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Manufacturing to motorsport by students

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Abstract

The student's participation from the Polytechnic University of Valencia in the international competition Formula Student and the teacher's collaboration in the area of manufacturing processes has created a framework for the academic improvement. This article describes the conceptual and ideological framework of the project and also the new development.

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1. Introduction

Nowadays on the Spanish universities does not exist a specialization in Motorsport at the end of the career. Filling this requirements, a Motorsport project called Formula Student in Europe, Formula SAE in the rest of the world, was created. Participating in a project like this, the student could acquire motorsport knowledge without going into a university that offers this kind of specialization for certain engineering careers. This project is usually created by the students, in some cases with more support of the university than others.

Design and manufacture a racing car, acquire new skills and transversal competences, is un-doubted one of the most exciting teaching frameworks. It is not easy to evaluate these skills in time, ECTS or curricular items, but it's not important. Students participate only for the passion of design, manufacture, compete and, of course, for pleasure. Collaborative work, coexistence and the work brings great pleasure to the team members.

The Formula Student competition has its origin in the Baja SAE competitions organized by the Society Automobile Engineers (SAE) in USA. The objective of this student's competition is to manufacture and design a car

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similar to a car-cross. In the year 1979, Professor Mark Marshek (University of Houston) proposes a new kind of competition, giving different freedoms of design and changing the rules in a drastic way. Since then both are organized in USA; Formula SAE and Baja SAE, both competitions are international references for the automobile engineering industry.

This document summarizes the technology development that has been carried out in the Formula Student Project at the Universitat Poliècnica de València. This Formula Student project is created with the objective of designing the first prototype at the university. The whole project is created and addressed by the students, been them the core of the project, searching for partners that could support the project inside and outside of the university. The document is structured as follows. Section 2 is devoted to the Formula Student project explanation, then section 3 is going to explain the design process that the FSUPV Team carries out each season. The section 4 explains the integration of the manufacturing process on the different phases of the project. Finally the paper ends with a short summary.

2. The Formula Student Project

A Formula Student project needs support from all the different engineering and non-engineering careers, since it is a multidisciplinary project and simulates a mini-enterprise. As the people of the Institution of Mechanical Engineers (IMechE) says: "A Formula Student project promotes careers and engineering excellence, by challenging university students to design, build, develop market and compete as a team with a small single seater race car". Formula Student is an international competition which provides the students with a real-life exercise in design and manufacture in a highly competitive context. The competition was established by the Society of Automotive Engineers (SAE) in 1981 as Formula SAE in USA. SAE and Institution of Mechanical Engineers (IMechE) have been holding Formula Student competition in United Kingdom since 1998. Seven years later, there are additional European competitions conducted in Italy, Germany, Spain, Austria, and Czeck Republic. The competition is not simply won by the team with the fastest car, but rather by the team with the best overall package of design, manufacturing and performance, presentation and documentation as well as financial and sales planning.

In this way, Formula Student enables engagement in the creative and innovative development of engineering technology, at the same time that it enables students to: resolve conflicts and create, maintain and enhance productive working relationships; communicate with others at all levels; and present and discuss proposals. It is a starting point on the route to continuing professional development necessary to maintain and enhance competence in own area of practice.

2.1. FSUPV Team

In 2012 a group of young and ambitious students started to think about creating a Formula Student team that could design and build the first prototype in the Universitat Politécnica de València. Nowadays the team is composed by 34 students from all the different engineering and non-engineering careers available at the university. Since the beginning, the team was formed with a main philosophy: "A project created by the students for the students". This philosophy allowed the team to be formed by a multidisciplinary group of students, separated from any department that could change the direction and main objectives of the team.

The team members profile is really diverse, goes from electrical engineering to mechanical engineering or even to business and administration. During the 2013-2014 season, the team designed and manufactured the first ever Formula Student prototype at the Universitat Politécnica de València, the FSUPV01. The prototype weight was 230 kg, with 65 hp of power and a carbon fiber monocoque with a tubular rear chassis as the main structure of the car. Fort the 2014-2015 season, the team already designed the second prototype, the FSUPV02, which improves all the weak points of the first prototype. The FSUPV02 is compared to FSUPV01 in the Figure 1.

Fig. 1. Design drawing of the FSUPV-02 versus FSUPV-01.

From a technical point of view, the project has a main objective that defines a direction and a methodology to follow in order to achieve it.

