Supervising multidisciplinary final-year engineering students to develop CubeSats with an innovative project management method

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***Abstract*—It has been shown that developing nano-satellites is a good platform to motivate and educate students in Science, Technology, Engineering and Mathematics (STEM) disciplines. In this paper, the authors have explained an innovative project management method, called major-project-review, and its implementations to supervise different batches of multidisciplinary final year engineering students to develop a CubeSat as their Final Year Projects (FYPs) in three to four years. The major-project-review approach has been successfully verified in our first CubeSat project, Galassia, and is continuously used to develop our second CubeSat, Galassia2. From the success of Galassia and student feedbacks, the method has been proven to be very efficient to control and monitor the CubeSat development progress, and to motivate and educate engineering students. With our continuous implementations in Galassia2 project, we hope to collect more experiences and data to further optimize the approach.**

Keywords—Science, Technology, Engineering and Mathematics (STEM); innovative project management method; major-project-review; multidisciplinary final year engineering students; CubeSat

I. INTRODUCTION

One unit of CubeSat, called 1U CubeSat, is defined with a size of 10x10x10 cm^3 and a weight less than 1.33 kg [1]. A CubeSat is made up of multiple one units with commercial off-the-shelf (COTS) components for their structure and electronics so as to meet some specific mission requirements. Due to its fast development durations and low costs, CubeSats have been very popular to be developed with missions such as Earth observation, communication, demonstration of new space technologies, scientific experiments as so on. Just recently, over 1000 CubeSats have been launched from 2012 to now, and the number of CubeSats planned to be launched is dramatically increased every year. Specially, a CubeSat consists of basic subsystems including Electrical Power Subsystem (EPS), On Board Computer (OBC), On Board Data Handling (OBDH), Attitude Determination and Control (ADCS), Telemetry, Tracking & Command (TT&C), Thermal Subsystem (TS), Structure and Mechanism (SM), and payload design. Together with environmental qualification tests for launches and payload operations after launch, a CubeSat has become a relatively inexpensive and yet effective way to train multidisciplinary engineering students in serious technical skills [2]. The multidisciplinary engineering skills gained from developing CubeSats can be highly transferable to design other complex systems such as robots, aircrafts, and underwater vehicles.

In 2012, National University of Singapore (NUS) embarked on an Aerospace Systems Initiative (ASI) in Innovation & Design Programme (iDP) of Faculty of Engineering (FOE). Under ASI, several modules are designed and offered in 3.5 years to motivate students from various engineering disciplines to build up their basic knowledge in aerospace system and hands-on experiences, and to train them to work like real engineers through developing real Cubesats in their final years. Therefore, final-year undergraduate Engineering students from various disciplines are involved in developing CubeSats as their Final Year Projects (FYPs). Each student has a task or project objective which contributes to some subsystem in the CubeSat. The challenges though are that final year students graduate by the time their individual project ends, and new batch of inexperienced students need to take a lot of time to understand the overall CubeSat development status and their individual FYP objectives. Hence, it is important to know how to successfully develop a CubeSat project for launch at the end of three or four years, with students moving out (graduating) at the end of each academic year.

In order to ensure an efficient development of the complete CubeSat crossing three to four years, we developed an innovative project management method based on the space mission lifecycles used in the European Space Agency (ESA) and National Aeronautics and Space Administration (NASA). In section II, we will describe the space mission lifecycles. In section III, we will explain modifications we made based on our resources. We call this innovative project management method as major-project-review approach. In section IV, we will show our implementations on our first CubeSat, Galassia, developed from 2011 to 2015, and current CubeSat developments, Galassia2. We will also discuss the results and student feedbacks. In section V, we will discuss and conclude our current findings.

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II. THE SPACE MISSION LIFECYCLES

As shown in Fig. 1, the fundamental concept used by both ESA and NASA for the managements of major space systems is the mission life cycle, which consists of a categorization of everything which should be done to accomplish a space mission into distinct phases [3] and [4]. During these phases, project reviews are planned as milestones in the project schedule to allow critical and independent assessment of potential problems and the proposal of solutions. The reviews organized at the end of each phase are used to verify if the objectives of the respective phase are met and all information necessary to commence the next phase is available. Partitioning the project into different incremental phases is a major contribution to the overall risk management.

