RPAS from Cradle to Flight: A Project Based Learning Experience

Adrián Gallego[*], Maria José Terrón-López[+], Rocco Lagioia[+,#], Carmine Valleni[+,#]

[*] Student of Aerospace Engineering, School of Engineering, Universidad Europea de Madrid, Spain
[+] School of Engineering, Universidad Europea de Madrid, Spain
[#] Green Aviation, Ireland

Email: 21201387@live.uem.es, m_jose.terron@uem.es, rocco.lagioa@uem.es

Abstract

Aerospace engineers face multidisciplinary problems. These require integrating technical knowledge from different subjects, balancing it with skills and competences. Third-year Aerospace Engineering students from the Universidad Europea de Madrid (UEM) have been asked to develop a project as if they were working for a company. They present their work here. It was done following the Project Based Learning (PBL) methodology implemented at the Project-Based Engineering School (PBES) of the UEM. The project was aimed to design, build and test a Remotely Piloted Aircraft System (RPAS) by involving four different subjects. A team of 10 students was involved in the project. It was not just an educational project but a real engineering project. Therefore, it has allowed the students to know, understand and practice the process through which a real product is made. The project has led the students to perform in a professional environment, getting them closer to their future jobs and thus motivating them. They have achieved deeper learning and developed key skills such as teamwork, decision-taking, planning and time management. It has also fostered entrepreneurial spirit by transforming the project into the seed of a Start-up company. It has been presented to the first "HUB Emprende" call of the Universidad Europea and it has been distinguished as one of the ten winners, being awarded with an incubation program that helped the students develop their business project.

Keywords: Project-Based Learning (PBL); aerospace engineering; Remote Piloted Aircraft System (RPAS); key skills.

1 Introduction

The aerospace engineering design process is complex and iterative, and it is normally not learnt when using traditional teaching at university. Projects and problems that must be solved by aerospace engineers usually require cooperative strategies. Aerospace engineers must be able to work following an iterative process where individuals and teams work in parallel. The problems they face are multidisciplinary and require integrating technical knowledge from different subjects. Besides, this problem solving process also requires fluent communication between the team members as well as good cooperation between them, balancing technical knowledge with skills and competences.

These are the main reasons why third-year students from the Aerospace Engineering degree have been asked to develop a project as if they were working for a company, using the Project Based Learning (PBL) methodology. This project involved 4 subjects: *Mechanical & Graphic Design*, *Fluid Mechanics II, Aeronautical Structures & Vibrations,* and *Aerodynamics*. Its scope included the design, structural and aerodynamic analyses, manufacturing, assembly, testing, entry into service and operation of a Remotely Piloted Aircraft System (RPAS).

This paper presents the project development from the point of view of one of the students involved in it. This way, a closer view is provided of what actually has been occurring during the development of the project.

1.1 The RPAS project within the Project-Based Engineering School (PBES)

Project Based Learning (PBL) is a methodology based on the concept of *learning by doing* (Blumenfeld, et al., 1991; Thomas, 2000). Using a project as the context, this approach seeks deeper learning among the students and development of transversal competences which are highly valued in the professional world (Fallows & Steven, 2000). Following this methodology, the Polytechnic School of the Universidad Europea de Madrid (UEM) established its own Project-Based Engineering School (PBES) in the 2012-13 academic year having the following global objectives (Gaya López, et al., 2014; Terrón López, García García, Gaya López, Velasco Quintana, & Escribano Otero, 2015):

1. Increase the motivation and pride of belonging of students and teachers.

2. Achieve a deeper learning in the students.
3. Develop key skills.
4. Bring the lecture room closer to the profession (and vice versa).
5. Focus on social, economic and environmental sustainability.
6. Encourage entrepreneurship, technological innovation and internationality.

Aerospace Engineering is one of the degrees involved in this PBES. Teachers are asked to propose projects that involve several subjects each year. Learning through projects will give students a hint of what they will find in their future professional careers.

