Sail Car - An EPS@ISEP 2019 Project

Abstract. This paper provides an overview of the development of a Sail Car project within the European Project Semester (EPS), the international multidisciplinary engineering capstone programme offered by the Instituto Superior de Engenharia do Porto (ISEP). The principal goal of the EPS@ISEP is to offer a project-based educational experience, improve teamwork, communication, interpersonal and problem solving skills in an international team of various types of engineering students. The Sail Car team consists of six Erasmus students, who participated in EPS@ISEP during the spring of 2019. The objective of the project was to design and develop a wind-powered land sailing vehicle, which would use the benefits of technology to be self correcting and easy to drive. In order to successfully match the requirements of the project, the team researched existing commercial solutions and the technical, marketing, ethics and sustainability implications of the project. Based on these studies, the team specified the full set of requirements, designed a solution and procured the components and materials needed to build a proof of concept prototype. Then, it assembled the structure and control system and is currently carrying out functional tests.

Keywords: Project based learning · Land sailing · Wind-power · Sustainability · European project semester.

1 Introduction

The European Project Semester (EPS) is a programme offered by several European universities, including ISEP, the School of Engineering of the Polytechnic Institute of Porto. During EPS, students from different countries and academic backgrounds design new products and develop proof of concept prototypes together.

The combustion of fossil fuels is considered a polluting, non-renewable form of power production. It is the job of future engineers to develop clean and sustainable means of producing energy, mostly for generating electricity, but also for powering the vehicles [9]. Furthermore, the main problem is that Earth's natural resources are limited. Through the sail car project, which uses wind as the main power resource, the team intends to raise awareness to renewable power sources. The target of sail cars are active people who like to practice a sport, feel adrenaline and compete with fellow practitioners, transforming sail car into a hobby. Above all, the team wants to promote the idea of sustainable and eco-friendly entertainment (hobbies, sports). Thus, with this project the team wishes to contribute to a better world, in which people adopt sustainable practices, and to the well-being of the practitioners, by offering a car sailing green solution.

The team chose this project because of the opportunity to practice sustainable design (a car powered by a free renewable energy source) and to develop a real size prototype (so it can be driven and tested afterwards). Table 1 displays the information about the team members.

Table 1: Background of members of Team 1.

Name	Country	Study field
Ana Zhu	Portugal	Mechanical Engineering
Christopher Beer	Germany	Mechanical Engineering
Karl Juhandi	Estonia	Manufacturing and Processing
Marko Orlov	Estonia	Transport and Logistics
Narcisa-Laura Bacau	Romania	Engineering and Management
Levente Kadar	Hungary	Electrical Engineering

This paper, which is a reflection of the work of Team 1 of EPS@ISEP 2019, is structured in four additional sections. First, the Background section, it presents related projects in the field of land sailing as well as studies on marketing, sustainability and ethical topics. Next, Design and Development, which describes the architecture of the prototype. Then, Tests and Results, describing the planned functional tests, the team is planning to carry out with the prototype. Finally, the Conclusions section draws the conclusions and identifies future directions.

2 Background

This section is intended to provide the results of all initial studies.

2.1 Related Projects

Blokart (see Fig. 1a) was created in New Zealand by Paul Beckett with the aim to create a fun, fast and compact wind-powered vehicle. There are rental places, which also offer lessons on how to use a Blokart, and clubs, where gatherings and national as well as international races are held [1]. The vehicle is hand steered, with a handlebar and a rope. Blokarts frame is built from a durable and rust resistant stainless steel. It is built in such a way that all of the components could be packed into a carry bag. The packed Blokart fits into a car trunk or qualifies as checked airline baggage, which one can take to a trip with themselves. Sail sizes vary from 2 m to 5.5 m height and are made from dacron sail fabric. Sails are reinforced with fibreglass battens and polyester film. Masts are divided into sections which fit together [3].

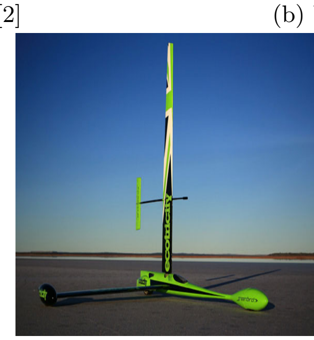
Whike (see Fig. 1b) is a pedal- and wind-powered land vehicle for leisure time made in the Netherlands intended to raise awareness of natural green energy [14]. Whike features a lightweight tricycle with a steering system, gears and

three mechanical brake disks. The vehicle comes with two soft sails that can be swapped, packed and carried on the tricycle. There is one $1\,m^2$ storm sail and one $1.6\,m^2$ mainsail, both are made of polyester film [13]. Frame and sails are designed and developed by the company themselves [12].

