

**The Virginia Space ThinSat Program: Maiden Voyage and Future Progressions**

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**ABSTRACT**

Science, technology, engineering, and mathematics (STEM) focus is rapidly being integrated into the modern-day classroom. This focus is essential for developing both the technical minds and creativity of the next generation. The education industry cannot push STEM activities to the next level without the help of outside partners who have industry insight and experience. This is why Virginia Commercial Space Flight Authority (Virginia Space), Twiggs Space Laboratory, LLC (TSL), Northrop Grumman (NG), NASA Wallops Flight Facility (WFF), and Near Space Launch Corp (NSL) have all partnered together to develop the Virginia Space ThinSat Program. With our primary focus being on STEM outreach, the program has developed a new way to bridge the gap between satellite development and the education industry. By utilizing this platform, we have already seen development of beneficial research potential from numerous institutions that shows the promise of a bright future for the Virginia Space ThinSat Program and Extreme Low Earth Orbit (ELEO) research.

**PROGRAM OVERVIEW**

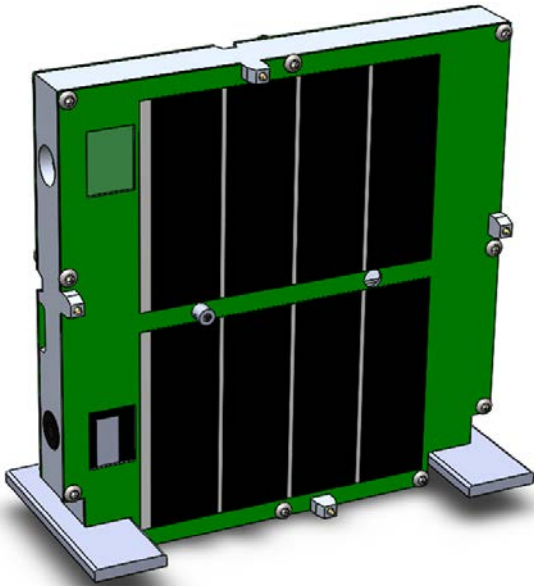
STEM advancement is on the forefront of most technical educator’s minds as the next generation of students are being molded to become the future technical minds of the world. Previously, the ability for educators to have students work on actual hardware and true engineering projects was limited, due to both resource availability and cost, but now outside resources have developed STEM outreach programs to work with the next generation of engineers and scientists.

The Virginia Space ThinSat Program is a great example of a STEM outreach project, that is providing many students the opportunity to see real-world applications of engineering and science. This program has been made possible through the collaborative efforts of Virginia Commercial Space Flight Authority (Virginia Space), Twiggs Space Lab, LLC (TSL), NearSpace Launch, Inc. (NSL), Northrop Grumman Innovation Systems (Northrop Grumman), and the

National Aeronautics and Space Administration (NASA). The ThinSat Program was developed with the vision to allow students to design and build their own payloads in order to be challenged with an engineering project, which can be tailored for a wide range of technical skill levels. For students to have the ability to partake in a small satellite program, like the ThinSat Program, at such a young age, allows them to develop essential skill-sets that will help them throughout their higher educational and professional careers.

Following the design of the CubeSat concept, the ThinSat is a small pico-satellite that can be utilized to both engage students in STEM activities, as well as provide a smaller, more accessible platform for space science research (Figure 1). A ThinSat is approximately a seventh the size of a 1U CubeSat, allowing 21 ThinSats to be packaged into a 3U Canisterized Satellite Dispenser (CSD). Virginia Space, through a long-term partnership with Northrop Grumman, has acquired payload space on the second stage of the

