The CAMAQ project: a virtual immersion in aerospace industry practices

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ABSTRACT: Initiated under the impulse of the Centre for Aerospace Manpower Activities in Quebec (CAMAQ), the *CAMAQ project* represents a unique *Conceive – Design – Implement – Operate* (CDIO) learning experience for the training of aerospace engineers. Each year since 1999, some 15 students work on the redesign of an aircraft pylon to allow the retrofit a new engine to the existing fuselage. In order to accomplish their task, they dispose of a dedicated workspace located at École Polytechnique, Montréal, Canada, which offers a teaching laboratory, meeting rooms, and access to digital mock-up and product lifecycle management technologies. The three industrial partners supervising the project – Bell Helicopter Textron Canada, Bombardier Aerospace, and Pratt & Whitney Canada – provide the team with a complete heritage design information package, which includes technical standards, existing CAD parts and assemblies, and certification regulations. Overall, the authors outline in the article how the CAMAQ project successfully trains innovative systems integrators to utilise standard engineering and manufacturing practices typically deployed in the aerospace industry.

INTRODUCTION

The defining of the 21st Century aerospace industry has triggered many challenges in terms of training and developing new skills and practices. The emergence of a global competitive market has imposed new demands for aerospace engineering education, as reported by Crawley in the *Conceive – Design – Implement – Operate* (CDIO) syllabus [1]. In order to counter the negative effects of this new trade environment, coupled with the aging of the workforce and the availability of new information systems, aerospace companies have singled out the need to implement *wise* teaching strategies. The *CAMAQ project* presented in this article is an innovative training scheme in the field of aerospace engineering. This hands-on project was developed under the impulse of the Centre for Aerospace Manpower Activities in Quebec (CAMAQ), IBM and three large aerospace companies based in the region of Montréal, Canada, namely: Bell Helicopter Textron Canada, Bombardier Aerospace, and Pratt & Whitney Canada. The CAMAQ project selects some 15 students to redesign a pylon for the retrofit of a Pratt & Whitney Canada engine to a Bombardier Aerospace aircraft fuselage.

The CAMAQ project answers at least two major preoccupations outlined by employers in the aerospace industry, reported in sections 4.2, 4.3, 4.4, and 4.5 of ref. [1]. It exposes students to current industrial practices that are not usually experienced by engineers before several years of work in the trade and it demonstrates the impact of strategic new information technologies utilised by aerospace product development teams. This novel educational experience has become part of the mechanical engineering curriculum strategy at École Polytechnique and other universities that form part of the CAMAQ initiative– the Virtual Environment (VE) option – directed towards familiarising students with virtual product development technologies and methodologies [2].

The VE teaching scheme at École Polytechnique aims at representing aerospace industrial realities and developing soft skills, such as project management, communication and leadership, within this new digital environment. As illustrated in Figure 1, the current version of the VE option includes two courses and the CAMAQ project, a two-semester capstone project. The first course, *Integration of Design and Manufacturing*, covers the concurrent engineering methodologies and technologies required to develop a complex product in an industrial setting. The second course, *Project Management in Aerospace Engineering*, comprises a number of topics related to project workflow, specifically: risk management, certification issues, project planning and control, and manufacturing issues.

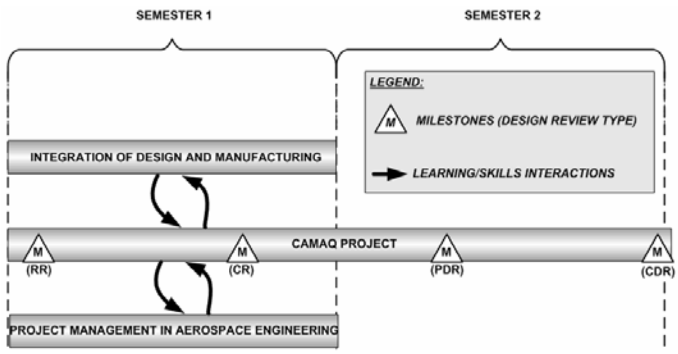

Figure 1: Structure of the virtual environment option.

In order to accomplish their task, the students participating in the CAMAQ project dispose of a unique VE laboratory, located at the École Polytechnique, Montréal, Canada, which offers access to state of the art digital mock-up (DMU) and product lifecycle management (PLM) technologies. Students are also encouraged to utilise the latest communication technologies, such as videoconferencing, in order to gain experience in new collaborative environments. Prototyping facilities are also at students' disposal so that they can produce and visualise the final design in a solid form.