The Greenbird (see Fig. 1c) was a UK based project with the aim to build two wind-powered vehicles, one meant for driving on land and another one on ice. Both of them had one common goal - to break the speed record of a wind-powered vehicle on a given surface. On March 26, 2009, their land yacht set a new speed record of 203,1 km/h. [10]. The Greenbird has a rigid sail which is adjusted by a tail attached to its back. The goal is to achieve higher speeds, without a more strong wind. That is done by minimising the drag and maximising the lift. For that, The Greenbird used the resultant of a manmade wind, which is created when an object moves forward, and the true wind, which is a natural breeze. Adding those two winds to the ride, the feeling is somewhere between those two - the apparent wind. Using this perk, The Greenbird team was able to reach speeds 3 to 5 times higher than the wind itself [11].

(a) Blokart [2]

(b) Whike [12]



(c) Greenbird [10]

Fig. 1: Related products

2.2 Marketing

The team decided to create a land sailing car intended for people who are interested in land sailing, both the experienced and the ones who are just starting to take up and experiment with the sport. The main aim is for customers with average or higher income because our product cannot be considered as a cheap one. The goal for the team is to stand out on the market by differentiating the product from the competition.

Our potential customers are: (*i*) beginners, who are interested and curious in taking up land sailing; (*ii*) intermediate land sailors, who want to try new technology; and (*iii*) experienced land sailors, who want to sail faster than with a soft sail.

Adapted Marketing-Mix While the 4 Ps appear to be more marketer-oriented, the 4 Cs focus on the client or consumer or customer. That is why the team chose to build the adapted marketing mix strategy based on 4 C's: (*i*) Customer/Consumer value; (*ii*) Cost; (*iii*) Communication; and (*iv*) Convenience.

2.3 Sustainability

The team chose to use quality materials in the construction of our product. The intent is to produce a quality product that would last and at the end of its life cycle, many of the used materials could be repurposed or recycled. The sail car is to be eco-friendly during the manufacturing process and during its usage time.

Resources The team will use wood for the ribs in the sail, steel frame, rubber wheels, PVC for the sail glued with silicone. This, of course, is not very sustainable but the team intends to make up for it by repurposing the used materials at the end of the life cycle of the product. Steel will allow us to construct a durable and firm frame for the car; it can be remelted at the end of its use. PVC is durable and lasts for a long time, it is also recyclable, as do the other materials used in the project.

Manufacturing would be done in Portugal. It would be more expensive, but more eco-friendly to have the production in Portugal than for example in China because then the product would ship from China over long distances, which causes more pollution in the supply chain. The manufacturing process has to be efficient as not to waste any materials, this the project is more cost-efficient.

Storage The team will partner with a well-known logistics company which will take care of the logistics and storage, for example DHL. The team will find a central warehouse for our product from where we could ship globally the most effectively.

Retail Customers will only have the option to order our product online and not buy it directly from a store. This would mean lower costs, because the team does not have to run a retail shop with workers.

Transportation Shipping from Portugal to most of Europe one would have to use land transportation options. This would be more polluting but would save money on costs and a lot of time. Most of the clients want the product delivered

to their doorstep and in order to achieve that, the best option is to use land transport.

Use The customer can use Sailo on flat terrain, preferably on the sand like a beach or the desert. All the customer has to do is sit in the car and sail. It has been made possible by the self-correcting sail technology.

2.4 Ethics and Deontology

The team will follow the Code of Ethics for Engineers by National Society of Professional Engineers while advancing in the project. While marketing the product the team strives towards an honest and transparent attitude and aim to be ethical towards the customers and also competitors. For the environmental point of view, the weight could be on power, which makes the vehicle move - the wind. The product has no emissions and the ecological footprint is small.

The product will comply with the following European Commission standards:

The Machine Directive In the product, there are not many components from the machinery field, but it is essential to ensure, that piloting and steering the car, while on the move, is safe [4].