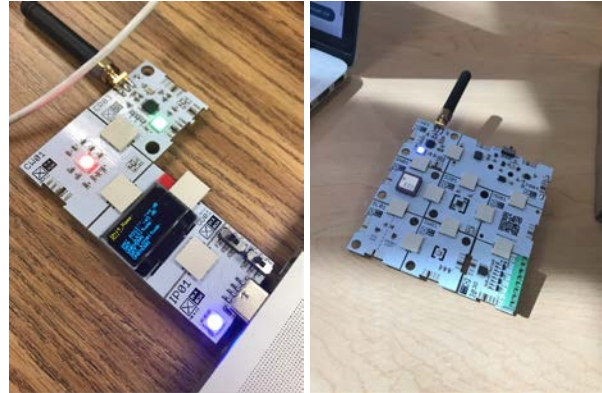
Northrop Grumman Antares vehicle. A volume size of 12U will be dedicated to the ThinSat Program, allowing space for 84 ThinSat units in total on each mission. The International Space Station Commercial Resupply Services (CRS) missions aboard the Antares vehicle will be occurring approximately every six to nine months, with the maiden mission scheduled for November 2018. The vehicle will deploy the ThinSats from an altitude of approximately 250km with an expected orbit of 5 days.



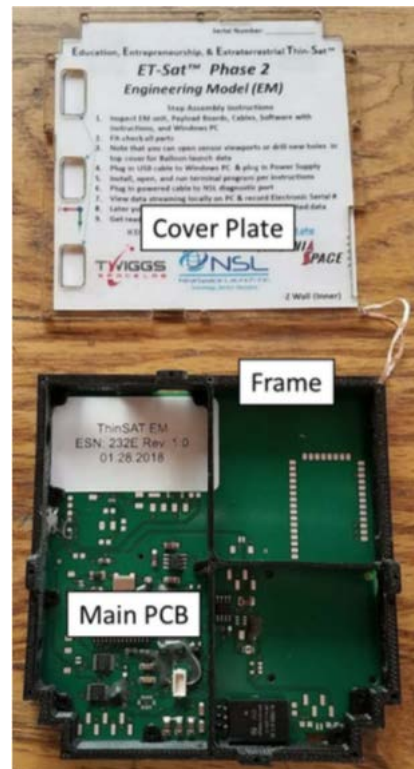
**Figure1: 3D Model of the ThinSat**

The ThinSat Program not only gives students a ride into orbit, it also provides the STEM development opportunities during three separate build up phases prior to launch. The three-phase program provides STEM students with valuable insight into the iterative process of engineering. The initial stage of the program, Phase 1, is a weather satellite development stage that allows students to utilize “plug-and-play” sensor technology, developed by Meta Economic Development Organisation (MEDO), to capture and analyze atmospheric data. This data is able to be viewed and downloaded via the ThinSat Programs Space Data Dashboard (SDD), which is the main interfacing tool between the ThinSat team and the program participants. Phase 1, encompasses both development of a weather satellite and a ground station, allowing valuable teaching moments to show the fundamentals of satellite communication (Figure 2). Phase 2 of the program is the stage in which students are given an Engineering Model (EM) of the ThinSat. The EM consists of a 3D

printed frame, utilized to properly develop their payload to fit in the designated payload area and communicate correctly with the ThinSat EM bus (Figure 3). After completion of the EM development, students are to perform troubleshooting if needed and send their EM to NSL for launch on a high-altitude balloon. The EM is returned to the students for an inspection and evaluation of their payload performance based on data received and analyzed. Students make any modifications necessary to their respective payloads and send to TSL for integration into the Flight Model (FM).



**Figure 2: Phase1 Ground Station (Left) and Weather Satellite (Right)**



**Figure 3: ThinSat 3D Printed EM**

Although the ThinSat Program was primarily developed to support STEM outreach, it has also attracted the interest of many higher-level institutions. The 3-phase layout of the program is ideal for STEM outreach aspects but is not as applicable to higher-level institutions as it is to the K-12<sup>th</sup> grade students. This broad range of institutions attracted to the ThinSat program has both furthered STEM education and ELEO research within the same platform. These higher-level institutions are given the ability to utilize the ThinSat platform for research, with the understanding they are required to mentor multiple STEM outreach schools throughout the duration of the program.

**MAIDEN VOYAGE**

With the ThinSat Program being focused around STEM outreach, the lead institutions are brought into the program with the primary objective of being mentors to the STEM outreach schools in their regions. In return for performing STEM outreach, they receive an additional ThinSat for payload development. Throughout the first mission of the program, this has been beneficial for both the lead institutions and STEM outreach schools. The ability for the STEM outreach schools to work with the lead institution professors and students has shown to provide a more robust knowledge and understanding for both parties.

