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Building an Academic Community SmallSat Program

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ABSTRACT

The US Coast Guard Academy (CGA), which educates future officers for service in the US Coast Guard, is developing a multifaceted program in SmallSats. The CGA space initiative includes undergraduate courses, such as a recently-created Remote Sensing course. It incorporates Virginia Space's ThinSat Educational Program, providing hands-on experience in designing, building, and testing miniature satellites through space mission engineering; this involves collaboration between Science and Engineering and is extended to local high schools through their participation in SmallSat projects with CGA faculty and students. An important addition to the CGA space initiative is an MC3 ground station atop the Science Department building at CGA. It will be used to train cadets in satellite operations and ground station hardware, and to acquire data from satellites, allowing for training in cyber security and data analysis, and for use in student and faculty research projects. Sequential year-long senior student capstone projects in the Engineering Department to design, build, and test CubeSats, including new components and innovations, have already begun and will continue. Additional capstone projects involving CubeSats sensors, the use of UAVs, and remote sensing data analysis, including data from the CGA ground station, are planned in the Science Department with the 2020 implementation of a revised Science major.

MOTIVATION AND GOAL

The US Coast Guard Academy (CGA), one of four U.S. military service academies, prepares young people to be future officers in the U.S. Coast Guard (USCG) upon graduation. The three-fold education of our student cadets consists of four years of academic, athletic, and military training. The academic curriculum consists in part of a largely STEM-based common core of courses, and students graduate with a B.S. degree in one of nine majors (four engineering disciplines, science, operations research, cyber security, management, government). Upon graduation, students serve for a minimum of five years in the USCG, which performs 11 official missions, including Port & Waterway Security, Drug Interdiction, Search & Rescue, Defense Readiness, Marine Environmental Protection, Ice Operations, and Law Enforcement. All 11 missions of the USCG could greatly benefit from the use of aerial and space-based missions and data. Tracking icebergs, detecting oil spills, surveying disaster areas, monitoring coastal marine and vegetative health, identifying illegal fishing vessels, and receiving ship distress signals, are only a few examples. Real time (high temporal resolution) data, especially combined with geospatial intelligence tracking capabilities, have the potential to revolutionize the efficiency and success of Coast Guard missions.

The miniaturization and standardization of components and technology has propelled the rapid advancement of CubeSat development. The combination of this with reduced cost and risk failure has resulted in the proliferation of CubeSats and other SmallSats as viable alternatives to full-scale satellite missions. The term 'CubeSat' is now part of the common vernacular, with the demonstration of SmallSat utility in government and military operations as well as interplanetary missions.

The Coast Guard recently entered the field with the launching of Polar Scout in 2018, which was a proof-of-concept study of the viability of CubeSats for USCG operations in the Arctic. Global climate change is associated with variations in the migration patterns of fish populations and increased ice melting at high latitudes (*e.g.*, [1][2]). The subsequent opening up the Arctic regions to commercial transport and fishing requires increased Coast Guard monitoring of vessels for safe and legal trafficking and commercial fishing, as well as marine resource preservation. Receiving automatic identification system (AIS) signals and ship distress calls with traditional antennas along nearby continental shores is restricted by the excessively long Alaskan coastline and precluded by the curvature of the Earth, which disrupts the line-of-sight beacon signals emitted by the vessels. Space-based monitoring of the Arctic region overwhelmingly seems the optimal, and perhaps only, solution to the emerging need for increased Coast Guard presence and high latitude communication in the polar region. Although the Polar Scout mission had limited success, it did result in many lessons learned, and represented the CG's entry into the the space-based realm.

The eventual use of CubeSats or other SmallSats to support Coast Guard missions seems inevitable. Whether the Coast Guard concentrates on the creation of its own satellites, or contracts with external companies for needed data, the future Coast Guard workforce needs space-based training to design and execute successful missions and/or understand the process and details for intelligent decision-making and negotiating. Additionally, institutions of higher learning are centers that foster advancement in knowledge for the benefit of the local and global community. Whether CGA students remain in military service as a career or youth from local institutions with whom we partner enroll at CGA, the next generation needs education in space-based technology to encourage their future success and benefit society. This understanding propelled faculty members at CGA in the Science and Engineering Departments to create a space program in which students can take coursework to study the fundamentals and work with instruments and data; engage in related research projects; design, test and build a SmallSat; and, in the future, train in satellite operations and ground station hardware using our M3C ground station.