- 2015 Goal: to consolidate a competitive Formula Student team able to design, test, and race a reliable and competitive car.
- Technical objectives:
  - *To have a manufactured and assembled car as soon as possible: one month designing is worth the same lap time reduction as a day on track*
  - *To reduce weight in the parts which do not change the reliability of the car, and don't modify any of the deadlines of the project. The second objective may not alter the first one.*
  - *To simplify some of the designs from the FSUPV_01, in some parts that have to keep the same characteristics, with easier manufacturing and assembly processes. The third objective may not alter the second one*

3. Design process

The design from scratch of a Formula Student prototype knowing all the different areas involved, meets a point were sometimes the try and error is the best solution for certain situations. The ideal methodology that must be followed in order to achieve a good "first design" and its improvement during a normal season of Formula Student is presented in Figure 2. During the two years of experience in this project, the FSUPV Team has developed its own design philosophy and know-how to achieve the main goals of the season.

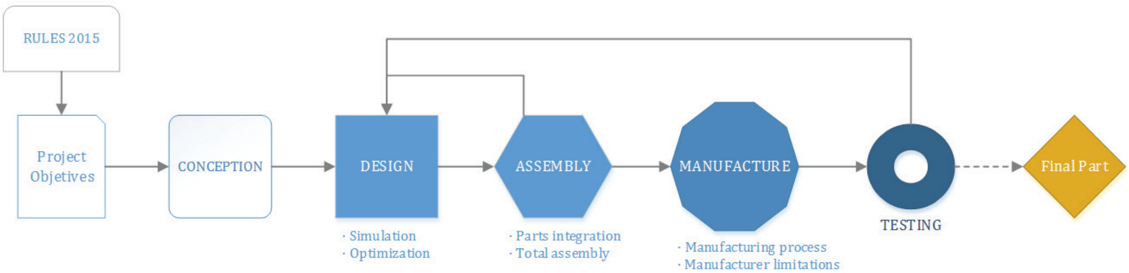

Fig. 2. Complete design process in the whole project

The timing of each stage of the project is part of an academic year, beginning in September and ending in September next year. The following Figure 3 shows the timeline of the project.

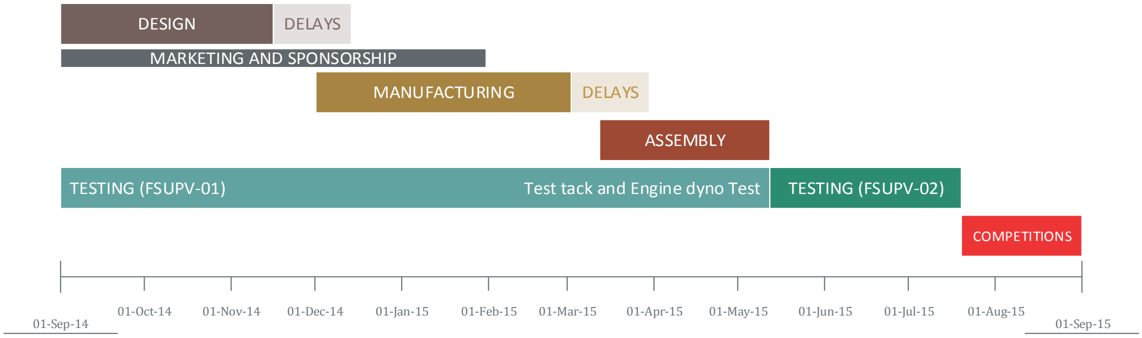

Fig. 3. Project timeline

3.1. Design, Assembly and Manufacture

At the beginning of the process, the first steps on the new prototype design are dictated by the own Formula SAE committee, defining the rules for each new season. The SAE rules [1] delimits the design and the methodology that the team must follow during the season, but always keeping in mind that the student creativity is not too limited by the rules. From this point on, the team must work on the main objectives taking into account the rules, the resources, the infrastructure and the budget available for the season. Once the Project main objectives and timeline is defined, the team starts to design and developed the different parts of the new prototype. The starting point is the last year prototype and his weak points, from this point of view the imaginary preliminary design of the new prototype is done. Each of the technical areas that compose the team starts to design and developed the part that must be improved, the interactions between the different technical areas is really complex since all of them must meet the same requirements and deadlines.