The ThinSat Program has already reached a wide range of higher-level institutions that are serving as leads for the maiden voyage. The lead institutions that are currently involved in the program range from governmental entities to liberal arts colleges. Below, Table 1, is the list of lead institutions for the OA-10 mission.

**Table 1: Lead Institutions (OA-10)**

<b>Lead Institutions (OA-10)</b>
Northrop Grumman
NASA Wallops
NASA Langley
Old Dominion University
William and Mary
University of Virginia
Eastern Shore Community College
Twiggs Space Lab
NearSpace Launch
United States Naval Academy
United States Coast Guard Academy

Within the program, as previously stated, there are different levels of technical involvement through payload design and construction. This difference is accompanied by multiple payload options for the different technical levels. It is not feasible to require a STEM outreach school to produce a payload on par with a lead institution. Therefore, three levels of payload options were developed for the participating groups to choose from for the program.

The first payload option is referred to as a Standard Payload. This option consists of a mixture of pre-built and programmed sensor chips developed by MEDO. These chips are referred to as the XinaBox Phase 1 chips, which provide a user friendly “plug-and-play” interface. The simplicity of the XinaBox chips allows for the less technical groups to build a payload without the difficulty of designing and building the hardware. The payload, although straight forward to assemble, still provides the instructors with valuable data as a supplemental teaching tool. The Phase 1 option is an integral stepping block that the STEM instructors utilize to accompany their science lesson plans. This allows for students to be able to take textbook activities and apply them to real experimental data that is returned from the payload.

For the schools that are pursuing more complex challenges, there are two options available for payload development. The first of these options is the full development of a Custom Payload, which means that the schools are given interfacing requirements, payload volume restrictions, and safety regulations, but the developers otherwise have complete freedom on design of the payload. This option allows students to be in control of the hardware and software development of the payload in order to perform valuable research in the ELEO region.

The second option for Custom Payload development is a Printed Circuit Board (PCB) that has been developed by TSL. The TSL PCB provides the user with the ability to develop a custom research payload without the complexity of having to develop their own PCB. The TSL PCB package is comprised of a Primary Board, Secondary Board, and Expansion Development Kit. The combination of these three kits provides the participants options in terms of payload development complexity.

The TSL Primary Board (TSLPB) is responsible for the interfacing with the ThinSat bus terminal, and it contains the microcontroller and additional sensors to provide a built-in sensor suite for the student payload section of the satellite (Figure 4). The microcontroller is an Arduino ProMini, allowing



for easy customizability with regard to data acquisition and processing. The additional sensors on the primary board include a solar sensor, infra-red sensor, multiple temperature sensors, and an Inertial Moment Unit (IMU). The IMU will output accelerometer, gyroscope, and magnetometer data in reference to the three axes of the spacecraft. The addition of the TSLPB to the realm of options for ThinSat payload development has allowed for many students to get an initial grasp on the complexity of fully developing a payload from scratch.



**Figure 4: Twigg's Space Lab Primary Board (Bottom) and Secondary Board (Top) Separated**

Once they have grasped the function of the primary board and Arduino programming, they are then able to utilize the TSL secondary programming board (TSLSB). The TSLSB design is merely a pin out board that has built in connectors to interface with the TSLPB (Figure 5). The secondary board gives the user the ability to add additional sensors that are not available on the primary board, making it possible to acquire additional data for research. The secondary board is also able to be designed and tested through the Expansion Board Development Kit, all provided by TSL. The Expansion Board Development Kit is completely separate from the payload boards, allowing for testing and developing of payload options prior to final integration into the flight model hardware.



