Cases on Technological Adaptability and Transnational Learning:
Issues and Challenges

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Information Science REFERENCE
INFORMATION SCIENCE REFERENCE
Hershey · New York

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Printed at: Yurchak Printing Inc.

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com/reference

Library of Congress Cataloging-in-Publication Data

Cases on technological adaptability and transnational learning : issues and challenges / Siran Mukerji and Purnendu Tripathi, editors. p. cm.
Includes bibliographical references and index.
Summary: "The case studies in this volume enforce technology is a principle catalysts for transnational collaborative interventions in providing learning and professional development opportunities to the people of both developed and developing countries"--Provided by publisher. ISBN 978-1-61520-779-4 (hardcover) -- ISBN 978-1-61520-780-0 (ebook) 1. Educational technology--Cross-cultural studies. I. Mukerji, Siran. II. Tripathi, Purnendu, 1975-
LB1028.3.C327 2010
371.33--dc22
2009036915

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Chapter 17
Effectiveness of Problem Based Learning for Engineering Curriculum

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ABSTRACT

The main purpose of this case is to describe the process by which an initially limited-range practical experience, within the frame of a given course in an aerospace engineering degree, might be expanded to become the mother-course itself. Particularly, the practical experience is a Model Rocket Workshop (MRW), where students design, simulate, build, test and launch a small model rocket. The workshop is a Problem Based Learning (PBL) experience that covers a wide spectrum of educational aspects, ranging from theoretical disciplines, such as fluid dynamics and rocket dynamics, to topics more related to experimental work and hardware utilization like the certification of the rockets, as well as the rocket altitude measurements. Students get rapidly involved in the project, and acquire several practical and transversal abilities, while developing a solid knowledge of the physics underlying aerospace engineering. The case study shows some problems and improvements, academic results and lessons learned from the PBL approach. Finally, a series of new ideas related to MRW and to the course it belongs to are presented. The objective is to expand the MRW so that it embraces the totality of the activities that constitute this mother-course. As a consequence, the former would then become a new course entirely based on PBL. The strategy aims at enabling an optimum transition from conventional learning to PBL.

DOI: 10.4018/978-1-61520-779-4.ch017

ORGANIZATION BACKGROUND

The Universitat Politècnica de Catalunya (UPC) is a public higher education institution and one of the leading universities in Spain. The fields of research and education of the university are architecture, sciences and engineering. The schools and research centers are known, nationally and internationally, for educating and training technological professionals and for the high-quality research done in these areas. The university seeks excellence in teaching technical courses that are responsive to the training needs and requirements of traditional, evolving and newly-developing production sectors, including aerospace engineering, photonics, supercomputing, bioengineering, water resources and management and energy. All of them meet the criteria and requirements of the European Higher Education and Research Areas. Also, the substantial ability for technology transfer insures that the research generated by the technological and scientific teams has a real-world impact not only within Spain but also world-wide.

The University was officially founded in March 1971 and at present it offers 61 graduate and undergraduate official degrees, enrolling a total of about 29,500 graduate and undergraduate students. For some of these programs the university has international agreements with other technical universities to endorse double-degree diplomas, totaling 82 double-degree programs. Thus, the university has an international profile and it has about 2,300 students in international exchange programs. It is the Spanish university with the highest number of master's degree students from abroad. These programs have a natural continuation in 47 doctoral programs, enrolling 2,900 students.

The research activity of the university is undertaken by 40 departments, and it is funded by about 6,600 research projects, with a global research income of 72 million euros. It is the Spanish university with the highest research income from the European Union VI Framework Program. The overall scientific production during the last year was 1,600 papers, some of them in the most prestigious journals, like Science or Nature, to put some examples. It is the Spanish university with the highest citable output in the fields of Computer Science and Information Technologies; Mechanical and Aeronautical Engineering; Civil Engineering and Architecture; Electrical and Electronic Engineering and Automatic Control; and Electronic and Communications Technologies. The faculty and research staff amounts to 2,600 people, whereas the administrative staff amounts to about 1,500. The total budget of the UPC is 320 M€. Finally, the UPC is member of several international university networks (CLUSTER, CESAER and CINDA…).

The Escola Politècnica Superior de Castelldefels (EPSC) was founded in 1991 with the clear purpose of specializing in innovation in teaching methodologies. Since then, it has achieved a solid reputation among the Spanish universities in teaching excellence. It offers several bachelor degrees in engineering, including a bachelor degree in Aerospace Engineering. Special emphasis has been laid on using fully cooperative or Problem Based Learning (PBL) techniques. Student performance is evaluated using continuous assessment. Additionally, virtual campuses and interactive learning platforms have been developed from the very beginning and are intensively used in all courses (a couple of these tools are presented later on). Most of these techniques or tools have been subsequently used in other engineering schools or campuses of the different universities in Spain.

SETTING THE STAGE

Problem Based Learning (PBL)

Graduate coursework in aerospace engineering is intended in large part to prepare students for professional practice of engineering in companies and state or international agencies and, in some cases, for post-graduate research, either in public or private sector. Accordingly, the most complete and successful graduate programs in aerospace engineering are devised to provide a solid basis in physics and mathematics. Moreover, some topics – like, for instance, aerodynamics and flight dynamics or aeroelasticity, among others – involve an accurate knowledge of the underlying physics and a considerable load of relatively complex mathematical tools. Consequently, students quite frequently become overwhelmed by the intrinsic difficulties of these topics and, also quite usually, the success rate of regular courses is small. Furthermore, in most engineering schools and for most of the relevant topics, the assessment of student performance depends largely, or even entirely, on written exams. The traditional exams involve usually a variety of problems that are prepared to be completed in typically two hours of work in the classroom. A consequence of this way of assessing student performance is that the problems should be easy enough for the students to be able to solve them in a limited amount of time. However, in practice such simple problems do not occur in the professional exercise of aerospace engineering.

With the advent of physics and engineering education research as a research field, many initiatives are currently being developed. The generic goal of these initiatives is to improve the teaching of intrinsically complex topics using reform-based approaches. Consequently, there exists now an opportunity to move beyond the classical structure of engineering and physics courses to new experiences in which the students are the real and leading actors of their education. Many of these experiences involve the concept of PBL. In PBL experiences, students work in teams to explore real-world problems, learning whatever they need to learn in their way to the solution to the problem, under the conduct of their teachers. Additionally, in PBL, students identify problems of interest to them and experiment to find solutions. Moreover, they also design complex systems that integrate engineering fundamentals in a multidisciplinary approach. Compared with conventional learning, where the students work alone and learn from textbooks or class notes, this approach has several advantages. Among these advantages a few are worth mentioning. In particular, students develop a deeper knowledge of the subject, increase self-direction and motivation for the particular course, and, moreover, they reach improved research and problem-solving skills. In summary, PBL has now become a widespread teaching method in disciplines where students must learn to apply knowledge not just acquire it. More information on PBL can be found in literature (Doppelt 2005; Novack & Gowin 1988; Boud & Feletti 1997; Brodeur et al. 2002; Delisle 1997; Wilkerson & Gijselaers 1996).

However, PBL is not an easy thing to do, since it involves a deep transformation of the classical course organization. Students may feel disoriented and anxious as they have to decide how to proceed. On the other hand, teachers must devote time to follow the work of their students and give feedback, and may experience an increase in their teaching workload. And finally, teamwork, which is a central aspect of PBL, may be frustrating for both teachers and especially students.

Frequently, frustrating PBL experiences lack positive interdependence and/or individual accountability. When the PBL activity has positive interdependence, good performances of all team members are necessary for the project to succeed (e.g. everyone must complete his or her part). Moreover, when the activity has individual accountability, every team member is responsible for the whole task, and cannot concentrate in his or her part of the task, ignoring the tasks of the other teammates.

