Sail Car – An EPS@ISEP 2019 Project

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***Abstract*—This paper provides an overview of the development of a Sail Car within the European Project Semester (EPS), the international multidisciplinary engineering capstone programme offered by the Instituto Superior de Engenharia do Porto (ISEP). The main goal of EPS@ISEP is to offer a project-based educational experience to develop teamwork, communication, interpersonal and problem-solving skills in an international and multidisciplinary set up. The Sail Car team consisted 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, easy to drive land sailing vehicle. First, the team researched existing commercial solutions and considered the marketing, ethics and sustainability dimensions of the project. Next, based on these studies, specified the full set of requirements, designed the Sailo solution and procured the components and materials required to build a real size proof-of-concept prototype. Finally, the team assembled and tested successfully the prototype. At the end of the semester, the team considered EPS@ISEP a mind-opening opportunity.**

Keywords—Project-based learning, Diversity in Engineering Education, Active and Collaborative Learning, Student-Centred Learning Environments, Land sailing, Wind-propelled, Sustainability, European Project Semester

I. Introduction

The European Project Semester (EPS) is an engineering capstone programme offered by several European universities[1], including ISEP, the School of Engineering of the Polytechnic Institute of Porto. This one-semester programme, which accounts for 30 European Credit Transfer Units (ECTU), adopts a student-centred project-based learning framework to foster technical, scientific, soft and professional skills, emphasising on sustainability-driven and ethically aligned design [1]. Students from different countries, genders and academic backgrounds design together new products or services and develop proof-of-concept prototypes [2]. Due to these characteristics, EPS is a *capstone engineering education framework for the future multicultural, connected, smart world*.

In the spring of 2019, a team composed of six students (two women and four men) from Estonia, Germany, Hungary, Portugal and Romania, studying mechanical, manufacturing and processing, transports and logistics, management and electrical engineering (four in the third and two in the fourth year of studies), embraced the sail car project.

According to their report [3], they were motivated by the opportunity to promote sustainable and eco-friendly leisure, help people improve their well-being (practise of outdoor sports), practice sustainable design (wind propelled vehicle) and develop a real size prototype (to be driven and tested).

This learning journey started with a set of initial studies anchored on the project support seminars, ranging from related projects, marketing, sustainability and ethics, to define the solution requirements. Based on the derived requirements, the team embraced the design of an ethically aligned and sustainability-driven solution, followed by the development and test of a real size prototype. The team was responsible for the management of their teamwork and applied Scrum to ensure the fulfilment of all milestones.

This paper, which reflects the sail car teamwork, is structured in four additional sections. First, the EPS@ISEP section provides an overview of the EPS implementation at ISEP. Next, the Sailo section details the devised solution, including the following subsections: Preliminary Studies (related work, marketing, sustainability and ethical dimensions), Design and Development and Assembly and Testing. Finally, the Conclusions section draws the conclusions and shares the testimonials of the team members on the EPS@ISEP learning experience.

II. EPS@ISEP

EPS is offered by ISEP since the academic year of 2010-2011 and has, so far, welcomed 181 students from 22 countries and 55 engineering, product design and business programmes. The syllabus encompasses the project module (20 ECTU), a set of intensive project support seminars (8 ECTU), including team building, project management, communication, marketing, sustainability, ethics, and local language and culture (2 ECTU).

The project briefs are originated by research groups, companies and project coaches and refer to open, ill-defined, multidisciplinary problems. The students are organised into multidisciplinary, multicultural teams of four to six members, according to the EPS concept rules [2] and their Belbin teamwork profiles [4]. To date, EPS@ISEP students have successfully developed 36 multidisciplinary projects,

[1] www.europeanprojectsemester.eu

[2] www.europeanprojectsemester.eu/concept

proposing sustainability-driven [6], bio inspired [7] or smart city [8] solutions.

The learning process is based on project-based learning and autonomous teamwork, relies on the intensive seminars and weekly meetings with a panel of multidisciplinary project coaches for further brainstorming and joint discussion. These meetings are prepared, by defining and sharing the agenda with the coaches, and conducted by the teams. The teams maintain throughout the semester a project wiki, comprising logbook, planning, deliverables and report sections. The wiki not only is a collaborative tool but the project showcase, remaining online after the end of the semester.

The first half of the semester is dedicated to exploratory studies regarding the different problem dimensions and aims to define an ethically aligned and sustainability-driven solution in terms of requirements, design and elements required to build a proof-of-concept prototype. It is anchored around the project support seminars and the weekly project meetings. This half semester involves the production of several deliverables (project wiki, diagrams, schematics, drawings, lists of materials and components plus the interim report and presentation) and ends with the interim presentation and feedback provided by teachers and students (self and peer) alike.