**Figure 5: TSLPB and TSLSB in EM**

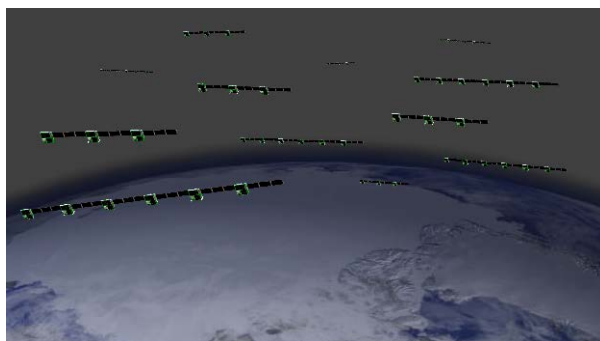
The TSL boards have proven to be an enticing option for many high school participants and lead institutions. Some teams have decided to utilize the TSL boards due to the ability to capture the data necessary for their experiments without having to design and build the payload from scratch. This option allows students with minimal payload development knowledge to take a somewhat smaller task on, while still being able to perform their experiments and collect the necessary data. The TSL boards also provide the high school students with an alternative and robust option in comparison to a Standard Payload. With the addition of the TSL boards, the payload development gap between the Standard Payload option and the Custom Payload option was effectively bridged for teams participating in the program.

#### ***Maiden Voyage Payloads***

The research that will be performed on the first mission varies in levels of complexity. Ranging from raw data collection and analysis to mechanical system testing with minimum data collection and analysis. As a program that prides itself on diversity and applying to a wide range of technical development levels, Virginia Space is very pleased with the manifest for the OA-10 mission.

A few of the lead institutions that are completing Custom Payloads for the maiden voyage include Taylor University, United States Naval Academy (USNA), and Old Dominion University (ODU). All three institutions are performing different experiments throughout the orbit duration, with each providing valuable data.

The Taylor University team is utilizing the ThinSat platform as a proving ground for a CubeSat design they are developing. The experiment is called the Phantom Loop. The experiment utilizes a thermionic emitter, that is needed to output large electric current. Once the electric current has been discharged, the satellite is equipped with an electron collector that will provide the data to verify the passing of electrons via space environment. The satellites, while in orbit, will be connected by an articulating fanfold in strings of three or six ThinSat units (Figure 6). The Taylor payload will slowly deploy one of the ThinSats in its string to test the range on the phantom loop design providing very valuable information in reference to the electric field in the ELEO region.



**Figure 6: 3D Model of Strings in Space**

The United States Naval Academy's custom payload is comprised of a sensor suite providing orbital degradation research and characterization of the ELEO region of the ionosphere throughout the mission. The orbital degradation analysis will be performed in Systems Tool Kit (STK) by utilizing orbital insertion parameters to map out the simulated path and compare with the GPS data from the satellite. They will also be collecting electron density data throughout the duration of the orbit to characterize the ELEO region of the ionosphere. This data will be compared to public National Oceanic and Atmospheric Administration (NOAA) data in order to determine any abnormalities in the ELEO region. In addition to performing that analysis, USNA will also be taking the electron density data and converting it into a sound profile in order to perform a data sonification analysis, with the hope that additional abnormalities will be detectable through the audio file.

While building custom sensor suites and capturing data to compare to theoretical models is all very valuable information, mechanical design iterations of mechanisms within the ThinSat are also being developed by lead institutions. ODU, located in

Norfolk, Virginia, is a key lead institution in the Virginia Space ThinSat Program.

ODU students have worked with the ThinSat design team in order to alter a mechanical design on the articulating fanfold. In the current design, the fanfolds are comprised of solar panels, data transmission lines, and nitinol wire. The nitinol wire gives the fanfold its spring constant for separation of subsequent ThinSats, but the design does not include a locking mechanism to help dampen the dynamic characteristics between satellites by creating a rigid structure. ODU has developed a locking mechanism that will theoretically help with dynamic characteristics between ThinSats while in orbit. The first iteration of the mechanism has been built and tested in a neutral buoyancy tank to verify the device meets the set expectations of creating a rigid fanfold. In order to prove the theory of dynamic dampening between ThinSats utilizing the locking mechanism, ODU will be flying an IMU to collect data. This data will be compared to IMU data from ThinSats utilizing the original fanfold design in a separate string. This open source data sharing for participants in the program is made possible via the Space Data Dashboard, which is the central information location for all aspects of the program.