Group Puzzle Theory

One way to reinforce the positive interdependence and individual accountability in a PBL activity is to use the group puzzle technique (Freeman &

Jigsaw, 1994) to organize part of it. In a puzzle, the tasks to be done in a given phase of the project are split into several independent parts, so every member of the team ("core groups") is responsible for one of these parts. Then, it is said that every team member has a different role, or that each member is the expert in relation to a particular topic.

From time to time, members of different groups sharing the same role meet in groups of three or four (meetings of "expert groups") to clarify doubts about their roles or to complete together parts of the tasks they have been assigned. This in fact means the creation of a set of parallel groups, aside from the core groups. After these expert meetings and/or once the experts have finished their tasks and fulfilled their particular goals, they return to their core groups to share and to transfer the acquired knowledge to the rest of their teammates. Therefore, a significant part of the teaching process actually involves the students themselves.

Summarizing, each member must do his part of the task in order for the group to be successful in completing the activity (positive interdependence). Moreover, individual accountability is further reinforced if students must complete from time to time an individual exam about any of the roles of the activity. As a result, once the entire process is finished, each student should be able to understand the whole problem and develop a solution to solve it. Therefore, the success of a group means the success of all its members.

In the PBL, the puzzle technique is used as a key element to organize and distribute the tasks of the students.

CASE DESCRIPTION

Experimental Techniques in Aerospace Engineering (TEA) & Model Rocket Workshop (MRW)

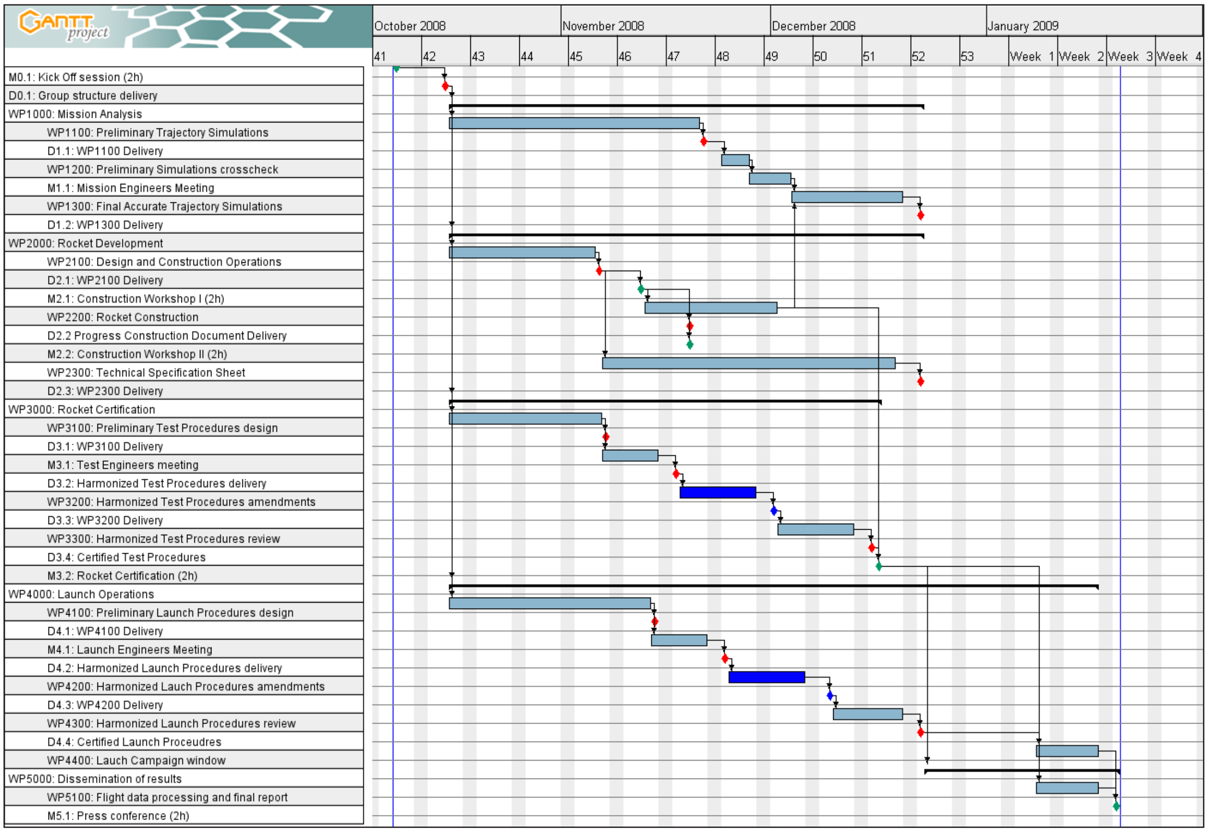
The course called Experimental Techniques in Aerospace Engineering (*Tècniques Experimentals en Aerofísica*, TEA from now on) is a teaching unit of third-year course included in the Aeronautics Engineering degree at EPSC. This course addresses several experimental techniques and serves as a means to complement and intensify some of the theoretical aspects taught during the whole bachelor degree. For example, wind tunnel experiments are used to introduce experimental fluid dynamics to students, the functioning of an engine is taught in a practical way and some tests are proposed to study material properties. Further details are presented later on. The class involves weekly two hours of classes at the University, for which the attendance is mandatory, plus 4 to 6 hours of homework, but this latter number depends strongly on the activity.

Originally, the Model Rocket Workshop (MRW) was a PBL solution designed to conduct a limited-range aerospace educational activity and was proposed within the framework of TEA. In particular, this experience consists in the design, simulation, construction and launching of a model rocket. After the launch, the payload is recovered and the measured flight parameters are analyzed and compared to the numerical calculations. Above all, the activity is based on the utilization of cooperative learning and PBL techniques.

First Edition of the MRW

The first edition of the Model Rocket Workshop (MRW) took place during the academic year 2005-2006. Some changes and improvements have been made afterwards and will be presented later on.

Figure 1. Gantt Diagram showing the schedule of the MRW during the academic course 2008-2009. The diagram was elaborated with Gantt Project open access software (credit: this figure was obtained using Gantt Project[1]).



Organization of the Activity

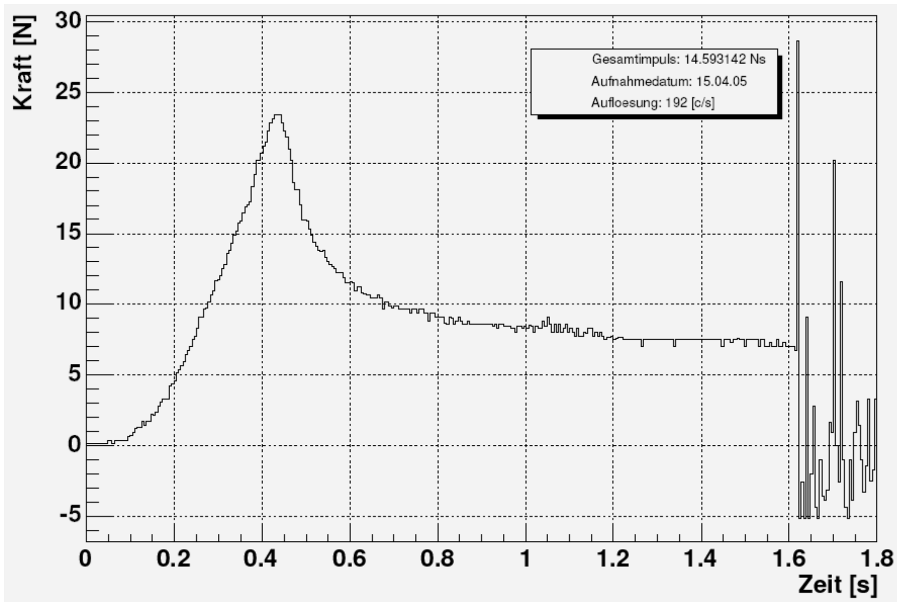
In this section, the organization of the workshop as it was first completed is presented (Rojas et al. 2008). Regarding the schedule of the activity, the MRW lasts approximately twelve sessions. A Gantt Diagram of the schedule is shown in Figure 1.

