Breizh Spirit, a Reliable Boat for Crossing the Atlantic Ocean

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Abstract To meet the Microtransat challenge, ENSTA Bretagne chose to realize several sailing robots. The first, having served as a test platform, allowed us to develop two new boats, one for research and one for the Atlantic crossing. The different tests in the bay of Brest allowed us to improve the reliability of systems on our sailboat. Various studies have been conducted to improve reliability of sailboats both mechanically and electronically. This tests allowed us to test different concepts on the three Breizh Spirit boats. The results are very positive and we can now say that we have a boat able to resist to strong storms, to follow a predifined route, to supply its own energy and to navigate in sea waves. From the experience acquired from Breizh Spirit 1, we hope we will be able to cross the Atlantic Ocean.

Index Terms Autonomous, Sailboat, WRSC/IRSC 2011, Naval Architecture, Transatlantic.

1 Introduction

As part of the international Microtransat challenge between different universities and scientific schools, ENSTA Bretagne decided to develop several sailing robots. In 2009, ENSTA Bretagne developped a 1.3m sail-boat (Fig. 1) named Breizh Spirit 1. The boat meets several of the required criteria [3], i.e. a sailing boat able to follow a predefined route in fully energetic and decisional autonomy. It was capable of crossing the Bay of Brest in September 2010 as a validation test. Nevertheless,

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this boat was largely destroyed during a test between Brest and Morgat. To establish models of behaviour at sea for crossing the Atlantic Ocean, ENSTA Bretagne decided to build a second boat named Breizh Spirit 2 which is fully instrumented and drawn from studies in CAD (Computer-Aided Design). Finally, in view of participating in the Microtransat challenge in November 2010, the students in Naval Architecture (ANO) and Mechanical Engineering decided to start the design and construction of Breizh Spirit 3 which is 1,4 m long, and designed to be able to cross the Atlantic Ocean autonomously, based on the experience of the previous two sailboats.

The main objective for us, as we will present in this paper is to improve the reliability of Breizh Spirit for the Microtransat challenge. The design of the last two boats is the result of several studies based on the experiences of Breizh Spirit 1 and other boats. In the first part we develop some points which were particularly studied. Moreover, electronics were also completely rebuilt to improve reliability. Nevertheless Breizh Spirit 2, beyond the crossing of the Atlantic, is also used for research programs to study the behaviour of the boat at sea. That is what we will develop in the third part. Finally, we will present the results of our work at different validation tests.

Table 1 Boats Characteristics

-	unit	Breizh Spirit 1	Breizh Spirit 2	Breizh Spirit 3
LOA	m	1.5	2.3	1.7
LWL	m	1.3	2	1.4
BWL	m	0.35	0.8	0.45
T	m	0.8	0.8	0.8
SA	m	0.8575	2	0.75
Disp.	kg	13	55	13
Cb	-	-	0.6	-

In the Table 1,we characterize our boats by Length Overall (LOA), Waterline Length (LWL), Displacement (Disp.), Waterline Beam (BWL), Draft (T), Sail Area (SA) and Block coefficient (Cb).

2 Development of a platform adapted for crossing the Atlantic Ocean

2.1 Design of a transatlantic boat

After the damages caused during the endurance test between Brest and Morgat, we chose to draw conclusions from Breizh Spirit 1 to finalize the construction of Breizh Sprit 3. With regard to the first boat we realised that the weight of the vessel had

Fig. 1 Breizh Spirit 1 on the Ty Colo Lake

been underestimated, the reserve buoyancy became insufficient. That is why the first sailing boat plans, [5], and expanded the hull and increased its height while keeping the same form which showed a very good behaviour in manoeuvrability and seakeeping. As explained in [5], we chose to inspire the forms of an Open 60 boat from the class IMOCA which is accustomed to facing the Atlantic Ocean at various regatta.