PARTNERSHIPS AND RESOURCES

CGA is a small undergraduate institution with ~1000 student cadets. We have limited funding and no additional personnel for our newly designed and evolving space program. It remains to be actively championed by CG headquarters. The success of the program relies heavily on partnerships created with external institutions, including the CG RDC (Research and Development Center) and other military and academic institutions.

MC3 Ground Station

Fig. 1. An MC3 ground station, consisting of a radome housing a 9-meter long antenna, was placed on the roof of the Science building at CGA for use in the Polar Scout mission, and beyond.

The CG RDC spearheaded the Polar Scout mission, and our connection with them secured the placement of one of the MC3 ground stations used for the project on the roof of the CGA Science building (Fig. 1). The use of the ground station, consisting of a radome housing a 9-meter long antenna, is being turned over to CGA for educational use. As it remains on the MC3 network, maintenance costs are paid for by the National Reconnaissance Office (NRO), which is a huge benefit. The antenna will allow us to receive data from CubeSats created by partner institutions, as well as our own creations. Educationally, it will be used to train cadets in satellite operations and ground station hardware, and to acquire data from satellites, allowing for training in cyber security and data analysis, and for use in student and faculty research projects.

The addition of an MC3 ground station has given us much of the ability to introduce courses like Remote Sensing, and provides us the opportunity to develop additional relationships with other Service Academies and governmental entities.

Sensor and Instrument Acquisition

Lawrence Livermore National Labs, through funding by the RDC for Polar Scout mission support, supplied us with two custom-built specialty spectrometers (~$25K value each); one was developed for use in the Remote Sensing course and one as the payload on a CubeSat being designed and created by Mechanical Engineering students in a capstone project.

Funding from the Center for *Arctic* Study & Policy (*CASP*), established at CGA to promote academic research on *Arctic* policy and strategy, allowed us to purchase an entire suite of instruments for use in the Remote Sensing (RS) course, including a VIS multi-spectral sensor, and UV, NIR, and SWIR cameras and accessories, since the RS course has many polar applications. Similarly, funding from the High Energy Laser Joint Technology Office (HELJTO) allowed training and space-related conference trips for faculty and students.

We have joined forces with the other service academies that have CubeSat or CubeSat payload programs (Navy (USNA), Army (USMA), and Air Force (AFA)) and partnered with the Air Force Institute of Technology (AFIT) and Naval Post-Grad School (NPS), forming Military Service Institution of Higher Learning (MSIHL). The purpose of this coalition is to capitalize on the strengths and expertise of its member institutions. For example, AFA has a successful CubeSat payload program, supporting military and NASA missions; USNA and USMA have well-established CubeSat programs; we have an MC3 ground station on our roof, and our space program, which includes the building and launching of SmallSats, is underway. Our partner institutions have been a valuable intellectual resource, especially as we initially created our program, and provide needed CubeSat testing facilities. The coalition has submitted requests for funding for continued development of a joint high-end and versatile CubeSat program that can meet the needs of military, academic, and research interests. This is a huge benefit of the partnership and truly capitalizes on the combined strength of each member institution.

Additionally, we have formed collaborations with faculty members at several educational institutions, including Connecticut ("Conn") College across the street from CGA and the University of Rhode Island (URI) in Providence. Conn College physics students have taken the Remote Sensing course at CGA and worked in the CGA Plasma Physics Lab; Remote Sensing projects involving Conn College students are anticipated in the future. Plans with URI include grant proposal submissions to fund a remote sensing project, including the acquisition of a comprehensive UAV system with a 400-2500 nm hyperspectral sensor, LiDAR, and a thermal IR camera integrated onto a drone. (Funding for this UAV system has already been included in a proposal submitted by MSIHL, and if not funded will be included in the URI submission.)

The UAV will be used in both the Remote Sensing course, as well as in CubeSat design to test communication between CubeSat components/payload/bus and the MC3 ground station at low altitude, including accuracy of the transmitted data through comparison with data collected by sensors onboard the UAV. Additionally, the data collection and analysis will serve as an amazing educational tool for the students both for class and capstone and research projects.

A new CNC machine, requested in a proposal submitted by MSIHL to replace our ailing one, will facilitate the design and fabrication of satellite structure and mechanisms.

VA Space Partnership

Virginia Commercial Space Flight Authority ("VA Space"), owner and operator of the Mid-Atlantic Regional Spaceport (MARS) at NASA Wallops Flight Facility in Virginia, launched a ThinSat educational program which provides students hands-on experience in designing, building, and testing miniature satellites called ThinSats (thin miniature satellites developed by VA Space). VA Space chose CGA, among other schools, to test pilot their program by providing three ThinSat missions to CGA. The ThinSat program, in addition to the MC3 ground station from Polar Scout, has been an essential component in the launch of our space program.