The planning is strict and clearly sets up procedures and deadlines for every group. Several milestones are placed along the project, as well as deadlines to deliver partial reports and results.

During the first session, after the presentation of the workshop, the teaching staff assumes the role of a client company and gives the students information regarding the requirements to be fulfilled during the mission. Technical information is also provided such as, for example, the rocket engine thrust profile, given by the manufacturer of the rocket engines (see Figure 2). Also a list of available material is given to the students. Special emphasis has been made in using inexpensive and readily available material for all the equipment needed to complete the whole teaching unit. Most of the needed items, such as cutters, scissors, adhesive tapes, painting and so on, are inexpensive and readily available at regular stores, whereas others can be purchased either in specialized stores or directly from the manufacturers. In particular, rocket motors, fuselages and nose fairing are purchased to a specialized manufacturer.

As mentioned above, the learning methodology in the MRW is mainly inspired on the technique

Figure 2. Rocket engine thrust profile (in Newtons) versus time (in seconds) as provided by the manufacturer of the engine (credit: Noris-Raketen©).



called group puzzle (Freeman & Jigsaw, 1994). Hence, in the class context, once the first session is over, the students are allowed to self-distribute and to organize themselves into the core teams. Shortly after this, each team decides how to assign the different roles to the several members within the group. These roles are explained later on in this section.

After its formation, each core group has to consider itself as a space agency, in charge of planning and accomplishing the design, construction and launching of the rocket, taking into account the mission requirements that the instructors have issued. All relevant tasks and duties are clearly indicated in Figure 1. The first task for the students consists in performing the mission analysis. It is followed by the development of the rocket. The rocket is then certificated and finally launched. Once the payload, the altimeter, is recovered, the flight parameters are analyzed and compared to the theoretical expectations. The software needed to download and to process the data acquired and stored by the altimeters during the flight is provided by the manufacturer of the altimeters.

Most of the data and information needed by the students is loaded and available in the dotProject web platform, which is explained in a further section. For instance, technical documents, such as rocket motor performances and features, safety code for rocket launching or list of materials, are available to students since the beginning of the activity.

All documentation of the project is in English and the whole teaching unit is also given in English, in order to create an environment with the highest degree of realism, that is, as similar as possible to the one found in international agencies or aerospace companies.

When designing the MRW, it was decided that the core groups were to be constituted of four members, although this number can be made larger if desired. Therefore, according to the Group Puzzle methodology, the project was divided into four main tasks. Again, in order to simulate the real environment of a space agency or an aerospace company, the task distribution inside every group is done as it occurs in real space agencies. To that end, four roles or types of Expert Engineers (EE) are identified, each one associated to clearly defined responsibilities and duties:

- Mission Engineer (ME):
    - Mission and team coordinator.
    - Leader for tasks related to mission analysis: rocket flight equation computation and simulation (assuming a two-dimensional, symmetric trajectory).
    - Team spokesman: presents the overall results during the final session of the workshop.
- Development Engineer (DE):
    - Leader for tasks related to rocket design.
    - Leader for tasks related to rocket construction.
- Test Engineer (TE):
    - Leader for tasks related to rocket certification tests design.
    - Referee for the certification tests of the rocket of another group during certification campaign.
- Launch Engineer (LAE):
    - Leader for tasks related to rocket launching procedures design.
    - Supervisor during rocket launching campaign to guarantee safety.
    - Ignites the rocket at the launching ramp.

The expert engineer acts as team leader and spokesman for the specific assigned tasks and work. It is important to remark that the expert engineer is in charge of leading these tasks, not of completing them all. Every member of the team should contribute and help the expert engineer in his specific responsibilities so that all team members participate in the learning process associated to that work. Note that the activity can be adapted to allow core groups of more than four members by extending the previous list with additional roles, according to the common practices in industry. A proposal for a new role will be explained later, in the description of the last edition of the MRW.

During the workshop, besides the individual work of each student, several meetings take place, bringing together either all members within a core group, or particular experts from every group. For example, the first session without instructors corresponds to a meeting where the roles of the experts have to be distributed within a group. Then experts from each team meet in order to identify their main tasks and responsibilities, the problems involved in designing and building the rocket and some other issues. Afterwards another meeting within a group is organized to share the acquired knowledge among experts and to transfer the results to all team members.

Both kinds of meetings are fundamental to guarantee the correct development of the tasks, which requires a high level of interaction between group members because of the existence of strong interdependency between data and results, inputs and outputs of every task. To make expert meetings more profitable and productive, experts are asked to deliver, before any meeting, brief and concise reports about the work they have previously done and about the matters to be commented in the corresponding meeting. This also gives the teaching staff relevant material in order to continuously evaluate the tasks of the students. Depending on the nature of the meeting, the minutes of the meeting may also be requested, stating the work done during the meeting and the achieved milestones. In total, the work completed by each core group consists in four partial reports and one final report, which must be delivered according to the deadlines given in the Gantt diagram shown in Figure 1. Details about these reports are given in the following section. If a group does not deliver a report within the deadline, the instructors can deny the launching permission for the model rocket of that group. The delivery of the reports is done through the dotProject platform, where the core group members can upload the files containing their respective reports.

The penultimate session of the workshop is the launch itself. In our case, the model rockets were launched from a site located in the vicinity of the University Campus, after having asked permission both to the City Council and to the owner of the launch site. In the present case, these two kinds of permits were the only ones needed to fly model rockets. Furthermore, according to Spanish regulations, no special permit from the Civil Aviation Authority is needed, since the site is outside any area controlled by the Air Traffic Management (ATM) and the maximum altitude reached by the rockets is below 1000 feet (the maximum allowable altitude above ground level for unmanned flying devices in Spain). The maximum flight altitude had been previously computed by integrating numerically the equation of motion and was confirmed by the experimental flight. An example of rocket velocity components versus time as obtained by numerical integration of the equations governing the rocket flight trajectory is shown in Figure 3. No license is neither necessary to use the rocket motors given that D-category motors were used and that a license is only compulsory when using H-category motors or above. Note that depending on the country where the workshop is realized, special permits may be required and local legislation concerning unmanned flying devices and motors should always be checked.

Finally, the final report is delivered during the last session. In addition, during the final session, each core group gives a formal presentation to present its work and results to the rest of students and teaching staff. Following the presentation, the team members are asked about technical, managerial and team performance issues. More details about this final session are given in the following section.

Calculation of the Rocket Trajectory

As they are important for further sections, we briefly present here some details related to the rocket motion equations integration. Particularly, we are requesting the students to make the following assumptions when performing the trajectory calculations (Heister & Messersmith, 1996):

- To consider a two-dimensional, symmetric (no slipping) trajectory.
- To assume that the rocket operates under a ballistic trajectory in which its angle of attack is zero (that is, the rocket longitudinal axis and its aerodynamic velocity are parallel).
- To assume there is neither lift nor lateral forces generation, which is valid provided we assume that the rocket's angle of attack is null.
- The engine thrust is aligned with the longitudinal axis.

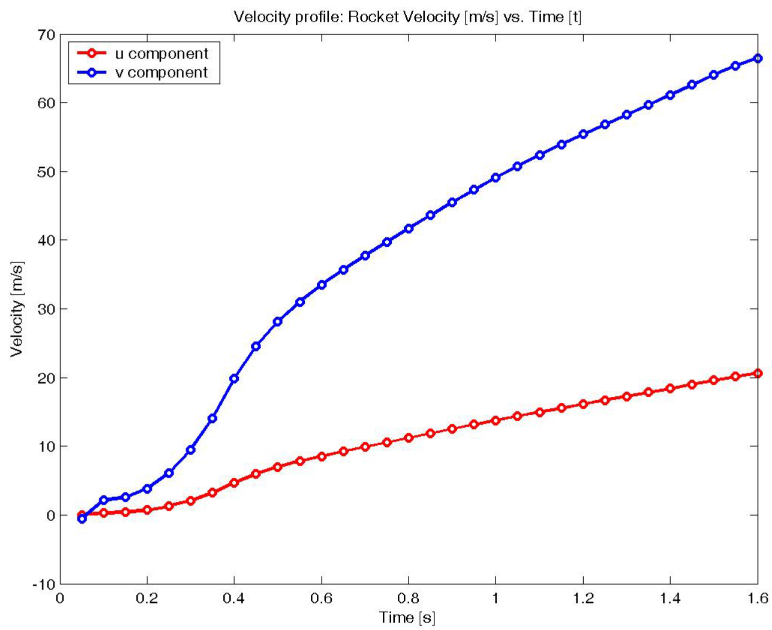
According to these hypotheses, among the lift, drag and pitching moment coefficients, the drag coefficient is the only one that the students really need for their calculations.

