SSC19-WKIII-06

The Role of Small Satellites in the Establishment of the Gulf Region's First Graduate Level Space Studies Program

Carlos G. Niederstrasser
Northrop Grumman Corporation
45101 Warp Dr., Dulles, VA 20166, USA; +1.703.406.5504
Carlos.Niederstrasser@ngc.com

Dr. Prashanth Reddy Marpu, Adham Alkhaja, Thu Trong Vu
Khalifa University
Masdar City Campus, Abu Dhabi, UAE; +971.2.810.9242
prashanth.marpu@ku.ac.ae

Dr. Efthymios Kontogiannis, Ahmed A. Alshaer
Al Yah Satellite Communications Company (Yahsat)
P.O. Box 93693, Yahsat HQ, Sweihan, Abu Dhabi, United Arab Emirates; +971.2.507.6344
ekontogiannis@Yahsat.ae

ABSTRACT

Yahsat, Northrop Grumman, and Khalifa University created the Gulf region's first master's level advanced studies space program. To date this program has graduated three classes of master's students and received accolades from the UAE Space Agency and Abu Dhabi's Mubadala Investment Company. The program's primary goal is to develop the resources and work force that the UAE requires to establish itself as a space-faring nation. Integral to this program are small satellites, initially used to train and educate the students and ultimately growing to accommodate new technologies and scientific payloads developed in the UAE. The first of these small satellites, a 1U CubeSat named MYSat-1 was launched in November of 2018 and deployed from the Northrop Grumman Cygnus on 13 February, 2019.

In this paper we present the role small satellites played in the establishment of this program. We discuss the challenges of establishing a satellite program at a university without a formal aerospace curriculum and how the small satellite became the anchor project for the student development. In this context, we explore the advantages of making use of the broadly established small satellite COTS component marketplace relative to the didactical benefits to be gained from having the students develop the new hardware in-house. Finally, we review the process of setting up a new small satellite lab established to be used as the primary resource for developing and testing small satellites in the country.

HISTORY AND MOTIVATION

For the emerging United Arab Emirates space sector, workforce development and capacity building are as important as the technology itself. The importance of such programs was reinforced when the UAE's *National Innovation Strategy*, first announced in 2014, established seven areas of focus for growth and innovation for the country, including the development of a space program.

In 2014 Northrop Grumman (then Orbital Sciences) and Yahsat came together to develop the Al Yah 3 spacecraft. Beyond the development of the satellite, Northrop Grumman and Yahsat created a multi-faceted effort to focus on human and intellectual capital to drive the country's growth in the space sector in particular, and more broadly in other high-technology fields. The results of these efforts provide the UAE with human capital and technological advances in space as well as in other key sectors, including defense and energy.

In 2015, as part of the UAE's "Year of Innovation" Yahsat, Northrop Grumman, and Masdar Institute (now part of Khalifa University) entered into a partnership designed to foster innovation and the development of a vibrant workforce and industrial base for the space industry in the country. This partnership was instituted to further the nation's goal of space exploration and followed the establishment of the UAE Space Agency and the announcement of the "Hope" Mars probe to be launched in 2021.

Aimed at facilitating the growth of UAE National students into diversified, high-technology areas of study, this new program provides rigorous academic grounding in a multitude of space-related scientific and engineering disciplines. The culmination of the program is a Master's degree in engineering, with a Concentration in *Space Systems and Technology*. This new multi-disciplinary program is a first-of-its-kind in the Gulf Cooperation (GCC) Region and is fully accredited by the UAE Ministry of Higher Education and Scientific Research.

THE SPACE SYSTEMS AND TECHNOLOGY PROGRAM

Yahsat and Northrop Grumman conducted a survey of existing academic programs in universities across the UAE. Although at the time the program was established Masdar Institute did not have an aerospace engineering department, the Institute's academic rigor and focus on graduate level education made it an ideal choice for the establishment of the new course of study.