CGA SPACE PROGRAM INITIATIVES

The need for space missions as a solution to meet the growing demands on the CG in the Arctic and globally, seems evident. Current space program initiatives (*e.g.*, the new ground station at CGA), related courses (*e.g.*, Remote Sensing) and cadet capstone projects (*e.g.*, designing, testing, building CubeSats) are underway at CGA to prepare our students for emerging technology they will likely see in their future in the Coast Guard and in the world.

Faculty Training

To support the creation and evolution of its space program, invested CGA faculty members engaged in extensive training in the field. This included a 4-Day Short Course on Astronautics and Applications of Satellite Systems, offered by Allen Blocker from Sydrus Aerospace and tailored to the specific needs of our program. Twelve people, including CGA and Conn College faculty members, four CGA students in engineering CubeSat capstone projects, and RDC members involved in the CG Polar Scout mission, attended to learn about space mission design, including mission concept, architecture, analysis, & geometry; the space environment; orbit, payload, spacecraft, & subsystem design; launch system selection; ground segment & mission operations; relevant computer systems; reliability, safety, & system validation and verification. The course, funded for CGA attendees by HELJTO grant money, was on-site at CGA which provided enormous savings to the government on travel, lodging, and per diem costs.

Additionally, persons involved in SmallSat companies or missions relevant to our program were invited to give presentations in our Saul Krasner Memorial Science Lecture Series. Faculty members engaged in self-study, extensive reading and webinars, and meaningful conversations with collaborators.

Coursework

The CGA space initiatives include a recently-created Remote Sensing course that has been offered yearly since 2018 and is still evolving, a Mathematical Methods in the Natural Sciences course offered for the first time in spring 2020, and an in-depth astronautics course currently in development for spring 2021.

Coincident with the launch of our space program was the development of a revised Marine & Environmental Science (MES) major at CGA to better prepare our Science majors for their service in the US Coast Guard and our changing world. MES is the only Science major at the Academy, and now offers three major Concentrations, of which students choose one. The Remote Sensing course attracts cadets from Operations Research, Engineering, and the Marine Science major, as well as Connecticut College students. It is a required course in both the Marine Environmental Physics Concentration (which focuses on understanding the physics of energy, climate drivers, and measurement techniques in the space and marine environments), and in the Geospatial Intelligence Track within the Marine Science Concentration. It is a possible elective in the third MES Concentration (Environmental Science), and has been placed by the Cyber Council in one of the offered course sequences in the new Cyber Security major, which is housed in the Engineering Department.

The Remote Sensing (RS) course has three main components. Students study theoretical foundations of RS, such as radiation, sensor characteristics and capabilities, and orbital dynamics, including basic exploration using the (free educational version of) Systems Toolkit (STK) software. They perform experiments in labs using hands-on UV, VIS, NIR, and SWIR sensors; and they apply aerial and satellite data analysis using GIS, MulitSpec, and SNAP (Sentinel Toolbox) software. The course format incorporates short lectures, interactive student worksheets applying the concepts learned, and in-class labs applying satellite data on a range of topics, such as image interpretation, emissivity and brightness temperature of sea ice, supervised and unsupervised classification schemes; calculation of vegetation indices, application of algorithms to determine snow depth, correction of distortions in synthetic aperture radar (SAR) images, and the use of interferometric SAR to explore landslide deformation. The third evolution of the course, offered in Fall 2020, will include greater study and application of SAR and LiDAR, and potential use of data from Planet's Education and Research Program; this program allows free monthly access to (limited) 3-5 m resolution global imagery for educational purposes.

Students are required to do a project for the course, individually or in groups. For example, they may choose to build a ThinSat through CGA's partnership with VA Space, investigate the potential use of satellite data to increase situational awareness during a CG Catastrophic Incident Search and Rescue case, collaborate on an NGA-sponsored project, or investigate a topic of their choosing, such as change detection of the landscape of their local hometown over time.

Mathematical Methods in the Natural Sciences is an elective course which exposes students to mathematical tools used in the sciences and engineering, including applications. Topics include Fourier series and analysis and complex numbers, as well as linear algebra, vector and tensor analysis, power series, partial and ordinary differential equations, and special functions and their solutions. The future astronautics course, scheduled for spring 2021, will include material learned from the 4-Day Short Course on Astronautics and Applications of

Satellite Systems described previously, and incorporate use of the MC3 ground station and hands-on elements of designing, building, and testing ThinSats and CubeSats.