Method of Evaluation

This section presents the main issues concerning the evaluation of the students in the first edition of the MRW, which took place during the academic year 2005-2006. On the one hand, the evaluation method was thought in accordance to the educational philosophy at EPSC, still valid nowadays, that is the method is to be based in continuous evaluation. On the other hand, it was decided for that edition that all the members of a same team would be assigned an identical mark. Thus, this section reports the criteria used to obtain a team's mark, not the mark of a particular member.

Generally, grading a PBL experience is a difficult matter, but it should be made as practical as

Figure 3. Plot of rocket velocity components (in meters per second) versus time (in seconds) obtained by numerical integration of the equations governing the rocket flight trajectory using Matlab© (credit: this figure was obtained using Matlab – MathWorks[2]).



possible (Brügemann et al. 2005; Doppelt 2005). In accordance to this, we decided for the first edition that the final mark of a team would be based on the evaluation of the following concepts:

- The quality of a series of documents that the team has to deliver throughout the course. In this first edition, the delivery of these reports was made through the web tool named dotProject. In a later edition it was decided to migrate to Atenea (the Moodle-based institutional digital campus) due to several reasons, as explained further on. The documents to be delivered were the following ones, in chronological order of their due time (see also the Gantt diagram of Figure 1):
    - Report on rocket flight trajectory results obtained by numerical simulation of the rocket flight equations (see example plot in Figure 3).
    - Report on rocket test and certification procedures design.
    - Report on rocket launch procedures design.
    - Final report (see more information below).
- The degree to which the team had fulfilled the scheduled deadlines for the various deliveries. The students are properly informed about the deadlines at the beginning of the MRW, since they are clearly defined in the kick-off documentation relating to MRW planning provided by faculty members.
- The degree to which the team has achieved the objectives given by faculty members, as for instance, the accuracy in fulfilling the procedures published by faculty members in the kick-off documents. These

procedures refer to the management of reports, notification of the status and progress of tasks, etc.

- The quality of the presentation and final report. As previously mentioned, the presentation takes place during the last session of the course, which corresponds also to the deadline for the delivery of the final report. Both should be a concise summary of all the work done by the team throughout the workshop. Nevertheless, special attention should be paid to the following parts, which we consider the most relevant ones of the presentation and final report, since other matters have already been addressed in the previous reports:
    - The processing of the experimental results obtained from the readings of the altimeter on board the rocket (see example plot in Figure 4).
    - The comparison of these results with the theoretical results calculated by means of numerical simulations for previous deliveries.

Each team performs its presentation in front of an audience consisting of all other remaining MRW participants (faculty and students). A question time is allocated at the end of the presentation. Both the faculty and students may ask questions to each of the team members. This is especially valuable to ensure that all of them have properly assimilated the knowledge associated to each of the different roles, not only the knowledge associated to the member's particular role.

The authors would like to remark that up to four faculty members were used to conduct this activity and a minimum of two during the latter editions, and that all the deliveries represent a considerable amount of documentation to be evaluated by the educators. These facts are significant, since evaluation may require an important coordination effort or otherwise an important individual effort, depending on the number of participant faculty. For the first and following sessions, it was decided that all faculty members participating in the MRW would be responsible for assessing student performance in this activity.

RESULTS OF THE FIRST EDITION OF THE MRW

Marks of the Teams

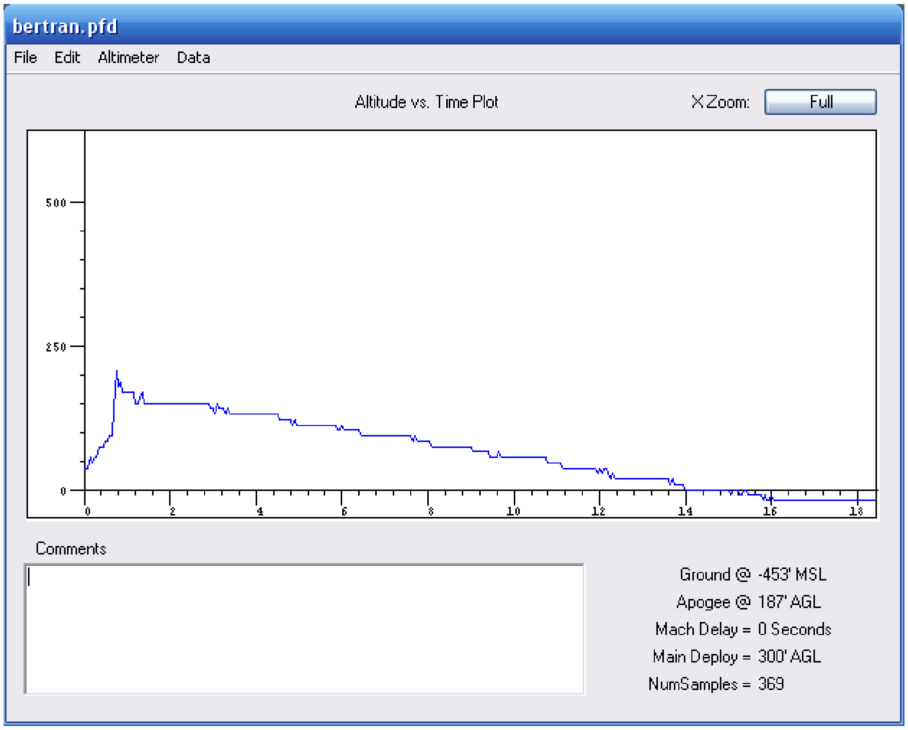
The marks of most of the students in the first edition of the MRW were very high. The average mark was 8.71 over 10. Among the five participant teams, for three of them, constituted of five people, the marks were significantly high: two of these teams were rated 10.00 and the other one 9.00. The reason for this high marks is that these groups over-performed, that is, they worked even more than what were requested to do, and showed outstanding initiative. The average is lower due to problems occurred in another team. In this group, which was constituted of four members, we detected that a couple of students were not performing as requested. Exceptionally, they were rated with different, far lower marks respect to the other two members. This made us aware of the problems of the evaluation method, since maybe similar problems were taking place in other teams without us knowing.

Assessments & Comments from the Students

In the following section, some brief feedback is presented, as it was received from students or deduced from their comments after they conducted the first edition of the MRW:

- Students in general enjoyed the activities within the frame of MRW.
- Students liked to do hands-on activities that were based on a previous work they had done on paper (e.g. build physically

Figure 4. Plot of the altimeter readings of height (in feet) versus time (in seconds) presented in a typical window by PerfectFlite[3] Mini ALT altimeter software, after the data has been downloaded. The picture depicts some of the common features of these plots. Namely, for time 0 the height is higher than 0, since the altimeter stores data only starting from the moment it detects the launching has occurred, which happens after a given variation of height in time is exceeded (credit: this figure was obtained using PerfectFlite© Mini ALT altimeter software).



the model rockets or the recovery systems after they have designed them).

