Satellite Simulator for Hands-on Systems Engineering and Verification Training

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ABSTRACT

Most space education programs, both at University and for post-graduate professional development, focus on the "front end" of systems engineering, i.e. concept development, architecting and design. Many new graduates arrive at their first jobs and find themselves working in assembly, integration and test facilities on the "other side" of systems engineering. Most of these young professionals need a formal introduction to the disciplines of requirements verification and systems validation or "V&V".

TSTI has helped fill this need by integrating a new Applied Space Systems Engineering text with desk-top satellite simulator called EyasSAT. The result is a one-of-a-kind educational experience that has been adopted by a wide range of partners both in Europe and the US, including ESA, NASA and a number of commercial companies.

The new text was published in 2010 and combines the expertise of 25 authors from all aspects of the space industry to distil the best practices and processes across the entire range of space systems engineering. A major contribution of this text is a comprehensive treatment of all aspects of system V&V including requirements validation, model validation, product verification, product validation and flight certification. The EyasSAT desk-top satellite allows students to learn these concepts and then immediately apply them to real, flight-like hardware and software. By touching actual systems and subsystems, they see the V&V processes "come alive" in a controlled, low risk environment.

NASA, ESA and a variety of commercial companies have adopted the resulting educational experience. This paper provides a brief overview "Verification and Validation" (V&V), describes the EyasSAT desk-top satellite and gives an overview of the Space Systems V&V course.

INTRODUCTION

Aspiring young engineers and scientists are motivated to pursue difficult, technical programs at university because they want to design and build things. For all kinds of good reasons, our university programs respond by structuring programs and curricula that emphasize that "front end" part of the design cycle. Virtually all of the academic course work leading to an engineering degree focuses on engineering fundamentals, analysis and design. Most capstone projects for undergraduate and graduate engineering students consist of design projects which deliver paper products or, at best, single prototypes. Little time is available to address the real-world issues of product integration, verification and validation, even in a classroom setting. In the aerospace arena, the application of these ideas to spacecraft systems in a laboratory experience would require hardware and facilities that are often not available or are prohibitively expensive.

However, a large percentage of new space engineers arrive at their first jobs and find themselves working not on "design" but supporting some aspect of "test". In order to help them prepare for this environment and understand their jobs in the bigger perspective of systems engineering, they would benefit from a formal introduction to the requirements validation, system verification and product validation.

A satellite simulator, the "EyasSAT" was invented at the US Air Force Academy, in partnership with industry, to support this need. TSTI, with funding from NASA, integrated the EyasSAT with a new Applied Space Systems Engineering (ASSE) text to build a unique educational experience that teaches satellite verification and validation (V&V) by allowing students to "do" V&V on flight-like hardware and software before they touch the real thing. NASA, ESA and a number of commercial customers have now adopted that course for training of their personnel.

DEFINITIONS AND CONTEXT

Before we describe the EyasSAT and its role in V&V education, we should define our terms and describe V&V in the larger scope of space systems engineering. Every discussion of systems engineering begins the famous "V diagram". Various renditions appear in many textbooks, as well as ESA and NASA engineering handbooks and standards. A typical example is shown if Figure 1 here (from the ASSE text). All begin with stakeholder needs, goals and objectives followed by design. All end with capabilities delivered to the users and operators. Preceding that delivery is "Verification and Validation" or V&V.