All the initial process is concentrated on the design, using design software to help draw the part, and them all this designed parts are assemble on the main design that will be the final prototype. In this big assembly all the parts are put together, with the main goal of analyzing the interaction between them and the possible problems that can be spotted. As it can be seen on Figure 4, the design process is defined by an optimization and simulation process. The majority of the designed parts are been developed to accomplish certain function under different conditions that dictates the design of each part The design-optimization-simulation loop is one of the more complex and important phase of the project, since this will determine the overall performance, ergonomics, reliability and lifetime of the car. Knowing how much time the team must spend on the design phase is crucial, since more time on the design phase is less time for testing which is also an important phase of the project if the team wants to have a competitive prototype.

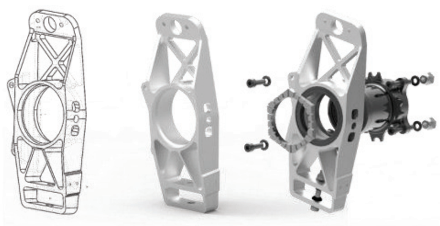

Fig. 4. Upright part and assembly

The optimum point on the mechanical simulations is only achievable by testing each design part and adjusting the simulation conditions and values, so is more or less a feedback process. Each part is restricted by the main design of the prototype and the initial decisions. An example is presented in Figure 3.3, where an evolution of the front upright can be seen, this part connects the suspension wishbones to the wheel assembly.

3.2. Testing and Final part

As it was explained before, the design process is not completed until the part or prototype is tested. In this phase the testing is performed in different ways to test all the different parts of the car, to check the behavior, performance and lifetime. There are important parts of the prototype that must be well tested in order to improve the simulation conditions or the manufacturing process. In this phase of the project the main objective is to test the car every single opportunity that the team could have and must be the priority of the team. With no testing, there is no improvement or development for next seasons. In the Figure 5 some FSUPV01 testing photos can be seen.

Fig. 5. Some photos of the FSUPV-01 testing

This phase, as it was explained before, is as important as the design phase since is the phase that determines how the car will perform at the competition. Is also important to be able to record all the possible data as possible because one of the important parts of the competition is the explanation of the design of your car and how it correlates with his performance on the reality. This recorded data, will also help the improvement of new prototypes for the next years.

4. Manufacturing integration

Leaving all the phases of the project behind, this section will talk about the manufacturing process and how they play an important role during the different phases of the project. The design methodology must take into account the manufacturing process, and also the timeline and resources to manufacture all the different parts that could affect the timeline of the project phases. At the FSUPV Team the manufacturing philosophy is: "If it can be made by the team the timeline can be more strict", so the manufacturing in the workshop is prioritized in all the possible situations, but in some cases the resources that the team disposed are not enough to manufacture certain parts of the car. A more detailed description of the workshop and some of the machines that the team can operate are described in [2] by Garcia. For the manufacture of some complicated parts, the team search local companies that could have the know-how to carry out this tasks and want to participate in the project. The team gives certain privileges to the enterprise that support the project, by doing publicity, networking events, etc. The number of processes that can take place during the manufacturing of the prototype are countless. In total, the number of parts that must be manufactured are around 300 different parts. The principal manufacturing processes used on the prototype are presented in Figure 6. As it can be observed, there are so many different manufacturing processes, going from the machined mechanical parts to the composite materials that conform the monocoque and other parts of the prototype.

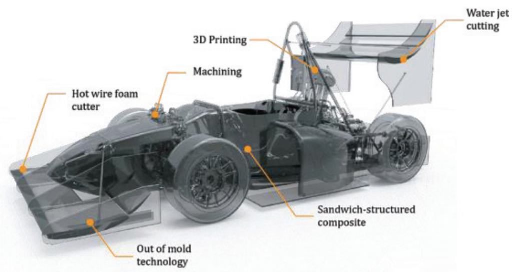

Fig. 6. Used manufacturing processes for FSUPV-02 prototype fabrication

4.1. Material characterization

The composite materials manufacturing was one of the biggest aims of the team at the beginning. Nowadays the team has a developed know-how, focused on the composite materials manufacturing. As an example, the characterization of the carbon fiber that is given by Gurit International, one of principal enterprise that supports the project. With this characterization the team can correlate the different simulations performed on the design phase of the project, and also check the good properties of the material. In Figure 7, some photos of the process that the team performs in order to characterize the material. The number of tests is determining by the different tests performed, traction tests, shear tests and 3 bending point tests. In addition, some of these tests are demanded by the competition in order to check that for example your monocoque complies with all the rules and is safe to be race at the competition.