As seen from the above examples, the participants in the program are already planning on performing tremendous research in the ELEO region. Satellites do not nominally orbit in this region of space, even though it is the closest region of space in earth's atmosphere. This program, while primarily developed to focus on STEM outreach, is also able to perform valuable research. With the program now starting to become more developed, while moving towards its first launch, new lead institutions have started applying for the next manifest. Due to having a set number of 84 ThinSat units available on each mission, the addition of new lead institutions is proving to be a highly selective process that will improve the quality of research and propel the growth and development of the ThinSat Program for the future missions.

## **FUTURE MISSIONS AND BEYOND**

The space industry has a track record of extensive timelines to reach the final product, but with the advent of CubeSats this timeline was shortened. However, the turnover of students, particularly undergraduates, in long-term academic programs is high, with a loss in project momentum and knowledge graduating each year. Maintaining a constant student presence over the course of several years is difficult.

One of the huge advantages of this program is the ability to go from payload development to launch

within a year timeframe. With the Virginia Space ThinSat Program having the ability to fly on the CRS missions, occurring every six to nine months, creates a unique and sought-after rollover period for the program. Allowing for the ThinSat development team to work with current program members on design iterations, while also bringing in new lead institutions in a timely manner to facilitate with payload development. The six to nine-month continuous flow not only allows for iterative research development, it also allows for STEM schools to have constant interaction and training with their respective lead institution. This will allow for the students to continually work with scientific hardware in order to keep developing their technical knowledge of space systems.

For the early 2019 mission and beyond, Virginia Space will be expanding the capacity of the ThinSat program, from the initial 63 ThinSat units that will be launched on OA-10 to a total of 84 ThinSat units. This will allow the program to expand the STEM outreach initiative, as well as increase the diversity in payload designs. With the program focus on STEM schools being well mentored by their respective lead institution, a limit of two STEM outreach schools per lead institution per flight has been set. This will help STEM outreach schools obtain as much knowledge and experience as possible. Currently, there are 13 lead institutions across the country, and we plan to expand to 28 leads for the next mission.

Due to this increase in the number of lead institutions on future missions, an application process has been implemented. As an invitation only program, with a large focus on Virginia based institutions, the application process has the potential to allow for a far wider range on national and international payloads to be chosen for the future missions. Also, the application provides for two STEM outreach schools for each lead institution, but there has already been interest in expanding that number to provide more STEM outreach schools the opportunity to work with the hardware. The two schools chosen by the lead institution for enrollment in the program will still be the designated schools to receive a flight model ThinSat for the mission, but the goal of many leads is to be able to utilize Phase 1 hardware to reach a larger audience. This outreach has been proposed to be conducted via workshops and additional instruction opportunities by the leads with their local communities and schools. This would allow the STEM aspect of the program to be broadened even though there is limited space on the vehicle for flight hardware.

Further, educational programs are prone to shifting timelines throughout the school year, which

then can possibly lead to delays in payload deliveries. With the consistency of launches, as well as a rolling application process, there is the ability to manage the manifest if teams are unable to meet deadlines. This allows for the institutions that are not able to meet mission deadlines to continue to develop payloads, with the guarantee they can be included on a subsequent mission; thereby providing for the acceleration of teams onto an early mission if a spot becomes available. Having this type of flexibility allows the program to incorporate both veteran aerospace institutions and higher-level institutions that have never had the opportunity to develop satellites.

This diversity in the levels of experience from the lead institutions has shown the wide applicability of the ThinSat Program. Many of the lead institutions involved in the program are in the initial stages of development for their respective science departments, and this program allows for these institutions to create a satellite that is much more manageable than trying to utilize a full CubeSat for their first mission. While being a great option for new departments, the program has also shown to be a great test bed for institutions with already well-developed space departments. Applying to both new and veteran institutions has shown to be a tremendous asset of the program.

With the manifest for the early 2019 mission filling quickly, new lead institutions for the program are presenting promising research opportunities and STEM initiatives. Four of the new lead institutions include NASA Johnson Space Center (JSC), George Mason University (GMU), American University (AU), and Salisbury University (SU). These institutions have shown, via the application process, that they have a very strong initiative to perform high levels of STEM outreach, as well as develop custom payloads that will contribute significantly to the already existing research manifest.