The Electromagnetic Compatibility Directive It is used for the companies to make sure that their products are safe and match the requirements of CE certification marking. Since the team does not produce the components themselves, it is mandatory to make sure, that the suppliers comply with this directive [6].

The Low Voltage Directive The product will be working with a voltage between 5 V to 10 V [7].

The Restriction of Hazardous Substances (ROHS) in Electrical and Electronic Equipment Directive It bans the use of ten materials, but probably the most known and also the most likely material, that could end up in the product in and, is lead (Pb). Lead is used in the soldering process of electronic components. Since again, the team does not solder the components by themselves, it must be ensured, that the suppliers follow the RoHS directive and use lead-free substances in their processes [5].

3 Design and Development

The proposal for the project put the team up for a task to "Design, build and test a light sail car, following sustainable and ethical practices. The purpose, target user segment and the full set of device requirements are to be defined by the team based on the state of the art, marketing, sustainability and ethical analyses" [8].

The requirements for the project are [8]:

- Wind propelled;
- Use or reuse low cost hardware solutions;
- Use open source software;

- Adopt the International System of Units (NIST International Guide for the use of the International System of Units);
- Comply with the 2006/42/CE 2006 05 17 0517 0517 , 2004/108/EC 2004 - 12 - 15, 2014/35/EU 2016-04-20, 2014/53/EU 2014-04-16 and ROHS EU Directives.

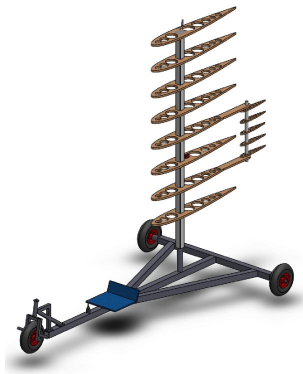
3.1 Design

The analysis made with the self-trimming wingsail is subcategorized into electronics and mechanical sections. The electronic analysis consists of the power transmission, hardware, servomotor, sensor and code design. The mechanical analysis is based on the design of the product using static and dynamic analysis to make preliminary design decisions. Afterwards, construction of the prototype of a real scaled model to test and validate the data made initially. Fig. 2a displays a structural drawing of the final prototype.

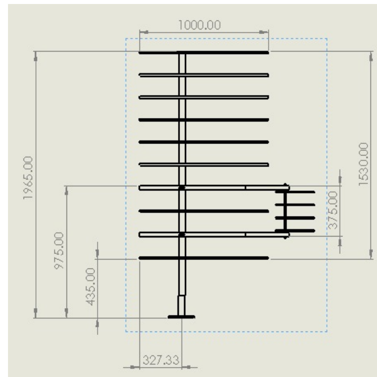
Robotic analysis The mast of self-trimming wingsail is free rotational, meaning that no control is needed in this aspect. However, the control over the mainsail comes from the actuation of the trim tab controlled by a servomotor is directly linked with the angle of attack of the mainsail. The ideal α (angle of attack) to produce the most useful force is around 10° to 15° from the apparent wind. Fig. 3a displays the coefficients for the lift and the drag. It can be seen how important the angle of attack is. If the angle is too high the flow becomes turbulence and breaks off. So, an angle above 17° is counterproductive. The most lift can be generated with an angle of 14° and the maximum lift compared to drag (C_L/C_D) can be generated with an angle of 6.25°, thats the most efficient angle.

Mechanical analysis

Wingsail The wingsail is the component that will provide the forces needed for the sail car to move, while the tail controls the direction of the wingsail for maximum angle of attack. Symmetrical airfoils were necessary because the wingsail was required to generate lift while at both positive and negative angles of attack. Using the airfoil catalogue provided from airfoiltools.com, NACA 0015 (see Fig. 3b) was the selected airfoil due to the highest lift to drag ratio with a maximum thickness of 15 % at 30 % chord. Moreover, calculations were made to determine the size of the wingsail (see Fig. 2b) considering: (*i*) angle of attack; (*ii*) atmospheric properties; (*iii*) coefficient of drag and lift; and (*iv*) Reynolds number.