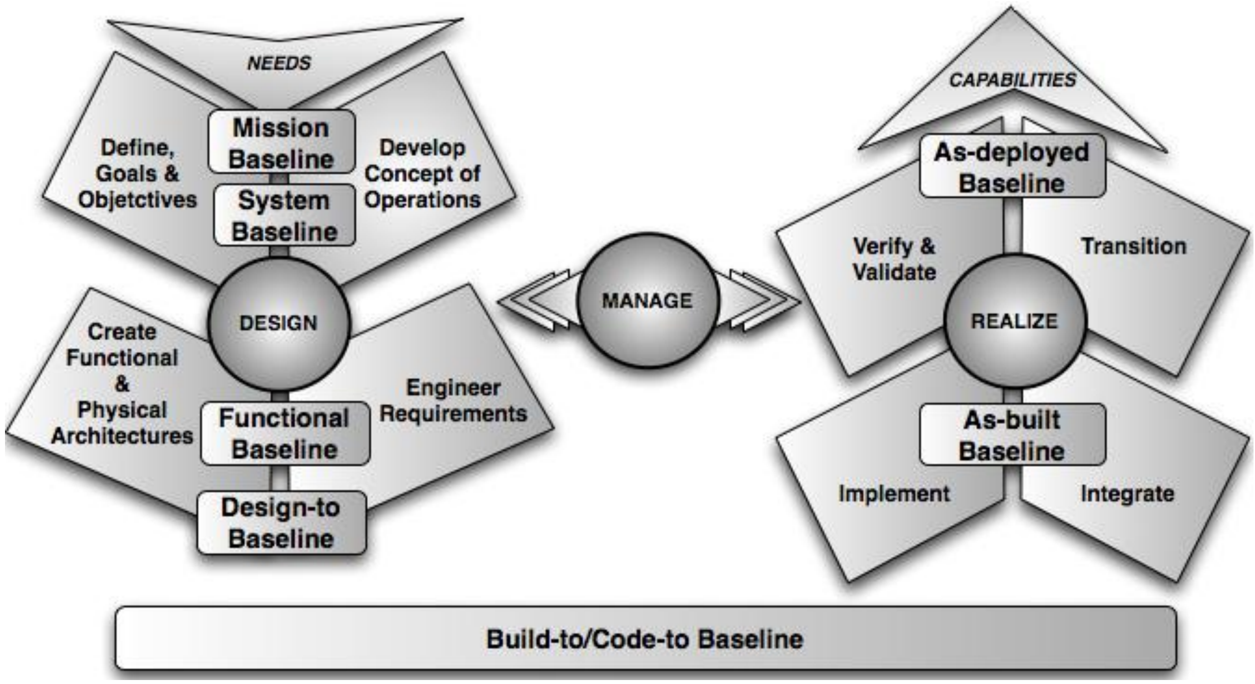

Figure 1. The Systems Engineering V Model (from ASSE ref.1)

The ESA and NASA definitions of these terms are very similar. Verification is *proof that the product complies with specification* (did we build the product right?). Validation is *proof that the product accomplishes its intended purposes based on the expectations of the stakeholders* (did we build the right product?) To meet these overarching V&V goals, the five V&V activities shown in Figure 2 have to be accomplished. Requirements Validation confirms that the stakeholder expectations and environmental constraints have been accurately and completely captured in requirements needed to design, build, test and operate the product. Model Validation ensures that all the hardware models, software models and analytic tools to be used during the product's life cycle are correct…or at least good enough for our application. Product Verification proves that the requirements have been met. Product Validation shows that the stakeholder expectations have been fulfilled. Finally, Flight Certification reviews all this body of V&V data to determine if the system is truly ready for flight.