Capstone and Student Projects

In-depth, experiential projects are invaluable teaching tools to students. Interdisciplinary partnerships across Sections in the Science and Engineering Departments have optimized benefit to the students.

VA Space ThinSat Program

In collaboration with Virginia Space's ThinSat Educational Program, CGA embarked on an initiative to educate the upcoming generation in space mission engineering through hands-on design, build, and testing of miniature satellites. The program was first introduced in fall 2018 into CGA's Remote Sensing course and with CGA cadets involved in senior capstone or independent research projects with Engineering and Physics faculty. In spring 2019, it was incorporated into Project SPIL (STEAM Partnership for Innovation and Learning) - an educational partnership between the US Coast Guard Academy (CGA) and the Regional New London STEM Science & Technology Magnet High School (STMHS), New London High School, and Local Home Schoolers - that centers on innovative learning through Science, Technology, Engineering, Art, and Mathematics (STEAM). STMHS shares land with New London High school, which is less than two miles from USCGA, yet we recruit and admit very few New London students to the Academy. SPIL is a science-based program to benefit all institutions involved and attract local students to USCGA.

To captivate the students and inspire interest, we began the program for the SPIL students with a glimpse of the culminating goal: the SPIL students and their teachers, along with CGA faculty and cadets working on ThinSat and CubeSat projects, journeyed to Virginia in April 2019 to witness the launch of previously-created student ThinSats aboard the Cygnus space vehicle on the NG-11 mission. Immediately back in the classroom, the students then experimented with 3-D printed templates of the ThinSat engineering model that could be launched into space aboard the next VA Space mission. They learned about the sensors, photons and spectral signatures, the idea of a bus, power constraints, and the like (Fig. 2). This strategy was exceedingly successful, energizing both students and faculty alike. The SPIL students wanted to continue the program even during their summer vacation when they were not in school, meeting weekly with CGA faculty to learn how to create the ThinSat engineering model they tactilely explored which could be launched into space, as they witnessed.

Figure 2. High school students in Project SPIL learn about sensors and the meaning of data (top) and experiment with 3-D printed templates of the ThinSat engineering model (bottom).

The bulk of the program consisted of weekly meetings between the highschoolers and CGA faculty members in which students start from the ground up, learning the concepts of space mission engineering. Working with MEDO xChips designed by Virginia Space for the program, students designed a “weather station" connected to the computer which has sensors and takes and displays data, such as temperature, humidity, and light intensity. Using the xChips, students then designed a "ground station" connected to the computer, and a mobile "FlatSat", which contains the sensors taking data (Fig. 3). This was educational for both faculty and students, though initially hampered by Internet security and connection issues at both schools, which took considerable time to work out. The first phase of the project was set to culminate with the launch of the student-built FlatSats aboard CGA's FireFly 6 UAV to heights nearing 400 ft; the students would receive the data via their ground stations connected to computers, convert and analyze it, then interpret and discuss the results. Sadly, this never occurred due to an unfortunate mishap with the UAV that nearly resulted in its death; it still has not recovered. After a hiatus in the program, the onset of the COVID-19 pandemic shut it down. Nevertheless, the ThinSat program has become an integral part of SPIL, and will continue once the pandemic is over.

Fig. 3. A FlatSat created by students in the Remote Sensing course.

While SPIL students were building weather stations and FlatSats, CGA students and faculty involved in the ThinSat program were analyzing data collected by our first round of ThinSats on board the NG-11 mission whose launch they and the SPIL students witnessed. This included health and safety data from the ThinSats, and green and NIR luminous flux. Unfortunately, our plasma temperature and 3D magnetic field sensors all gave null values. Work began on our next round of ThinSats. From lessons learned, faculty and students would create a custom-built ThinSat and a ThickSat (created by the joining of two ThinSats), as described below.

Remote Sensing Data Capstone Projects

Capstone and student projects using remote sensing data are also underway at CGA. In collaboration with the Physics Section, two groups of senior Electrical Engineering majors embarked on capstone projects to apply machine learning to satellite & aerial data to recognize oil spills & oil spills on ice. The project involved investigation into feasible types of data, acquisition and analysis of imagery, including the use of SNAP software to analyze Sentinel SAR data, and application of machine learning to meet the project goals. This work was proposed by the CG RDC to benefit CG missions.

Future capstone projects involving remote sensing data analysis, including data from the CGA ground station and UAVs, are planned in the Science Department with the implementation of the revised Science (MES) major.