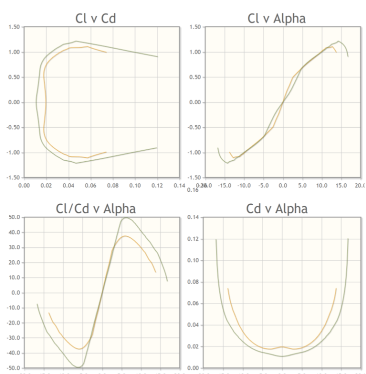
(a) Structural drawing of prototype



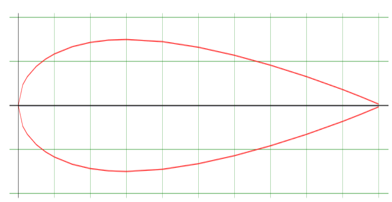
(b) Dimensions of the wing and tail

Fig. 2: Sail Car design

Frame First, it was needed to establish the dimensions of the sail car by calculating the external forces acting on the whole object using a moment equilibrium equation. This ensures the equilibrium of the sail car when a strong wind acts on it and will not tumble. Fig. 4a displays structural drawing of the base structure of the project.



(a) Airfoil diagrams

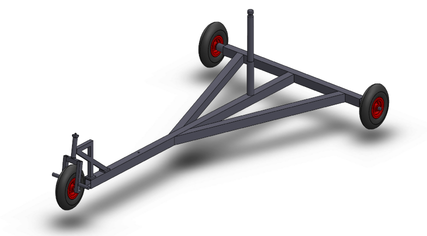


(b) NACA0015 airfoil

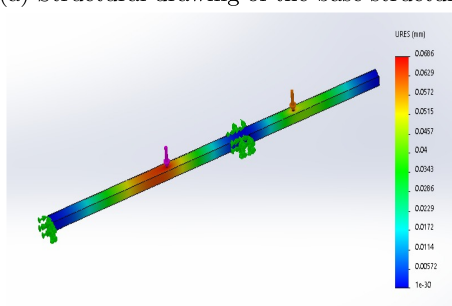
Fig. 3: Airfoil characteristics

The design and tests for the frame were made based on the prototype because this project was developed only for academic purposes with a limited budget, time and production. Having that in mind, the selection of materials and the actual production is not the most efficient, but is the most appropriate consid-

ering all the aspects mentioned above. Not only that, there are other important parameters to have in consideration as well, such as lightweight structure, good mechanical resistance, good weldability and easy to produce. These features can be found on structural steel S235 with a 50x50x3 mm profile. Fig. 4b displays the simulations carried out on the frame profile chosen by the team.



(a) Structural drawing of the base structure



(b) Square profile 50x50x3 mm

Fig. 4: Sail car design

3.2 System Architecture

The internal system in the project, which operates the self-correcting system is controlled by an Arduino UNO unit, with a voltage of 12 V. The microcontroller gets its information from a wind sensor placed on the top of the mast. The wind sensor will be built by the team, using a rotary encoder. Based on the data, the Arduino unit gives out commands to the servo motor, which operates with a tail attached to the back of the wing. By moving the tail, the wing also turns to the desired direction.

The driver of the sail car will also have an option to control the sail manually, using the data provided by the wind sensor. In order to do that, there is an override switch in the system, which gives control over the servo over to the

driver, who can operate the motor using a joystick. The system will be powered by a 12 V battery. Fig. 5 displays the detailed schematics of the project.