The second half of the semester is mainly devoted to the development of the prototype and involves recycling, procuring and acquiring materials and components, assembling, testing and debugging. The project weekly meetings are focussed on the discussion of construction and implementation issues, the design and implementation of functional and non-functional tests. During this stage, the team has to maintain the project wiki and develop an academic paper, brochure, leaflet, final presentation, poster, prototype, final report, user manual and video. The semester culminates with the final presentation, assessment (teachers, self and peers), prototype demonstration and certificate awarding.

This learning process addresses the development of the 4C2S competencies in engineering undergraduates [9], where the 4C match critical thinking & problem solving, effective communication, collaboration & team building and creativity & innovation identified by [5] and the 2S correspond to socio-professional ethics and sustainability. Specifically, the 2S are at the core of the teamwork process since teams must derive the requirements, design a solution and develop a proof-of-concept prototype following sustainability-driven and ethically aligned principles. It also complies with the recommendations of the Conceive Design, Implement and Operate (CDIO) initiative for the undergraduate engineering curriculum by educating students to participate in the conception, design, implementation and operation of systems, products, processes and projects [10]. The Conceive and Design phases correspond to the first stage of EPS, ending in the interim presentation, and the Implement and Operate phases to the second stage of EPS, culminating in the final presentation and assessment.

III. Sailo

Earth's natural resources are limited and, in the case of fossil fuels, are dangerously approaching depletion. The combustion of fossil fuels, a non-renewable form of energy production, remains the main worldwide source of energy and pollution. Consequently, a major challenge for future engineers is the development of clean and sustainable means of energy production, mostly for generating electricity, but also for propelling vehicles [11].

Through the sail car project, which uses wind for propulsion, the team intends to raise awareness to renewable power sources and promote sustainable and eco-friendly entertainment (hobbies, sports). The target of sail cars are active people who like to practice outdoor sports, feel adrenaline and compete with fellow practitioners. Thus, with this project, the team wishes to contribute to a better world, in which people adopt sustainable practices and improve their well-being, by offering a sailing car green solution. This idea is aligned with the United Nations Sustainable Development Goal 7 “Affordable and clean energy”, by increasing the share of renewable energy in the global energy mix [12].

The project brief stated that the goal was 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*”. Moreover, it specified the maximum budget (300 €) and the following set of broad requirements: “*be wind propelled; use or reuse low cost hardware solutions; rely on open source software; adopt the International System of Units; and comply with the applicable European Union directives*” [13].

The team adopted the Scrum agile project management framework to organise teamwork. They adopted one-week sprints, matching the weekly coaching meetings. It helped the team to successfully meet deadlines, procure materials and providers, produce deliverables, recover from delays and develop mutual trust and respect.

A. Preliminary Studies

The displacement of a land yacht depends on the aerodynamic force generated from the interaction between the sails and the apparent wind, which results from the application of the true wind force to a moving yacht. The produced aerodynamic force is decomposable into lift (perpendicular to the direction of the apparent wind) and drag (parallel to the direction of the apparent wind) [14]. To optimise the impact of the apparent wind force on the vehicle, it necessary to minimise the drag and maximise the lift.

In terms of related projects, the team identified Blokart [15], Whike [16] and The Greenbird [17] as the most interesting commercial land sailing solutions:

- Blokart, displayed in Figure 1 (a), was created in New Zealand by Paul Beckett with the aim to create a fun, fast and compact wind-powered vehicle. It is composed of a stainless-steel frame, a mast and a dacron soft fabric sail with reinforced with fiberglass battens and polyester film. The vehicle is hand steered through a handlebar and a sheet rope. It offers a range sails, with height varying from 2 m to 5.5 m, and multi-section masts, ranging from fiberglass to carbon or ultra-carbon. All components are easily mounted/unmounted and packed into a carry bag, fitting into a car trunk or qualifying as checked airline baggage [15].
- Whike, shown in Figure 1 (b), is a pedal- and wind-powered recreational land sailing vehicle. It was made in the Netherlands with the aim to promote natural green energy. Whike features a lightweight

tricycle with a steering system, gears and three mechanical brake disks. The vehicle comes with two soft mylar fully battened sails (1.0 m^2 storm sail and 1.6 m^2 mainsail), that can be swapped, packed and carried on the tricycle, and a carbon mast. The Whike is controlled by an under-seat handlebar with bar end gear shifter, brakes, sail release and electric assist controls. The sail is controlled by a mainsheet which is fed through a selection of pulleys to be easily accessed in front of the rider at the mast foot just below the attachment point for the ride computer [16].

- The Greenbird, depicted in Figure 1 (c), is a UK-based project with the aim to build wind-powered vehicles capable of breaking the world speed record on land and ice surfaces. In fact, the land craft set a new speed record of 283.1 km in 2009 [17]. This vehicle is equipped with a rigid self-trimming wing-sail, which is adjusted through a back tail. Using this perk, The Greenbird team was able to reach velocities three to five times higher than that of the actual wind [17].