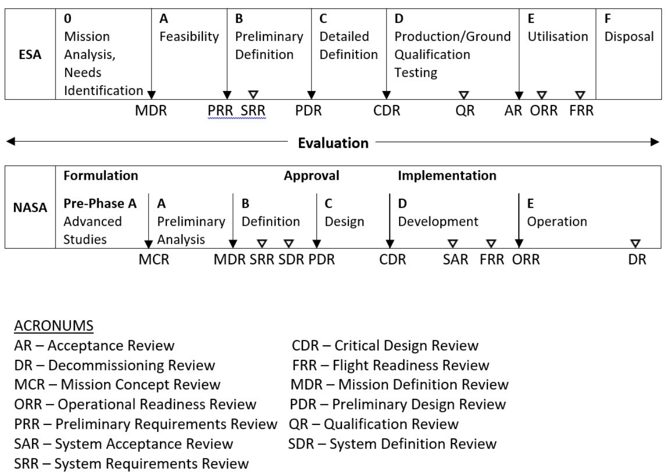

Fig. 1. Typical space mission lifecycles

III. MAJOR - PROJECT - REVIEW APPROACH

There are 9 and 11 project reviews in ESA and NASA standards, respectively, and each review takes at least three to four weeks for preparation, review meetings, discussion and conclusion. It is not practical for us to go through all reviews as suggested in Fig. 1. Therefore, we need to strategically select some specific reviews based on available funds, team's capabilities, supporting facilities, difficulties of the project, and the possible launch schedule. After carefully considering our resources and significances of each review, we decided to choose only four major reviews, which are System Design Review (SDR), Preliminary Design Review (PDR), Critical Design Review (CDR) and Operational Readiness Review (ORR). Our CubeSats usually are built and qualified within 3 to 4 years, and 4 batches of FYPs students are involved to develope one CubeSat. After SDR, the mission requirements should be well understood and verified, and system and subsystem specifications should be defined clearly in order to fulfill the missions. After PDR, subsystem prototypes should be designed and verified. After CDR, an Engineering Model (EM) should be designed and verified. The EM is functionally the same as the final CubeSat, and it is tested with qualification levels and durations, provided by a launch company. After ORR, a Proto Flight Model (PFM), which is the final CubeSat, should be integrated and qualified with the qualification levels and acceptance durations. These review presentations are scheduled to align with students' project continuous assessment (CA) presentations, which also makes this innovative project management method fit into academic activities and milestones. We call this project management method as major-project-review approach. The detailed objectives of each review based on ESA and NASA standards are listed in the table I below.

TABLE I. MAJOR PROJECT REVIEWS AND THEIR OBJECTIVES

Review	Defined objectives
System Design Review (SDR)	Examine the proposed system architecture and design Define system functions
Preliminary Design Review (PDR)	Ensure that all system requirements have been validated, allocated, the requirements are complete, and the flow down is adequate to verify system performance Show that the proposed design is expected to meet the functional and performance requirements Show that the design is verifiable and that the risks have been identified, characterized, and mitigated where appropriate
Critical Design Review (CDR)	Ensure that the "build-to" baseline contains detailed hardware and software specifications that can meet functional and performance requirements Ensure that the design has been satisfactorily audited by production, verification, operations, and other specialty engineering organizations Ensure that the production processes and controls are sufficient to proceed to the fabrication stage Verify that the final design fulfills the specifications established at PDR
Operational Readiness Review (ORR)	Establish that the system is ready for transition into an operational mode through examination of available ground and flight test results, analyses, and operational demonstrations Confirm that the system is operationally and logistically supported in a satisfactory manner considering all modes of operation and support (normal, contingency, and unplanned) Establish that operational documentation is complete and represents the system configuration and its planned modes of operation

Besides the supervisors and examiners, several internal reviewers and external reviewers from research institutes and companies are invited in each review to give their comments. After each review, the FYP supervisors gather all the feedbacks from the reviewers and determine if the review has achieved its defined objectives before carrying on the next phase.

