Collaborative Space Design project: A student's experience

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Abstract

The student members of the Collaborative Space (systems) Design (CSD) project discuss its implementation and highlight its concepts. The CSD project is an elective course at the MSc Space Flight programme at the Delft University of Technology, Faculty of Aerospace Engineering, where students exercise the design process of a space mission, spacecraft or a major spacecraft subsystem in a team setting, along with several important external stakeholders. Focus was given to the application of concurrent engineering and systems engineering techniques. Interaction between the students and the external stakeholders was also extremely valued. Two teams participated, one designing a liquid oxygen electric pump and one a CubeSat asteroid observer mission. In this work the students report their experience, highlighting how they approached the different phases of the design process. Positives and negatives of the course are also presented, together with some feedback on potential modifications to future editions of the course.

Keywords

Engineering, Space, Education, Design Project

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Acronyms/Abbreviations

All used acronyms and abbreviations used in the following paper are listed in alphabetical order, as follows:

CAO	*CubeSat Asteroid Observer*
CSDP	*Collaborative Space Systems Design Project*
DARE	*Delft Aerospace Rocket Engineering*
ECTS	*European Credit Transfer System*
EP	*Electrical Pump*
ESA	*European Space Agency*
LOX	*Liquid Oxygen*
RPM	*Revolution Per Minute*

1. Introduction

This paper wants to highlight the experience, from a student point of view, of a method, performed, during the academic year 2020/2021, in the first edition of the Collaborative Space Systems Project Design (CSD) course of the MSc program at TU Delft Aerospace Engineering faculty. It is based on concurrent engineering, which is a work methodology that emphasizes the simultaneous performance of different tasks, within the group. This course offers students the unique possibility to get engineering design experience through engineering design projects within the space engineering field.

In the CSD course, focus lies on simulating a potential future realistic career situation, where a design project is executed for a certain customer. The primary goal is to acquire concurrent design skills and abilities in a teamwork setting, while also taking into account system engineering aspects like stakeholders, requirements, planning and costs among others.

The experience this course offers is very different from the rest of the courses given in the MSc program. While the whole theoretical knowledge is meant to be already obtained by the student himself from previous courses and their theoretical lectures, the practical knowledge is to be acquired, practicing what has been taught earlier. It is not only meant as manually build something, but also, and especially, differently from all the other courses, in terms of both being in contact with stakeholders and clients interested in the project and working, within a team, on multiple aspects of space engineering.

Two student project teams were given an assignment by their respective customers. Main interactions with the customer at the beginning of the project were several iterations on product requirements and constraints. Later these were followed by design reviews. In the end a design deliverable and report were supplied. Each team had their own supervising professor, providing feedback content-wise and coaching on concurrent design processes. In one of the two projects, the customer and supervisor coincided, and the professor had to simulate two different roles. In the other case, professors were just supervisors, while a company was the true customer.

Within the two teams, expectations were the learning of how to design a complex dynamic mechanical system as part of a rocket engine experiencing the full design process on the one hand, and on the other one, acquiring engineering skills on how to design a space mission from scratch.

The following paper is organized in such a way that it introduces the student experience of this new Collaborative Space Systems Project Design course with its general organization and then explains, in chapter 2, the design phases adopted by both teams such as problem introduction meeting with clients, problem exploration and literature study, the generation of requirements, the concept creation and trade off, and the design reviews. Furthermore, there are the recommendations for future steps, in chapter 3 that should be followed to make the best out of this innovative and promising new educational method. In chapter 4, a few things have been reported also with regards to the changes done for the course in this new academic year. Conclusions, with a very brief summary, are then reported in chapter 5.

2. Design Phases

This section will describe the course organization structure and given tools, to then proceed further into the different design phases of the two projects.

2.1. Organization and Tools

The course setup has already shortly been discussed in the introduction. The two teams were given a design problem by a customer, who in the end expected a solution and certain design deliverables. Supervision was done by professors and internal supervisors which provided technical feedback on engineering quality, work approach and engineering support.

Next to the professors, the teams also had a SCRUM supervisor. SCRUM is a framework for project management in a complex environment or team [1]. Team members divide their work into smaller parts called sprints, often two weeks in length or shorter. At the end of each sprint, completed work is shared with all stakeholders, and then the sprint is reflected for improvements in the next one.