(a) Blockart [15] (b) Whike [16]

(c) The Greenbird [17]

Figure 1 – Related products

Based on this review, which allowed the comparison between soft ([15] and [16]) and wing-sail ([17]) solutions, the team chose a self-trimming wing-sail over conventional sail designs due to its higher performance and simpler control.

A wing-sail is a rigid structure presenting an aerofoil cross-section (like an airplane wing), which provides increased lift to drag ratio when compared with a conventional sail [18]. In fact, the lift on an aerofoil is primarily the result of its angle of attack, defined as the angle between the direction of the apparent wind and the mean chord of the wing [14]. The self-trimming version is composed of the mainsail, which rotates freely around the mast, and a smaller tail tab, which can be used to set the angle of attack. This means that to operate the sail car it suffices to control the tail sail angle.

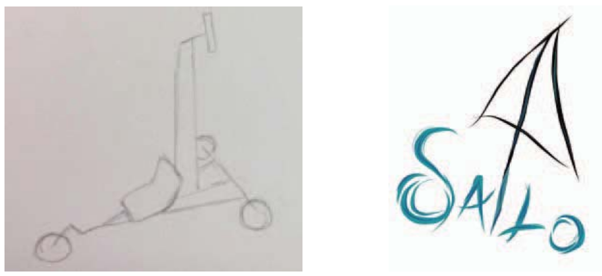
In terms of marketing, the goal is to stand out on the market by differentiating the product from the competition. The team decided to create Sailo, a wing-sail car for average or high-income people motivated by the thrills of land sailing. The potential customers can be grouped into three levels: beginner, who are interested and curious in taking up land sailing; intermediate, who want to improve and try new technology; and experienced, who look for a top performant craft. The team created an adapted marketing mix strategy based on the customer/consumer value, cost, communication, and convenience. To keep cost low, the team decided to offer just online retail.

Considering sustainability, the team decided to use long lasting quality materials in the construction of the product, which, at the end of its life cycle, can be re-purposed or recycled. Sailo is intended to be eco-friendly during manufacturing, shipping and fruition:

- Choice of materials includes wood, transparent ultraviolet-resistant polyvinyl chloride (PVC) and water-resistant glue for the wing-sail, stainless steel for the frame and rubber wheels.
- Manufacturing will be done locally to minimise pollution and waste, making the project more cost-efficient.
- Storage, logistics and shipping will be delegated to a partner company. Long distance shipping will be done by ship, medium distances by train and short distances by truck, in an attempt to minimise pollution.
- Repair and part substitution service will be provided on a fee to customers (land sailing induces naturally fatigue in materials).

Regarding ethics and deontology, the team adopted the Code of Ethics for Engineers by National Society of Professional Engineers [19] to govern their professional conduct. This included embracing an honest and transparent attitude towards customers and competitors and designing an eco-friendly (wind-propelled, emission-free and reduced ecological footprint) product. In addition, it will comply with the European Union Machine Directive to ensure that piloting and steering the car, while on the move, is safe; the Electromagnetic Compatibility Directive by guaranteeing the compliance of the suppliers; The Low Voltage Directive since the prototype will be working with voltages between 5 V and 10 V; and The Restriction of Hazardous Substances in Electrical and Electronic Equipment Directive by ensuring the compliance of suppliers (mainly use lead-free substances in their processes).

These initial studies allowed the team to define the full set of requirements, the first draft (Figure 2 (a)) as well as the brand name and logo (Figure 2 (b)).



(a) First draft (b) Logo

Figure 2 – Sailo draft and logo

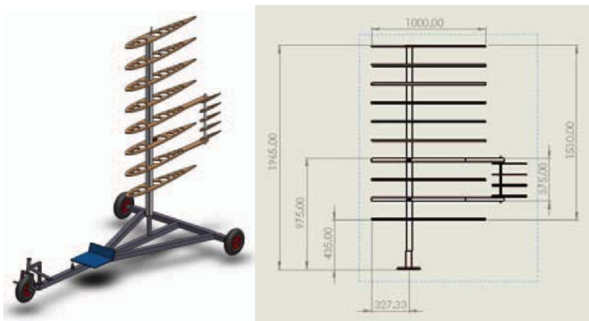
B. Design and Development

The design contemplated the car frame structure and the wind-propulsion system, comprising a self--trimming wing--sail and a free rotational mast.

The self-trimming wing-sail, which includes the mainsail to generate lift and the tail to control the angle of attack, is mounted vertically on the mast, ensuring free rotation in azimuth. The frame supports the user, the user interface, the mast and the wing-sail.