The academic year structure at the UEM is divided into three quarters. Each quarter, students are enrolled into usually 3 or 4 subjects of 6 ECTS (European Credit Transfer System) each. During the 2014-2015 academic year, the project for third-year Aerospace Engineering students was to develop a Remotely Piloted Aircraft System ("RPAS project") in order to learn the technical competences required to develop such vehicle while examining the currently widespread interest in the development of civil applications for this technology (Hsiao, et al., 2005). RPAS, colloquially known as *drones*, are aerial vehicles that fly without an on-board pilot, as well as the systems that support them to do so (Boucher, 2014). Perhaps the most established and visible applications of RPAS are for military purposes, but many applications have been identified for domestic uses and therefore the gradual integration of civil RPAS into normal airspace is a current reality. This is one of the main reasons for the project: to motivate the students by doing work which is closely linked to what is happening nowadays regarding their field of study.

The students involved in this project were those enrolled in at least one of the following subjects of the 3rd year of Aerospace Engineering: *Mechanical & Graphic Design*, 1st quarter (September-December, 2014); *Fluid Mechanics II*, 1st quarter (September-December, 2014); *Aeronautical Structures & Vibrations*, 2nd quarter (January-March,2015); *Aerodynamics*, 3rd quarter (April-June, 2015). They had to design and build the RPAS in a team involving at least 10 students, operating in a collaborative environment (working with others efficiently and sharing responsibilities). The project was divided into different phases based on those of a real aerospace engineering project cycle (Kamp, 2011): explore the options, conceptual design, detail design, test and simulate, and verify and validate. These phases were adapted to the subjects involved in each quarter. The project should be finished by the end of June 2015.

1.2 Scope of the RPAS Project

The scope of the project focused on the following tasks or phases in order to reach the final product: Design of the RPAS; Structural and aerodynamic analyses; Manufacturing and assembly; Testing; Entry into service and operation of the RPAS. Performing all these tasks should help the students know the process through which a real engineering product is made, understand how it works and train through its application, as well as help them develop some key skills required in their future jobs. The final goal is to provide an overall view, during the university course, of the entire Vehicle Life-Cycle through the integration and interrelation of the subjects involved in the project.

2 RPAS project development and phases

A team of ten students from the four main subjects detailed in section 1, mentored by their teachers, was in charge of transforming the idea presented in this paper into a final operative RPAS. Therefore, their first task was to organize the team (establishing rules, team roles and responsibilities). The project was structured in a similar way to a real engineering project. The teacher defined the 6 main departments in which the project should be divided and named a student as the "Program Manager". This student had to decide who the "Chief Engineer" would be. The "Chief Engineer" then had to decide the students in charge of each department (i.e. "Chief of Design", "Chief of Systems", "Chief of Stress", "Chief of Aerodynamics", "Responsible of Payload" and "Communication Officer"). These students were responsible for their respective departments but everyone could work in a certain task of a different department if their help was required. The rest of the students would work for the different departments depending on the tasks being performed at each time. The project structure is graphically shown in the following figure:

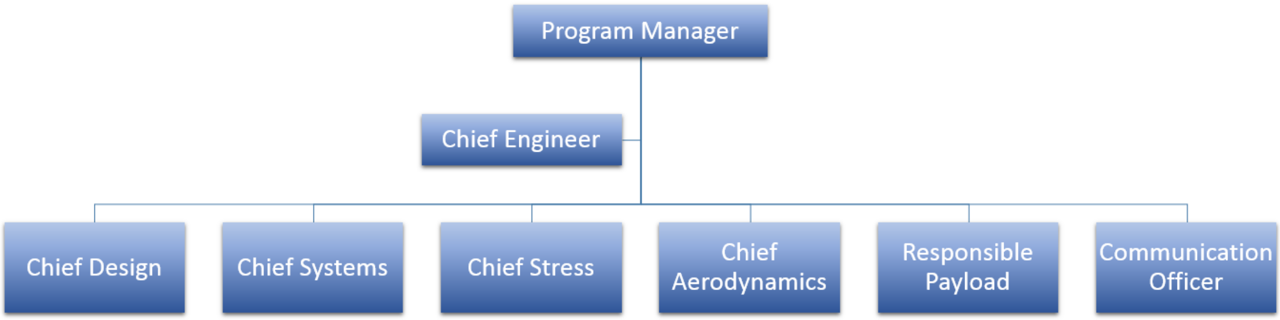

Figure 1: Initial project structure (assignment of roles)