In order to expedite the establishment of the program and get all the appropriate accreditations, the partners decided to establish the Space Systems and Technology (SST) track as a certificate program overlaid on top of Masdar's regular Master's programs. This approached also matched nicely with the multi-disciplinary nature of space programs. Students in the SST would graduate with a Master's degree in their chosen discipline and be further awarded the SST certificate. Since January 2016, when the concentration first launched, students from different Master's programs – including Mechanical Engineering, Materials Science and Engineering, Computing and Information Sciences, Electrical Engineering, Engineering Systems and Management, Microsystems Engineering and Water and Environmental Engineering – have added the concentration in Space Systems and Technology to their degree.

In addition to the Certificate program, it was envisioned from the start that the university would host a lab that would become a world-class facility for the development of small satellites, and specifically CubeSats, in the UAE.

Being a wholly owned subsidiary of Abu Dhabi's Mubadala Investment Company, Yahsat's goals align with those of the government with regards to growing and nurturing a pool of talent that can contribute to the UAE's growing space industry. Yahsat is funding the SST program, which includes the lab with all of the required machinery and test equipment needed to construct and test the CubeSats. Construction of the Yahsat Space Laboratory completed in 2017 with facilities necessary for the conceptualization, design, assembly, integration and end-to-end testing of a CubeSat as well as its operation through an on-site ground station. The satellite company also provided an Initiation Program before the first semester began, which offered 16 hours of seminars to introduce new students to concepts related to satellite business, engineering and operations. This was especially important for the first cohort of students, as none of them had envisioned adding a space concentration to their degree program. Yahsat continues to mentor the students and faculty involved in the concentration to ensure the program's quality and ability to develop the highly-skilled human capital needed to advance the UAE's nascent space industry. Completing this cycle, a number of graduating students have gone on to obtain full time positions at Yahsat, amongst other space institutions in the UAE.

Figure 1 shows some members of the first graduation class shortly after receiving their degrees in May of 2017, less than two years after the program was officially launched. They are joined by executive leadership from Yahsat and Northrop Grumman; such executive support was key to the establishment of the program.

Figure 1: Members of the Graduating Class of 2017 with Executives from Yahsat and Northrop Grumman

Northrop Grumman engineers developed the initial program concept and worked with the faculty at Khalifa University to develop the details of the academic curriculum. Experts in spacecraft design then provided more than thirty hours of space systems training to the faculty to expand their knowledge beyond their areas of expertise. The company also gave advice on the establishment of the new laboratory and continues to actively mentor students in the program.

Masdar is now part of Khalifa University, an institution with undergraduate and graduate programs and which does offer aerospace engineering as part of its curriculum. These new academic and student resources are already strengthening the program allowing the lab to diversify beyond Yahsat funded projects and permitting the growth of new areas of research.

ACADEMIC RIGOR THROUGH A MULTI-DISCIPLINARY APPROACH

Since the SST certificate program was established as a multi-disciplinary overlay on top of the university's existing academic programs, some compromises had to be made. Students could not purely focus on their SST curriculum, as they still needed to complete all the requisites for a Master's degree in their chosen discipline.

The concentration currently relates to the following Master's programs at KU:

- MSc in Electrical and Computer Engineering;
- MSc in Computing and Information Science;
- MSc in Materials Science and Engineering;
- MSc in Mechanical Engineering;
- MSc in Engineering Systems and Management.

To help accommodate these requirements, a three-pronged approach was established consisting of coursework, student research, and a CubeSat development program. This approach also served to strengthen a key goal of the program. The SST program, from its inception, was envisioned as a multi-disciplinary program. Space science and technologies, by their very nature, span across many traditional engineering disciplines, including mechanical, electrical, computer science, materials, and, of course, aerospace. By creating a certificate program with the three-pronged approach, emphasis was placed on multi-disciplinary collaboration amongst both students and faculty.

Figure 2 shows the curriculum of the space systems and technology concentration.

