they are less subjected to waves, giving them a stable position even if there is a harsh sea state. In scientific applications this can be really useful because it will give a more accurate and precise conditions for any measuring, mapping or even bathymetric research of a vessel.

2. MISSION REQUIREMENTS

In order to achieve most of the required ASV competences, it was decided to design not only one, but three different types of vessels: one to operate in lower sea states and the other two, able to operate with higher sea states. The vessel designed to operate in calm waters must have as mission requirements: stability to allow good measurements, enough cargo volume, for equipment transportation, system reliability, and low draft as an important requirement, to avoid any grounding or risk of get stuck at algal.

In a way to study the different types of hulls that are mostly used on ASVs, a monohull and a catamaran-SWATH were chosen for the design of the two vessels. The monohull vessel will be smaller and slower, than the cat-SWATH, with enough cargo space to carry several electrical devices, to perform any necessary measurement. In this case, the objective is to maintain all boarded devices, electrical powered, excluding any combustion component. The hull shall be built from composite materials and shall have means to be lifted, in order to facilitate deployment and recovery. The speed is not a requirement, but must be sufficient to allow AUV following missions.

On the other hand, the catamaran-SWATH vessel is the biggest and the fastest one. Following the idea of (Brizzolara & Chryssostomidis, 2013), this vessel is to become a part of the new generation of ASVs, where the speed is one of the most relevant requirements. The vessel must be large enough to carry at least one AUV, for transport, deployment and recovery and must be able to recharge it on site as well, enlarging its autonomy. The ASV is also to be capable of performing oceanographic measurements, like bathymetry and wreck spotting, leading to extra cargo capacity.

3. CATAMARAN

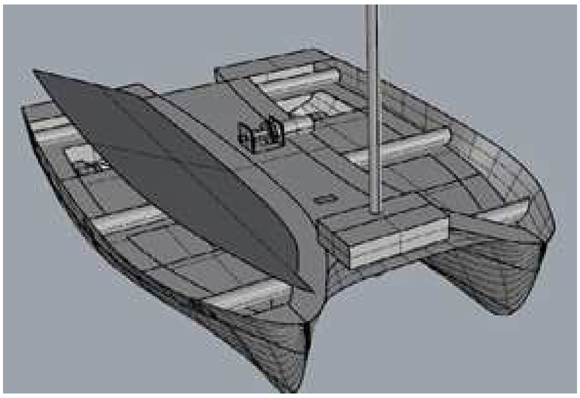

Figure 3.1. Catamaran model.

3.1 Hull type and form

A catamaran hull is a really good solution when payload and stability are required, due to the presence of two hulls. By designing a catamaran vessel, low draft was achieved and since this hull was designed to operate in shallow waters, there was the objective of maintaining the design draft as low as possible. For the design of the hull, the NPL High Speed Round Bilge Displacement Hull Series (Bailey & M.R.I.N.A, 1976) were adopted., where some minor changes had to be performed.

Table 3.1. Catamaran main design dimensions.

Catamaran designed dimensions		
LOA	2.00	[m]
LPP	1.96	[m]
B	1.50	[m]
D	0.50	[m]
T	0.26	[m]

Both hulls are symmetric, connected by three aluminum bars and a composite platform. Both the shaft and the propeller are protected by a composite duct. The hull was designed to be a single skin laminate, for being the most appropriate for small vessels (Greene, 1999), resulting in a very light weight structure.

3.2 Hull Resistance and Propulsion

The resistance of the vessel was obtained using the *NavCad* software which has a large variety of calculation methods to predict the resistance of the hull. One of the possible methods that the software is able to use is the NPL. The requirements which are demanded by NPL resistance prediction (certain Froude and form coefficient intervals) were fulfilled, therefore the method was acceptable and possible to be used.

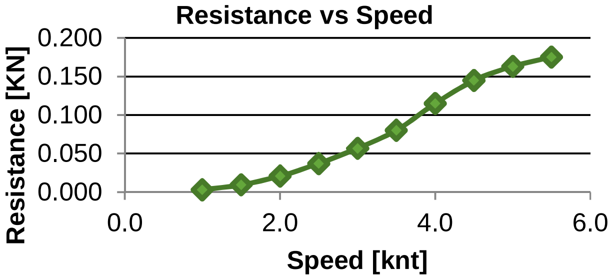

Figure 3.1. Catamaran resistance evolution, due to the effect of the speed.