The VE laboratory is a true representation of the digital setting in which aerospace engineers are working today. Full DMU management, along with document and configuration management of the product definition, are possible within this environment. It is composed of classical design and analysis tools (eg CATIA V5, ANSYS, etc.) managed by the latest PLM modules: ENOVIA VPM from Dassault Systèmes for Product Data Management (PDM), and Polyplan for Manufacturing Process Management (MPM). These technologies facilitate the concurrent development of products and their manufacturing processes within an integrated and secure environment. Indeed, the systems are configured to protect the confidential and proprietary data (drawings and CAD files) provided by the industrial partners, which is made available only to those students involved in the CAMAQ project.

This authors now outline the skills and experience gained by students within this unique teaching environment. The description of the CAMAQ project is then complemented by selected comments from students and supervisors that underline the success of this high profile educational initiative.

DESCRIPTION OF THE CAMAQ PROJECT

The CAMAQ project is a *design and implement* assignment where a single group of students must retrofit a Pratt & Whitney Canada engine on a Bombardier CRJ700 aircraft. The students involved in the project come from varied cultural and educational backgrounds; they are usually graduate students enrolled in one of the aerospace engineering Master's programmes offered in the province of Quebec.

At the beginning of the first semester, the industrial experts representing each company dispatch all the necessary information required to complete the project, ie standards, company guidelines, design manuals, aircraft and engine geometries, CAD models, 2D layouts, certification regulations, etc. They also present the Statement of Work (SoW) and the Technical Requirements Document (TRD), which define the requirements for the development of the flight ready prototypes including the expected deliverables for each design review.

The following paragraphs present the organisation of the project and detail past student achievements according to four essential learning objectives singled out by the industrial participants of the *2nd North American CDIO Meeting* in Dulles, DC, during October 2005. These includes concurrent engineering and project management practices, certification and testing issues, design integration of structures and systems, and manufacturing and prototyping considerations.

Organisation of the Project

The project is monitored by four formal design reviews (shown by the milestones in Figure 1), namely: the Requirements Review (RR), the Concept Review (CR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). This recalls the aerospace product development control process, composed of formal design reviews, which guides the organisation of large engineering teams and verifies the quality of the work achieved [3]. During these meetings, students are required to submit a detailed report and to formally present the work to the industrial partners who will asses the progress and approve important issues in collaboration with the teaching staff coaching the project team.

During the first three weeks, students have to prepare the RR. This involves reading the documentation, detecting missing or conflicting information and data, and deciding how to organise the team to produce the new pylon. At the RR, students must present a schedule for the entire project, a detailed planning of the engineering activities up to the CR, the team organisation to fulfil the tasks and a draft of the cost management plan. For the CR, students have to present the various concepts explored with their advantages and disadvantages, their concept selection process with a detail of the evaluation criteria, a risk assessment plan that identifies the major risks and their mitigation, and any adjustments made to the project schedule or budget.

In the second semester, the adopted solution is presented at the PDR. A first estimation of the product cost and weight is made, and analyses of critical parts and systems are presented. A configuration methodology must also be discussed with the partners.

At the end of the second semester, the final report and a prototype of the structural elements of the new pylon are presented at the CDR. Over the last two years, the CDR presentation has taken place at one of the industrial sites. In the morning, the detailed design is reviewed for three hours. In the afternoon, an executive version of the project is presented to senior management staff of the participating aerospace companies. This new event has proven to be an ideal opportunity for students to meet their future employers and for the CAMAQ project to expose its significant value as a new and successful training scheme for system integrators in aerospace engineering.

Concurrent Engineering and Project Management Practices

At the start of the CAMAQ project, the team needs to organise itself in order to manage and accomplish the various tasks implied by the SoW and the TRD. This means that the participants must agree on a hierarchy of responsibilities, a decomposition of the problem into Domains of Competence (DoC), and a set of working practices, which follow typical Integrated Product Team (IPT) requirements.

The organisational structure of the CAMAQ project team can vary from one year to another, but the following roles and responsibilities are usually observed: a project leader, an assistant to the project leader, a communication manager, and a team leader for each DoC (structure design, systems design, certification/airworthiness, manufacturing, configuration management, etc). Because of the relatively small number of participants, a student can effectively shoulder several roles in the project; students undertaking project management responsibilities are also encouraged to take on a role in one of the DoC. Finally, the academic supervisors help to compose the DoC teams by submitting students to a MBTI test [4].

The project management team must learn to master four management tools commonly deployed in industry in order to ensure concurrent engineering, specifically: GANTT charts for planning activities, project roadmaps to monitor engineering processes, a risk management plan to evaluate and mitigate risks, and a budget evaluation sheet to monitor provisional costs.

