CDF AS A TOOL FOR SPACE ENGINEERING MASTER'S STUDENT COLLABORATION AND CONCURRENT DESIGN LEARNING

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ABSTRACT

The IDR/UPM Institute (*Instituto Universitario de Microgravedad 'Ignacio da Riva'*) established a Concurrent Design Facility (CDF) for space mission design in 2011. This facility is used primarily for academic purposes within the Master in Space Systems (MUSE) [1] organized and managed by IDR/UPM also. This CDF is based on the Open Concurrent Design Tool (OCDT) from ESA, which allowed a group of students from the master to participate in the Concurrent Engineering Challenge organized by ESA Academy in September 2017.

Since the early days of this facility, the development of tools and utilities for space mission design has been conducted by aerospace engineering students at IDR/UPM under the direction of professors. At present, MUSE students are programming a new set of models for the main spacecraft subsystems, to analyze space missions beyond Earth.

In order to make easier for MUSE students to achieve a proper level of knowledge and experience in Concurrent Design, a frame of cooperation has been established between the students from the first year, who are new to concurrent engineering, and second-year students, that have gathered a significant level of experience in the previous year. This cooperation enables the comprehensive and resource-effective use of the CDF and ensures the success in the academic skills related to space systems engineering and mission design.

It should be also said that this cooperation between two different year students is carried out through different activities conducted in the CDF, involving Concurrent Design (CD) of space missions, and working with the available material of own creation. Through this method, collaboration and communications skills are improved. Additionally, Concurrent Design concepts are more easily learnt.

In the present work the activities in relation to this process of cooperation are described, how they fit in the master's academic program, and the results of the method implementation during the academic year 2017/2018. It also includes the working methodology employed in the CDF, developed mainly by students and that is being improved progressively with each new student generation.

1. INTRODUCTION

IDR/UPM Institute (*Instituto Universitario de Microgravedad "Ignacio da Riva"*)[2] established a Concurrent Design Facility (CDF) in 2011, similar to the one that ESA created in 1998 [1]. Since then, different projects have been developed based on Concurrent Engineering methodology. Most of them have been conducted by collaboration between students of the Master in Space Systems (MUSE), fully organized by IDR/UPM [2] and conducted in *Escuela Técnica Superior de Ingeniería Aeronáutica y del Espacio*[3] (ETSIAE/UPM), and IDR/UPM staff.

Although a set of academic works, including internships, bachelor degree's thesis dissertations and master's thesis dissertations, have been carried out to develop the CDF capabilities, the evolution and improvement of this facility is due to real engineering projects developed together with other institutions (e.g., the design of the UNION Lian-Hé preliminary phases [3]).

Among the CDF activities carried out within the last year, the 1st ESA Concurrent Engineering Challenge should be mentioned. In this challenge the present authors, in collaboration with the rest of the master last year students and supported by IDR/UPM system engineers (Fig. 1), designed a mission whose objective was the observation of the Moon South Pole [4].

Figure 1. MUSE professors and last year students in CDF during ESA Challenge.

1 *Master Universitario en Sistemas Espaciales*

2 http://www.idr.upm.es/

3 https://www.etsiae.upm.es/

The aim of this paper is to provide a description of the working methodology employed at IDR/UPM in the CDF, the activities conducted by students to improve and accelerate the learning process of Concurrent Design (CD), the relationship between the CDF activities and the MUSE academic program, and finally, the results obtained in the academic year 2017/2018. It should be also underlined that the experience from MUSE student is included in this work, reflecting the students' point of view.

This paper is organized as follows. In Section 2 the evolution of the working methodology is described. In Section 3 the main activities carried out during the academic year are explained. In Section 4 the results from a MUSE student's survey on the CDF activities within the academic program are included. Conclusions are summarized in Section 5.

2. WORKING METHODOLOGY

The CDF provides an environment for close interaction among the designers and subsystem specialists. The facility itself consists of 13 computer stations, specific multimedia hardware for teleconferences and presentations, a server for data storage, and a software infrastructure for the generation of the mission design and data propagation between disciplines in real time. It was established in 2011 and operated with Concurrent Design software.

At the early days of the CDF, a Concurrent Design software was developed, using python language, by IDR/UPM, called Concurrent Design Application [5]. At this design phase, multiple modules for the study of different spacecraft subsystems were elaborated by students during their internships in IDR/UPM and as final dissertations in both, bachelor's and master's degrees.