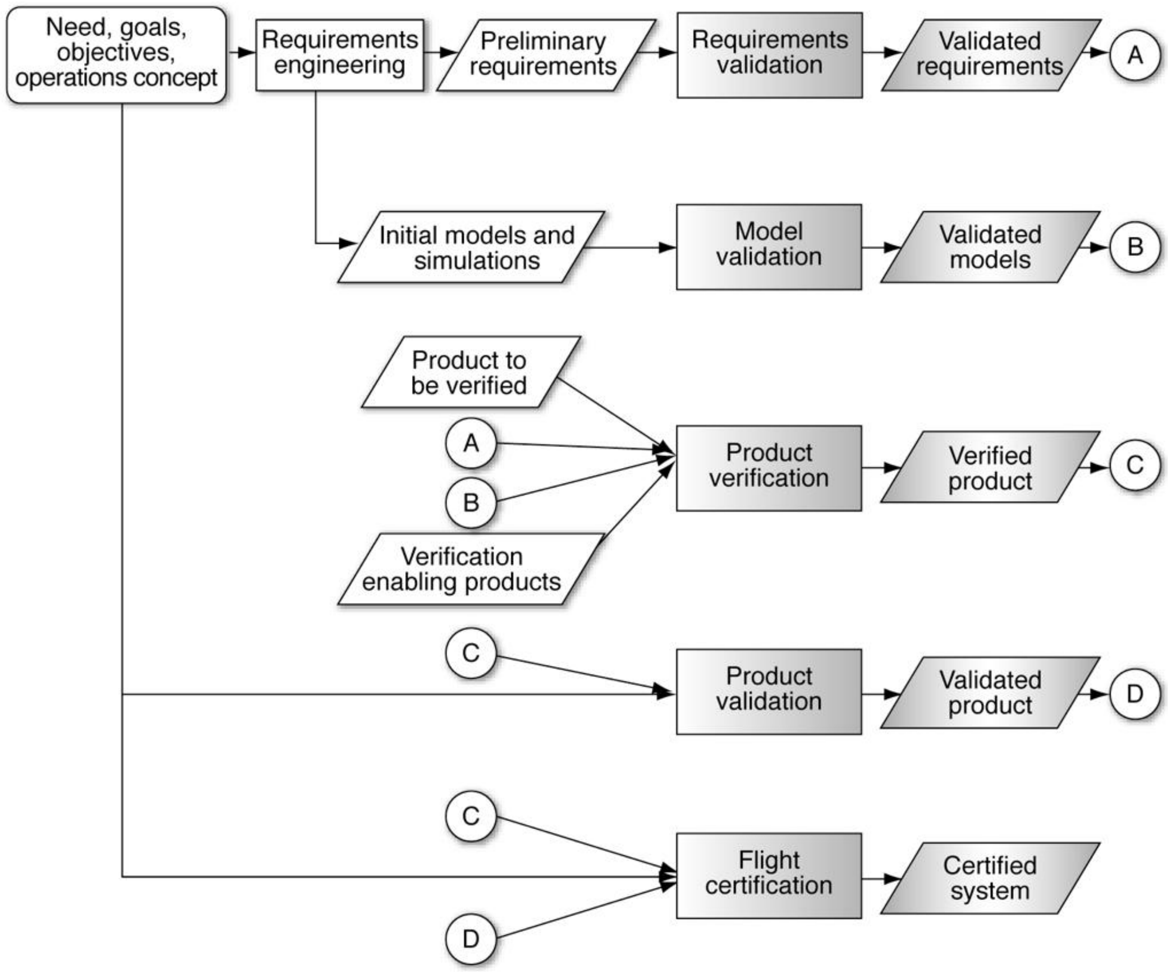

Figure 2. Five V&V Activities (from ASSE ref. 1)

The EYASAT DESKTOP SATELLITE SIMULATOR

To enable participants to actually do each of these activities in a safe, affordable environment, TSTI has designed a three-day class wrapped around a realistic EyasSAT V&V campaign. The EyasSAT is a three-kilogram, desktop satellite simulator that has all six of the traditional satellite subsystems: Structure, Power, Communications, Data Handling, Attitude Control and Thermal Control. It communicates wirelessly via a commercial-off-the-shelf radio to a "ground station" hosted on a laptop PC.

Structure Subsystem:

As is typical for any satellite structure, the EyasSAT structure encloses the payload and other subsystems, supports solar panels and thermal control panels, and provides a lifting point. It also provides locations for power and separation switches, an omni-directional antenna, attitude control sensors and a battery charge port. Plexiglass panels allow visibility into the interior of the EyasSAT even after it is fully integrated into its "flight" configuration. Dimensions are roughly 22 centimetres on a side.