3.3 Hull equipment and ship light weight

The propulsion system should be constituted by electrical devices only. Two electrical motors, one in each demi-hull, provide the necessary thrust for the catamaran. Maneuver can be achieved by applying differential propeller revolution. Other equipment like gear box, batteries and drivers are also included onboard and are necessary for the vessel to sail. It was estimated that with the existing equipment, the vessel would be able to operate for at least 20 hours. The vessel is also equipped with a winch and a mast, to increase its versatility and allow even more applications. The winch can be used either for trawling or for collecting samples and the mast is where the communications and the navigation equipment shall be placed.

The composite structure weight was calculated according to the density of the E-Glass polyester woven roving (1700 kg/m^3) and the thickness of the material. Based on some of the already developed works (Ferri et al., 2011), a thickness of 3 millimeters, for the composite structure, was assumed. The equipment weight is provided by the suppliers.

Table 3.2. Catamaran Light weight

	Weigth [kg]	Lcg [m]	Tcg [m]	Vcg [m]
Light weight	93.20	0.842	0.000	0.337

Six compartments were defined as cargo holds, with the possibility of adapting the bottom void space for water sample tank. The numbers of compartments allow several divided spaces for different equipment.

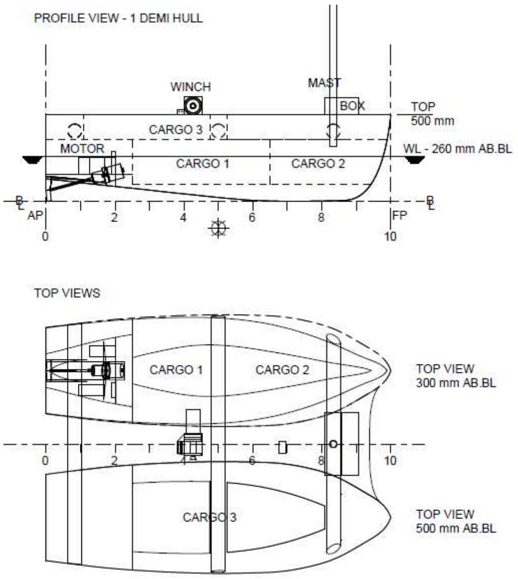

Figure 3.2. Catamaran general arrangement

With a deadweight of 130, the total catamaran displacement is of 223.2 kg, with a draught of 0.26 meters.

4. MONOHULL

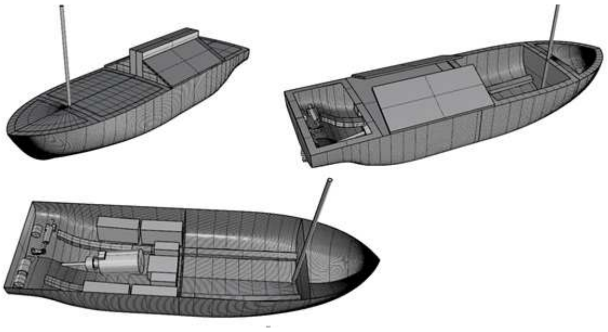

Figure4.1. Monohull model.

4.1 Hull type and form

The monohull is a vessel designed to operate in open waters and therefore it must have enough stability to guarantee the safety of the equipment. It was important to balance the vessel in order to have good behavior at relatively high Froude numbers and also have good cargo volume, therefore it was chosen a semi-planning hull type, which possesses a little of the planning hull characteristics and a common displacement hull, balancing the most important requirements (Codega &

Blount, 1992). This type of hull form has a flat area with a certain degree of inclination located at the keel, which provides enough lifting capability to reduce wave resistance and the development of the outer shell doesn't creates any visible edge, instead a round bilge provides a development of the hull which allows a very good flat of side area, increasing the cargo space.

Table 4.1. Monohull design parameters.

Monohull main parameters			
LOA	LOA	5	[m]
Lpp	Lpp	4.833	[m]
B	B	1.5	[m]
D	D	0.7	[m]
T	T	0.4	[m]
Disp	Disp	1862	[kg]
Cb	Cb	0.627	[-]
Cm	Cm	0.852	[-]
Cwp	Cwp	0.881	[-]
Awp	Awp	6.378	[m^2]
S	S	8.146	[m^2]
Lcb	Lcb	2.404	[m]
Vcb	Vcb	0.24	[m]

The composite E-Glass Polyester Woven Rovin was once again used, but this time it should not be a single layered vessel, but a sandwich laminate composite hull, for higher structural strength. Scantlings were performed by using the International Standard ISO/DIS 12215 (International Organization for Standardization, 2004).