Students in the Master's Concentration in Space Systems and Technology are expected to achieve the following learning outcomes:

- Successfully apply advanced concepts of fundamental sciences and engineering to identify, formulate and solve complex engineering problems;
- Successfully apply advanced concepts of engineering science to the analysis, design and development of industrial processes and plants to meet desired needs of society professionally and ethically;
- Use advanced techniques, skills, and modern scientific and engineering software tools for professional practice;
- Apply advanced methods to design and conduct experiments, and to analyze and interpret data;
- Communicate effectively in written and oral form both individually and as a member of a multidisciplinary team; and
- Engage in life-long learning and self-education.

Additionally, the students are expected to attain the following concentration specific outcomes:

- Demonstrate proficiency in the aspects of space systems design and analysis; and
- Design and build a small-satellite as a part of a multi-disciplinary team.

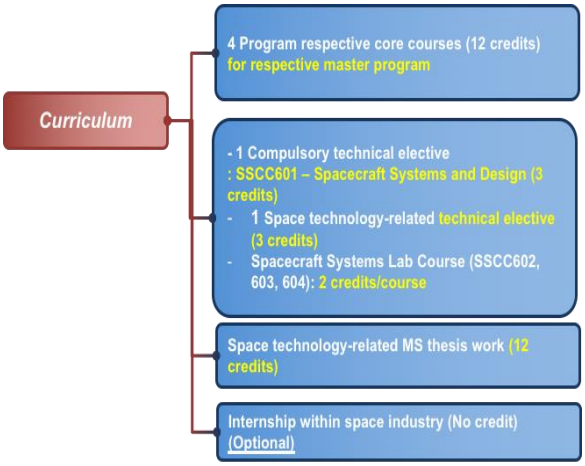

Figure 2: Curriculum of the Space Systems and Technology Concentration at Khalifa University

Core Courses

Since students are obligated to meet their chosen discipline requirements, it was not feasible to add a significant number of new courses to the curriculum. Limiting the number of new courses also expedited the accreditation process for the program, allowing it to grant certificates within two years of its inception.

Only one course was developed specific to the program. This course is compulsory for students in the concentration and takes the place of an elective that students would otherwise have been able to choose from. The "Spacecraft Systems and Design" course provides students with specific knowledge in the field of spacecraft design and utilization. The course also includes some hands-on demonstrations, such as the download of NOAA weather satellite images, in order

to provide students with a primer on space data applications.

To further strengthen the space background of the students, it was originally hoped that some other non-space-related courses could be modified to include a space component in the form of problem sets, independent research, or final class project. While some progress was made in this area, it has proven to be more challenging than anticipated. Significant changes to existing courses requires resources, and can sometimes also lead to a review of the new material by the accreditation authorities. Furthermore, faculty is naturally reticent to expand the content of their courses to areas outside their primary technical expertise.

While the hardship in adding additional space content to the curriculum was unexpected and unfortunate, the merger of Masdar Institute with Khalifa University has increased the amount of space-related offerings as the university does have a full aerospace department. Although a stronger emphasis on aerospace engineering is now possible, the program will continue to retain its multi-disciplinary approach, especially in the student research and small satellite development.

Student Research

A second key component to the student's certificate is research in a space-related field, culminating in a Master's thesis. Although the students are permitted to choose a thesis topic in their home department (e.g. mechanical engineering) they are encouraged to select a topic related to the space concentration, preferably one that also benefits the development of the CubeSat

Establishing a new research program in a new lab is a challenge. During the first few years of the lab, most of the faculty's effort is spent in creating the new curriculum, designing the facilities, and guiding a new set of students who may not have originally intended to focus on a space-related field. This was not unique to Khalifa University program, as similar challenges have been seen at other universities around the world.

The first few cohorts in the program had a mixed success with the thesis topics being related to space technologies, let alone the CubeSat development. Some of the more successful initial student research projects included the study of organic solar cells and development of a test plan for the first CubeSat project. The first CubeSat project in the lab was also able to host an experimental lithium ion battery designed and manufactured at the university.

