Space-Based Capstone: Public-Private-Academic Partnership in the Making

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Abstract

The Electronic Systems Engineering Technology (ESET) Program at Texas A&M University provides a recognized undergraduate program with an emphasis in electronics, communication, embedded systems, testing, instrumentation and control systems. The program combines engineering and industrial knowledge and methods to develop, design, and implement new innovative products through a two-semester long Senior Capstone Project.

Capstone is designed to prepare future engineers by bridging the gap between the classroom and industry. Students are required to form teams of two to six members which allows them to develop the skills necessary to succeed in a diverse industry setting. Each team is required to use their knowledge and skills to design, develop, document, and deliver a real-world project equivalent to the assignments they will soon receive as professional engineers.

Following NASA's approval for funding the development of a research facility named Hermes, a Capstone team, named Microgravity Automated Research Systems (MARS), was sponsored by T STAR, a local space commercialization company, to develop the electronics portion of the facility. Hermes will reside on the International Space Station for five years in the hopes of streamlining the development of experiments that require extended periods of time in microgravity environments.

The Hermes facility will host and manage up to four experiments at a time while allowing for the downlink of experiment data to an Earth station, and the uplink of commands to change experiment parameters. Experiments will adhere to a power budget and communication standard established by MARS so that experiments can be swapped out during the facility's lifetime. MARS will work with the Mobile Integrated Solutions Laboratory (MISL), an undergraduate applied research lab, in order to prepare them to maintain support for Hermes in the future.

1. Introduction

1.1 ESET Program

Since 2013, the Electronic Systems Engineering Technology (ESET) program at Texas A&M University has had a focus on electronic product and system development. Three of the primary reasons for this particular focus were input from the industry that hires ESET graduates, the interest and background of the ESET faculty, and the effect of a curriculum focused in these areas has on recruiting and retention. To this end, the degree program has required course work in four areas: analog and digital electronics, wired and wireless communications, embedded hardware and software, and system level design of monitoring and control applications. In addition, the curriculum is augmented through courses in industry-applicable skills including project management, new product development, quality control, leadership skills, and device/system testing. Finally, while the curriculum has always had a laboratory component associated with almost every course, the new focus area has driven an increase in project-based learning as well as an increase in industry involvement through funded courses and Capstone projects.

This experiential learning component is considered a critical part of the curriculum and is at least in part responsible for the increasing interest that new students and industry have shown in the ESET program and graduates. The new focus has resulted in an increase in program enrollment from 140 students in 2011 to 270 in 2017. Today, most of the graduates of the ESET program take jobs that support product and system development through positions in operations, maintenance, design and testing. In addition, students go to work in a very diverse set of industry sectors that include automotive, medical, semiconductor, measurement and automation, oil/gas/energy, networking, social media and communications.

1.2 Capstone Description

As indicated above, the ESET program has steadily augmented the experiential education component of the curriculum over the past four years. Not only do the vast majority of the courses have a lab, but now over fifty percent of the courses have an open-ended project that is often sponsored by industry. Most importantly, the Capstone course sequence taken by students in their senior year has undergone many changes over several years and is now considered to be the pinnacle of the curriculum. From what was once a single semester course that resulted in very low-level paper-based projects, the Capstone experience is now a rigorous two-course sequence where teams of students develop tangible products and systems based on customer input.

1.3 Partnerships

Experiential learning requires that ESET undergraduate students have multiple opportunities to work and interact with representatives from the public and private sectors. The ESET Program provides a wide range of possibilities for the students to appreciate what the real world will be like following graduation. One of the most meaningful and visible of these is the Capstone Design Sequence. Many teams will spend two semesters solving a real problem for an external customer. A number of these Capstone projects have led to long-term development partnerships. Large and small companies have found establishing such relationships with the ESET Program, its students and faculty can pay significant benefits in terms of product and systems development through sponsorship of Capstone project(s). Although the specific industry segment can vary widely, a number of recent partnerships have been formed to pursue opportunities in the area of space-based products and systems.

Small companies such a Texas Space Technology Applications and Research (T STAR) have found that partnering with the ESET Program provides access to state-of-the-art resources and capabilities while allowing the company to manage its overall costs of design and development. As T STAR contracts with NASA to provide new capabilities for the International Space Station (ISS) and other space exploration, the Public, Private, Academic Partnership model works well in meeting scope, time and budget constraints. Based on these successful prior projects, T STAR and its partner, the Mobile Integrated Solutions Laboratory (MISL) at Texas A&M, have been again selected by NASA scientists to design, develop and maintain a new class of system that will operate over an extended period on the ISS. This type of student real world experience could not be possible without the Public, Private, Academic partnership established by NASA, T STAR and MISL.