Project planning is based on a formal decomposition of the product development process, where the design reviews mentioned previously separate the project into four phases. Deadlines are set according to the various deliverables defined by the industrial supervisors in the SoW and TRD. The provisional budget must be revised and presented at each design review. Students must take into account the labour costs, the prototyping and tooling costs, and the costs of the expertise provided by the industrial experts (review time and e-mails). The SoW defines a limit for the overall budget and the team must respect it throughout the project.

Project and team management are probably the most difficult aspects of the CAMAQ project because students have little experience in this field, which requires strong communication and *people* skills.

Certification and Testing Issues

Since the notions of airworthiness and certification are new to most students, the group of students must nominate a dedicated certification team. Theoretical aspects of the certification process, a major constraint in aerospace engineering activities, are introduced during the lectures proposed in the *Project Management in Aerospace Engineering* course. Students are guided through all the formal procedures that have to be followed in order to certify an aircraft and speakers from the industry provide pertinent industrial examples for each product development phase. The principles and mechanisms taught during the lectures are then put into practice in the CAMAQ project.

The overall objective of the certification team is to review airworthiness issues and produce a General Compliance Plan (GCP). This document, a standard industrial practice, compiles the list of applicable regulations that constrain the product development activities (design, manufacture, assembly and validation of parts and systems). Therefore, the work of the certification team consists in studying the applicable Federal Aviation Regulation (FAR) sections, compiling the rules required for the redesign of the pylon and disseminating them to the structure and systems team.

The Design Integration of Systems and Structures

The core engineering tasks involved in the redesign of the pylon, which links the Pratt & Whitney Canada engine to the Bombardier Aerospace aircraft fuselage, are managed by two teams: the structure team and the systems team. These carry out the essential design and analysis activities related to the development of new parts of structural and system assemblies. Figure 2 illustrates the structure of a new pylon and the essential systems involved in the redesign.

Hence, the structure team is in charge of designing and analysing the structural elements of the pylon. This task has four major constraints, ie the outer shape of the pylon cannot be modified (aerodynamic lines are fixed), the changes made to the existing structural elements must be minimised and the weight must be kept to a minimum (an overall target weight is fixed for the entire pylon). The design is carried out on CATIA V5, but a number of analyses are also requested, such as loads, stress analyses for parts and fasteners, thermal analyses, the impact of rotor burst calculations, engine bearing seizure analysis, vibration and fatigue calculations, etc. The analytical activities usually involve specialised calculation tools like ANSYS, CATIA simulation modules or company design manuals.

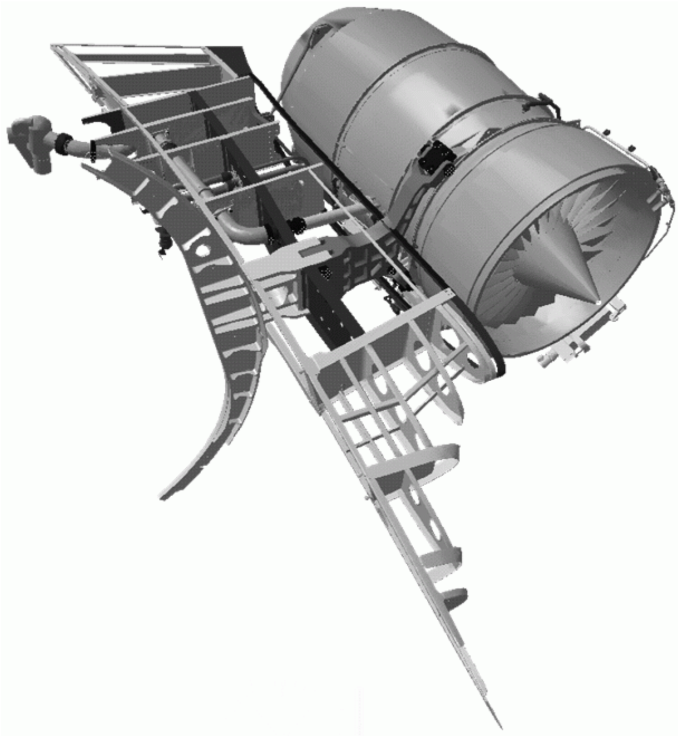

Figure 2: Illustration of the structure and associated systems involved in the CAMAQ pylon retrofit project.

The systems team must redefine the routing of several major systems that pass through the pylon, namely: fuel lines, bleed air ducts, electric wiring, hydraulic lines and the deployment of a new firex system. The major constraints for the systems design tasks are as follows: respecting safety regulations, the use of standard parts and assemblies, minimising the overall weight of the systems, the use of existing connectors at both interfaces (engine and fuselage) and the accessibility for maintenance purposes. Just like the structural components, the systems are designed using CATIA V5 and a number of performance analyses are also requested, including fuel and bleed air pressure loss analyses, bleed air thermal analysis, bleed air duct vibration analysis, etc.