As the program has matured the areas of research within the lab have begun to expand. This year the lab welcomed its first PhD candidate, a graduate of the second cohort of SST certificate students. New research is now being carried out in the areas of orbital dynamics and attitude control. Furthermore, as the lab matures, external funding resources have started to become available. This should further expand the SST program as a research laboratory on par with other more established labs within the university.

Small Satellites as Key Enablers

In addition to their academic curriculum and research goals, students in the program work towards designing, building, testing and flying a CubeSat. CubeSats are small spacecraft, originally conceived by Stanford University and California Polytechnic State University (CalPoly) in the United States. The first satellite in the program, MYSat-1, is a "1U" CubeSat and carries an imager and an experimental Lithium Ion battery developed by Khalifa University. This small satellite measures just 10 cm on each side and has a mass of approximately 1.3 kg. . Figure 3 illustrates the small size of the satellite as it undergoes final checkouts in the clean room of the Yahsat Space Lab.

In June 2016 students completed the first year of the program which concluded in a Systems Requirements Review for MYSat-1. Subsequently, students followed a design process similar to that used by professional institutions such as NASA or the Mohammed Bin Rashid Space Center. Students participate in design reviews, which are commonly held in industry, and are

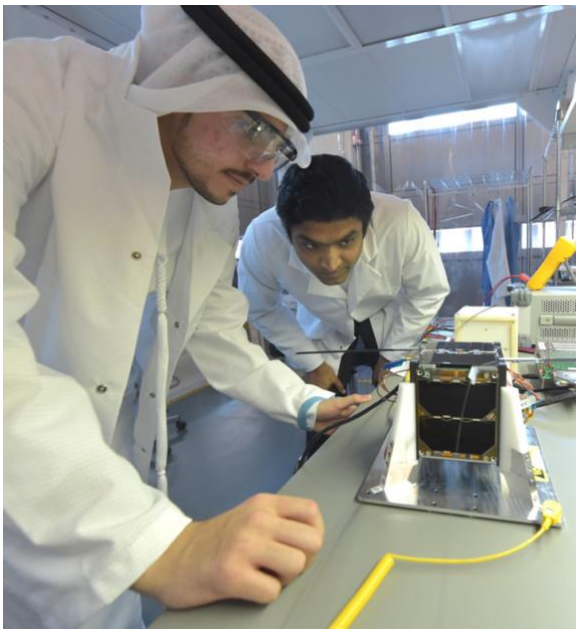

Figure 3: MYSat-1 Undergoes Final Inspection at Khalifa University's Yahsat Space

held to a high standard of scrutiny by reviewers with academic and industrial backgrounds. The students' work on the CubeSat provides them with a unique, industry-centered educational experience that will facilitate their entry into the workforce. Throughout this process engineers from Yahsat and Northrop Grumman offered mentorship and guidance related to the spacecraft design, ground hardware procurement, and flight hardware development.

The development program culminated in November 2018 with the launch of MYSat-1 hosted onboard a Northrop Grumman Cygnus vehicle bound for the International Space Station, as shown on Figure 3.

After completing its mission at the ISS, Cygnus successfully deployed MYSat-1 on 13 February 2019, and the satellite's radio signal was received shortly thereafter by the Khalifa University ground station at the Masdar City Campus in Abu Dhabi.

Students in the Concentration are now working towards designing, building, testing and flying MYSat-2. Concurrently, The Yahsat Space Laboratory has also started additional satellite projects under the sponsorship of the UAE Space Agency.

The CubeSat component of the program is the key enabler in the multi-disciplinary curriculum. Satellites, by their nature, are not limited to a single engineering discipline. Even a small satellite has a computer running software, hosted inside a mechanical platform, with electrical and ratio interfaces. Mechanical and thermal analyses and tests need to be conducted on the satellite. Orbital dynamics and attitude control systems all need to be taken into account for a successful mission. While each of the students may focus on a particular area of expertise, to be successful all the students need to work together. In such a small group, every student becomes a systems engineer and is exposed to areas outside of their core expertise.