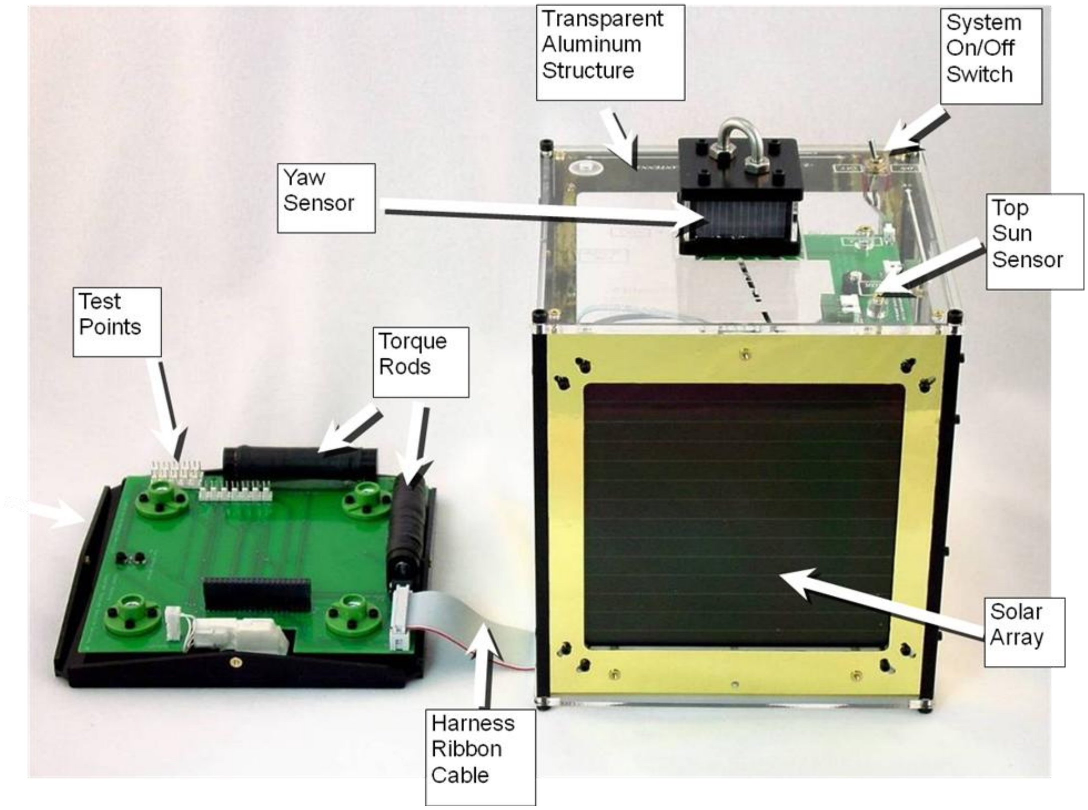

Figure 3. The EyasSAT Structure Subsystem

Power Subsystem:

The EyasSAT accomplishes all three functions of a normal satellite power system: generate, store and distribute electrical power. Two low efficiency (i.e. affordable) solar panels are attached to the structure. They demonstrate the concept of primary power generation but cannot actually run the satellite in an indoor, shirt-sleeve environment. A nine-volt battery pack mounted below the power module provides enough energy to complete several hours of operations and testing before requiring re-charge. The power board itself provides three- and five-volt regulated power plus nine-volt unregulated power to the rest of the satellite. Prior to EyasSAT integration, telemetry from the power board is linked via data port to a laptop for board level verification.