Along with SCRUM, another given tool was CDP4. This engineering tool is meant to support and facilitate multidisciplinary design teams in complex concurrent design challenges [2]. The tool is primarily used to keep track of design variables and their correlations for all team members. Design requirements and constraints are monitored to maintain compliance with changing variables in the design process. Variables can be connected with other design programs like SolidWorks. Updated variables in the process are then linked back to CDP4 and can be shared online with other team members, after which the variables in their design programs are automatically updated. This program is also used by ESA and other institutes in their multidisciplinary projects.

Furthermore, the Collaborative Design Lab (CDL) was facilitated as working environment on the Aerospace faculty. This lab is equipped with all needs for such concurrent design projects like the one undertaken by the teams. The lab includes a large audio system room with many working spaces, several interactive whiteboards, equipped with Starleaf software, projectors, cameras and microphones that also facilitate online meetings. A visual representation of the course organization and tools can be seen in Figure 1.

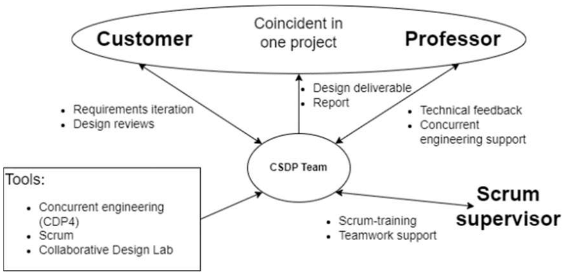

Figure 1. CSDP course structure

2.2. Problem introduction

A kick-off session was held for both the CSDP teams to introduce the students to their projects, to provide them useful tools to be used as a support to their work (like SCRUM and CDP4), and mostly important to present them to their customers.

The first team, formed by four students, was chosen to perform a preliminary design of an electrically driven centrifugal liquid oxygen (LOX) pump for Project Sparrow's Firebolt engine, developed by Delft Aerospace Rocket Engineering (DARE) [3]. The aim of Project Sparrow (DARE's flagship project) is to produce a liquid bipropellant rocket engine 'Firebolt' capable of delivering 14 kN of thrust, running on liquid oxygen (LOX) as oxidiser and ethanol as fuel.

The actual customer for the EP project was a member of DARE who was closely following the team and planning weekly meetings to keep track of the progress made. The students were mostly interacting with this person, with less frequent meetings with the complete DARE Firebolt team to discuss important points of the design phases. Along with the customer, the students were also introduced to an internal supervisor from TU Delft, whose role was to guide and advice the group on the design choices. Meetings with the supervisor were more frequent (also twice a week when necessary) and more informal than the meetings with the customer.

The second team of four students was chosen to design a CubeSat asteroid observer mission. Asteroids are of great interest to the scientific community. Thus, the design of a relatively cheap and quick (in terms of development time) mission to a near-Earth asteroid would open many opportunities to scientists and allow engineers to test state-of-art instruments in the space environment.

The solution to such a challenge is a CubeSat mission. A team of four students was tasked to design a CubeSat mission with the appropriate payload for observing a near-Earth asteroid. The main challenge of the mission was that the CubeSat had to be a standalone spacecraft in deep space. There are not many examples of CubeSats used for deep space missions. The large distance between a spacecraft and Earth combined with the limited capacity of a CubeSat put significant constraints on the mission design.

This project did not have an actual customer. The main stakeholder of the project was TU Delft. Every week the progress was presented to three TU Delft professors and experts who would provide the feedback and guidance for the next steps. These people represented the customer and were the team's supervisors simultaneously.

2.3. *Problem Exploration/Literature Study*

The first part of the project consisted of an exploratory phase in which the teams gained information in the respective fields. For the electric pump team, this meant researching pump systems while for the asteroid observer team this was mostly a target selection. Although it was a positive experience to explore fields that were relatively new to both teams, this research phase took more time than initially expected. This resulted in a decrease of available time for the remaining design phases of the project.

From the literature study, primary and secondary science questions were established. This was an opportunity for the students to come up with their own research objectives, whereas in other projects these are generally provided at the beginning. Because the project covers multidisciplinary topics, different roles and responsibilities were allocated early in the process. For example, the asteroid team had a science officer, a systems engineer (originally scrum master) and a project manager who kept track of the project timeline. The next steps were to convert the research questions/objectives into requirements.