- Students appreciated the possibility of refining in parallel their former calculations and simulations as the hardware they used or built differed from their original designs.
- Students especially liked the MRW to be scheduled in 3rd grade, since at this point they have assimilated many theoretical concepts, but have not put most of then physically into practice yet.
- Students in general complained that in reality more allocated time was necessary than the one scheduled for some of the sessions or tasks, since they had to rush excessively in many cases and the quality of their work was affected.
- Students felt that the activities had been planned precisely in most of the cases, but they also commented that sometimes there was a lack of suited materials to properly perform some of the scheduled activities. For instance, students in this first edition of the MRW complained that the saws provided by the faculty were not suited for cutting the marquetry wood for building the fins (according to some students, the saws needed more teeth and harder, and also compatible handles). Other students complained that there were not enough

thermal blankets for every team to build parachutes, etc.

- Some students commented that the splitting of tasks and responsibilities among the expert engineers was not optimum. From their standpoint, during the MRW course each engineer was being sequentially overwhelmed by his particular tasks and deadlines during the corresponding period of the MRW. As a consequence, sometimes they felt they were not really doing any teamwork.

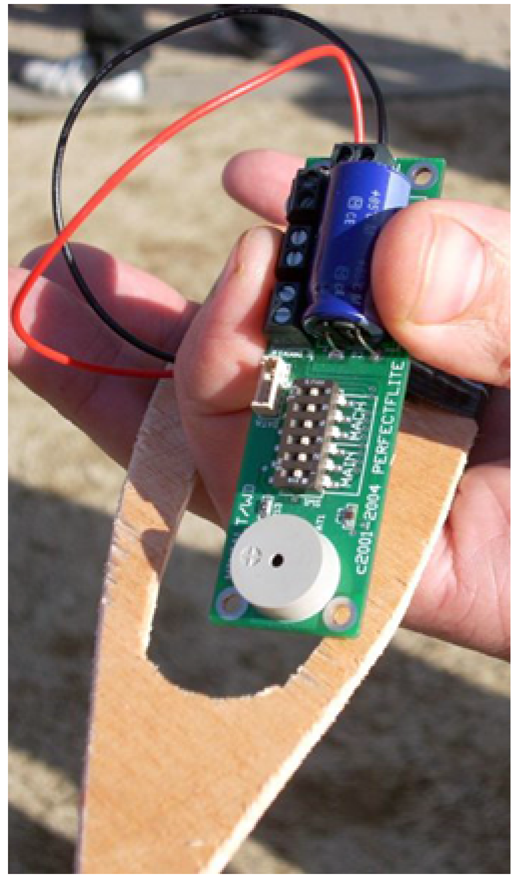
The last comment made us aware of an important problem, which is that some students had misunderstood what really was the role of the experts. This is addressed in the following section.

Problems Detected & Lessons Learned

First, some minor defects or problems that were detected during the first edition of the MRW are reported in the following list:

- It is important for the faculty staff to be aware of some deadlines too, not only relating to the deliveries of the teams but also related to the acquisition and renewal of some equipments and materials to be used by them. That is, it is important to accurately control and monitor the inventory and the schedule, and to remember to buy on time some missing items or materials, or to book on time some rooms, etc.
- It is critical to ensure that the students read, understand and use appropriately all the documentation that they have been provided with, since we noticed that some groups did not pay attention to certain documents (e.g. the altimeter user's guide).
- The upper load limit of the scales that the students use for the certification tests should be carefully taken into consideration, since the requirements of load to be applied to some parts of the rocket during the certification tests may exceed this upper limit.

Figure 5. Picture of an altimeter prior to its integration inside the nose fairing.



- Special attention should be paid to rockets having unnoticed excess weight or overweight, as compared with the maximum recommended take-off weight provided by the manufacturer.
- Some altimeters did not work adequately (see picture of an altimeter in Figure 5). A process of proof testing should be performed prior to the launch campaign.
- Some parachutes were not folded adequately by the students. Faculty should monitor

this process, for instance during the launch campaign.

- Some parachutes did not deploy adequately while the rockets were in flight.

Second, a more important problem is reported. Due to an excess of students, some groups were finally constituted of more than four people, which was not in accordance to what had been initially planned. As a consequence, there was an undesired redundancy of some roles in some teams. We decided to propose a new role, as explained later on, which in addition would help face a further increase in the number of students in subsequent editions, while preventing the number of teams and rockets to grow excessively.

Another aspect of the first edition that the authors did not consider satisfactory was the evaluation method, since in some cases the performance and commitment of different members of the same team had been significantly unbalanced. To better assess the performance and the achievements of every single member of a team, the authors opted in later editions for implementing a new evaluation method where the grading was individual. This method will be explained later on.

Finally, in many cases the students did not understand what the authors expected when designing the MRW, in relation to the role of the experts. For some reason, maybe due to a deficient communication or coordination, or to a misunderstanding, some teams did not realize that the experts were only the leaders or coordinators of some given tasks. Somehow these groups behaved and worked as if the experts were the ones to perform completely all their corresponding tasks. Instead, the students should have understood that the experts were the ones in charge of leading the team to fulfill the respective tasks. It is vital to ensure that the students understand this point. So this was an important problem that we had to deal with and to solve for future editions.

IMPROVEMENTS INTRODUCED

The last edition of the MRW so far, corresponding to the academic year 2008-2009, has been the fourth one. Next, some improvements introduced in the last editions of the MRW are reported. These modifications are related to the first version of the activity. In a particular manner, this section reflects the present day status of the MRW.

Modifications in the Rocket Certification Session

As reported above, among others, we detected the following problems:

- Some altimeters did work adequately.
- Some parachutes were not properly folded by the students.
- Some parachutes did not deploy adequately while the rockets were in flight.

To avoid these problems we decided to introduce some modifications in the MRW. Concretely, we specified new certification requirements for the rockets to obtain the launch authorization during the certification session:

- In order to assess the correct functioning of the altimeters, we included mandatory altimeter tests to be performed during the certification session.
- In order to guarantee the correct deployment of the parachutes during the launch campaign, we included mandatory tests to be performed on the recovery system during the certification session. Faculty should monitor the folding of the parachutes and should provide advice or guidance when necessary, either at the certification session or during the launch preparation.

A New Type of Expert Engineer is Proposed

As previously explained, each member of the team is assigned a different role, each of which has some specific responsibilities. The following expert engineers are those of the first edition of the MRW (Rojas et al. 2008), as this activity was initially designed for teams ideally constituted of four people:

- Mission Engineer (ME).
- Development Engineer (DE).
- Test Engineer (TE).
- Launch Engineer (LAE).

As mentioned before, the number of students for some teams exceeded four members in the first edition, which lead us to think about and create a new role for subsequent editions. This would prevent the number of teams and rockets to grow excessively over a given desired number, and would reduce the possibility of redundancy of roles. The proposed new role was:

- Logistics Engineer (LOE):
    - Leader for tasks related to rocket materials acquisition, storage and retrieval.
    - Leader for tasks related to laboratory equipment well-being maintenance, manipulation and storage.

Modifications in the Evaluation Method

Since the first edition in 2005-2006, there have been significant improvements in many facets, and particularly in the evaluation method. Nevertheless, it is worth saying that the present evaluation method is still coherent with the educational philosophy at EPSC, as was the initial one, i.e. it is based on continuous evaluation.

The main difference between the first and subsequent editions is that, in the latter, each member of the team is assigned a particular mark, so all members in a team may not have the same mark. This difference arose due to the following. We realized that credit had to be given effectively to the achievements of the team as a whole, but also the individual contributions to the team results had to be acknowledged. Consequently, the evaluation method had to allow each student to be graded individually.

The reason for this mark distinction within a group is also that on the one hand, pure team-based assessment might be a disadvantage to the stronger students and also be misused by weaker students. This should be prevented. On the other hand, the grade should reflect the evolution of each particular student during the workshop.

Thus, we still bear in mind the student evaluation criteria reported in a previous section for the first edition of the MRW. Nonetheless, there are some differences and innovations: 1) there have been some important changes in the first criterion, 2) we incorporated new criteria, and finally 3) as mentioned above, we use all these criteria to obtain a particular mark for every single MRW participant. These changes and new criteria are detailed in the following.