Breizh Spirit 1 had also shown that it is difficult to have a sail boat completely waterproof. Various technologies exist to solve this problem. For example we can use an automatic bilge pump to drain water [4]. However, this solution is very energy intensive. We can also choose to seal as perfect as possible, but this solution is very expensive and not always very reliable [2,7]. That is why we chose to make a completely unsinkable sailboat building it from blocks of closed cell foam. So, even if the boat suffer any collision damaging the hull, as we saw with Breizh Spirit 1, there is no risk of sinking because the rest of the hull will keep its own reserve of buoyancy. However, the integration of electronics and actuators requires waterproof

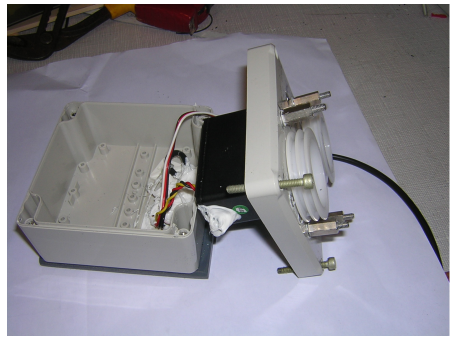

Fig. 2 servo-motors protection system

areas. That is why we chose to make a boat with three zones with three different levels of sealing:

- The first level is the area behind the cockpit which is semi-sealed, protected by the solar panels and it contains all components as we can see in Fig 4. ;
- In this area, the movable portion of the actuators is placed in a watertight compartment almost like the one for Breizh Spirit 1, in which water can enter only by the outputs of the sheets. ;
- The servo motors and any part of electronics are placed in a fully watertight compartment as we can see on Fig. 2 And Fig. 4. For this, we chose to use IP 67 certified boxes, which are fully waterproof and suitable for use in very hostile marine environments.

The Brest-Morgat test also demonstrated that all that exceed outside of the hull may be torn by waves or collisions. Indeed, on the Breizh Spirit 1, we chose to put the actuators and the sheets outside. Both have been uprooted and lost during the Brest-Morgat test. Therefore, on Breizh Spirit 3, we chose to protect these elements. As a matter of fact, the box containing the actuators is placed under the bridge, just behind the stern, to be fully protected from waves and water infiltrations. The circuit of sheet of Breizh Spirit 1 which was around the boat had shown good reliability, particularly because the sheets didn't bring water inside the hull. We have therefore chosen to design a similar system. Moreover, the entire circuit is placed in machined channels in the hull that allow us to protect the whole circuit with solar panels (Fig 4 and Fig 5). The rudders are controlled in the same manner which limits water infiltration especially in the box containing the actuators. Moreover, the fact of separating the electronic actuators ensures a perfect seal for the battery and electric circuits.

2.2 Use of a simulator to design the rudders

To illustrate our strategy for the choice of the different components, we present in this chapter the entire strategy for choosing the motors for the rudders of Breizh

Spirit 2. The other components and architectural choices have been taken in the same manner for Breizh Spirit 2 and Breizh Spirit 3.

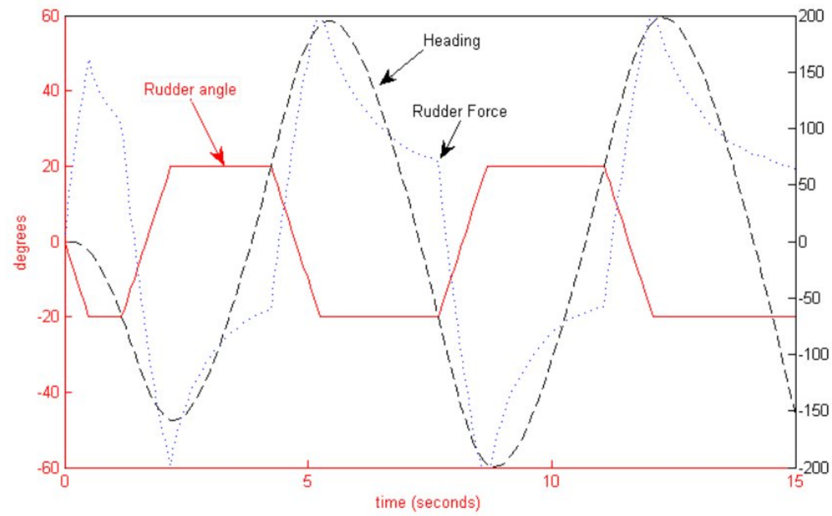

Fig. 3 Evaluation of the force acting on the rudder by manoeuvring Zig-Zag simulation