CubeSat Capstone Projects

USCGA is new to satellite design and operations, but is working toward the creation of a comprehensive CubeSat program that can meet the needs of military, academic, and research interests. The Engineering Department (Electrical and Mechanical Engineering Sections) has a long history of engaging in Capstone design projects that require the design, build and test of a prototype. The last three years, Electrical and/or Mechanical Engineering has had at least one CubeSat project, and the last two years, has partnered with the Physics Section in the Science Department, including on a joint satellite project that is co-sponsored by the Aerospace Department at the United States Naval Academy. CGA has recently created a custom-designed ThinSat, ThickSat, and CubeSat for launch through a partnership with VA Space, Inc.

VA Space granted us three missions as part of their pilot ThinSat program, described previously. On the first mission, NG-11, three ThinSats with the standard suite of sensors were launched into extreme low Earth orbit (ELEO), with a perigee and apogee of 201 km and 250 km, providing data and many lessons learned to CGA students and faculty [3][4][5]. For the second mission, scheduled for launch in Spring 2021, CGA and AFIT students and faculty have designed and created a ThinSat with the standard sensor suite and a custom 8-band VIS/NIR multispectral sensor onboard, and joined two ThinSats together to form a 'ThickSat'. The ThickSat has a custom-designed impedance probe plus the same multispectral sensor onboard as the ThinSat, but with the addition of a lens to reduce the sensor field-of-view. The main mission of the payload is to test a miniaturized version of an impedance probe. The Naval Research Labs currently has a full-scale impedance probe attached to the International Space Station, ISS. This probe measures the charge state of the ISS and plasma density and temperature that the ISS encounters in low Earth orbit. This plasma is excited by space weather, which includes events such as solar flares and Coronal Mass Ejections. Impedance probes have also been used in plasma research to measure plasma temperature and density in laboratory experiments. Specifics of these creations are given in a separate paper (SSC20-WKVII-08) at this conference by the same authors.

CONCLUSION

The world is rapidly evolving. Today's youth need knowledge and skills to optimally adapt, and hopefully thrive in (or despite), global climate change, the implementation of increased cyber security measures, the opening up of the polar region, and an exponential increase in space-based technology involving SmallSats. Space-based technology informs intelligent responses to global climate change, monitors the Arctic, and employs cyber security. It is the perfect vehicle by which to educate students in all four of these dominant areas of their future.

Educational programs in remote sensing and the design of SmallSats or their payload are emerging throughout the country to meet the demands of our evolving world. CGA has joined this effort to prepare students as a powerful workforce to optimize CG missions, to educate the youth in the local community, and to advance additional military operations and academic interests.

CGA has created a new interdisciplinary program, drawing on the strengths and expertise of people across departments at CGA. We have launched new courses, including Remote Sensing and Mathematical Methods in the Natural Sciences, and are developing an astronautics course for spring 2021. Science and Engineering faculty and students have begun collaboration on remote sensing projects and the design, build, and testing of SmallSats and components, including a custom-designed ThinSat, ThickSat, and CubeSat through a partnership with VA Space, Inc.

We have created a coalition with our sister service academies who already have established CubeSat programs (US Naval and US Military Academies) or CubeSat payload programs (US Air Force Academy), and partnered with other military institutions of higher learning (AFIT and NPS). We boast an MC3 ground station on top of our Science building, and have recently submitted multiple proposals to fund a comprehensive UAV system. Our ultimate goal is the development of a space literate cohort of students from across disciplines that will serve the CG for decades into the future as cyber-security and satellite-communication become increasingly critical issues of interest.

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References

1. Fossheim, M., R. Primicerio, E. Johannesen, E. et al. "Recent warming leads to a rapid borealization of fish communities in the Arctic," Nature Clim Change vol. 5, 2015.

2. Serrseze,, M. C. J. Stroeve, A. P. Barrett, and L. N. Boisvert, "Summer atmospheric circulation anomalies over the Arctic Ocean and their influences on September sea ice extent, A cautionary tale," J. Geophys. Res. Atmos., vol. 121, 2016.

3. Clark, S., "Antares rocket boosts Cygnus supply ship toward International Space Station," SpaceFlight Now, 18 April 2019.

4. Krebs, G. D., "ThinSat 1A, ..., 1L," Hunter's Space Page, 18 June 2019. https://space.skyrocket.de/doc_sdat/thinsat-1.htm

5. Werner, D., "Will ThinSats inspire the next generation of engineers and scientists?," SpaceNews, 23 Oct. 2017.