The whole virtual product is, therefore, composed of a vast amount of CAD models, analytical data, etc, and the project team as a whole must develop and agree upon an effective configuration and change management plan. These guidelines and procedures reviewed by the supervisors are essential for students to work collaboratively with large amounts of data. Version tracking, naming conventions and the definition of user roles are some of the configurations and change management aspects taught in the *Integration of Design and Manufacturing* course that students can put into practice during the CAMAQ project.

The structure and systems teams also need to learn to work closely together and a good communication process between both parties is essential to the project's success. Indeed, the solutions proposed by the students involved must seek the best compromise between the structure's stability and performance, and the systems' safety and accessibility. Of course, all the designs and choices of materials are also trade-offs between minimal weight and minimal cost. Both teams are jointly responsible for the design of the firewall and access panels. While the firewall acts as a major constraint for the systems routing, the access panels must be carefully placed in order to enable access inside the pylon to connect the systems, retrofit new parts or perform any necessary maintenance duties. Once the pylon and its systems are completely designed, students are asked to demonstrate the overall accessibility using the DMU and a virtual dummy mock-up test.

Manufacturing and Prototyping Considerations

The manufacturing concerns, which are an important part of the CDIO Syllabus content, represent an important dimension of the project [1]. The student team must provide detailed retrofit and assembly process plans for their solution and the manufacturing process for the machining of a major component of the new pylon must be defined. The fundamental manufacturing process, which can include forging, casting or complete machining from a solid stock, must be justified along with its corresponding detailed instructions. The total retrofit and manufacturing cost is calculated from these detailed instructions.

A prototype is manufactured at the end of the project with a 3D printer prototyping technology. This prototype is used at the CDR to discuss some of the design features of the final design with senior engineers. Even though students do not build a complete prototype of the pylon, the detailed definition of the manufacturing processes brings the *design and implement* dimension to a significant level.

FEEDBACK FROM STUDENTS AND INDUSTRIAL SUPERVISORS

It now seems important to let past participants describe the CAMAQ project with their own words. Here are some of the comments made last year by the students who participated in the project:

- *The CAMAQ Project is the most ambitious project I ever had during my studies at École Polytechnique. I discovered multiple aspects related to the development, validation, and certification of aerospace products. This experience will certainly be useful for my future profession* (Philippe, CAMAQ structure team, April 2005).
- *I think the project was a great experience. I learned a lot of new things. At the beginning of the project, I didn't know what the FAA or JAA were, and now I know how an aircraft is certified. With the group we had, I experienced working with many different cultures at the same time, and I also learned how important team communication can be* (Sokthy, CAMAQ certification team leader, April 2005).

Finally, with the aim of continuously improving the CAMAQ project's *design and implement* experience, a survey was carried out in 2005 to gather feedback from the industrial supervisors and other professionals who observed the CAMAQ design reviews. Below are some of the comments received by the authors:

- *Good luck with this program, I believe that for most engineers, this program is much more valuable than an MBA. I would like to see this sort of program an inherent part of engineering degrees. No MSc should be granted without having gone through a project along these lines. I guess I'm converted!!!* (Ron, 39 years experience in the aerospace industry).
- *Based on my experience to date, I find this an exceptional learning process for those who participate, both from the industrial and academic point of view. The quality of students graduating from the CAMAQ program is very high* (Warren, 10 years experience in the aerospace industry).

CONCLUSION

The Virtual Environment option developed at École Polytechnique, in collaboration with the CAMAQ organisation, three aerospace companies and four other universities from the Canadian province of Quebec, has evolved over the years as a proper training environment for system integrators in aerospace engineering. Significant efforts are required in order to develop and maintain the technologies and academic syllabus of this specific option. However, the results of the last eight years have conclusively demonstrated the viability and added value of the programme, which develops many of the outcomes, defined in the CDIO Initiative and, therefore, successfully trains engineers to develop complex products in a collaborative environment using modern concurrent engineering processes.

ACKNOWLEDGEMENTS

This initiative has been made possible with the financial support of the Centre for Aerospace Manpower Activities in Quebec (CAMAQ), which funded the Virtual Environment Laboratory in collaboration with Bombardier Aerospace, Pratt & Whitney Canada, and Bell Helicopter Textron Canada. The strong financial support of IBM and also of Polyplan Technologies, now owned by PTC, has also been important for the implementation of the various software solutions in the laboratory. The authors would also like to acknowledge the internal support of the Fonds de Renouvellement des Approches Pédagogiques dans les Programmes (FRAPP) of École Polytechnique. This programme provided major financial support to develop and adapt the various laboratory sessions in each of the three Virtual Environment courses mentioned in this article.

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