One of the most important points for such a small craft is the energy balance, because there is a very small area where to lay solar panels. The question of energy consumption is more important for the rudder than for the sail. You can keep the sail fixed for a quite long time while you must control the rudder quasi-continuously. Thus the question of the design of the entire steering gear is crucial. We decided to build a 6 degrees of freedom simulator to evaluate the forces acting on the rudder of Breizh Spirit 2 in order to choose an appropriate actuator. The principle of the simulator is thoroughly described in [1]. For the current study we do not need such a precise hydrodynamic model. Thus, we use the very simple and classical one by [9]. For the forces on the rudders and the keel we use the model derived from air-foil theory proposed by [10].

The dimensioning case is a boat speed of 10 knots and the rudder moving alternatively from starboard to port with 20 degrees in magnitude. The time to move the rudder from starboard to port is about one second. The rudder law is driven accordingly to the zigzag test ITTC standards. Fig. 3 shows that for such a configuration the force acting on the rudder reaches 200 N.

2.3 Choosing the rudders motor.

After a study to determine the necessary torque for the rudders motor, we selected the following actuators:

- servo motor Hitec HS 805 BB +;
- servo motor Dynamixel RX 28;
- servo motor Futaba Robbe BLS 151;

The comparison table shows various criteria including:

- Durability which is an important factor when considering the crossing of the Atlantic. Longevity depends on the technology used. Indeed, brushless motors (like RX 28 Dynamixel) have a far superior life in comparison to current engines. However, considering a voyage across the Atlantic for about five months, the rudders being controlled only a tenth time to save energy, we can expect that we will use the motors for a period between 300 and 400 hours.
- Waterproofness must be taken into account on a sailboat because it would be faced with a marine environment during the Atlantic crossing. The lack of waterproofness may force us to realize a complex system to prevent water from entering the motor.
- To calculate the torque, we need to determine the movement of the cables which control the rudder during the rotation for an angle of 35 degree and the force on the rudders. The calculated nominal torque taken into account for the rudder is then 127.8 N.cm i.e. 12.78 Kg.cm
- The DC motors having no common current limiter, can withstand peaks equal to 5 times their rated torque. However, the peaks create an overheating of the motor. Brushless motors with a current regulating cant withstand overload greater than 50 of their rated torque. According to calculations, the maximum torque supported by the motor is 504.9 N.cm id 50.49 Kg.cm
- the Input voltage gives us information on the consumption of the engine.

Table 2 Comparison Table

Servo motor model Criteria	HS 805 BB+ Hitec	RX 28 Dynamixel	BLS 151 Futaba Robbe
durability	More than 100 hours	More than 100 hours	More than 1000 hours
Waterproofness	Designed for wet environment	Designed for dry environment	Designed for wet environment
Nominal torque	19.8-24.7 kg.cm	28.3-33.7 kg.cm	9.6 kg.cm
Maximal torque	79.8 kg.cm	113.2kg.cm	14.4kg.cm
Input voltage	4.8-6V	12-16V	4.8V

The Table 2 clearly shows that, despite their durability, the BLS151 motors can't bear the torque generated by the rudders. The RX 28 has the disadvantage of not being designed for marine environments and therefore requires to be sealed. Moreover it is difficult to use because of its high consumption. Therefore we chose the servo motor HSB 805 BB + from Hitec which seems to be the best for Breizh Spirit 2.