Figure 4: Launch of MYSat-1 Onboard the Antares NG-10 Mission to the ISS

Through the CubeSat development the students in the program have also been exposed to other aspects not normally covered in a university environment. Early on in the development of the CubeSat a decision had to be made on whether to design and make all components or whether to buy commercial off the shelf (COTS) components.

Fifteen years ago, as CubeSats first emerged, there was no choice – students had to make all of their own components including structures, flight computers, and radios. While designing and making components from scratch obviously has a significant academic value, it tends to make students focus on very narrow development projects. Development also invariably takes longer than expected, slowing down the program.

Today, thanks to the broad success of the CubeSat platform, a vibrant marketplace exists for all components required to build a satellite. As a result, students can focus on the systems engineering of the entire spacecraft rather than designing an individual electronic board or structural component. In fact, because so many vendors exists, the students are able to carry out trade studies comparing the different commercially available solutions to select the one that makes the most sense technically, financially, and schedule-wise. These sorts of trades are not unlike what graduates will encounter once they enter the professional workforce.

A reliance on COTS components does not decrease the potential for specialized development, however. MYSat-1's hosted payloads, a camera and experimental Lithium-Ion battery, needed to be hosted on a single electronic board that could reliably interface with the COTS components ordered for the spacecraft. The opportunity was seized to internalize development of a purpose-built board that could host the experimental battery as well as support the camera along with a microcontroller that could relay data back to the COTS onboard computer. This board now flies on MYSat-1.

Coursework and research are important, especially in a university setting. But it is the hands-on experience of building a satellite that allows students to excel after

graduation. Designing, procuring, building, testing, and operating a satellite provides the core of the multi-disciplinary approach in the Space Systems and Technologies program. Empowered with this experience the graduates of the program are ready to join the ranks of industry, academia, or government.

CONCLUSIONS

One of the primary purposes of universities is to develop the country's human capital in science and technology.

To date, 47 students have participated in projects hosted by the Yahsat Space Laboratory and the Space Science and Technology program, and in keeping with the UAE's goals of diversity and inclusion 24 of the students have been women. Future CubeSat projects are expected to focus on education and training, technology demonstration, scientific research, communications, and earth remote sensing. They will be used for training across multiple engineering disciplines such as aerospace, electrical, mechanical, and computer science, as well as for testing efficiency of future spacecraft components such as novel solar panels, batteries or microelectromechanical systems (MEMS) devices.

The goal of any spacecraft development program is the launch and operations of the spacecraft. However, nearly 95% of the educational goals of this program are met the moment the satellite is delivered to the launch vehicle. The combination of coursework, research, and spacecraft development prepares the students to contribute in the UAE's rapidly growing space sector. University programs are mainly about workforce development, skill-building, and creating in-country capabilities. A student-satellite is also a hands-on project in arguably the 'most attention-getting' of engineering disciplines – space exploration.

In today's world technology is changing at an ever-growing speed. The space industry is not immune from this change. Technological change is impacting all areas, whether it is in the emergence of new small launch entrants, the growth of large communication constellations, the development of new cutting-edge scientific sensors, or the deployment of disaggregated systems for national security needs. To stay competitive, a country needs to invest in its most precious resource – human capital. At Northrop Grumman, Yahsat, and Khalifa University we are proud to have established a **Partnership for the Future** which is helping the United Arab Emirates achieve its ambitious space exploration objectives.

Acknowledgments

The authors would like to thank Masood Mahmood, CEO of Yahsat, and David Thompson, former CEO of Orbital ATK, who provided the vision for the creation of this program. We also acknowledge all the students, but especially the first cohort, who helped grow and shape the program during its first years.