Virginia Space not only administers the ThinSat program, but the company also owns and operates the Mid-Atlantic Regional Spaceport (MARS), which is located in Wallops Island, Virginia on the Delmarva peninsula. SU is a local university on the peninsula, and therefore a partnership with them will help to build space interest and knowledge in the local community. MARS is rapidly growing and developing in the area and continually trying to perform outreach to the local community. This outreach is now being enhanced by developing the ThinSat Program, and having a STEM centered local institution dedicated to increasing the knowledge of space systems in the area. SU's application showed a tremendous custom payload

concept, and much detail and thought into the STEM outreach aspect of the program.

In addition, AU and GMU have also shown, via the application process, that they have high levels of dedication and focus on STEM outreach within the ThinSat Program. They will be lead institutions that are responsible for management of the Fairfax, Arlington, and District of Columbia regions. The teams have planned to have four prestigious high schools join them in the program, while also providing workshop opportunities for other local elementary, middle, and high schools in the area. These workshops are not a requirement for participating lead institutions, instead they are an additional STEM outreach mechanism that has been proposed by AU, to grow interest and knowledge of space systems in the local community. This type of STEM dedication is exactly what the program is looking for via the application process.

In addition, these lead institutions will also be designing and building payloads that will add more depth to the manifest for the next mission. The ability to both focus on STEM outreach and produce a payload, providing valuable ELEO research, is exactly the type of lead institution looked for during the application process. Adding leads that follow this same vision will allow the program to continue growing the STEM outreach coverage throughout many regions of the country.

While continually growing and diversifying the manifest, the program also has a technical team whose main focus is on the development of the ThinSat hardware. NSL, the technical lead of the program, is already working on an iteration of the ThinSat sub system and improvements to the Space Data Dashboard (SDD) for the future missions. The updates to the SDD will allow for participants in the program to have one central location to acquire all of the information necessary to follow the program layout and complete the development of their payloads. The SDD also serves as the central location for all data acquisition and viewing, therefore allowing participants in the program to utilize the open source design for data comparison and sharing.

After the maiden voyage aboard the OA-10 vehicle, lead institutions will be required to create scientific papers for the data collection and analysis they perform. This will give STEM outreach schools the opportunity to analyze data from the custom payloads, while also providing valuable technical writing examples that can be utilized as teaching tools for the instructors. In addition to being an integral teaching tool, the scientific papers will also provide a

historical archive of the research that is being performed via the ThinSat Program.

With the manifest for OA-10 complete and the next missions manifest quickly being filled, the future of the Virginia Space ThinSat Program is looking very bright for STEM outreach and ELEO research.

## **CONCLUSION**

A topic always on the forefront of all educator's minds is how to reach and grow the next generation of students. Similarly, to every other aspect of education and science, teachers want to keep building and enhancing skills in order to provide industry with students that will continue to push the boundaries of what is possible. The Virginia Space ThinSat Program has shown to help fill this void. With STEM outreach being the groundwork for the program, the next generation of students are able to work with real flight hardware and create a satellite that will be launched and orbit the Earth on a bi-annual basis.

The program has already been able to reach many areas of the country to help progress STEM outreach, but expansion and enhancement of that outreach is the primary focus for all members of the program. Students need to have the ability to take the classroom lessons and apply them to an actual hands-on project, thus gaining a better understand of science and engineering at a fundamental level. With a dedicated group of industry professionals and educators involved in the program, the future of both STEM outreach and research in the aerospace field is very promising.

The Virginia Space ThinSat Program continues to innovate and develop program tools, with the intent to better reach this next generation. The OA-10 maiden voyage has only given a glimpse of possibilities, and the real potential of this program has yet to flourish. The future of science and engineering is already promising, but it will take continued commitment and foresight from industry experts to mold and build this next generation.

## ***Acknowledgments***

The Virginia Space ThinSat Program would like to thank the entire ThinSat team for their hard work and dedication to the program. Without the collaborative work of all parties involved, this program would not be possible. Specifically, the team would like to thank the Commonwealth of Virginia for their continued financial support of STEM outreach within the aerospace industry.