2.4 Construction of the hull from a digital model

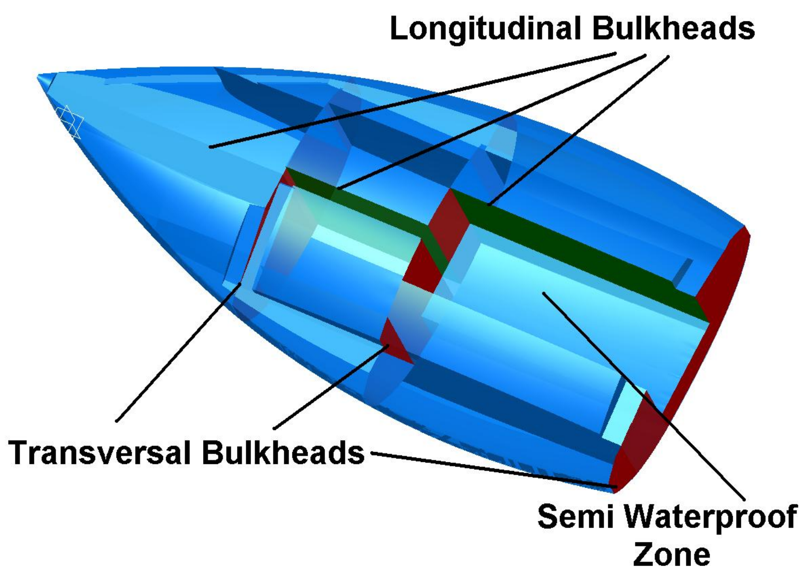

Fig. 4 Digital model of the hull

For Breizh Spirit 2 and Breizh Spirit 3, we decided to make a digital model of the boat and its components to facilitate the design of elements of the hull. In this section, we will focus primarily on the achieving of Breizh Spirit 3.

As we have seen before, using foam blocks has an obvious advantage in terms of unsinkability. The second advantage is that we do not have to make a mold as was done for Breizh Spirit 1. Using the digital model allowed us to obtain a perfect hull shape. However, the choice to build this boat from foam blocks machined with a milling machine required us to fully draw each block. We used the software developed by Dassault System, Catia, which allows us to fully define the geometry of the hull form from a surface recovered from the naval architecture software DelftShip. Once the hull is designed, Catia generates all the programs that are then given to the milling machine for the machining of the foam. The definition of the blocks has been conditioned by different parameters:

- The movements and courses of the milling machine.
- The position of the partitions.
- The integration of components.
- The thickness of the foam raw.

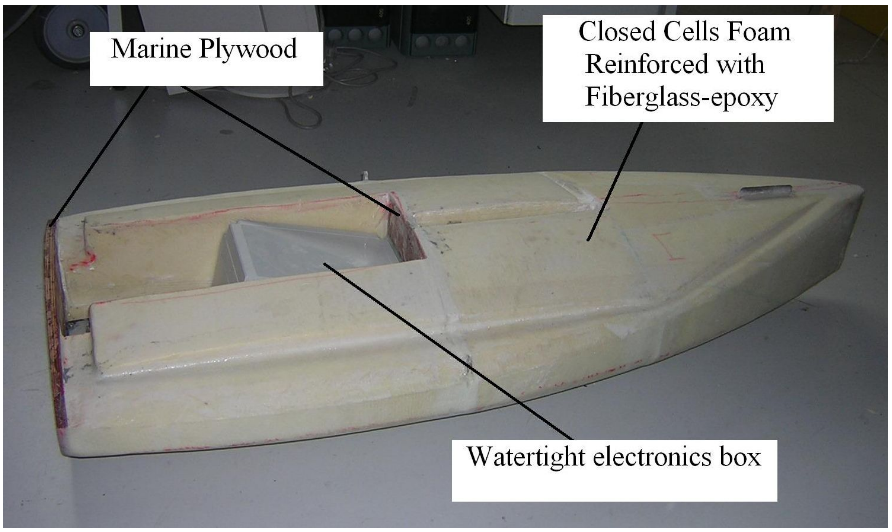

Fig. 5 Breizh Spirit 3's hull

Indeed, because the movement of the machine is limited to 0.5m in length and width, and 0.3m in height, we were forced to carry out at least 6 blocks being given the dimensions of our hull. Otherwise one of the major points during the design of a boat is the consideration of the bending moment and the torsion moment due to the keel and shrouds. That's why we built the hull with longitudinal divisions (in green on the Fig 4) to withstand the bending moment due to wave action and tension in the rig. The transverse bulkheads (in red on the Fig 4) withstand the torque moment.

Finally, we got a shell constructed from 13 blocks machined with the milling machine. The cutting of a block of the hull was made from a rectangle of foam. Once the blocks were cut, they were assembled to obtain a stiffened shell with walls made from fibreglass impregnated with epoxy. The boat was finally covered with an external skin using a vacuum pump to impregn fiber with epoxy to creat a composite as we can see in Fig 5.