Fig. 7 Process of characterization of Gurit's carbon fiber material

4.2. Model – Mold – Part

One of the main carbon fiber parts that are been manufactured by the team is the monocoque, which is the more complex of all the carbon fiber parts that conform the FSUPV02. This monocoque is the front of the chassis and is composed by a carbon fiber sandwich with a Kevlar honeycomb core and high density foam for the hard points. On the FSUPV01 the manufacturing process was using a Wisa wood mold and the process was already mentioned in [3] by Garcia et al. For this new prototype, the manufacturing process is going to be a model-mold-part, because the precision of certain areas of the monocoque is higher and the finished product is better. The mold manufacturing was made at Sinergia Racing Group and in Figure 8 are presented the different phases of the process, from the design, passing through the machined process in foam, to the layup of the mold.

Fig. 8. Manufacturing process of monocoque mold from CAD part to final mold. Photos by a project's partner, Sinergia Racing Group.

The final part that is going to be manufactured is showed in Figure 9. In this front part of the chassis is going to be attached, the front suspension, the pedal box, the steering system, the front wing, the impact attenuator and other parts. The rear part of the chassis is a tubular frame that holds the engine and the rear assembly of the suspension and drivetrain.

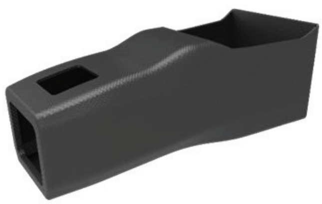

Fig. 9. Monocoque of FSUPV-02 made of sandwich-structured composite.

4.3. Hot wire foam cutting, welding and machinning

This manufacturing process is utilized to manufacture the profile of each flap that conforms the front and rear wing. In Figure 10 some photos can be observed during the process of the hot wire foam cutting for the main flap of the rear wing. The material used for this process is low-density polyurethane foam given by the partner ZFOAM. After the cutting process is completed, the foam is layup with carbon fiber to increase its rigidity and mechanical resistance.

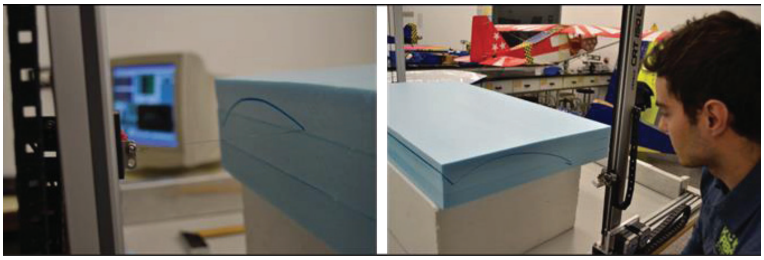

Fig. 10. Cutting an foam airfoil of FSUPV-02's rear wing by hot wire

The welding plays an important role in the manufacturing process of the prototype, since the rear part of the chassis; the exhaust manifold, the suspension wishbones and other small parts need welding to be manufactured. The welding process is done by the team members on the workshop, in Figure 11 some photos of the process can be seen. A big part of the mechanical parts that conform the prototype are been machined. One of the most used process is the five axis machining that allows the team to design very complex and lightweight parts. The team does not have the resources to own one of these machines, but some of the enterprises that support the project own more than one of these. In Figure 12 some photos showing the process on the machine, where a drivetrain part was been manufactured.

Fig. 11. Welding some steel parts of the race car

Fig. 12. Machined differential support by 5Axis CNC. Photos by a project's partner, UMESAL S.L

Below is a table 1 which detailing the type of manufacturing process performed for each technical division of the car.

Table 1. Description of the performed manufacturing processes

Division	CNC 3 Axis	CNC 5 Axis	Hor wire	Welding	Model/Mold/Part	Laser cutting
Aerodynamics	✓		✓		✓	✓
Chassis		✓		✓	✓	
Brakes	✓			✓		✓
Drivetrain	✓	✓		✓		
Electronics				✓		✓
Powertrain		✓		✓		
Suspension	✓	✓		✓		✓

5. Summary

The creation of a multidisciplinary group is the main structure of the Project. The philosophy on the design, manufacturing and testing phase are oriented as in the Motorsport world. The integration of the testing phase as part of the project and the loop that is performed with the design phase of the next year makes this a very complex and complete project. All the different phases of the project are directly related to the manufacturing process and the resources of the team.

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