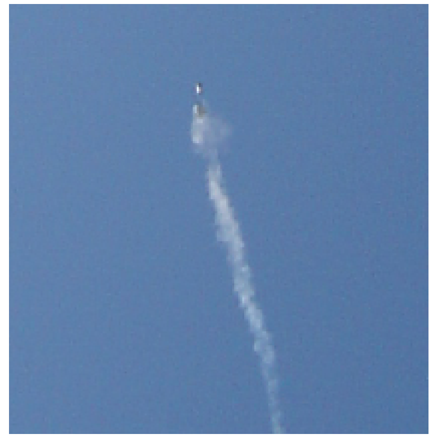
Regarding the first evaluation criterion in the last edition:

- Again, an important part of the mark of each participant depends on the quality of a series of documents that the team has to deliver throughout the course. As mentioned before, the delivery of these reports in this last edition was made through the web tool named Atenea, instead of dotProject. The reasons for the migration from dotProject to Atenea are presented in a later section. The documents to be delivered were the following ones, in chronological order:
    - Report on rocket design and construction operations.

- ◦ Preliminary report on rocket test and certification procedures design.
- ◦ Preliminary report on rocket launch procedures design.
- ◦ Progress report on rocket construction.
- ◦ Preliminary report on rocket flight trajectory results, obtained by numerical simulation of the rocket flight equations.
- ◦ Minutes of Test Engineers (TE) meeting.
- ◦ Harmonized rocket test and certification procedures.
- ◦ Minutes of Launch Engineers (LAE) meeting.
- ◦ Harmonized rocket launch procedures.
- ◦ Minutes of Mission Engineers (ME) meeting.
- ◦ Harmonized rocket test and certification procedures (after revision).
- ◦ Harmonized rocket launch procedures (after revision) (see for instance the ascending phase of a rocket in Figure 6).
- ◦ Rocket technical specification sheet.
- ◦ Final report on rocket flight trajectory results, obtained by numerical simulation of the rocket flight equations, using real updated data.
- ◦ MRW final report.
- ◦ Minutes related to some meetings of experts and meetings of core groups (these meetings have been previously scheduled when planning the MRW activity (see the Gantt diagram in Figure 1)).

In addition to the criteria previously reported for the first edition of the MRW, new evaluation criteria were considered in the last edition:

Figure 6. Rocket in the initial ascending flight phase, where the engine is still operative.



- To be able to define a particular mark for each student, we had to implement some innovations. First, the work done and knowledge acquired by each participant as the activity progressed had to be assessed on a continuous basis. We called this process "peer review". This evaluation was done through observation of:
  - ◦ Doubts raised by the student during and out of class-time.
  - ◦ Work done by the student during on-site sessions.
  - ◦ Answers to questions that faculty posed to the student after the delivery of some documents, during some meetings, etc.
  - ◦ The student performance at the final presentation.
- Second, all students must fill a self-evaluation form[4] the day of the presentation, taking place in the last session of the course. Through this form, the participants rate their team-mates and themselves and answer a series of concise questions confidentially. The list of questions includes, for instance, whether a given team member attended all team meetings, contributed to the activities, met deadlines by the team,

helped in keeping the team organized, cohesive, and progressing toward completion of the goals… and several others. The information provided is very valuable and may give clues to faculty about:
    - The attitude (degree of implication and participation), performance and functioning of each team member.
    - The member who has led the team.
    - Problems that arose during the course of the activity.
- We requested the teams to address new issues within the frame of their presentation and final report, e.g. suggestions, assessments, comments and opinions of students relating to the MRW, in order to improve the development of the workshop, etc.
- Frequently, the performance and initiative of one or more teams during an edition was outstanding, i.e. these teams have done much more work than requested. This has happened at least for one team for each MRW edition. We thought this should be especially taken into consideration.

The goal of the two first new criteria was to enable the monitoring and evaluation of the transfer of knowledge between group members with different roles, and the extent to which the work done and the reports delivered by the team are the result of teamwork, and not the result of the efforts of a single or a few individuals. Alternative or complementary options to allow grading of students individually were also considered. For instance, for the various reports delivered by the team during the teaching unit, each of the students is in charge of fixed duties and responsibilities. Accordingly, an individual grade can be assigned to each of them, although the reports are collective. The minutes of the meetings might also help in assessing student performances.

Finally, to obtain the global mark for a given student, we implemented a weighted mixture of team and individual assessment techniques, assigning 40% of the mark to teamwork, 30% to individual work and 30% to peer review.

Moving from dot Project to Atenea Web Tool

For the correct development of the MRW activity, a collaborative web platform is needed in order to manage the project, share documents, discuss some topics, etc. As mentioned before, the open access dotProject[5] platform was used in the first edition of the MRW activity. This web-based application is designed to provide project layouts and control functions, where a series of tasks can be structured, as well as the schedule associated with them. In addition, the platform provides a set of associated functions such as project planning, contract negotiation, risk management, cost management, task logging, forums for debate, file sharing, etc. Summing up, dotProject is a very user friendly platform to manage the day to day activities of a project progression and can be used by either project managers or down level project workers.

The initial idea was to use this web platform to achieve two main objectives. First, dotProject provides a standardized way of communication between the students (acting as industry) and the teaching staff (acting as the contracting company or customers). In this way, the description and scheduling of each task is presented at the kick-off session using the intrinsic functionalities that dotProject provides (automatic generation of Gantt diagrams, project organization, list of tasks, list of deliverables, file repository, etc). The second goal was to take advantage of the project management features of dotProject. In this context, the students were requested to enter task logs during the execution of the project, to update the tasks status and finally to use the forums to share experiences and doubts and to coordinate efforts, as it would be done in a real professional environment. However, this second goal was not achieved since the students only used the platform to share documentation (deliverables, input documents...) with the teaching staff.

In parallel, at University level, the web platform so-called Atenea was chosen to be the standard application to manage the different courses being taught at UPC. This platform is strongly based on Moodle, the most popular open source Learning Management System (LMS) nowadays. Atenea provides a wide range of tools aimed at a better management and promotion of learning. It is used at and among all the different schools that compose the UPC to conduct fully online courses, to promote blended learning and to establish a standardized and integrated way to exchange information between faculty and students.

For these reasons, and taking into account that the most significant features of dotProject were not being used by the students (partially because of the relatively small size of these projects and the teams involved), we decided to migrate from dotProject to the Atenea web application for the second and subsequent versions of the MRW.

RESULTS OF THE LAST EDITIONS OF THE MRW

Marks of the Students

The marks of the students in the last editions of the MRW have been 8.40 over 10 in average. Although we objectively think that the activity has been improved noticeably since the first edition, the average in the marks has diminished. The reasons for this fact might be the following:

- The level of complexity has aroused as we have been polishing the activity and enhancing the supplied documentation, etc. Thus, the MRW has become more demanding in relation to aspects such as quality, quantity and tightness-to-deadline of the various deliveries and reports, etc.
- Most of the students are still being rated with high marks. The average descent is due to very low marks that are assigned to students who do not show up, or significantly under-perform, etc. These cases are nowadays efficiently detected and assessed most of the times thanks to the modifications in the evaluation method.

Assessments & Comments from the Students

Next, some comments are listed. These come from feedback that was included by students in their final presentations in the last editions of the MRW (for these last editions, we requested them to do so, as previously explained):

- It would be very rewarding to make an important effort to minimize the total mass of the rocket. Namely, the battery (9V for which the mass is 40gr.) and some pieces of the fuselage are very heavy. Some solutions should be searched to reduce them in weight to the benefit of the rocket performance.
- The proper implementation of the recovery system is still problematic for the students (see example of descending phase in Figure 7). Maybe more guidance should be given to students on topics such as the gluing of parachute strings to the fuselage, the positioning of parachutes inside the body, how to correctly fold them, etc.
- Modify the engine bracket so the engine is completely fixed (it had about 5mm of free space).
- Students often complain about the altimeters, since in certain occasion they do not work well. In some editions a couple of altimeters obtained noticeably erroneous data. This issue should be studied in-depth, since the malfunction of the altimeters could be caused by an incorrect assembly

Figure 7. Descending phase in which nose fairing and fuselage glide and are recovered separately.

or disposal and not due to the altimeter itself.