However, during the development of the project, the students decided that this project structure was not very efficient due to the tasks that had to be performed (some departments had too many tasks and others had just a few). Therefore, a new project structure, with two main branches, was proposed and applied: "Design and manufacturing" and "Product development and marketing". Each one of these branches was then divided into small, task centred teams. Most of the students were involved in more than one of these "sub-teams". Besides, the different work packages that had to be delivered (with their respective deadlines) where defined according to the five project phases.

2.1 Phase 1: Design of the RPAS

First, the students had to define the mission and requirements of the RPAS. Therefore, they had to explore the different options following the aerospace engineering project cycle (Kamp, 2011). Then, they had to develop the optimum design to meet those requirements. The design phase took place during the first quarter and beginning of the second. It was divided into four sub-phases, defined as exploring the options, maturity A (involving the conceptual design of the RPAS); maturity B (consisted of the preliminary and detail designs); and maturity C (final design including the improvements defined at the end of maturity B). In this phase the students had to be aware of not only technical aspects but also other factors such as safety, available resources, and regulations since these are as important as the former ones. The operations optimization was sought during this phase. Special consideration was given to safety issues with regard to the final user of the RPAS. The main subjects involved in this phase were *"Mechanical and Graphic Design"* and *"Aeronautical Structures & Vibrations"*. During the former, the students had to present the progress of the project at certain key points of the design process. Two important presentations were prepared during this subject, after finishing maturities A and B. The latter subject was involved indirectly.

2.1.1 Exploring the options

The defined mission for the RPAS was infrastructures' inspection and surveillance. The device was intended to inspect and scan buildings in order to examine if there is any structural damage or loss of energetic efficiency. In addition, it could also be used for surveillance and event image streaming. Considering this, the first activity to be done by the students was a literature study to understand RPAS and their different configurations. By doing this the students developed their *autonomous learning skills*. However, this task was mainly done by the Program Manager and the Chief Engineer, who first did some research and then explained their findings to the rest of the team.

This was the first time students were aware of the importance of good planning. Therefore, they established some milestones in their long term plan and they scheduled meetings where they had to do checklists for each week's work. Meetings were initially done weekly, but then (during maturities A and B) the students decided to have meetings every three weeks due to the amount of workload they had. Meetings were usually defined to be right after the "Mechanical & Graphic Design" class to ensure that the students would be able to attend. This process involved developing skills such as teamwork, planning and interpersonal communication, together with teaching them to develop responsibilities.

2.1.2 Maturity A

After analysing different possibilities, such as fixed-wing versus rotatory-wing designs, the students decided to design and build a medium-sized quadcopter in X configuration. This configuration was chosen instead of a fixed-wing design in order to enable the RPAS to stay flying steadily at a single position. Then the team had to choose between the different types of multi-copters (see table 1). It was done taking into account project sustainability, balancing between complexity, payload capacity and cost of the possible designs. Bicopters and tricopters were rejected due to the low payload they could carry and octocopters due to their high complexity and cost. The hexacopter was explored because of redundancy and due to its ability to carry more payload. However, finally the quadcopter option was selected for simplicity as well as lower cost.

Table 1: Multi-copter comparison table *(The UAV Guide, 2014)*

Multicopter UAV Type	Complexity	Redundancy	Payload Capability	Cost
Bicopter	High	None	Lowest	Low
Tricopter	Medium	None	Low	Low
Quadcopter	Low	None	Medium	Medium
Hexacopter	Medium	Low	High	High
Octocopter	High	High	Highest	Highest

By the end of October 2014, the team did an oral presentation including the specification of the RPAS' mission and the conceptual design, the defined project structure (i.e. distribution of the different tasks) and the identification of the systems required. As teachers wanted to accommodate students' learning to their findings, they assessed them in a formative way (without grade), providing some feedback about the project. They suggested some technical aspects to improve but most were about how the project was presented.