3 Development of reliable and robust electronics

3.1 Reliable electronics

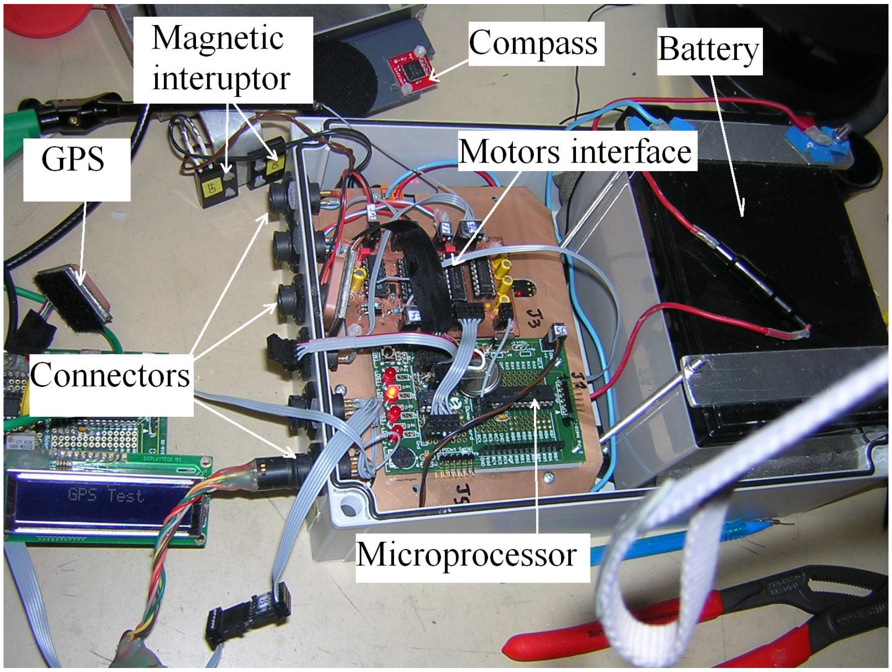

Fig. 6 Breizh Spirit 3's new electronics

To optimize power consumption on-board the electronics has been developed based on PIC microprocessor (PIC 18F2550 to have enough memory and calculation power).The sensors required to control the boat are chosen for their performance and low consumption:

- Wind sensor: Ultrasonic anemometer CV7 (LCF Capteurs, FRANCE)
- GPS: FV-M8 (SANAV, San Jose Technology, Inc., USA)
- Magnetic Compass:HMC6343 (Honeywell International, USA)

The servo-motors (Fig. 2) are powered by a circuit different from the microprocessor (on the centre of Fig. 6). The energy supply can be put on stand-by by the microprocessor in order to limit losses (load current supply and servo motors for the moments). All power supplies loaded (conversion of 12 V 5V, 3.3V, etc.) are selected for their efficiency (0.93). This energy management can lower the average consumption of between 100 and 150 mA. The embedded energy is stored in a battery of 12 Volts 12 Ah (on the right of Fig. 6). Conventional lead acid battery technology was chosen because of its reliability. Such a battery without electrolyte fluid is sufficient for a journey expected to last six months.

This system can supply the energy for 3 days minimum. The recharge of the battery is provided by solar panels that can charge up to 500 mA. These panels can charge the battery during the night operation with a slight margin for the days of low sunlight. For the proposed crossing of the Atlantic (tropical road), such days should be rare. However, in the case of a loss of battery power, a charge controller can turn off the electronics and actuators power. A memory system allows the boat to restart when the battery voltage reachs sufficient capacity to ensure proper operation. During these moments without power, the boat will behave like a drifting raft.

GPS position sent by the SPOT system has, for security reasons, a separate supply by a lithium battery to ensure the proper operation of sending the position three times per day for 6 months. For this, the SPOT casing has been modified to a microprocessor to wake him up only when it must send messages.

The entire equipment is housed in a waterproof case. Links to other elements (solar panels, sensors, microprocessor and memory programming way points) pass through a series of waterproof connectors. To ensure a complete waterproofness, a magnetic control system replaces a possible waterproof switch which isn't reliable.