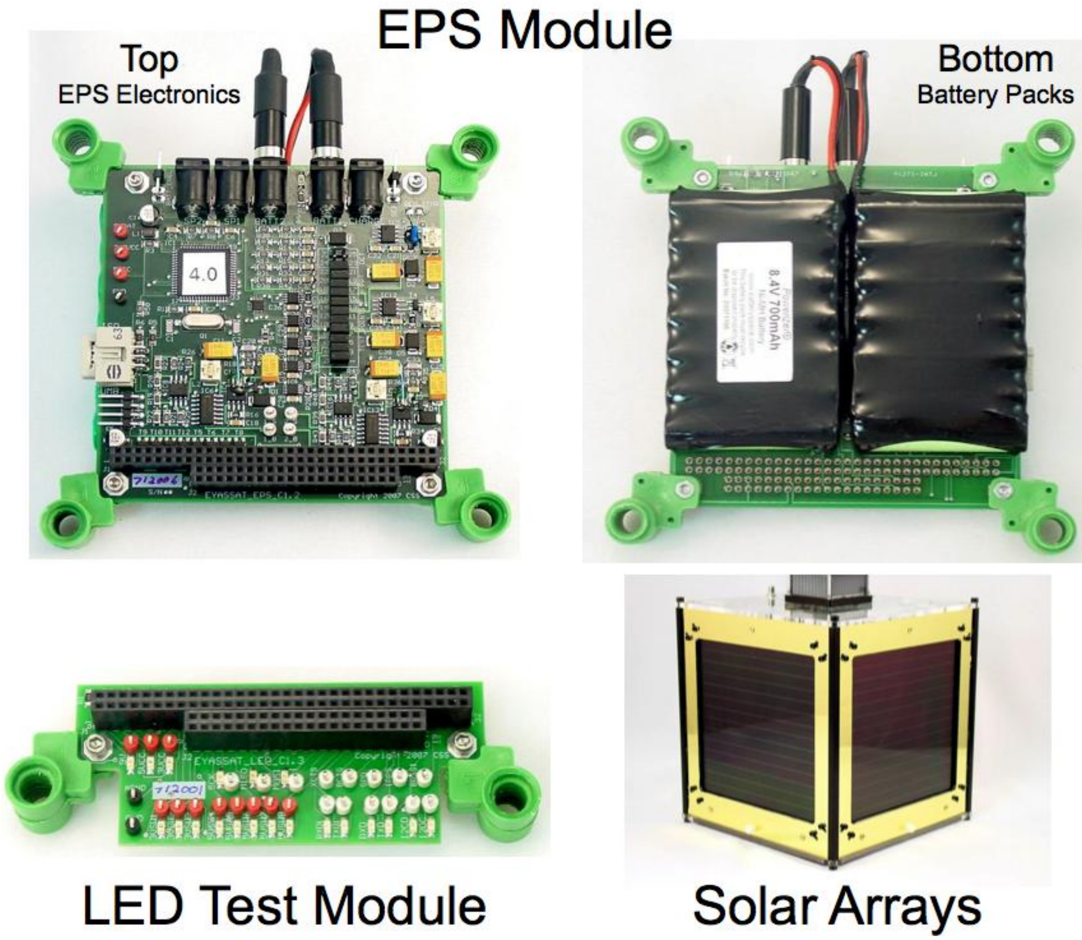

Figure 4. The EyasSAT Power Subsystem

<u>Communication Subsystem</u>:

The EyasSAT communication module enables a wireless command and telementry link through a commercial-off-the-shelf radio transmitter and receiver operating in the 900 MHz ISM band. The module operates at 9600 baud and uses frequency hopping so multiple EyaSAT units can be operated simultaneously in the same room. The communications module can also verified at the board level before being integrated into the complete stack.