2.1.3 Maturity B

During this phase, the design of each one of the components of the RPAS 3D-model was done in the "Mechanical and Graphic Design" subject using CATIA (Computer Aided Three-dimensional Interactive Application). It is worth noting that as it was a real project, the students had to analyse the resources they have access to. So they could not just conceive incredibly outstanding ideas; instead the product had to be realistic and feasible ("closeness to the profession" competence). A final presentation was done at the end of the subject including the detail design of the RPAS, the selection of the systems and the estimated budget of the project. They also specified the improvements that would be done to the design during maturity C. This delivery (together with the assessment of the progress of the project throughout the entire course) was a 40% of the final grade of the "Mechanical & Graphic Design" subject.

Even though the subject of "Aeronautical Structures & Vibrations" is taught in the 2^{nd} quarter, it was also involved in this phase because the concepts from this subject were necessary to be able to complete the RPAS design. Therefore, the students needed to have tutoring sessions in order to understand these new concepts, required to progress with the project. In particular, this subject helped with the sizing of the structural components and with the number and location of bolts and fittings to join components together.

Besides, during maturity B, the students found the opportunity of presenting the project to an entrepreneurship contest: the first "HUB Emprende" call (HUB Emprende, 2014).

2.1.4 Maturity C

In this sub-phase, the suggested improvements from maturity B were applied to the design. Maturity C indicated the end of the design phase. It was a very interesting moment for the students since they had come up with a final design and they were able to see the first results of their work (figure 2).

Figure 1: 3D model of RPAS final design

2.2 Phase 2: Structural and aerodynamic analyses

Parallel to the design phase, the structural and aerodynamic characteristics of the vehicle had to be analysed in order to demonstrate that the design of the RPAS would be both structurally robust and aerodynamically efficient so that it can be able to fly. The main subjects involved in this phase were *"Fluid Mechanics II"* (together with concepts from *"Aerodynamics"* in some aspects) and *"Aeronautical Structures & Vibrations"*. As it happened during the design phase, the former was involved directly and the latter, indirectly.

During the subject of "Fluid Mechanics II" the preliminary aerodynamic analysis of the RPAS was performed, using both theoretical concepts and a Computational Fluid Dynamics (CFD) software. This analysis had to be presented both orally and written. Three different presentations were performed in class, in October, November and December 2014 respectively, and a final report had to be submitted by the end of December 2014, having a weight of a 30% in the final grade. The first presentation included the stage of the project at that date, in order to show the main features of the project which started in the subject of "Mechanical and Graphic Design". The second presentation explained the general progress of the project and a conceptual analysis of the aerodynamics of the RPAS, including a comparison with existing designs. The third and last presentation showed the progress of the project and the preliminary aerodynamic analysis using CFD software. The final report contained all the different analyses, both conceptual and CFD, which were performed throughout the subject. The results and conclusions included in this report were not only focused on the technical data extracted from the analysis. They also explained the learning process attained through the different errors that appeared while performing the CFD analysis until the final solution was reached.

The subject of "Aerodynamics" was indirectly linked to this analysis too and some concepts were also explained in tutoring sessions with the "Aerodynamics" teacher. Besides, the "Aeronautical Structures & Vibrations" subject was again involved indirectly since a basic study of the resistance of the main structural components of the RPAS had to be done. A structural analysis report was done mainly due to necessity rather than as a specific task for a certain subject.