2. Previous Projects

2.1 Deep Space Habitat Power Monitoring

Applied research has also created sponsorship for a number of Capstone projects. One of the most successful examples of this approach to Capstone is a competitive applied research project funded by NASA's eXploration Habitat (X-Hab) Challenge. The faculty team of researchers translated a portion of the research project into a Capstone project that was accomplished by a four-person team. The Capstone project created the prototype for a wireless power monitoring and control system for use in the NASA Deep Space Habitat at Johnson Space Center. The Deep Space Habitat is the facility that NASA uses to develop and test new technologies to support extended manned space missions such as traveling to Mars. This project was installed and accepted over two years ago and has operated 24/7 since its acceptance by the NASA engineering staff. An outcome of this work was a partnership that was formed with the Control and Data Handling (C&DH) Branch within the NASA-JSC Division. The partnership, which continues today, is designing and developing a space-qualified, rack and stack Modular Integrated Stackable Layer (MISL) architecture for use in rapid product development. To date, ESET Capstone teams have created eight different functional layers for the MISL architecture. A number of these have been space qualified by the C&DH Branch and are now integral to several new systems operating on the International Space Station. The MISL architecture is finding value in undergraduate education as well as other industry segments such as oil & gas.

2.2 Schneider Electric Building Simulator

Another example of a sponsored Capstone project was the HVAC Building simulator funded by Schneider Electric. Schneider Electric is a company that specializes in building automation and control products and services. The goal of this project was to develop a stand-alone embedded system that would simulate a commercial building's HVAC system, would interface to existing company products and would emulate the feedback signals normally provided by sensors and actuators in an actual building. The system's target applications were for internal training as well as testing of Schneider HVAC control products. As in the previous example, Schneider Electric is an example of a large company with embedded system needs that are commiserate with the ESET curriculum goals. By sponsoring a project-based Capstone, Schneider Electric was not only able to outsource low-priority product development work but to also evaluate four potential new-hires in an actual work environment. Another benefit of this particular project was its multidisciplinary nature. The project integrated two teams, one from ESET that had the responsibility of developing the embedded system and one from the manufacturing and mechanical engineering technology sister program that developed the HVAC emulation algorithms. This type of project not only provides ESET program students with valuable experiential learning in the area of product development but also presents an opportunity for students to work in a real-world, multidisciplinary team environment.

2.3 WTA Technologies LLC Wireless Bovine Monitor

The ESET Program has also been highly successful in working with small companies in addition to large companies and the public sector. In these cases, the small or startup companies do not have the ability to bring on a full-time engineering group or equip this group with expensive design, development, test and validation tools to support idea to working prototype translation. These companies can use the ESET Capstone design process to take their new product ideas and convert them to fully functioning prototypes in nine to months at a far more manageable cost. One such example is the recent project that was conducted for a Brazilian company, WTA Technologies LLC. WTA is a small company headquartered in San Palo, Brazil that specializes in bovine reproduction processes and technologies. WTA was very pleased with the results of their first sponsored project to create a scalable wireless system that measures motion and body temperature of cattle being prepared for artificial insemination. The ability to periodically collect and conduct real-time analysis of these data will significantly improve the probability of successful fertilization. WTA now plans on commercializing the prototype created by the Capstone team. The company also plans on extending its relationship with the ESET Program moving to a more partnership-like arrangement that would include one to two Capstone projects sponsored each year with the possibility of funding additional applied research efforts.

3. Partnerships

Of all the partnerships that the ESET Program enjoys, one clearly epitomizes the true educational value to the undergraduate students participating in applied research or completing their Capstone experience. T STAR is a small startup company in the Bryan/College Station area that focuses on enhancing commercial space enterprise, providing educational tools and collaborating on research opportunities in the space industry. To accomplish its mission objectives T STAR has developed a strategic alliance with the ESET program's MISL. The partnership encompasses applied research, educational, and STEM outreach activities.