3.2 Hardware and software organisation: the algorithm

As we said before, the boat is using three sensors: a compass, a GPS and an anemometer. With the compass we get the direction of the boat, with the GPS the position. To be sure there is no error, the program make the boat head to the next point after checking four times it is near the buoy as we can see in Fig. 7. The anemometer gives the wind direction to the boat. In order to be not too sensitive to the variation of wind direction, we prefer checking this direction from time to time. We do not follow the wind variation and therefore we choose a minimum angle between wind and boat direction equal to 50 degrees.This angle has been tested and we are sure that the boat may not stop. We also do not adjust the rudders exactly for the precise direction, we prest five discrete rudder angles chosen with four filter angles: if the angle between buoy and sailboat direction is between 0 and 13 degrees, we do not adjust the rudder, if the angle is between 13 and 28, we turn the rudder of 10 degrees, between 28 and 55 degrees, we turn of 20 degrees, between 55 and 80 degrees, we turn of 30 degrees and finally if the angle is bigger than 80 degrees, we turn the rudder of 45 degrees. We prest the same strategy for the sails angle as shown in Fig. 8.

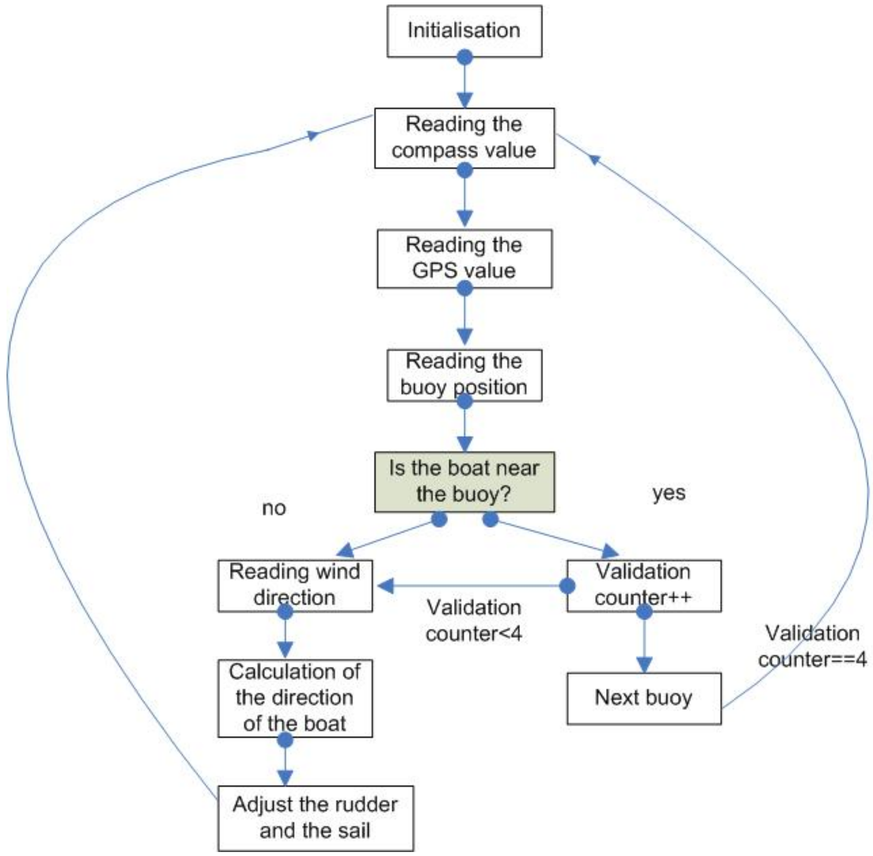

Fig. 7 Navigation algorithm

4 Development of research programs around Breizh Spirit

A research program is in current development to provide experimental data to validate the seakeeping codes that are realised at LBMS/ENSTA Bretagne.

This program consists of realising a measurement system for recording the movement of a boat at swell. The interest of using a sailing robot is first off all its small size. Thus sailing in a usual seastate condition gives situations where the waves become big compared to the boat dimensions.

The second interest is the control we have on each actuator of the boat. This is very important, because with classical sailing boat tests there are big uncertainties concerning the crew behaviour, the positioning and the trimming of sails [8]. Of course it is possible to get information from video recording. But it complicates and delays the analysis of the experimental data recording. Sailing robots have the advantage that all parameters can be easily known at each time step of the experiment.