Table 4.2. Total laminate panel thickness.

Foam thickness	2.0	mm
Fiber thickness	4.0	mm
Composite thickness	6.0	mm

The vessel is to be 100 % electrical, and since it is to have a good autonomy solar panels were installed.

Another characteristic of the vessel is the capability of ballasting the small sampling tanks, located forward. There are a total of six small water sampling compartments, divided by single skin composite lamination, for different types of measures. The flat area above them, allows the installation of any necessary equipment to the water measurement procedure. The vessel is also equipped with a mast, and since it is to operate in open water, the mast will have not only the role of support a GPS or antennas, but also lights to maintain the vessel visible even at night.

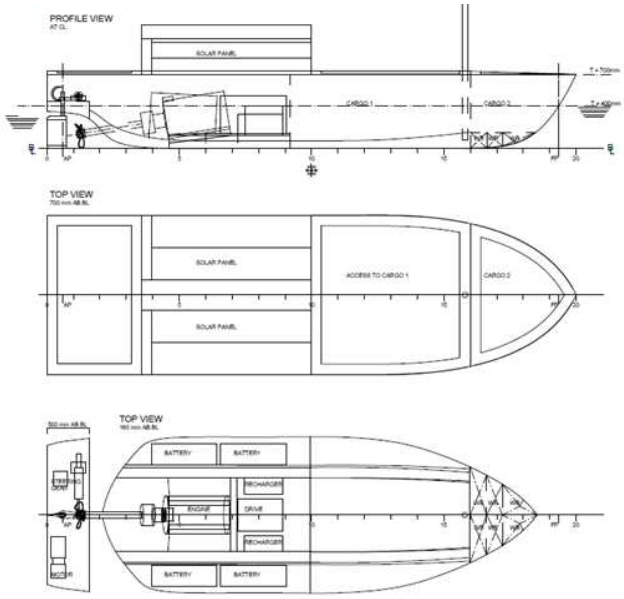

Figure 4.1. Monohull general arrangement.

4.2 Resistance and propulsion

Using again NavCad, but this time the NTUA method (Tzabiras & Kontogiannis, 2010), which is a method based on Computed Fluid Dynamics (CFD) tests, in models, the resistance was calculated.

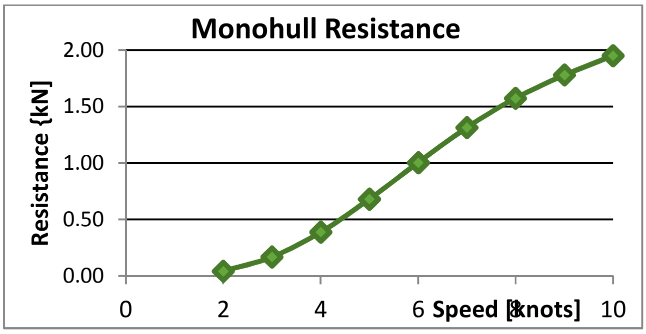

Figure 4.2. Monohull resistance curve.

The next step consisted in choosing an electric motor that could provide the necessary amount of power.

4.3 Hull Equipment and Light Weight

A total of four lithium-ion batteries are installed onboard. The battery rechargers, the drivers and a customized steering gear system are also part of the hull equipment. Two solar panels are located on top of the weatherdeck, one at each side of the vessel. The rudder, the propeller, and the mast are built from aluminum.

Table 4.3. Monohull light weight.

	Weight [kg]	Lcg [m]	Tcg [m]	Vcg [m]
Light weight	784	1.710	-0.001	0.374

With a max deadweight of more than 1 ton, the cargo must be is be well distributed through the compartments. The heavier cargo is supposed to be placed at the aft cargo compartment, for being closer to the center of buoyancy.