IV. IMPLEMENTATIONS ON GALASSIA AND GALASSIA2

A. Galassia

Galassia is the NUS' first CubeSat. It is a 2U Cubesat with a size of 10 x 10 x 20 cm^3 and weight of 1.64 kg. Galassia is designed to host three missions in space, which are to measure

Total Electron Content (TEC) in the ionosphere above Singapore, to do Small Photon-Entangling Quantum System (SPEQS) experiments in space, and to conduct experiments on satellite attitude control using onboard sensors and actuators such as magnetometers, gyroscopes and magnetorquers [5] and [6].

The project started in 2011 and the CubeSat was planned to be launched in the end of 2015. Based on the launch schedule, the PFM of Galassia should be ready by the middle of 2015 to be shipped to the launch site. It was our first attempt to build a CubeSat, and the overall objectives for us were to train engineering students and to build our own capabilities in the CubeSat area. We decided to spend one academic year to conduct one review only, as listed in the table II.

TABLE II. GALASSIA REVIEW SCHEDULES

Reviews	Completed time
SDR	Apr 2012
PDR	Apr 2013
CDR	Apr 2014
ORR	Apr 2015

Each year, there were 5 to 9 FYP students working on this group CubeSat project. Each of them was working on an individual subsystem or mission payload design. Every student had their specific project objectives which were defined to achieve the overall review requirements. The review presentations were scheduled to align with their final year project (FYP) presentations. Fig. 2 shows the incremental achievements over the 4 years. Galassia was successfully launched into its desired orbit on the 16th of December 2015 at 20:30 Singapore time on board of the Indian Polar-Satellite-Launch-Vehicle (PSLV) C29 mission. The communication contact from NUS CubeSat Ground Station to the orbiting Galassia was established during its first pass above Singapore. It has since been working well in space and we are still operating the Galassia to carry out several mission operations.

B. *Galassia2*

Galassia2 is a 3U Cubesat with a multispectral imaging sensor. The missions are Earth remote sensing and qualifying in-house developed subsystems. The project started in 2016, and Galassia2 is planned to be launched in the middle of 2020. Based on this schedule, the PFM of Galassia2 needs to be ready by the end of 2019. The challenge here is that the end of 2019 is not the end of an academic year for final FYP CA presentations. In order to overcome it, we decided to split ORR into 2 phases. ORR phase 1 will be conducted in April 2019 to review the functions of the PFM which will still be served as the final FYP CA presentations. ORR phase 2 will be conducted in November of 2019 to be the intermediate FYP CA presentations to review the PFM after the environmental qualification tests. That batch of FYP students will continue to

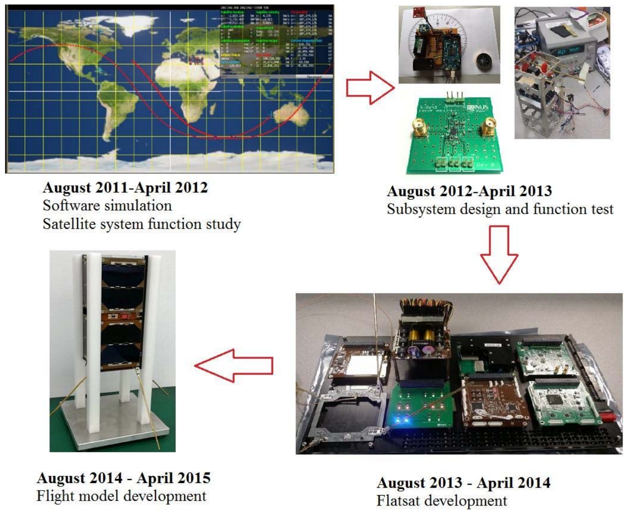

Fig. 2. Galassia incremental achievements over 4 years

operate Galassia2 once it is launched and present mission data in their final FYP CA presentations. With the experiences and references gained in Galassia developments, we noticed that students did not need to spend the whole year to fulfill the SDR and PDR requirements. Therefore, for the first batch of FYP students, their intermediate FYP CA presentations were organized as the SDR, and their final FYP CA presentations were organized as the PDR. Both presentations accomplished review requirements. The Galassia2 review schedule is listed in the table III.