One of the more significant applied research projects that demonstrates the impact of such a public-private-academic partnership was Strata-1. The NASA-ARES Division representing the public sector, T STAR representing the private sector and MISL representing academia came together to create Strata-1, an experiment which studied the evolution of small body regolith through long-duration exposure of simulant materials to the microgravity environment on the International Space Station (ISS). Strata-1 also serves as a pathfinder mission for future Class 1E missions which will interact with the science community. The public sector partner was composed of thirteen NASA and university scientists who defined the overall experiment and then led the development of the overall requirement definition and performance specifications for the project. The private sector partner provided overall management of the project development and the experiment's long-term support. The academia partner was tasked to develop the electronics and embedded software for the mission which included all monitoring, control and recording capabilities. Strata-1 was transported to the ISS, successfully operated for over a year, and then returned to the NASA scientists. The public-private-academic partnership has been cited for its unprecedented ability to respond to an opportunity to deliver a Class 1E experiment in a compressed time frame and remaining within a very conservative budget. The overall success of this project has solidified this public-private-academic partnership and is the primary reason that the NASA scientists have been awarded follow-on funding to pursue the first of its kind Class 1-E Facility that is intended to operate for over five years on the ISS [1].

This same type of partnership has also been used to support a number of Capstone projects. One of the most visible of these was the design project conducted by T STAR in collaboration with the C&DH Branch at NASA-JSC. Using the C&DH Modular Integrated Stackable Layer architecture, T STAR commissioned a Capstone team to develop a new sub-gigahertz point-to-point communications layer to support T STAR's development of its T SAT, a CubeSat class satellite. The new layer had to take full advantage of the architecture and reuse of existing layers to create a rack-and-stack prototype capable of transferring data and information from a small-form factor T SAT operating in Low-Earth orbit to Earth. Again, leveraging the public-private-academic partnership, the Capstone team was highly successful in delivering a fully operational system to T STAR for use in its T SAT satellites. The team was also highly successful in using the project to win a number of contests including: Best Capstone Project for the TAMU College of Engineering Showcase, Best New Business Idea in the TAMU Mays School of Business Ideas Challenge, and First Place in Texas Instruments International Innovation Challenge.

Both the Strata-1 applied research project and the T SAT Communications Layer Capstone project laid the ground work for the most ambitious partnership project to date, Hermes. This new project will necessitate not only the design and development of a new embedded intelligence monitoring, control and communications capability, but require the partnership to establish a long-term maintenance and support relationship for the new facility being developed for operation on the ISS for five-plus years.

4. Hermes Project Overview

4.1 Project Description

Testing ideas and equipment meant to perform in microgravity environments is difficult on Earth for various reasons. Solutions for microgravity experiments that need less than twenty-five seconds or even less than five seconds have already been developed. These solutions include the reduced-gravity aircraft that follows a parabolic flight path to achieve twenty to twenty-five bouts of weightlessness during free-fall, and drop towers at NASA research facilities that drop payloads in a vacuum for roughly five seconds of free-fall. However, when a science team requires long-term monitoring of an experiment in microgravity they have to resort to sending their experiment into orbit.

The main goal of the Hermes facility is to streamline the process by which scientists can send microgravity experiments to the International Space Station. Developing Class 1-E payloads can be a lengthy and daunting process for some science teams that have limited experience with that aspect of a project. However, a facility that is capable of supporting multiple experiments would allow that same team to focus the majority of their development time on the integrity of their science, while most of the design work for supporting it on the ISS will be supplied through the standardizations and examples from previous experiments on the facility.

Hermes will be capable of hosting up to four sub-experiments at a time that can be changed out for new sub-experiments throughout the facility's lifetime. Hosting sub-experiments will include providing, monitoring, and controlling power to each sub-experiment as well as providing a means for science teams to downlink files from their sub-experiments or to uplink commands to change sub-experiment parameters. The electronics providing this capability will be housed within an enclosure within the facility so that all electronics will be kept safely isolated during sub-experiment change-outs. Also included will be the capability for sub-experiments to have external peripherals such as lighting and cameras connected to the Hermes Electronics Box that can be adjusted with commands.

This electronics box is expected to be capable of operating for the full duration of the facility's lifetime, but future additions to the peripheral capabilities of the electronics could mean that the enclosure will be removed and replaced with a new enclosure containing a similar configuration with added capabilities.