5. CATAMARAN-SWATH

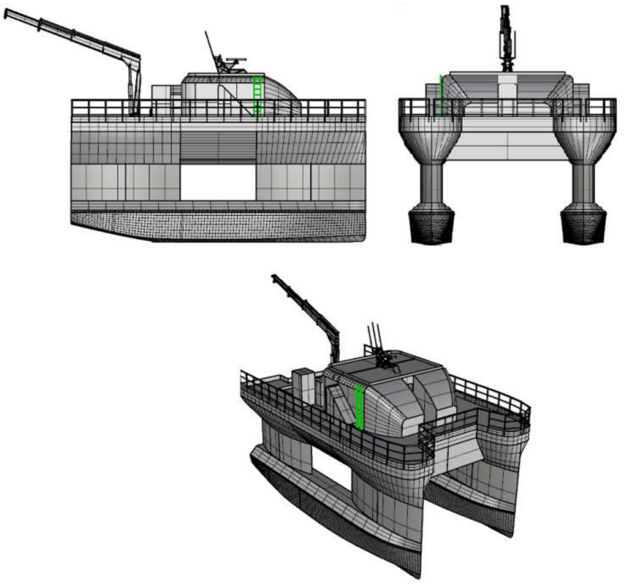

Figure 5.1. Catamaran-SWATH model

This type of ship is now being more and more commonly used for transporting people, they can be from fast ferries to work boats, per example to transport operators and engineers to windmills, but due to the versatility that comes with this design, these ships can become a really good solution for unmanned purposes. The main advantages of this design are the ability to reach high speeds when sailing in the catamaran mode and the ability to stay almost completely steady when it changes to the SWATH mode.

Normally, catamaran-SWATHs are divided in four main parts (Kennell, 1992): the pontoons, the struts the haunches and the platform.

5.1 General Arrangement

The fact that the ship is to be of fast speed and the size is considerable bigger, the ship can be a serious threat to any other vessel. Rules and international conventions were used has guide lines of the design.

The speed that this vessel should reach is of 20 knots in the catamaran mode, making it really fast for an unmanned 16 meter vessel. In the SWATH it is not intended to have any operation speed, although it should be able to have some minor maneuvering or sailing speed, because the ship will only be in SWATH mode when it is necessary to stay in a completely steady position.

In the catamaran mode, a low design draft of 1.5 meters can be achieved only if the vessel is built from light materials, therefore it was chosen to use carbon fiber as the building material, giving really good mechanical properties and at the same time, being a light construction. Carbon fiber is a good choice for small ships, but at the same time is much more expensive than steel, aluminum of glass fiber.

There a few methods for calculating the optimum spacing between the demi hulls, per example the method of Tuck and Lazauskas (Tuck & Lazauskas, 1998) which calculates the impact on the wave resistance due to the distance between hulls, but they are based in complex calculations and the hull shape must be already defined. The decision for the catamaran-SWATH span was according to existing vessels with similar sizes.

The main concerns of a catamaran-SWATH are the ballast tanks. In order to change from the catamaran mode to the SWATH mode, the ship must be able to loose buoyancy and at the same time to guarantee that the trim doesn’t change to an angle where the propellers/ thrusters get out of the water. This loss of buoyancy is achieved by means of ballast tanks, where the compartments are flooded to increase the draught to the struts level. The problem of the ballast tanks is the necessary volume they need to have. When comparing the volume of the ship and the necessary volume of the tanks sometimes the tanks are more than one third of the volume of the ship. Since the propulsion system is normally located on the pontoons, there is not much space to properly fit the tanks in a way that when they are flooded, the trim is kept the same.

For the 16 meter catamaran-SWATH a total of four struts connect the pontoons to the upper platform. The struts have a length of 5.9 m and a maximum width of 1.0 m in the center area. They have an elliptical shape and the distance between the forward and the back struts' centerline is of 10 m. Making the struts long and at the same time narrow is a good solution for either having a small waterplane area, but at the same time to give the possibility of access to the pontoons. The space between the pontoons was intended to reduce the waterplane area, making the SWATH mode even more efficient.