- It might be interesting to keep track of the creative engineering solutions for the technological problems faced by the teams along the different editions. This way, we would detect which are the most common solutions, how students think and solve the problems, etc. This information sure would be important and helpful for the enhancement of the MRW and the formation of future students.

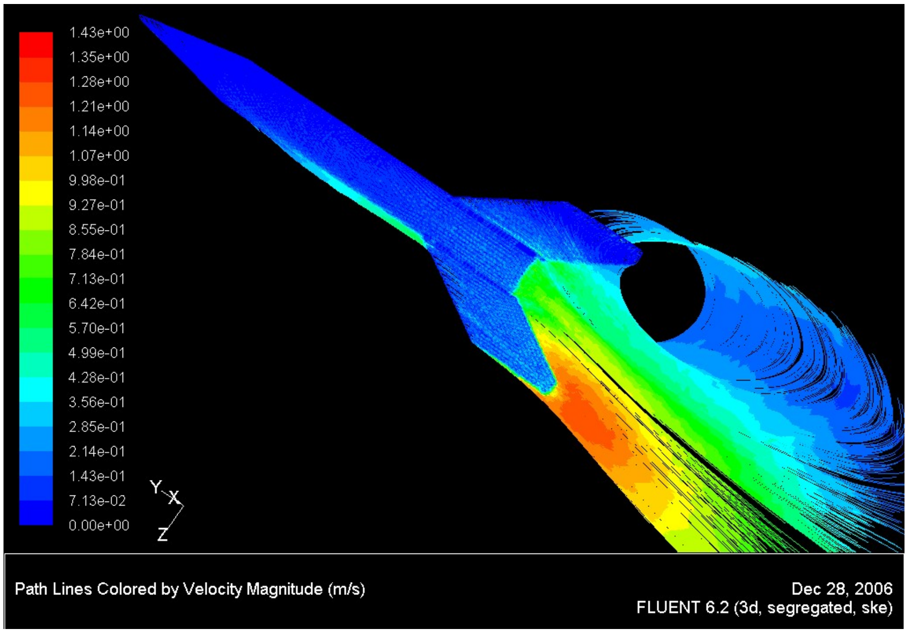
Problems Detected & Lessons Learned

A significant problem from our standpoint is that the launch campaigns often tend to evolve a bit anarchically. That is, even if there is an important work and organizational effort prior to the launch session (e.g. preparation of the harmonized rocket launch procedures), these sessions often turn into a small chaos. We should think of new ideas to guarantee that these sessions are conducted in a systematic and methodical way.

Some lessons were also learned from the past editions of the workshop:

- Some students and teams often perform complementary and/or un-requested work (e.g. CFD (Computational Fluid Dynamics) analysis of the rocket (see Figure 8), comparison of the trajectory simulation results with data obtained by other means like open access software (the Rocket Simulator[6]), etc.). This shows that they were really interested and motivated by the activity.
- Some teams elaborate excellent reports and complete a great work. This is a proof that the nature of the activity fosters the motivation of the students.
- Small groups of students perform better than big groups where two or more people assume the same engineer role. Thus, from our point of view it is highly recommended to stick to group sizes such that there is only one student per engineering role and exceptionally two people in the case of the Mission Engineer. In the last edition of the MRW it was preferred to form more groups (more rockets to be launched) rather than increasing the number of members per group. In our opinion, when a particular Engineering role is assigned to two or more students they do not commit with their responsibility as much as they would do if they were the only person assigned to that role. Regardless the fact that all the activity is strongly based on a team and that cooperative work is paramount, the fact that each student assumes an Engineering role implies that they assume as well a responsibility within the group and the quality of the cooperative work is improved.
- The continuous effort of the faculty members (improving the quantity and the quality of the documentation provided to students year by year) is also another key element for the incremental success of the activity. The unification of the documentation and an improved scheduling of activities and milestones have proved to be very important for a more correct and efficient evolution of the activity. The preparation of such detailed documentation involves a

Figure 8. Plot of path lines colored by velocity magnitude (in meters per second) obtained after a CFD (Computational Fluid Dynamics) analysis of a rocket (credit: this figure was obtained using Fluent© CFD[7]).



significant initial workload for the faculty. It is worth paying special attention when elaborating this documentation in order to eliminate the large amount of potential misunderstandings and to minimize the tedious job of solving them for each group.

ADAPTATION OF TEA TO PBL METHODOLOGY

This section contains a brief description of the activities within TEA, the course that MRW belongs to, and some ideas that the authors are considering in relation to them. As mentioned before, these ideas aim at expanding the MRW so it embraces the totality of the activities that constitute TEA at present day. As a consequence of the inclusion of these activities in the MRW, TEA would become a new course entirely under the umbrella of PBL.

Description of the Activities within TEA

Aside from the MRW, there is at present day a myriad of smaller independent activities included within the course called TEA. In principle, none of these activities is linked to the MRW in any way. Next we depict briefly all these activities:

- Fluid mechanics and aerodynamics workshops: to recall and enhance their knowledge on these subjects, the students perform an extensive series of hands-on activities. In the following, a list of these activities is presented:
    - Point measures in the fluid field: this activity consists in measuring physical and dynamical properties of a fluid. In particular, in the frame of this session the students perform the following tasks:

        - Analysis of experimental data of laminar and turbulent flows.
        - Direct pressure measurements.
        - Basis and utilization of a Pitot tube.
        - Pressure drop measurements.
        - Flow rate measurements.
    - Visualization of fluids: in this session several fluid visualization methods are described:
        - Particle image velocimetry.
        - Shadowgraphs.
    - Anemometry and velocimetry: this session consists of the following:
        - Description of hot wire anemometry and laser Doppler anemometry.
        - Measurements using hot wire anemometers in a wind tunnel (see picture of the wind tunnel in Figure 9).
        - Measurements of the average and turbulent velocity component in an airfoil wake.
    - Experimental measurement of aerodynamic performances of several models (e.g. NACA airfoils and a cylinder) in a wind tunnel.
- Hardness and tensile stress-strain tests: the students perform, in respective sessions, hardness and tensile stress-strain tests on samples made of several representative engineering materials (e.g. aluminum, copper, iron, steel and tin). Through the realization of these hands-on activities two goals are achieved:
    - The students learn the basis of the functioning and operation of a hardness tester and a Universal Testing Machine (UTM).
    - The students recall theoretical concepts and knowledge on materials' properties acquired in the frame of a previous course: Materials Science and Technology.
- Mechanics of gyroscopes: this is an introductory activity on mechanics of gyroscopes. It consists of a brief explanation on gyroscopes followed by a hands-on activity aiming at describing precession and nutation.
- Thermodynamic cycles: within this hands-on activity the students perform the following:
    - Review the Stirling cycle.
    - Record pressure and volume along the cycle.
    - Compute the mechanical work and the total power of an engine.
    - Compare the performances measured experimentally with the theoretical predictions.

Description of New Ideas & Future Work

The authors are considering the following ideas in relation to activities belonging to TEA:

- Fluid mechanics and aerodynamics workshops: as mentioned above, hands-on activities about fluid mechanics and aerodynamics are being performed nowadays as part of TEA, based on the use of a wind tunnel and other experimental equipment. These activities might be slightly redefined such that their particular contents become part of the MRW. The following possibilities are being considered in this sense, namely:
    - The student model rockets, once built, could be tested in the wind tunnel, instead of the models that are tested at present day in TEA, that is, instead of the NACA airfoils and the cylinder. The aim of these tests would be to characterize the aerodynamic

Figure 9. Picture of the wind tunnel for aerodynamic testing at the Aerospace Laboratory of the EPSC.

performances of the rockets, for instance the lift, drag and pitching moment coefficients. To perform the preliminary simulations of the trajectory, which take place before the rocket construction, students would use a drag coefficient provided by the faculty as initial data. Then, after the rocket construction and testing, they would use the drag coefficient and other data experimentally determined to refine their calculations and perform the final accurate simulations.