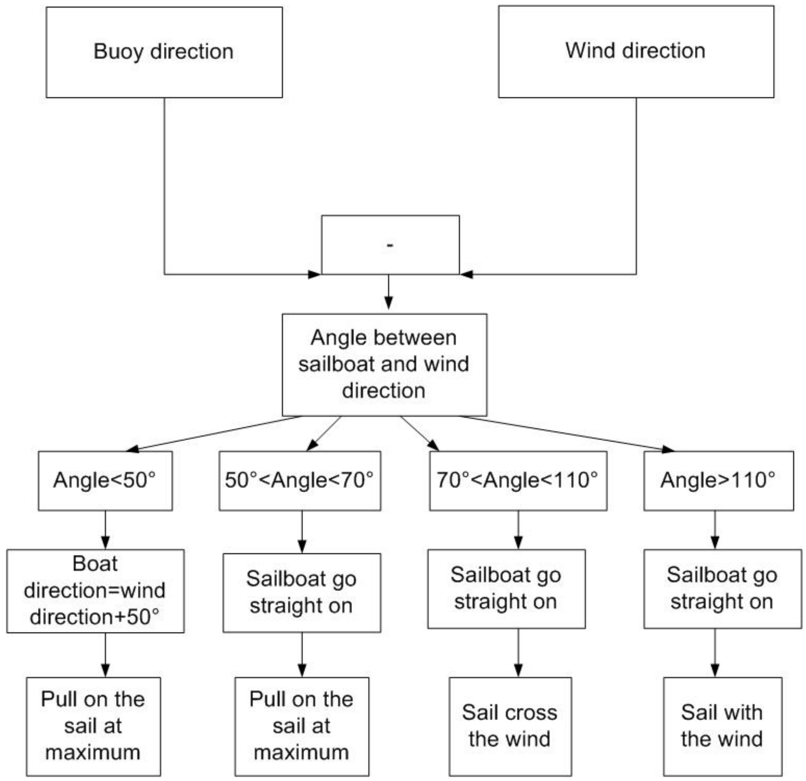

Fig. 8 Direction algorithm

5 Tests and Results

The very first tests of Breizh Spirit 1 were conducted during the WRSC 2009 in Porto. Obviously, they were not successful. From discussions with the other participants it was clear that the development of such a project should lean on three tools:

- a light prototype, easy to carry and implement
- a simulator, useful to detect bugs and to avoid spending time on water.
- a monitoring system to get information from the tests and understand the boat behaviour.

During the following weeks a monitoring system was implemented. The first successful tests were carried on the small lake Ty Colo near Brest. Basically the boat managed to turn around 3 way-points. Then it was decided to attempt the crossing of the Brest Harbour from Cosquer to Lanveoc in early September. The wind was north-east 15 to 20 knots during the main part of the crossing and then dropped to less than ten knots and turned east to north-east at the end. The boat was totally

Fig. 9 Brest Harbour crossing. The yellow points correspond to the waypoints. Breizh Spirit 1 sailed 6.5 nm at average speed of 3 knots

autonomous until it reached the Lanveoc shore. Then we took the control to end the course and to pass the Pen ar Vir point just in front of the French Naval academy. Breizh Spirit 1 did 6.5 nautical miles at an average speed of 3 knots, and it reached several times a maximum of 5.6 knots.

The following year was dedicated to enhance reliability and to develop a system validation and verification procedures for each sensor and actuator. It remained to test the behaviour of the vessel at strong sea state. The vicinity of the Ushant Island (Ouessant in French) often offers extremely hard sea conditions, especially when the wind blows against the current. Thus it is an excellent playground for testing seakeeping ability and endurance of our platform. Two attempts were conducted and permitted to detect some weakness in our electronic and mechanical systems.

For the second attempt around Us Island, Breizh Spirit 1 travelled 12 nautical miles upwind, tacking in waves up to 2 to 3m. Its behaviour was very satisfactory

Fig. 10 Track of the Brest-Morgat test. On the center of the figure, we can see that Breizh Spirit 1 couldn't tack upwind on 30 knots wind speed.

beyond our own hopes. We considered then that only the endurance function remained to validate for crossing the Atlantic Ocean.