4.2 Partnership Goals and Impacts

Understanding the unique resources that T STAR has access to with its partnership with MISL and ESET, the NASA-ARES Division contracted T STAR to develop the electronic system that will control and support the Hermes facility that is being designed. T STAR selected, and is sponsoring, a five-person Capstone team named Microgravity Automated Research Systems (MARS) to develop the main electronics for the facility. MARS has been working within MISL throughout the project to ensure that MISL will have all the resources needed to maintain support for Hermes over the next five years alongside T STAR once MARS has completed their portion of the project.

Hermes will be an experimental microgravity facility that will be the first Class 1-E facility to be sent to the ISS. The difference of this facility in comparison to previous Class 1-E payloads is that this experiment has the ability to host multiple payloads, or sub-experiments, itself. The opportunity presented to undergraduate students to take an active part in the design and development of a brand-new facility like this creates a high-impact environment within the entire academic program. Many students outside of the program learn about ESET through these types of endeavors and it has likely been a major role in the growth of the program as a whole.

5. Hermes Electronics Implementation

5.1 Conceptual Design

Capstone teams generally follow a proven system design process that is presented to them during their first semester. This structured process allows the team, faculty advisors, and the customer/sponsor to follow and monitor the progress of the project. The first step in this process is working with the customer to identify the problem statement and concept of operation. Next, the functional requirements of the system are defined and agreed upon between all stakeholders. These are non-quantitative elements of the system that define the mandatory aspects of the system. Before completion of their project, each Capstone team must demonstrate that each functional requirement has been met.

These functional requirements are then used to create a conceptual block diagram (CBD) of the system, which is meant to depict the requirements of the system in a pictorial diagram format. The CBD is meant to aid the discussion with the customer and advisors to ensure that all parties are on the same page. It is also referenced while developing the performance specifications. The CBD developed by MARS for the electronics of the Hermes facility is shown in Figure 1.

Figure 1 shows the Hermes facility as being on board the ISS within an EXPRESS Rack. The system's power is received from an RPCM which provides 28 volts DC. Two DC-DC converters will be used in parallel as redundant power supplies which regulate the voltage down to 15 volts. This voltage is supplied to the MARS Support Board which is a printed circuit board (PCB) that will be designed and developed by MARS. This PCB will contain embedded intelligence as well as power distribution circuitry for the rest of the facility.

As seen at the top of Figure 1, Hermes will be making use of the ISS network. This network is a combination of the ISS, nearby satellites, and the Huntsville Operations Support Center, otherwise known as the HOSC. This already established network will provide a means for Hermes to downlink files to a ground station on Earth. The ground station will also be able to connect to the HOSC and uplink commands that will allow scientists to update parameters on their sub-experiments during runtime. Hermes will be connected directly into the ISS network through an EXPRESS data port which uses IEEE 802.3 (Ethernet). This EXPRESS data port will be connected to an 8-port router within the MARS Electronics Box, which will serve as a network address translator between the external ISS network and the internal private network that will be created. The switch ports on the router are shown connecting four sub-experiments, the MARS Support Board, and a BeagleBone Black (BBB) to create an internal, private network.

In order to utilize the ISS network and communicate with the HOSC, the Telescience Resource Kit (TReK), one of the software products that supports NASA's ISS program, will be utilized. TReK, which requires an operating system (OS) to function, will be hosted on the BBB running an Ubuntu Linux distribution. A powered USB hub will also be connected to the BBB which will allow four USB cameras to be connected, one for each sub-experiment. The BBB will provide the cameras with a means for communication that will allow images to be captured and stored. Parameters of the cameras can be adjusted from the MARS Support Board which will then trigger the BBB to take images.

Sub-experiments will use their Ethernet connection to send and save data to the BBB which will allow that data to be downlinked to the HOSC through TReK. User commands sent up through the HOSC will also come through this Ethernet connection and will allow experiment parameters to be changed from the ground.

5.2 Functional Design

The next step of Capstone is to define performance specifications that define each and every functional requirement. In comparison to functional requirements, performance specifications are quantitative attributes of the system. One example of a functional requirement for the Hermes Electronics Box is that a safe external temperature of the enclosure must be maintained. When this functional requirement is tested a performance specification of maintaining a temperature below 113 °F is used to determine if the system meets the requirement or not.