The main disadvantage of this approach is the excessively amount of time required to train students who would not continue their work next year. Additionally, most of the modules were closed designed and were independently developed, which made a harsh task to integrate them together. These modules exported their results into different formats and used their own data base.

This software developed by IDR/UPM was substituted in 2015 by the OCDT, a server software package developed under an ESA contract to enable efficient multi-disciplinary concurrent engineering of space systems in the early life cycle phases [6].

Due to the fact that the OCDT system employs Microsoft® Excel® as client application and that it is widely known by bachelor students, it was decided to develop Excel® calculation modules for the design of spacecraft subsystems. Nevertheless, as the achievable level of design and analysis when using Excel® is limited, the modules are usually focused to employ an external design software, depending on the subsystem, to export data and import results. These modules are similar to those developed for the SCDT[4] [7].

A timeline were all these activities are described, since the creation of the IDR/UPM Concurrent Design Facility to the actual design methodology, is shown in Fig. 2.

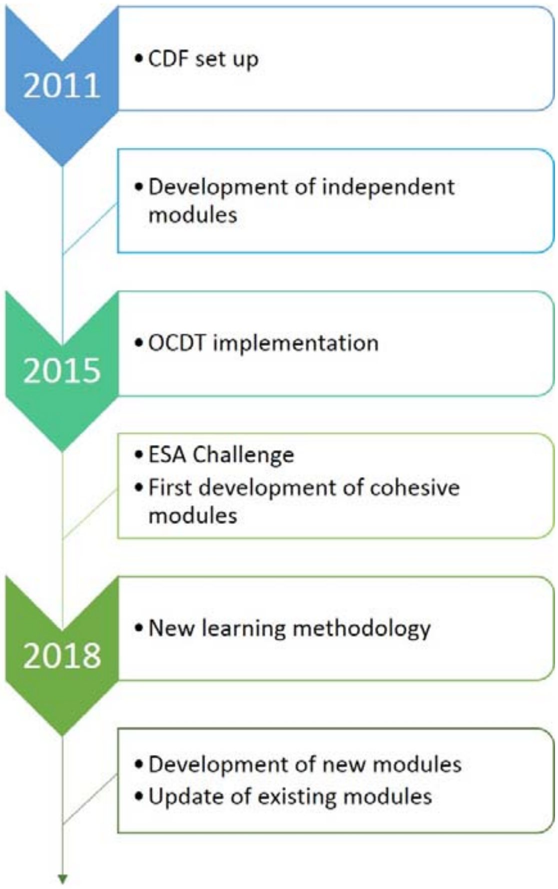

Figure 2. Timeline of IDR/UPM CDF evolution.

2.1 Concurrent Design learning through student collaboration

In order to transfer efficiently the acquired knowledge by the students working in the CDF, a collaborative frame of work between first- and second-year students was established. This frame involves the development or update of the available modules and also the establishment of a learning methodology for the continuous improvement of the CDF environment.

The collaboration among students is intended to facilitate the learning process of concurrent engineering and to improve their skills in terms of communication

[4] Student Concurrent Design Tool

and design thinking. A group of students from second-year organized a set of activities to train first-year students under the direction of professors and IDR/UPM staff.

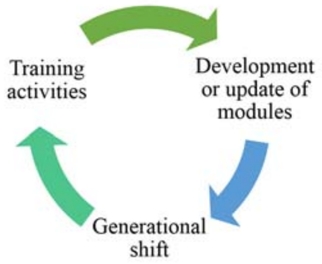

Figure 3. CDF learning dynamic cycle.

Such activities were defined to be repeated each year (Fig. 4), so the current first-year students will take charge of the training of new students about Concurrent Design and the CDF modules improvement.

3. ACTIVITIES DEVELOPED DURING 2017/2018 ACADEMIC YEAR

During 2017/2018 academic year, numerous activities took place in the CDF and the new learning methodology was implemented.

One of the activities developed with the CDF was the 1st ESA Concurrent Engineering Challenge in September 2017. In this competition, the second-year students were distributed in groups and assigned to each one of the subsystems that conform the mission architecture.

After the competition, several students from second year continued working in this area by developing, as Case Study II (a mandatory subject included in the MUSE program [8]), some of the modules that were thought to be implemented in the CDF for future preliminary mission designs.

In January 2018 learning sessions about the Concurrent Design methodology in a CDF were organized. In these sessions, second-year students taught first-year students the main concepts and characteristics of both Concurrent Design and the working methodology followed in IDR/UPM CDF, including the guidelines to develop new CDF modules. This learning sessions were divided in two stages (Fig. 3): first, an introduction to the Concurrent Engineering concept and the working methodology employed in the CDF; second, the design of a simple space mission using the available design tools of the CDF (design modules). All the students from first-year participated.