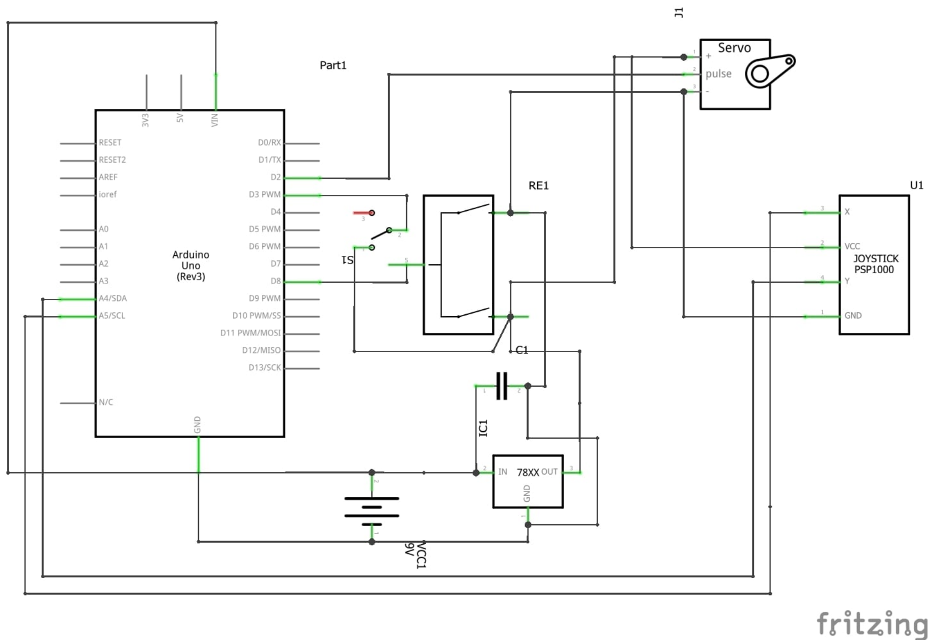


Fig. 5: Detailed schematics

4 Tests and Results

Electronics The Arduino is not capable to power the servo motor from its 5 V pin. Its laggy and takes a lot of time to get into position. Thats why the team decided to use a 12 V battery, and an adjustable DC-DC step-down voltage regulator. If the output voltage is set to 6-6.6 V, the servo motor works perfectly. The prototype works with a potentiometer, which provides a 270-degree range for detecting the direction of the wind. If the switch status is on automatic the Arduino is constantly checking the position of the potentiometer, and depending on the position of the servo motor, adjusting it. The team discussed that its enough if the servo motor rotates in a 40 degrees scale. That's why the middle point is set to 20 degrees, maximum left at 40, maximum right at 0 degrees.

Steering When the team finished welding the front steering system, immediately, an issue was recognized. The front wheel turned to either left or right steered the whole car in the same direction only a really minor amount. The reason behind the problem was discussed and found, that the fork of the front

wheel was attached to the frame with a too little angle. Therefore, the wheel fell too much to the side while turning, and the forces coerced the wheel to fall even more to the side, rather than going back to the neutral position. A new solution was developed and built. Pedals were placed right next to the wheel on the fork, the angle of the wheels fork was significantly increased, in order for the wheel to turn more, rather than fall on the side. The new solution proved itself to be much more useful and easy to control.

Free rotation Both the wing and the tail were constructed from plywood. The construction consists of ribs cut out with a CNC machine. The ribs are separated with spacers cut out from plywood. After the construction of both structures was completed, the plastic mast for the tail was inserted into designated openings and made sure, that the tail can move freely around it. The test was a success. For the wing, however, the technology was a bit different. The mast is made of composite and is a square shape. The frame has a metal mast base, on which the mast slides to and is secured in place with two pins. After that, the mast can rotate around its base and also move the whole wing. This test was also a success.

5 Conclusion

The goal for this project was to design and develop a wind-powered land sailing vehicle. One, that could be easy to drive, self correcting towards the wind and offering thrilling attributes to both, beginner and experienced land sailors. By developing the sail car the team aimed to raise awareness among the people, that there is a great option to have an thrilling and interesting hobby, which is at the same time sustainable and eco-friendly.

The more general aim of the programme was to offer a project-based learning experience to all of the participating students. Help to develop technical, scientific and communicating skills. The participants were placed in a multicultural environment, where they had to work as a team to achieve one common goal. All of this included planning, paying attention to the deadlines, respecting the team members, dividing the work and trusting others. The members of the team shared their thoughts about the EPS experience.

Really nice opportunity to learn new things. It's interesting to see how other students solve problems with a different fields of study, and culture.

EPS is a great opportunity to learn about different cultures and mindsets. It teaches us to think outside the box and to be creative in any subject.

European Project Semester is a really mind opening experience. There is a great opportunity to learn by building a project and apply all of the things absorbed to the development. It teaches to respect teamwork, trust others and not to let down the people, who rely on your work. Definitely a totally different semester that would be recommended to every engineering student.

EPS has been an eye opening experience, I have learned so much from the people that I work with and that surround me. ERASMUS and EPS are both experiences that I am grateful for experiencing and they will stick with me for the rest of my life.

EPS was both a personal and an academical journey. Studying Business Engineering I always wondered how and what my role would be in a technical team. That is why EPS helped me to understand more about what I want to do in the future and realize how important is every resource in this kind of project, especially the team itself.

EPS is a great experience. Work in a team with international students from different fields of study and see how they solve problems is really interesting. Furthermore, you can learn a lot from other fields and expand your own knowledge outside your field of expertise.

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