Once all requirements of the system are understood by the team on a qualitative and quantitative level, the team will develop a functional block diagram (FBD) of the system. The FBD is a tool used by both hardware and software engineers to achieve a functional understanding of how all components will interface with each other on both a system level and on the PCB being designed. The hardware engineer will use it to generate a pin-level schematic and the software engineer will reference it when developing the embedded software. This allows the hardware and software portions of this project to be worked on independent of one another while still being assured that they will integrate correctly.

Figure 2 shows a system level FBD that includes the MARS Support Board and all of the connections to and between external peripherals. Figure 3 shows a board level FBD which breaks down the connections between major components on the MARS Support Board PCB. Both of these diagrams were created by MARS and have gone through multiple iterations to keep them up-to-date throughout the first semester as the design and requirements of the system progressed. These diagrams will continue to be maintained and updated so that they reflect the most recent version of the design.

5.3 Accomplishments, Current Status, Future Plans

The MARS teams most notable accomplishments to date are the completion of a Preliminary Design Review as well as completion of alpha design reviews which include an Alpha Schematic Review and an Alpha Software Flowchart Review. Successful completion of these reviews signifies that the MARS team is ready to move towards developing and testing the electronics for the Hermes system. Such development will include designing and populating the alpha PCB, developing the alpha embedded software, and connecting all of the off-the-shelf equipment that will allow the Hermes system to function.

Beyond the current status of the project the MARS team will create a beta and final PCB as well as beta and final software. Before creation of the final version of the system MARS will be required to perform a Critical Design Review in which peers, faculty, and sponsors alike offer any final suggestions or advice for aspects of the design that need to be considered or changed. The team will then test and verify that the system meets all functional requirements set forth by T STAR and NASA. After the completed system is delivered to T STAR with all of the necessary documentation, the responsibility of any technical support for the Hermes system will be passed to MISL. A team within MISL is shadowing MARS and its development process of the Hermes facility to prepare MISL for this transition. The MARS team will not be responsible for supporting the Hermes system once they graduate and this transition of responsibility is necessary to maintain support for the facility throughout the facility's planned lifetime.

6. Experiential Education

6.1 ESET Program Perspective

The benefits of experiential education have been the cornerstone of engineering technology since its inception. From having a laboratory experience in almost every course to using project-based learning, all engineering technology educational programs ensure that students have multiple opportunities to put theory to practice during their education. From the perspective of the ESET program specifically, there are several specific values to offering experiential education opportunities through laboratory, course projects and Capstone. These include:

- Better engagement of students and industry in the learning process: From the stand-point of the student, real-world projects that involve current technology and industrial applications are motivational and help increase their level of interest in their coursework and studies. Industry participation in the degree program, a hallmark of engineering technology programs, is also increased when public and private partners are asked to support courses and degree programs through relevant projects. The value to them is obvious, students are better prepared for the workforce when their coursework includes meaningful experiences that are applicable to their future careers.
- Real-world learning environments: While one can lecture on the processes involved in product development, project management, interfacing with customers, and entrepreneurship, there is no substitute for applying those principles in a real-world project-based setting. It is the real-world learning environment that is emulated in many engineering technology programs that accelerate the learning curve and better prepare students for their first job.
- Application of theory to projects without predefined outcomes: A third advantage afforded by experiential education is the learning involved in projects that do not have predefined outcomes. Whereas the typical laboratory experiment is designed with a result in mind, most open-ended projects are not completely defined and require decision making and assumptions to be made on the part of the student. Similar to the industry environment, the development of these skills is essential for success in the real-world.
- Development of life-long learning skills: A final benefit to experiential education is the need for students to learn "on the fly." Similar to the previous bullet, most open-ended projects force students to develop skills in doing research and self-teaching in order to achieve a successful outcome.

6.1 Student Perspective

Some students outside of the program view the rigors of Capstone as a huge obstacle to graduating. In contrast, many students see the enormous value and opportunity that the Capstone experience provides that is unrivaled by any other academic activity. For many graduates of the program, their Capstone project served as a springboard directly into their first job and/or career.

Several companies that have sponsored Capstone have been so impressed with results that they wind up hiring one or several of the members of the team. Often times an ESET graduate will be chosen over other applicants to a job position because the company sees the scope of the Capstone project on the graduate's resume and realizes that that applicant will be a valuable addition to their business.