The first stage was conducted in one session and it was mainly dedicated to learn the essential aspects of concurrent engineering, which are usually unknown by the students. This process was carried out emphasizing the points that the present authors considered most important and less clear according to their own experience the previous year. It was also introduced the working methodology applied to the CDF, particularly, the basics of the OCDT system.

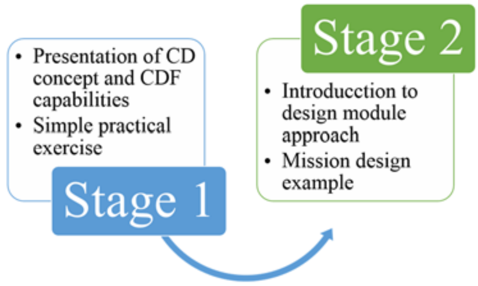

Figure 4. Activities stages description.

To reinforce the skills and enhance learning, a simple exercise was proposed to the students. In this practice, they were divided in pairs, with each couple dedicated to one main spacecraft subsystem, and they were asked to estimate the mass and power consumption of their subsystem, based on a set of simple requirements, and upload them to the CDF database. First design iteration was based on simple calculations from space mission design literature [9]. They were also required to base their estimations taking into account the values that other subsystems were providing. Through this simple exercise, several main ideas of Concurrent Design were illustrated, for example, the design loop that arises when the propulsion subsystem needs the total spacecraft mass as an input but it also must provide its own mass to calculate such input.

As a final step of the first stage, the working methodology was addressed in deep through the presentation of a functional module developed by a student of the second year. The students were encouraged to interact with the module, including all the decisions about the design options which have to be taken, so it was possible to make easier the understanding of the modules architecture and functionality. This activity was intended to teach the students the main points which have to be considered for a module development. Thus, preparing the students for the mission design exercise scheduled for the second stage.

At the second stage, with the aim of perform a mission preliminary design, the requirements were given and translated into formal words. After that, the students were divided again in pairs according to the same distribution made at the first stage. During all the design iterations, each one of the students from second year guided several groups, solving their questions and providing them with advices. The problems encountered and their corresponding solutions were shared and discussed. At the end of this activity and after fulfilling the mission requirements, each of the student groups elaborated a final report including the main characteristics and the design process of their subsystem.

In the following months, several students of first year developed modules for specific subsystems for its implementation in the CDF as Case Study I. During this work, first-year students were supported by both IDR/UPM professors and second-year students.

On account of the work carried out by all the students involved in the CDF development, a successful set of operative design modules was available at the end of the academic year, each one of them comprised of some interesting ideas based on the defined methodology.

A structure subsystem module was developed. It allows to connect the data base from the OCDT to an industrial design software, CATIA; after that, the module can generate a finite element method (FEM) model in NASTRAN©, finally reading the results and carrying them to the OCDT again. Also, a catalogue with a list of different Commercial off-the-shelf (COTS) elements was collected and assembled with some of the modules, e.g. the power subsystem module, the attitude and orbit control subsystem module or the propulsion subsystem module. In order to get a first step with the design iterations, a software was programmed to generate a set of initial values based on all the last satellite mass and the mission purposes designed. Another idea achieved was to connect the mission subsystem module to GMAT©, allowing to introduce the values of the initial and final orbits and get all the velocity increase needed.

Another developed tool implemented to the CDF was a document management software. It allows the access to project documents according to certain attributes given by the user. These attributes depend on the category of the user (basic user, subsystem responsible and project manager) and on the different subsystems involved in a space mission.

3.1 Future activities

In the middle of July 2018, some of MUSE students will participate in the "2nd BUAA International Academic Forum of Astronautical Science and Technology" at Beihang University, China, where they will present their work with CDF modules.

In September 2018 will take place design sessions in the CDF with the objective of performing the preliminary design of a CubeSat mission in L2, where modules developed by MUSE students will be used.

4. SURVEY RESULTS

In order to evaluate the effectiveness of the learning methodology employed, a survey about different CDF aspects was conducted among all the MUSE students to compare the evolution of the perception of the CDF and the acquired knowledge. A total of 21 students answered the questions, of whom 11 belong to the second academic year and 10 belong to the first year.

The survey was organized into three main categories: (i) related to the learning methodology employed, (ii) related with the CDF utilization and (iii) related with the CDF infrastructure. Students were asked to rate from 0 to 10 (where 10 is the highest score) the different aspects described in Table 1.