2.4. *Requirement Generation*

The requirements were a mix between stakeholder requirements and requirements set by the team itself. For the design phase of the project, each team member was responsible for the design of one or multiple subsystems. This division took place before the set-up of the requirements so that each team member came up with the subsystem requirements for their respective discipline. These requirements were then reviewed by the other team members, before they were presented to the stakeholders.

This already shows the constant communication between the team members themselves and with the stakeholders. To facilitate this communication between team members, the collaborative design software CDP4 was used. Via this software, team members could update the requirements and design parameters of the various subsystems and other team members could access these relatively easily, as previously mentioned.

2.5. *Concept Creation*

The next step was to generate multiple design concepts. The generated concepts lacked in detail, as teams concentrated only on feasibility and the potential to satisfy requirements.

The EP team utilized mainly empirical correlations found in literature to outline the main characteristics (Figure 2) of a centrifugal pump that could satisfy the flow, pressure and efficiency requirements set by the clients, DARE.

CDP4 was used at the beginning of the design phase, but after a few sessions, the asteroid team decided not to use the software anymore. As team members were still learning how to use the software, this often caused delays that were not compatible with the tight schedule. Also, as each team consisted of just four members and preliminary designs were considered, a simpler tool like Excel was deemed sufficient. After the concepts were developed, it was time to compare them and make a selection.

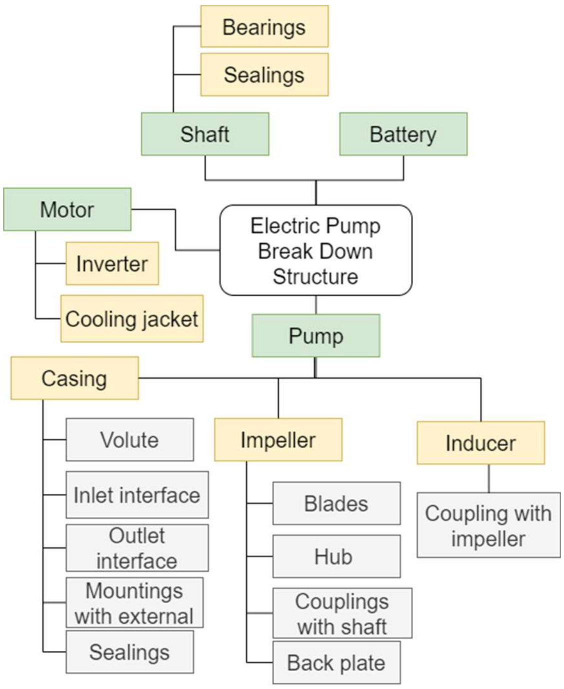

Figure 2. Electric Pump system architecture. Utilized in requirement flow-down and subsequently in concept generation.

2.6. *Concept Trade-Off*

For the Electric Pump group, two pump concepts were considered during the preliminary design, these being the conventional centrifugal pump, and the Barske pump. The latter, also called partial emission pump, has semi-open or open impellers and prove to be specifically useful in applications where high head is needed in combination with a relatively low revolution per minute (RPM). Conventional radial pumps, on the other hand, have curved, shrouded impellers, they are able to achieve relatively high efficiencies, and they are widely used in many different applications.

The trade-off for the pump selection has been done through a feasibility study: the power required for the functioning of each type of pump has been compared to the currently available electric motors on the market for these applications. The conventional centrifugal pump has been identified as the best option for the Firebolt engine, mainly because of the problems that arose with compatibility between pump efficiency and available motor powers. A comparison table has been created, a part of which regarding the motors' data can be seen in Table 1. However, as stated before, Barske pump gave promising outputs, which will be worth considering in case a wider and better selection of motors is found.

Table 1. Section of the comparison table used for the trade-off phase by the EP group. Uncertainty was determined by the utilization of empirical correlations and literature analysis.

	Barske	Conventional Centrifugal	Units
Power and efficiency			
Hydraulic power	18.39		[kW]
Brake horse power	Best 46	Best 27.04	[kW]
	Worst 52.5	Worst 31.7	
Efficiency	0.35 - 0.40	0.58 - 0.68	[-]
Motor			
Maximum continuous power	**36**		**[kW]**
Max RPM	50'000		[RPM]
Cooling needed	YES		[-]
Shaft diameter	10		[mm]
Motor diameter	60		[mm]
Motor length	142		[mm]

As for the asteroid observer mission, one of the main goals was to find an asteroid that is of interest for scientific community as well as that fits into mission constraints. Five asteroids were selected for the final comparison. These are 4660 Nereus, 21 Lutetia, 16 Psyche, 1989 ML, 2008 EV5.