For the third attempt the meteorological forecast was so uncertain that we chose only to go round the peninsula of Crozon from Brest to Morgat. Fig. 10 shows the track recorded before the crash of Breizh Spirit 1. One can see on course that there is a strong drift of the boat between the way-point. This drift is due to a bad setting of the rudder servo. This servo was changed for a better model just before the test and we just forgot to do new controls. As a consequence, for each way-point, the boat had to tack and go upwind to reach its way-point. The validation circle is about 400m diameter. When it was about to reach the Swensea Vale Way-point the wind suddenly strengthened up to 30 knots. As we can see the boat was no longer able to tack into the wind. Then it was tacking upwind for approximately 10 hours before it crashed on the rocks. Due to problems of accessibility, the boat was left there for three days. Two storms destroyed the entire rig and appendages, but the electronic system was intact despite some water ingression.

6 Conclusion

As a conclusion, we can say that the experience gained from Breizh Spirit 1 has enabled us to design a boat, Breizh Spirit 3, much more suited to cross the Atlantic. Indeed, we found some errors in the design of the Breizh Spirit 1. The electronics has been entirely rebuilt to ensure its durability. Now, the Microtransat project arouses a lot of interest from industry and research. Therefore, we will continue to develop various research programs on Breizh Spirit 2. The eventual aim being to cross the Atlantic, some tests will still be made with Breizh Spirit 3, drawing conclusions from the misadventures of Breizh Spirit 1. Indeed, despite of all the work, as can be seen from the Table 3, it remains to test the endurance of the boat but also its behaviour in wind less than 10 knots and more than 30 knots upwind. With these various experiences, we hope to be able to compete in September 2011 and meet the Microtransat challenge .

Table 3 Progress Table of Breizh Spirit

Test Platform (BS1)	Validated
Electronic architecture for BS1 and BS3	Validated
Autonomous navigation of 12 miles with BS1	Validated
Energetical design for 6 months of BS3	Validated
Mechanical design for Crossing the Atlantic of BS1 and BS3	Validated
Control of component's reliability with BS1	Validated
Setting Controls for BS3	In progress
Endurance test with BS3	In progress
Construction of BS3	In progress

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References

References

1. K. Roncin and J.M. Kobus. Dynamic simulation of two sailing boats in match racing. Sports Engineering, 7(3) :139152, 2004.
2. Y. Briere (2008), IBOAT: An autonomous robot for long-term offshore operation, in proceedings of MELECON 2008. The 14th IEEE Mediterranean Electrotechnical Conference, 5-7 May 2008.
3. Y. Briere, F. Bastianelli, M. Gagneul, and P. Cormerais, Microtransat challenge , in CETSIS2005, Nancy, France, vol. 5, Issue 2, DOI:10.1051/j3ea:2006031, 2005.

4. R. Stelzer and K. Jafarmadar, Communication architecture for autonomous sailboats, International Robotic Sailing Conference (IRSC), Porto, Portugal, July 2009.
5. J. Sliwka, P. Reilhac, R. Leloup, P. Crepier, H. D. Malet, P. Sittaramane, F. L. Bars, K. Roncin, B. Aizier,and L. Jaulin. Autonomous robotic boat of ensieta. In .2nd International Robotic Sailing Conference.,Matosinhos, Portugal. 2009.
6. Thomas, GA and Harris, D and d'Armancourt, Y and Larkins, I, The Performance And Controllability Of Yachts Sailing Downwind In Waves, Proceedings of the 2nd High Performance Yacht Design Conference, Auckland, New Zealand, pp. 8. Ferburary 2006.
7. P. Miller, O. Brooks, M. Hamlet Development of the USNA SailBots (ASV), 2009.
8. K.Roncin, J-M.Kobus, P.Iachkine, S.Barré, Méthodologie pour la validation du simulateur de voilier par des essais en mer, une première tentative, Workshop Science-Voile . école Navale, LanveocPoulmic. France, 2005.
9. D. Clarke, P. Gedling, G. Hine (1983), The application ofmanoeuvring criteria in hull design using linear theory. Trans (RINA) 125:4568
10. P. Van Oossanen (1979), Theoretical estimation of the influence of some main design factors on the performance of international twelve meter class yachts, presented at The Chesapeake sailing yacht symposium, Annapolis, Maryland, January 20