Table 1. Survey questions organized in three different categories: Learning methodology, CDF utilization and CDF infrastructure.

Learning methodology	**CDF utilization**	**CDF infrastructure**
Students satisfaction	Usefulness of CE concept	General infrastructure
Level of organization	Level of reality of proposed missions	Usefulness of developed subsystem modules
Improvement of student skills and capabilities	Need for increase the amount of CDF design sessions	
Capability to train next student generation		

The survey results, represented in a 10 points scale, where 0 represents complete disagreement and 10 complete agreement, are shown in the next figures: Learning methodology (Fig. 5), CDF utilisation (Fig.6) and CDF infrastructure (Fig. 7). In the graphs, the answers from first-year students are depicted in black and the ones from second-year students in grey. The scoring corresponds to the average of the answers obtained.

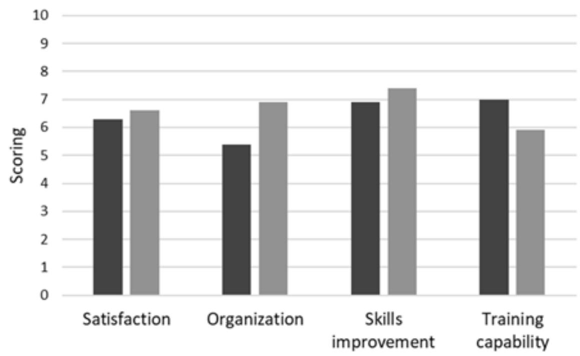

Figure 5. Survey results for learning methodology. In black and grey, the answers from first- and second-year students, respectively.

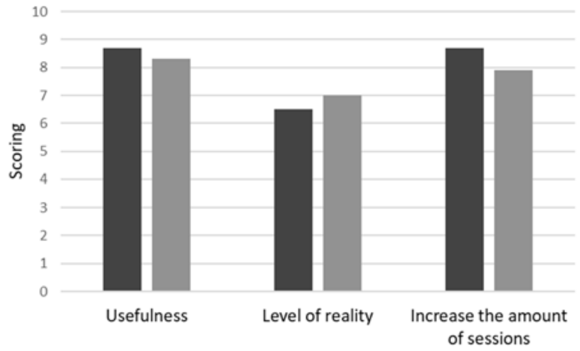

Figure 6. Survey results for CDF utilization. In black and grey, the answers from first- and second-year students, respectively.

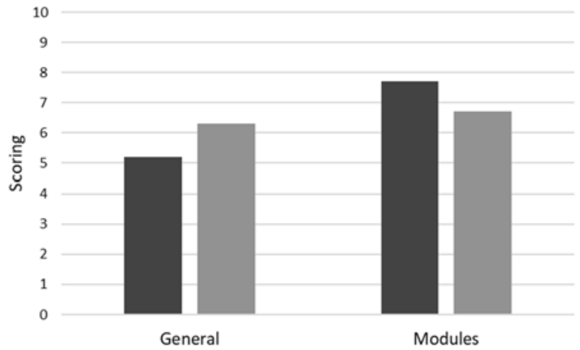

Figure 7. Survey results for CDF infrastructure. In black and grey, the answers from first- and second-year students, respectively.

In general, the students from both years have a positive point of view about the CD concept and they consider that more activities would be beneficial for the learning. Also, an improvement of the opinion about the modules has been noticed from the second-year to first-year students. Furthermore, students think that their skills have been improved due to the CDF activities, being such progress higher for the first-year students.

Nevertheless, some differences have been observed among the two years: the perception about the CDF activities organization has improved, the rate between theory-based and practice-based learning is more balanced and the opinion about the CDF functionality got better. On the contrary, first-year students think that they are less prepared to transmit their knowledge about the CDF to the next generation.

5. CONCLUSIONS

Once the first academic year using the described methodology finished, first-year students got a satisfactory knowledge about the CDF environment and how to face future academic work related to Concurrent Engineering. One of the main goals achieved was the capacity of developing new modules with the aim of performing the preliminary design of a mission by using the CD.

According to the survey results, the self-confidence on transmitting the knowledge and skills related to CDF is better in second-year than in first-year students. This might be the consequence of a lack of experience in CDF activities, combined with the logical lack of training on the second-year MUSE subjects.

However, to achieve the total usefulness of the described methodology, it is necessary to complete several academic years, in order to generate an appropriate dynamic.

6. REFERENCES

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