The trade-off for target selection has been conducted based on four criteria: feasibility, innovative knowledge that an asteroid can bring, uniqueness of the mission, and cost. This can be seen in Table .

As seen from the trade-off table, the winner is 4660 Nereus which is very accessible due to its regular and very close Earth flybys. Also, scientists find it interesting due to its past which may shed light on comet evolution.

Table 2. Target selection for the CubeSat Asteroid Observer mission.

	Feasibility	Innovative knowledge	Mission unique	Cost
4660 Nereus	High (very close and accessible target, small Δv required)	Might have been a comet in the past.	No-one ever visited it.	Low
21 Lutetia	Low (due to the thick layer of regolith covering the surface)	Might have been a planet core.	Rosetta flew by the asteroid.	Medium
16 Psyche	Medium (too big to orbit)	Might be a remnant of a planet core.	There is already a mission planned to visit it.	Medium
1989 ML	High (easily accessible asteroid)	Interesting for mining	No-one ever visited it.	Low
2008 EV5	High (favourable orbital properties, small Δv required)	Potential hazardous object for Earth.	No-one ever visited it.	Medium

Legend:

Green	Excellent, exceeds requirements.
Orange	Might reach requirements with some modifications.
Red	Unacceptable.

2.7. Design Reviews

After the preliminary design phase, a mid-term review meeting was held approximately halfway through the project. Here the student teams presented their work to the customer and to the supervisor. Moreover, the groups were given the possibility to also contact external experts in the field to get feedback on the work done and suggestions for the next steps. This was done to keep the experience as close as possible to reality and at the same time to give the students a good opportunity to show their project to potential future investors and/or recruiters.

Similarly, a final design review was held at the end of the course. Both teams were invited to attend each other's final review so to provide feedback to their colleagues from a student point of view.

For the EP group, several members in the DARE society who were not actively participating in the Firebolt project were also invited to join the reviews to give their insight, as well as professors from TU Delft, invited by the supervisor.

For the CubeSat Asteroid Observer (CAO) group, the midterm review meeting was visited by the group members and supervisors only, while the final review was joined by other professors from Space Flight department of TU Delft.

3. Recommendations for future editions

In this chapter the authors suggest which possible modifications and additions can be applied to the course to solve the issues previously highlighted.

3.1. Subject Selection

It must be noted that if the chosen design challenge requires a very large amount of literature research from the students, little time might be left to dedicate to the other design phases. On the other hand, research and self-learning are important skills that should be included in the course. Similarly, is dealing with the uncertainty caused by incomplete knowledge. Thus, a balance should be struck when choosing the design challenge.

3.2. Supervision Involvement Levels

A higher level of supervision reduces the educational advantages generated by having the student team operate autonomously. However, the authors feel that, if a complex design subject causes the team to get stranded due to lack of knowledge, especially during the problem exploration phase, a high level of supervision can help compensate the deficiencies and still lead to a positive educational outcome.

3.3. Increased Number of Participants and Diversification of Skillsets

A bigger student team would make team coordination techniques, such as stand-up meetings, more relevant and put a bigger focus on concurrent engineering. In addition, the inclusion of students from different academic paths provides the chance to teach real-life team coordination skills, such as collaboration with colleagues with different knowledge and, as far as the team manager is concerned, assigning task in way that positively exploits the individual strengths of each member.

4. Second edition of the Course

At the time of writing, the second edition of the course has already started, during the academic year 2021/2022. Some modifications have been applied. An additional educational credit was assigned to the course, bringing it to 5 European Credits Transform System (ECTS). The hours associated with this additional credit have been dedicated to workshops on the engineering design process and on further education on the SCRUM method.

5. Conclusions

An innovative course concept that challenges a student team to solve a design problem is presented, with a particular focus on the point of view of the participating students. After an introduction on the structure of the course, the students' experience during the different phases of the design process is recounted. This is followed by suggestions given by the students on how the course could be modified in the future, together with an account of the modifications already applied to the 2022 edition of the course.

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