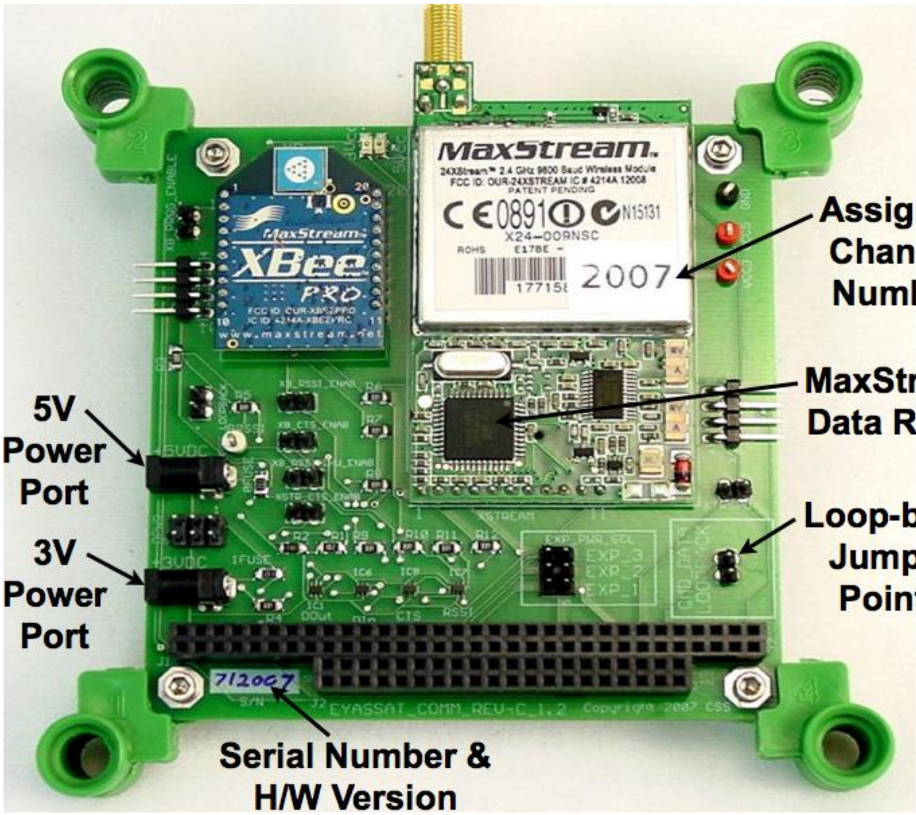

Figure 5. The EyasSAT Communications Module

Data Handling Subsystem:

The EyasSAT data handling function is accomplished with a commercial-off-the-shelf microcontroller. Prior to integration into the EyasSAT stack, it communicates directly with a PC for board level verification. Once the EyasSAT has been integrated, the data handling board collects and reports telemetry from all the subsystems. It also received commands sent to the EyasSAT via the communications subsystem and distributes them to the appropriate subsystems for execution. This subsystem also provides an interface for the EyasSAT "payload" which is simple thermistor for the purposes of this V&V exercise.