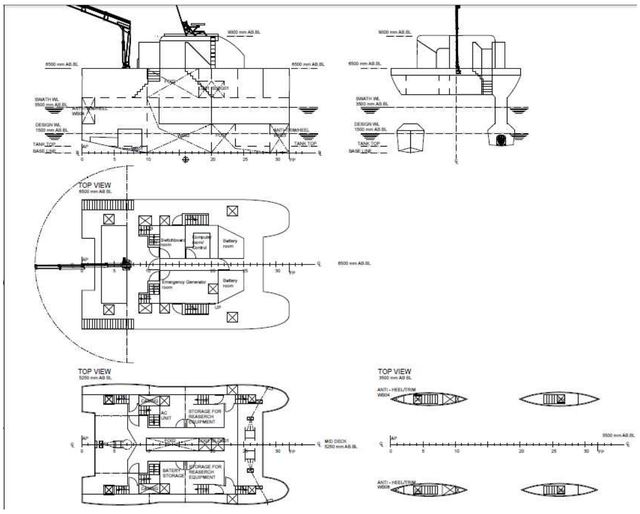

Figure 5.2. Catamaran-SWATH general arrangement.

5.2 Hull type and form

In the catamaran mode, the pontoons are the only components that are in contact with the water. In order to make the fast and less subjected to the water resistance, the hard chine concept was adopted. (Clement & Blount, 1963) A hard chine hull form is suitable for achieving high speeds and is commonly used in pleasures crafts, yachts and sailing vessels. The hard chine is achieved by having an angled ship bottom and having one or more visible edges in the transition bottom to the ship side. This characteristic gives the ability of the hull planning, reducing the volume inside the water and therefore reducing the resistance.

The bow shape was designed to be really sharp with the intention to make it similar to a bow shape of a wave piercing catamaran (Moraes et al., 2004). A wave piercing bow is a really good solution for high speed craft, it cuts through the waves, creating an extreme high pressure water flow in the edge of the bow and by that, the water resistance is lower.

Table 5.1. Catamaran-SWATH hull design properties

	Catamaran mode	SWATH mode
LOA (m)	16	
LBP (m)	15.985	
D (m)	6.5	
T (m)	1.5	2.7
B (m)	9.00	
b_demi (m)	2.2	1
Span (m)	7	
Displacement (ton)	69.492	116.019
Speed (knt)	20	5

The ballast system of the catamaran-SWATH consists in two groups; the main ballast tanks and the anti-heel/trim tanks.

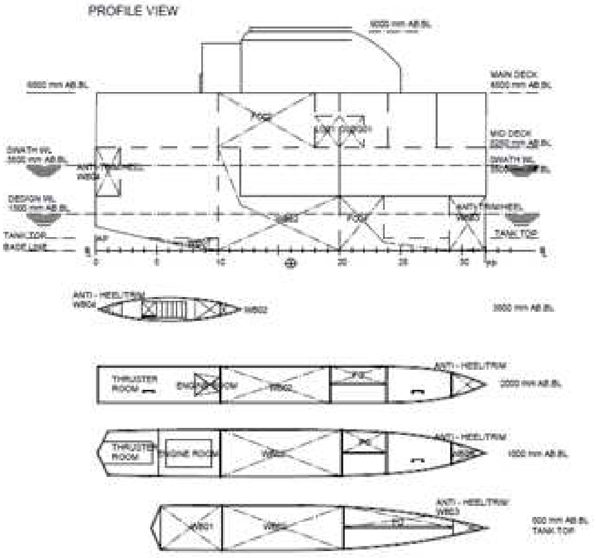

Figure 5.3. Tank plan of the pontoons, looking from different heights of the SB pontoon.

5.3 Resistance and Propulsion

The resistance and propulsion of the catamaran-SWATH was made using the software NavCad. The fact that the hull is intended to sail only when it is in catamaran mode, simplified a lot the calculation of the resistance because it was only necessary to take into consideration the shape of the pontoons and the distance between them. Similar to the other two designs, the input in NavCad consisted on the hull dimensions and coefficients, the design speeds and the water density. The method used to calculate the resistance of a single pontoon was the method of DeGroot (DeGroot, 1955). This method is suitable for hard chine hull shapes with a vertical stern transom.