2.3 Phase 3 (manufacturing and assembly), phase 4 (testing) and phase 5 (entry into service and operation of the RPAS)

Once the final design had been defined, the components of the RPAS would have to be first manufactured and/or bought, and then assembled so as to obtain a physical prototype of the designed vehicle. However the project has been stopped for external reasons and this phase won't be completed for this project. This issue generated two different reactions on the students. Some students have become demotivated and have lost the interest in continuing with the project. However, others enjoyed so much the idea of the project that they are looking for alternative ways to build a prototype of the RPAS (outside the subjects but always with the support of the University). Two possible options are to build it with the help of "HUB Emprende" and/or to take advantage of the currently emerging "Aerospace Club" inside the UEM.

Once the RPAS is built, flight tests would have to be performed in order to demonstrate that the RPAS works as expected.

After completing all the previous phases, the RPAS would be ready to start operating for the defined mission. The initial idea was to use the RPAS to record the UEM graduation ceremony. Unfortunately, this wouldn't be possible since the Spanish regulation around RPAS has significantly changed in the past months and currently it is not permitted to fly these devices over crowded places.

3 The students' experience: developing transversal skills

This was not just an educational project but a real engineering project. On top of the importance of delivering a product by entry into service, it allowed deep knowledge of the process through which the product is made, facing the short and midterm challenges of the decision-making process. Likewise, it has stressed the importance of not so technical aspects such as procedures definition, the strict adherence to the requirements and the need for documentation of the entire process. Therefore, this project has led the students to perform in a professional environment and thus has motivated them. As previously mentioned, the project included a ten students' team. Other projects developed in previous academic years and subjects involved just up to four students. Therefore, students had to learn to coordinate larger groups of people, which made more problems and conflicts to arise. Together with *teamwork*, the students have developed several other transversal competences:

- *Ability to apply knowledge to practice*: the students had to use the knowledge they had from previous and current subjects in order to design the RPAS. On the other hand, as the project was a real one, they developed *closeness to the profession*.
- *Autonomous learning*: the students had to learn by their own several concepts that are not specifically taught during the degree. In addition, previous "forgotten" or "not completely understood" concepts had to be re-studied in order to understand certain issues of the RPAS.
- *Decision-taking*: as a real project, many decisions had to be taken during the design phase (such as the fact of selecting a quadcopter instead of any other type of RPAS).
- *Information management*: they searched about different RPAS designs and how they work, as well as for information related to the selection and characteristics of the components to be bought, such as the electronics and engines (during maturity B of the design phase).
- *Initiative and entrepreneurial spirit*: due to the good expected results the project has motivated the students to take it further presenting it to an entrepreneur university contest (HUB Emprende, 2014).
- *Innovation and creativity*: the innovation component of the RPAS design is of key importance in this project and the students had to focus on these aspects mainly during the design phase.
- *Interpersonal relationships skills*: developed in the same way as teamwork, through the constant communication and relations between team members.
- *Oral and written communication*: oral communication was developed through several presentations that had to be done along the design process; students had to document every modification made and deliver technical reports for the aerodynamic and structural analyses.
- *Planning and time management*: the need to coordinate the team members with every modification that has been made during the project helped students to improve this skill. Each team member had a different role and responsibility in order to diversify and better distribute all the necessary tasks.
- *Problem solving*: problems appeared and students had to find the optimum solution in each case.
- *Responsibility*: since the project requires performing a lot of tasks in a challenging time, responsibility was a key skill necessary in order to meet the different deadlines.

However, several drawbacks have also been present. On the one hand, the assignment of roles and distribution of the workload have in fact distributed the knowledge and thus not every member has learned the same, neither with the same deepness. On the other hand, since the distribution of this workload depended on the roles assigned, this has also caused some disagreements and frictions within the group members. In addition, although it was the same project, it was carried out in a different way in each subject, leading sometimes to students' confusion and more amount of workload.

4 Results and students' reflections

Students feel to have increased their motivation in their studies. As a matter of fact, even though they have just completed the first two phases (design and analyses), due to the motivation generated during the project development they are looking for alternative ways to build the RPAS elsewhere (still with the support of the University). The project has allowed the students to know, understand and practice the process through which a real engineering product is made. During the different phases of the project, the students have acquired deeper learning (integrating the knowledge from several subjects) and have developed certain specific competences mainly with respect to the design of the vehicle, while leading them to perform in a professional environment, getting them closer to their future jobs and motivating them.