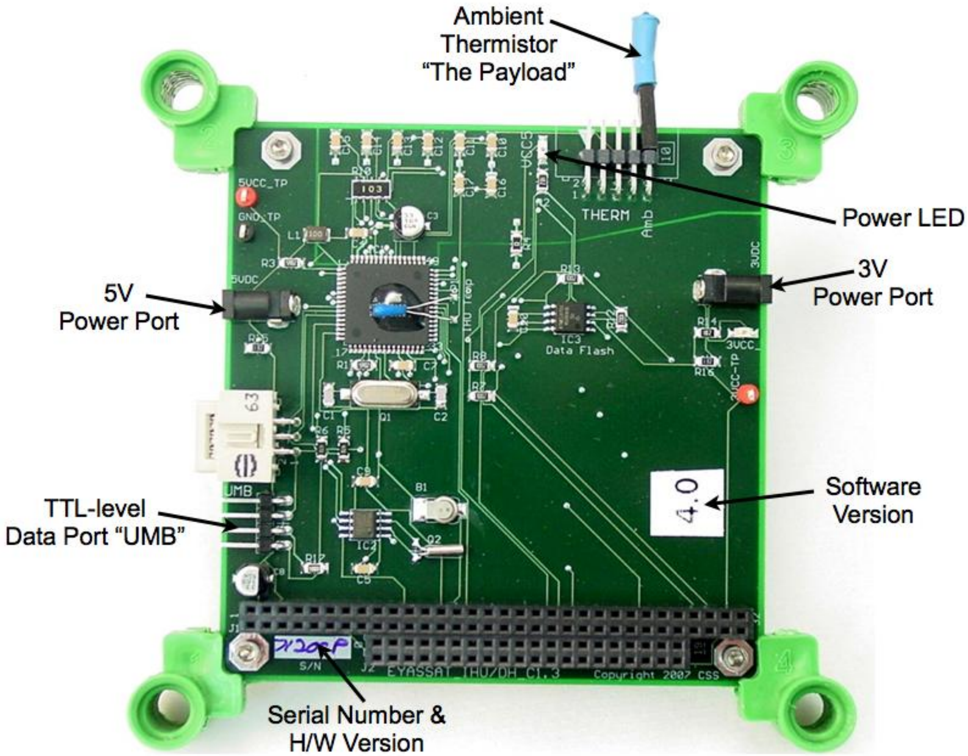

Figure 6. The Eyasat Data Handling Module

Attitude Determination and Control Subsystem:

The EyasSAT Attitude Determination and Control Subsystem (ADCS) consists of a commercial-off-the-shelf microcontroller and a suite of sensors and actuators. The attitude determination sensors include sun sensors and yaw sensors mounted on the structure and micro-mechanical gyros and accelerometers located on the ADCS board itself. Single axis attitude control is accomplished with a reaction wheel located on the ADCS board and two electro-magnetic torque rods mounted on the base of the structure subsystem. As with all the other modules, the ADCS board can communicate directly to a PC for subsystem verification before the EyaSAT stack is integrated.

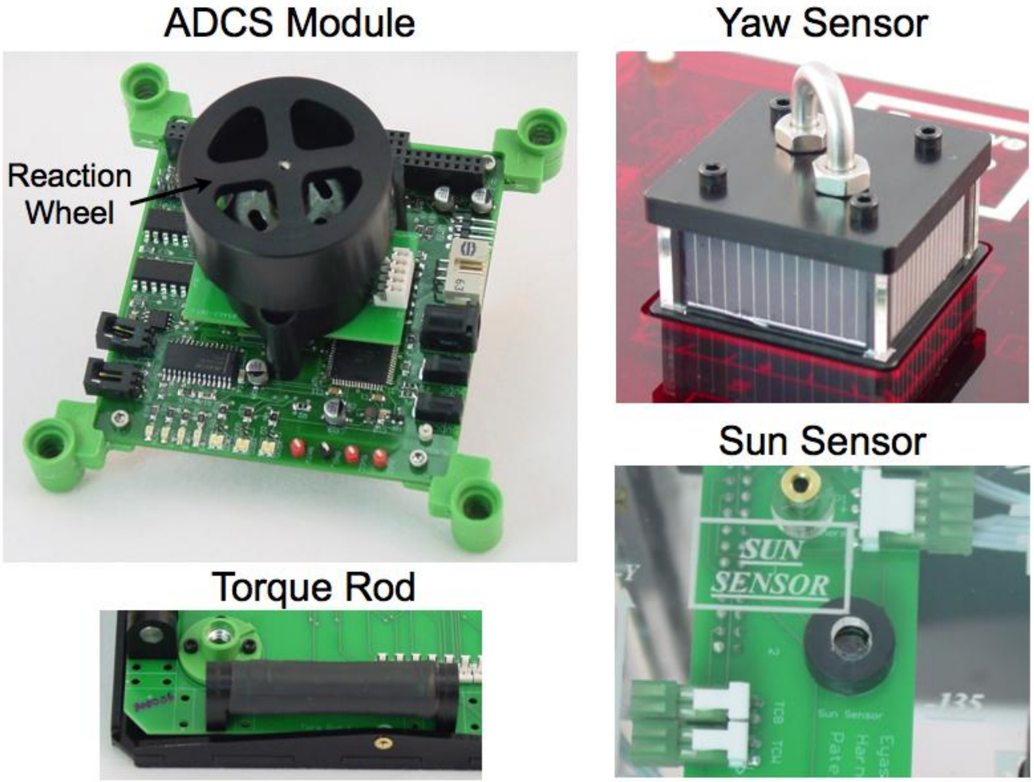

Figure 7. The EyasSAT ADCS Hardware

<u>Thermal Control:</u>

Thermal control principles are simulated on the EyasSAT with two panels, one white and one black, attached to the EyasSAT structure. Temperature sensors are located on those panels, on the solar arrays and at several locations in the EyasSAT's interior. Thermal requirements are verified via test with a solar simulator (commercial halogen lamp).