For students and graduates alike, Capstone can serve as a source of confidence and pride. Coursework and projects in industry are all put in the perspective of the work that was completed in Capstone and can be used as motivation to finish other work and projects that seem simple in comparison. To students in programs around the world, Capstone signifies the culmination of all of the information they have learned throughout their coursework: it's the final test in which a student can prove they are ready to graduate and meet real world industry [2]. Several graduates have stated that a challenging Capstone project made them feel more confident once they started engineering projects in the real world. Another aspect commonly mentioned was the communication with the customer that was stressed throughout Capstone. Communicating through face-to-face meetings, professional emails, and conference calls proves to be a valuable learning experience for nearly every graduate, as communication in industry is practically mandatory on any project, major or not.

In addition to the level of work required by Capstone, most students are otherwise taking full course loads finishing up the last of their classes. As seen in another paper regarding a Capstone experience and the value of the experience, this experience serves as great practice for graduates who may plan on later pursuing a Master's degree while working a full-time engineering job [3].

7. Summary

The Hermes project is comprised of a multitude of teams from various private, public, and academic organizations, all working on the development of a facility that will be sent to the ISS by the end of 2018. The MARS Capstone team will deliver their final design and documentation of the Hermes Electronics Box to T STAR, who will finalize development and integration with NASA for the Hermes facility.

MARS has projected that their portion of the Hermes project will be completed on April 27, 2018. Completion of Capstone includes the fulfillment of all functional requirements laid out in the System Design Process document, the transfer of all hardware and software deliverables to T STAR, delivery of the Final Test Report, and the sign off of the Final Presentation, Final Demonstration, and Final Documentation. Approval must be given from all stakeholders, which will indicate that MARS fully understands the electronic system they created, has fully documented the design of that system, and that all functional requirements and performance specifications were met.

As mentioned before, T STAR and MISL will carry the Hermes project on following the completion of the MARS team's Capstone project. Any documentation produced by the MARS team will be conducted such that any engineer or student assigned to providing support or maintenance for the Hermes facility will have the material necessary. In addition, a shadow team has been created that will follow the MARS team throughout the duration of the Capstone project, and will be capable of supporting the project throughout its full lifetime aboard the ISS.

Throughout the course of the Hermes project, MARS will be responsible for the completion of a number of deliverables that will be received by T STAR. The timeline of major deliverables has been provided to T STAR in the form of a timeline graphic such that any team member or stakeholder can view the progress of the project and see an exact date and team member responsible for each specific deliverable. As previously mentioned, April 27, 2018 is the scheduled sign-off for MARS, and on that day all material pertaining to the project will have been turned over to T STAR. The sign-off will also signify and that all stakeholders are satisfied with the result of the project. From that point forward, the documentation and materials given will allow both T STAR and MISL to finish development of the facility and provide the necessary support for the remainder of the Hermes facility's lifetime.

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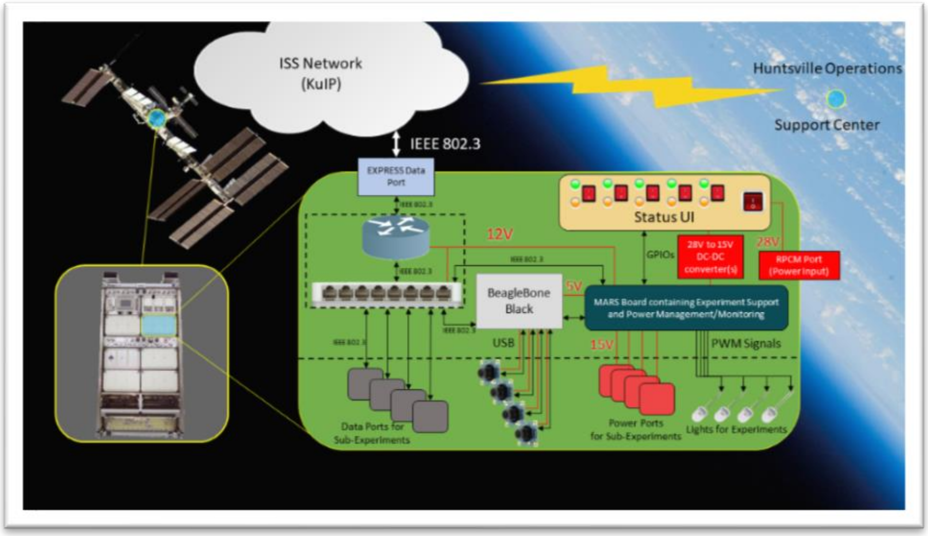