To design the wing-sail, the team had first to select a symmetrical aerofoil to generate lift with both positive and negative angles of attack. The team's choice was the NACA 0015. This aerofoil has the highest lift to drag ratio with a maximum thickness of 15 % at 30 % chord and an ideal angle of attack is between 10° and 15°. The highest lift can be generated with 14° and the maximum lift to drag ratio with 6.5°, corresponding to the optimal angle of attack. Next, the team had to calculate the dimensions of the wing-sail considering the expected wind conditions and the optimal angle of attack, the drag and lift coefficients. and the Reynolds number of the aerofoil. The result was a wing-sail with a wingspan of 1530 mm and a wing chord of 1000 mm.

Figure 3 displays the design of the real scale prototype, including the frame and wing-sail structures (Figure 3 (a)), and the dimensions of the wing-sail (Figure 3 (b)).



(a) Overall structure (b) Wing-sail dimensions

Figure 3 – Sailo design

The sail car was designed with two driving modes: manual control through a joystick and automatic control via a dedicated control system. Both modes control the wing-sail angle of attack through the actuation of the tail tab. The control system comprises a microcontroller, a wind sensor based on a rotary encoder, a servomotor to set the angle of attack of the main wing-sail and a battery. In automatic mode, the self-correcting system relies on the wind sensor data to operate the tail servomotor, setting the desired angle of attack. There is an override switch to change between modes.

C. Assembly and Testing

Finally, the team built a real scale prototype to test and validate the design decisions made. It involved the parallel assembly of the wing-sail and frame and the testing of the control, steering and propulsion systems. Figure 4 illustrates the assembly process of the sail car.

The test of the control system allowed setting the operation range of the servo motor (0° and 40° range) and of the potentiometer used to detect the direction of the wind (270° range). To ensure the proper operation of the servo motor it was necessary to include an adjustable direct current step-down voltage regulator.

The steering test identified a problem in the front steering system: the front wheel felt to the side when turning. The reason behind the problem was discussed and found: the caster angle between the fork of the front wheel and the frame was too small (Figure 4 (a)). A new solution was designed and built. The pedals were replaced right next to the wheel on the fork, increasing significantly the angle between the wheel's fork and the frame (Figure 4 (b)). The wing-sail (main sail and the tail) plywood ribs were cut using a computer numerical control machine. The ribs of the main sail were inserted through the composite mast and separated by glued plywood spacers (Figure 4 (c)). The tail was assembled around a light plastic axis, using the same process. Finally, the fully assembled wing-sail was covered with transparent ultraviolet-resistant PVC and sealed with water-resistant tape (Figure 4 (d)). The wing-sail tests showed that tail rotates freely around its plastic axis and the mainsail and mast rotate freely around its base on the frame.


(a) Caster angle problem (b) Corrected frame
(c) Mainsail assembly (d) Assembled wing-sail

Figure 4 – Sailo assembly

Figure 5 shows the car frame, with the driver seat and manual control joystick (Figure 5 (a)), and the completed prototype in operation (Figure 5 (b)). Further project details are available at the team's wiki.


(a) Joystick and seat (b) Operation

Figure 5 – Sailo prototype

IV. Conclusion

EPS@ISEP provided a project-based learning framework, supported by multicultural, multidisciplinary, autonomous and responsible teamwork and the application of sustainability-driven and ethically aligned principles.

This project was challenging and ambitious for a team of engineering undergraduates. It involved applied physics, electronics, control, design, Scrum-based project management, sustainability and ethical analyses, communication skills, multicultural teamwork and the development of a wide range of deliverables.

Not only the team members worked to deliver a wind-propelled, self-trimmed, easy to drive real size land sailing prototype in one semester, but developed together new scientific, soft and professional skills. These skills contribute to the development of the much-sought-after critical thinking & problem solving, effective communication, collaboration & team building and creativity & innovation, socio-professional ethics and sustainability professional competencies in engineering undergraduates.

The open nature of the initial problem together with the adopted supervision model, where close guidance has been substituted by consultancy, foster in students the required autonomy to think, develop and practice skills and competences. This way, the final grades reflect student work rather than supervisor "micro-management" of student tasks.

In the end of the semester, the team members considered EPS@ISEP a very fulfilling experience, as can be seen from some their opinions:

- *an opportunity to learn new things* – It was interesting to see how other students with a different field of study and cultures solve problems.
- *a chance to learn about different cultures and mind-sets* – It teaches how to think outside the box and to be creative in any subject.
- *mind-opening* – It was an opportunity to learn while building a project and apply all of the things absorbed to the development. It teaches to respect teamwork, trust and not to let down those who rely on your work. Definitely a totally different semester that should be recommended to every engineering student.
- *eye-opening* – 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 will remain with me for the rest of my life.
- *a personal and academic 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 realise how important is every resource in this kind of project, especially the team itself.
- *a great experience* – To work in a team with international students from different fields of study, see how they solve problems learn and learn from their expertise was really interesting.

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