◦ The students could use CFD software to characterize the aerodynamic performances of the rockets. Once the rocket has been designed and the coefficients have been calculated by this CFD analysis, they would use the data obtained by these simulations to compute the final accurate calculations of the trajectory.

These ideas can be implemented independently. Nevertheless, performing both experimental tests and CFD analyses to double-check the results would be a price-less educational asset to the benefit of the students.

- Hardness and tensile stress-strain tests: these tests might be easily included in the MRW by means of slight modifications only. There exists a variety of possibilities, for instance:
  ◦ The tests may be performed by students on samples made of materials that they are using or will actually use to build their model rockets (e.g. marquetry wood, polymers).
  ◦ The tests may be performed by students on samples made of other

materials (e.g. aluminum, composites, copper, iron, polymers, steel and tin) as if they were used in the model rockets, or as if they were from a real rocket launcher and actually had a structural application.

In any case, the students would proceed as if they were engineers from the Materials Department of their aerospace company. They would have to test the as-received materials to ascertain their mechanical properties and to verify that they fit to standards so that they will behave properly during their operational life.

- Mechanics of gyroscopes: again, this activity could be made part of the MRW by simply making a few changes. Namely, it could be reformatted such that, first, the fundamentals of rocket launchers' Attitude Control Systems (ACS) (e.g. space Inertial Navigation Systems (INS), Inertial Reference System (IRS)) would be explained in-depth to students. Second, this knowledge would be complemented when performing the practical experiences with the gyroscopes, which would be similar to the ones that students face at present day in TEA.
- Thermodynamic cycles: in this case, it might be more complex to adapt the actual hands-on activity such that it fits the contents and goals of the MRW. The reason is that the Stirling cycle and the Stirling engine have no relation to rocketry and launchers. Hence, a complete reformulation of the activity would be necessary. For instance, the session could be adapted in such a way that the fundamentals of rocket launchers' propulsion systems and space propulsion systems (e.g. solid, liquid and hybrid chemical propulsion) would be thoroughly explained to students. Afterwards, this knowledge would be put into practice by students by performing a set of hands-on activities.

Other important issues, ideas or modifications that should be addressed in the short-term are listed below:

- Modify and update the requirements relating to the rocket motion equations integration and simulation process. For instance, it would be interesting to assess the functionalities of the Rocket Simulator freeware. If feasible, it could be worth proposing the students to realize a comparison between the trajectories they compute numerically and the results obtained by using this open access software.
- It is necessary to redesign, rebuild and improve the present launch pad, since it is seriously degraded.
- Students often complain about the altimeters, since in some occasions they do not work properly. In some editions a couple of altimeters obtained noticeably erroneous data. This issue should be studied in detail, since the malfunction of the altimeters could be caused by an incorrect assembly or disposal and not because of an instrument error.
- Since the very beginning of the MRW, we consider that the batteries for the altimeters are too heavy (also students commented on that). Several ideas to counterbalance this problem are:
    - To increase the power of the rockets. So far, we have used rocket engines of category F, for which the maximum take-off weight is around 180 g. We could use category G engines, since still no license is needed for rocket engine operation in this case. Nonetheless, we should take into account that higher altitudes may be more dangerous depending on the

launching site and may require authorization from the civil aviation authorities.

- ◦ A circuit could be implemented such that smaller batteries could feed the altimeter.
- ◦ We could request the students or the University technical support team to design and build a cheaper, better altimeter.

Obviously, the implementation of all these new modifications represents a significant workload and would require an important coordination effort in order to schedule all activities in an optimum time. At present day, the activities that do not belong to MRW are almost scheduled randomly. Exception is made for the ones relating to fluid mechanics and aerodynamics.

CONCLUSION

The evolution of an initially limited-range practical experience within the frame of a given subject, in an aerospace engineering degree, is described in this paper. The original activity was the Model Rocket Workshop, which was successfully implemented within the Aerospace Engineering Program of the Escola Politècnica Superior de Castelldefels, belonging to the Universitat Politècnica de Catalunya. Within this practical experience, students design, simulate, build, test and launch a small model rocket. Also, students compare the theoretical results for the trajectory obtained by numerical integration with the experimental readings of altimeters on-board the rockets. The workshop is an experience based on cooperative learning and PBL, covering a wide spectrum of educational aspects, and that allows students to become familiar with the development and different phases of a space mission.

In addition to the description of the original workshop and its organization, the proposed case shows some problems that the designers have encountered while conducting the activity. Some modifications and improvements to solve these problems are also described, as well as several of the learned lessons. For instance, the authors review the evolution of the methods of evaluation, the educational results (student ratings) and some comments and assessments from the students, collected along the several editions. Finally, a series of new ideas related to the workshop and to the course it belongs to are presented. The objective is to expand the MRW so it embraces the totality of the activities that constitute its mother-course at present day.

As final conclusions we would like to emphasize that first, students are in most cases really interested and motivated by the activity. It fosters their creativity and initiative, while also improving their transversal skills. As a consequence, they often elaborate excellent reports and realize a great work. Second, a great sustained effort is necessary from the faculty members to ensure the success of the activity.

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KEY TERMS AND DEFINITONS

Altitude Control System (ACS): Spacecraft on-board system responsible to maintain its own correct orientation. These devices consist of a set of measurement devices, an active control system and one or several actuators that can induce movements to the spacecraft in order to point it towards the desired direction or orientation.

Computational Fluid Dynamics (CFD): Software package that uses numerical methods to solve problems involving fluid flows, like for example, the study of an airfoil.

Group Puzzle: Type of teaching activity where the tasks to be completed to achieve a specific goal are split into several independent parts, so every member of the team is responsible for one of these parts. Then, it is said that every team member has a different role, or that each member is the expert in relation to a particular topic. This kind of activity is usually found in Problem Based Learning courses.

Inertial Navigation Systems (INS): Navigation or positioning system that uses accelerometer sensors to continuously measure the acceleration that an aircraft or spacecraft is experiencing. From these measurements, the velocity, the orientation and the position of the aircraft/spacecraft can be drawn by the aid of some computational calculations.

Model Rocket Workshop (MRW): Activity that the authors propose in this work consisting into building a small model rocket as a central element in a Problem Based Learning teaching course.

Problem Based Learning (PBL): Learning strategy in which students solve one or some problems in a collaborative way. Students are separated in a few groups and the teaching staff gives them guidelines and a framework for the problem. Then, each group is responsible for organizing themselves and finding the way to solve the problem(s) with the support of the teaching staff.

Universal Testing Machine (UTM): Machine tool that allows testing the tensile and compressive properties of different materials. The applied force and the deformation on the material are measured and, in this way, the mechanical properties of the test sample can be drawn.

ENDNOTES

[1] http://www.ganttproject.biz
[2] http://www.mathworks.com
[3] http://www.perfectflite.com
[4] http://clte.asu.edu/active/team.htm
[5] http://www.dotproject.net
[6] http://www.rocket-simulator.com
[7] http://www.fluent.com

APPENDIX

LIST OF ACRONYMS

ACS: Altitude Control System
CFD: Computational Fluid Dynamics
DE: Development Engineer
EE: Expert Engineer
EPSC: Escola Politècnica Superior de Castelldefels
INS: Inertial Navigation System
IRS: Inertial Reference System
LAE: Launch Engineer
LOE: Logistics Engineer
MRW: Model Rocket Workshop
ME: Mission Engineer
PBL: Problem Based Learning
TE: Test Engineer
TEA: Teaching unit dealing with experimental techniques in Aerospace Engineering, which is called *Tècniques Experimentals en Aerofísica*
UPC: Universitat Politècnica de Catalunya
UTM: Universal Testing Machine