Fig. 1 Conceptual Block Diagram for the Hermes Facility

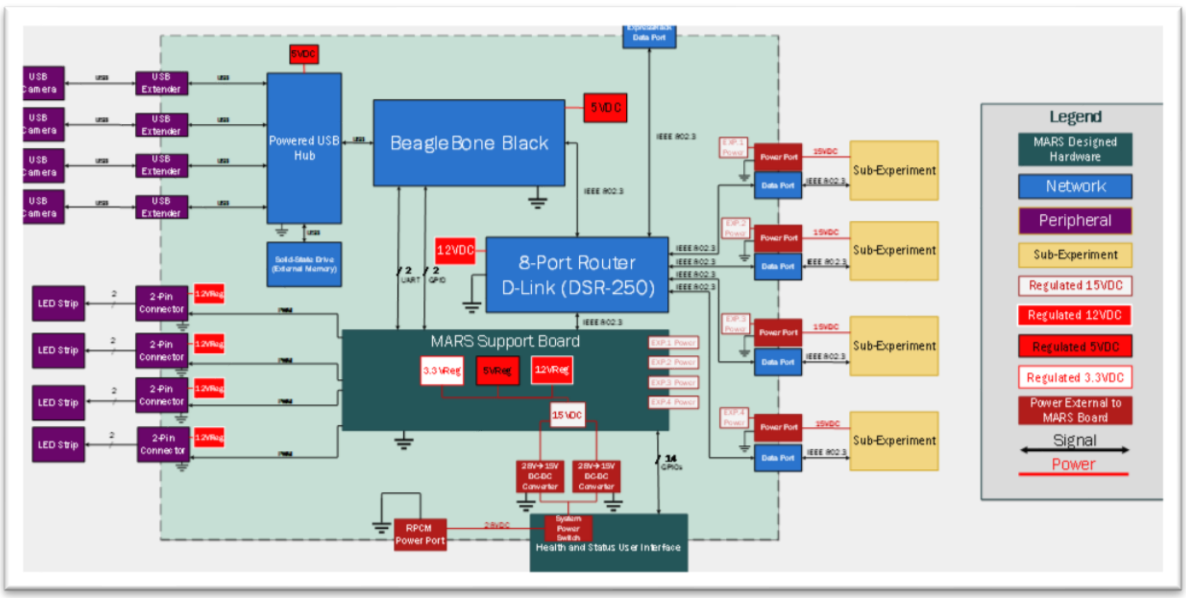

Fig. 2 System Level Functional Block Diagram for Hermes Facility

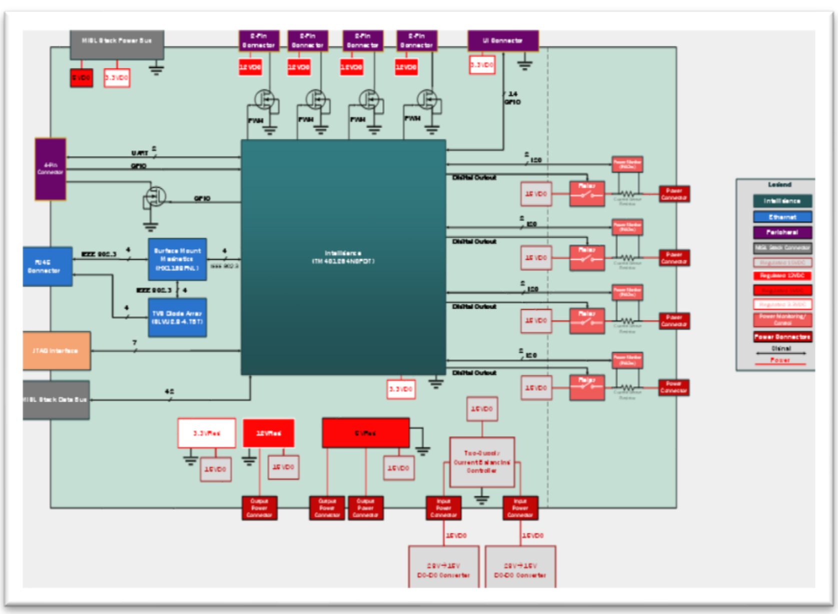

Fig. 3 Board Level Functional Block Diagram for MARS Support Board