TABLE III. GALASSIA2 REVIEW SCHEDULES

Reviews	Completed time
SDR	Nov 2016
PDR	Apr 2017
CDR	Apr 2018
ORR phase 1	Apr 2019
ORR phase 2	Nov 2019

Although it is at the supervisors' level to implement this Major-Project-Review in order to control and monitor the overall CubeSat developments, we conducted a survey among the students to find out how this approach help the students with their FYPs. The survey questions are displayed in Table IV.

There were 14 students involved in the survey. The survey results are shown in Fig. 3. It is seen that all the students were aware of the project management method, and most students could name correctly which reviews had been conducted and which review was going to be conducted. All the students understood the review requirements, and most student felt the review requirements were very helpful for them to understand their FYP objectives and timelines. All of them thought the project reviews gave them a good idea of the overall CubeSat development status. Most of them felt the project reviews highly increased their motivations for their projects.

TABLE IV. SURVEY QUESTIONS ABOUT PROJECT MANAGEMENT

	Project Management	Y	N
1	Are you aware of the project management methodology with certain milestone reviews has been implemented in the CubeSat team FYPs? If yes, which reviewers have been conducted during your FYP? a. System Design Review (SDR) b. Preliminary Design Review (PDR) c. Critical Design Review (CDR) d. Flight Readiness Review (FRR) Which review is going to be conducted right after your FYP? a. System Design Review (SDR) b. Preliminary Design Review (PDR) c. Critical Design Review (CDR) d. Flight Readiness Review (FRR)		
2	Do you understand the review requirements? If yes, were the review requirements helpful for you to understand your FYP objectives and timelines? 5(very useful) 4 3(more or less) 2 1(not useful at all)		
3	Do the project reviews give you a good idea of the overall CubeSat development status?		
4	Do the project reviews increase your motivation to achieve your FYP objectives? 5(very motivated) 4 3(more or less) 2 1(not at all)		

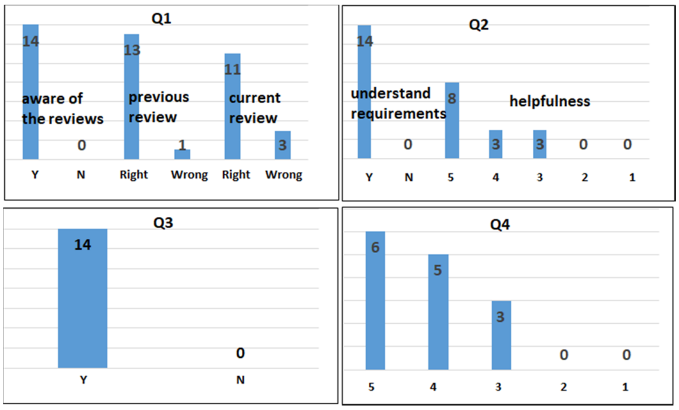

Fig. 3 Survey results

V. DISCUSSION

From the success story of our first CubeSat and student feedbacks, this major-project-review approach has been proven to be very efficient. The major benefits are summarized as discussed below,

- With a proper well-defined review conducted at each batch, students can gain a good idea of what have been done, where they can start, and what they should do. Based on the next review requirements, student are highly motivated to pursue the next phase of the project.
- The whole CubeSat developments can be effectively controlled with all the selected incremental reviews. In this way, the project will be progressing well year by year towards the final goal. It motivates students as they can see how they contribute to the overall project.
- Each review with external reviewers from the related research institutes and companies provides a good opportunity for the students to understand the real applications of their projects, and to have effective interactions with all the reviewers, which has also been approved to be very helpful for their job applications.

VI. CONCLUSION

In this paper, the space mission lifecycle which is the project management method used by ESA and NASA has been explained. Based on it, our proposed major-project-review approach has been introduced. The reasons of choosing these major reviews and expected results from each review have been explained. This approach has been implemented in Galassia and is currently implemented in Galassia2 developments. So far, from the success of Galassia and student feedbacks in Galassia2, the approach appears to be efficient. More data will be collected and analyzed after Galassia2 is completed.

ACKNOWLEDGMENT *(Heading 5)*

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