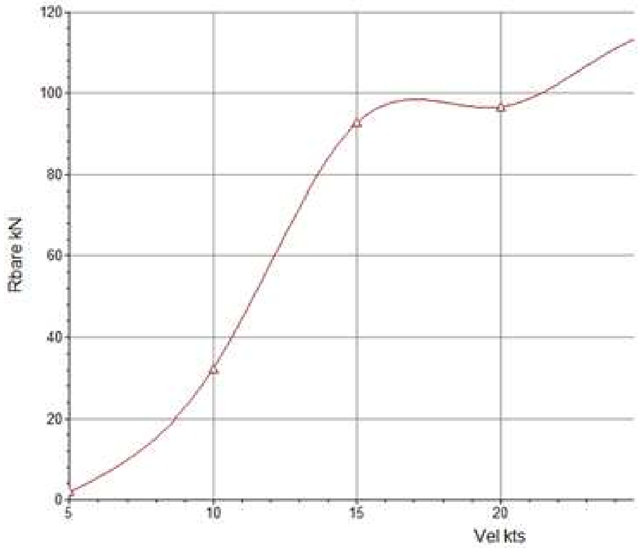

Figure 5.4. Graph of the effect of the speed in the resistance of the catamaran-SWATH.

The propulsion of the catamaran is to be driven by two waterjets. These thrusters were chosen according to the low draft line of the catamaran and its transom shape.

5.4 Light weight

The calculation of the ship light weight was divided in two main categories, one regarding the structural weight and other regarding the machinery and equipment weight. The calculation of the structure was based on the midship section and the equipment was estimated according to common equipment of existing vessels, plus the autonomous factor, which reduced a lot of necessary equipment like lifeboats, galley, stores or wheelhouse.

Table 5.2. Catamaran-SWATH light weight

	Weight [ton]	Lcg [m]	Tcg [m]	Vcg [m]
Light weight	52.56	**6.706**	**0.039**	**4.295**

As a preliminary stability checking, it was used the 2008 IS Code to evaluate if the vessel complies with its stability criteria. This calculation is only regarding intact stability and the righting arm only for the light weight condition (corresponding to having all the tanks and cargo spaces empty).

Table 5.3. Catamaran-SWATH stability calculation

		Required	Real		check
a1)	Area 15º	0.07	0.166	m.rad	**Ok**
a2)	Area 30º	0.055	0.351	m.rad	**Ok**
b)	Area 30 to 40º	0.03	0.056	m.rad	**Ok**
c)	GZ (30º)	0.2	1.668	m	**Ok**
d)	max GZ	>15º	28º	deg	**Ok**
e)	GM0	>0.15	0.262	m	**Ok**

6. CONCLUSIONS

The usage of drones is becoming more and more significant, not only in the marine sector, but also in land and air. The future of mankind will be followed by the development of these unmanned vehicles, because it is safer, more comfortable and is less subjected to human mistakes.

When talking about small ASVs, where the only requirement as a vessel is to have a floating platform and a small propeller, the main difficulties of the design will be on the electrical systems and on control algorithms to avoid collisions and accidents, but when the vessels start to be bigger and they need to be optimized to operate in a certain environment, it is necessary to have the hand of a naval architect to ensure that the vessel is reliable to operate.

The two smaller vessels (the catamaran and the monohull) were designed to be able to perform standard and usual scientific missions, giving a lot of flexibility due to their cargo capacity and autonomy. The fact that they are both equipped with only electrical components, makes them 100% environmental friendly, meaning that there is no risk of contamination of the studied waters.

The future will bring new technologies and new ideas in the marine sector. Bigger ships and fasters ships are always being designed and built, and every year there is a new perspective of innovation. Intelligent ships are also innovative and they are now starting to highlight the researchers, due to the amount of success and money that they can earn/save.

All three designs were made on composite materials because of the necessity to have a light weight structure, resulting in much more payload capacity which is important to these vessels.

The catamaran-SWATH is a very good solution when speed and precise measurements are the requirements. It is significantly bigger than the other two designs and the design became much more complex. Its size allows it to perform not only simple research missions, but also another large variety of applications like coastal surveillance, towing of small pleasure crafts or even search and rescue missions, it would all depend on who would operate the vessel and where.

The development of the catamaran-SWATH was done thinking about possible future crafts, where cameras and GPS coordinates will be the eyes of the captains.

REFERENCES

Alves, J., Oliveira, P., & Oliveira, R. (2006). Vehicle and mission control of the delfim autonomous surface craft. In *Control and Automation, 2006. MED '06. 14th Mediterranean Conference*, pp. 1–6.

Bailey, D., & M.R.I.N.A. (1976). *The NPL High Speed Round Bilge Displacement Hull Series* (4th ed.). London: The Royal Institution of Naval Architects.