Apart from the technical know-how, students have developed several transversal competences, from which teamwork, decision-taking, and planning and time management can be highlighted. As they had to manage a real project on their own, they had to plan their schedule and, in order to drive it in an efficient way, they needed to divide the work into different tasks to be done by different team members. They had to keep flexible in order to make the necessary changes throughout the project. Interpersonal communication (between students and with teachers) was also a key. Decision-making by multiple individuals (as a team) was relevant too. They had to share data, experience and opinions. The process may have been longer this way but decisions were more consistent, leading to better ones (compromise and consensus). Apart from this, they have also developed oral and written communication and responsibility.

They have worked with a project really close to the engineer profession. The process has shown the problems and challenges that appear in a professional environment, and it has helped them analyse possible solutions to those problems (such as re-defining the project structure to better suit the requirements of the project). Collaboration between the team members in order to reach the final goal was also necessary. During the decision making process some questions had arisen such as "how can I change this proposal so that it works for you too?", being similar to what a worker does in real projects, developing the ability to adapt to different situations.

They have focused their project on social, economic and environmental sustainability taking into account the civil applications and the safety requirements of the RPAS (social), the access to the available resources for it (economic) and the final design as a non-polluting and resource-optimized (environmental).

They have fostered an entrepreneurial spirit by transforming the project into the seed of a Start-up company, as well as technological innovation while developing a high-tech device. Converting the project into the seed of a Start-Up company has been explored, analysed and approved. This has shown how the PBL approach can substantially develop initiative and entrepreneurial spirit in the students when they enjoy and believe in what they are doing. The project has been presented to the first "HUB Emprende" (2014) call of the Universidad Europea and it has been distinguished as one of the ten winners (Universidad Europea, 2014). "HUB Emprende" is an ideas' incubator where entrepreneurship is supported. It is a business incubator open to the participation of students and alumni, as well as external projects of all sorts of sectors and disciplines. As one of the winners' project, the team has participated in a complete incubation program during 5 months (December-April). This program consisted in giving mentoring and specialized training to the students for free. Thus, they had the opportunity to receive counsel, advice and supervision to convert their business idea into a successful business project.

The incubation program comprised a training plan in which experts guided them in the key areas of the process: conception, maturing, contrast and definition of the idea; business plan, value proposition, innovation plan, legal support, communication plan, start-up pragmatic training and investment plan. By the end of these 5 months, on the 23rd April 2015, the team presented their project in a final "DemoDay" to the entrepreneurial and investing community (Hub Emprende Universidad Europea, 2015).

During the incubation program at the "HUB Emprende", the mission of the project has been modified in order to better meet both the demands of the current market and the requirements of the recent legislation that has emerged regarding RPAS. The business idea that has been developed there is to provide a service to the agricultural world by helping farmers optimize their resources. This would be done by using the RPAS to obtain critical information about the plantations. The fact of developing this project simultaneously at the University and at the "HUB Emprende" has in fact shown the students the importance of being able to adapt to different situations and has helped them develop even more their decision-taking skills.

5 Conclusions

The project has allowed the students to know, understand and practice the process through which a real engineering product is made, working in a professional environment and motivating them. However, drawbacks have also been present. The distribution of the acquired knowledge and the differences in the amount of workload for each student, both due to the assignment of different roles to each team member, has been seen as a problem. However, although several difficulties have emerged during the development of the project, it can be seen as a success. Some suggestions for improvement could be considered.

There should be a better coordination and communication between the different subjects involved in the project. Teachers should clearly identify which tasks would be performed in each subject and how to combine them with the others.

The project should be better organised with the subjects (in a chronological sense) so that students can apply the knowledge from each subject when required instead of having to grasp some concepts from future subjects beforehand, clarifying the real objective of the project from the beginning.

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