Bertram, V. (2008). Unmanned surface vehicles–a survey. *Skibsteknisk Selskab, Copenhagen, Denmark*, pp. 1–14.

Brizzolara, S., & Chryssostomidis, C. (2013). The Second Generation of Unmanned Surface Vehicles: Design Features and Performance Predictions by Numerical Simulations. *ASNE Day 2013*, pp.1–10.

Caccia, M. (2006). Autonomous surface craft: prototypes and basic research issues. In *14th Mediterranean Conference on Control and Automation,* pp. 1–6.

Caccia, M., & Bono, R. (2005). Design and exploitation of an autonomous surface vessel for the study of sea-air interactions. In *Robotics and Automation, 2005. ICRA 2005*, pp. 3582–3587.

Clement, E., & Blount, D. (1963). Resistance tests of a systematic series of planning hull forms. *Transactions of The Society of Naval Architecs and Marine Engineers*, *71*, pp. 491–579.

Codega, L., & Blount, D. (1992). Dynamic Stability of Planning Boats. *Marine Technology Society Journal*, *29*(1), pp.12–40.

Curcio, J. (2005). SCOUT- a low cost autonomous surface platform for research in cooperative autonomy. *OCEANS, 2005*, *1*, pp.725–729.

DeGroot, D. (1955). Resistance and Propulsion of Motor-Boats. *International Shipbuilding Progress*, *2*(6).

Eve, M., Posch, T., Pernthaler, J., & Siegwart, R. Y. (2012). Design and Application of a Surface Vessel. *Robotics & Automation Magazine, IEEE*, *19*(1), pp. 62–72.

Ferreira, H., Martins, A., Dias, A., & Almeida, C. (2006). Roaz autonomous surface vehicle design and implementation. In *Encontro Científico - Robótica 2006*.

Ferri, G., Manzi, A., & Fomai, F. (2011). Design, fabrication and first sea trials of a small-sized autonomous catamaran for heavy metals monitoring in coastal waters. *IEEE International Conference on Robotics and Automation 2011*, (4), pp. 2406–2411.

Greene, E. (1999). *Marine composites* (2nd ed.). Annapolis: Eric Greene Associates, Inc.

Higinbotham, J., Kitchener, P., & Moisan, J. (2006). Development of a new long duration solar powered autonomous surface vehicle. In *Oceans 2006,* pp. 1–6.

International Organization for Standardization. (2004). ISO 12215-5.2 - Small craft - Hull construction and scantlings.

Kennell, C. (1992). SWATH Ships. In *The Society of Naval Architects and Marine Engineers,* pp. 4–7.

Manley, J. (1997). Development of the autonomous surface craft "ACES." In *OCEANS'97. MTS/IEEE Conference Proceedings*, Vol. 2, pp. 827–832.

Manley, J. E. (2008). Unmanned surface vehicles, 15 years of development. In *Oceans 2008,*pp. 1–4. IEEE.

Manley, J., Marsh, A., Cornforth, W., & Wiseman, C. (2000). Evolution of the autonomus surface craft AutoCat. In *Oceans'00* , Vol. 1, pp. 403–408.

Moraes, H. B., Vasconcellos, J. M., & Latorre, R. G. (2004). Wave resistance for high-speed catamarans. *Ocean Engineering*, *31*(17-18), pp. 2253–2282.

Oliveira, P., Silvestre, C., Sebastiao, L., Rufino, M., Barroso, V., Gomes, J., Dando, P. (2000). Robotic ocean vehicles for marine science applications: the european asimov project. In *OCEANS 2000 MTS/IEEE Conference and Exhibition*, Vol. 1, pp. 409–415.

Roberts, G. N., & Sutton, R. (2006). *Advances in Unmanned Marine Vessels*. (D. P. Professor Atherton & S. Professor Spurgeon, Eds.). London: The Institution of Engineering and Technology.

Romano, A., & Duranti, P. (2012). *Autonomous Unmanned Surface Vessels for Hydrographic Measurement and Environmental Monitoring*. Rome.

Tuck, E. O., & Lazauskas, L. (1998). Optimum Hull Spacing of a Family of Multihulls. *Schiffstechnik*, *45*(4), pp. 180–195.

Tzabiras, G., & Kontogiannis, K. (2010). An integrated method for predicting the hydrodynamic resistance of low- ships. *Computer-Aided Design*, *42*(11), pp. 985–1000.