<u>The Integrated EyasSAT:</u>

After each subsystem is verified individually, the Power, Communications, Data Handling and Attitude Determination and Control modules are stacked together and then integrated into the EyasSAT structure. The antenna is connected through the structure to the Communication module; battery cables are connected and the structure is buttoned up. All the remaining system level verification and validation activities are conducted wirelessly via the EyasSAT ground station.

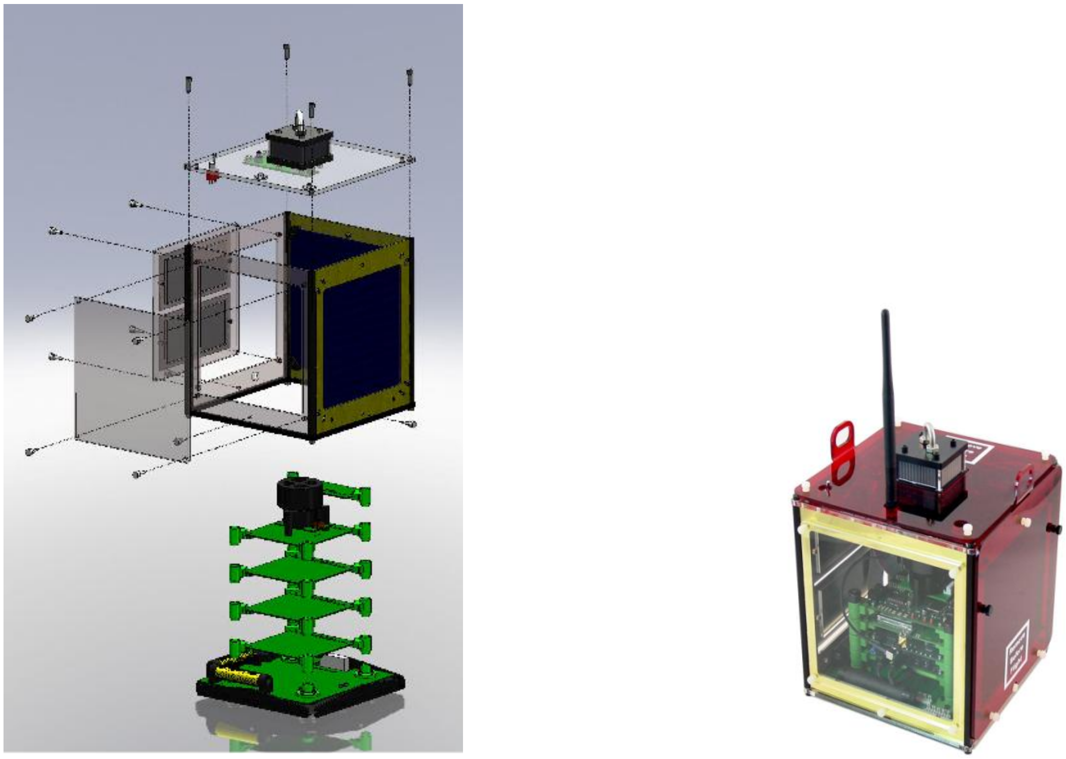

Figure 8. Eyasat Integration

USING THE EYESAT SATELLITE SIMULATORE TO TEACH VERIFICATION AND VALIDATION

In 2005, NASA commissioned TSTI to develop an educational course to teach Space Systems Verification Validation to its technical staff at NASA Centers across the US.

The objectives of TSTI's Space System Verification and Validation course are to:

- **Explain** the **end-to-end SE process** and how it applies to system (and lower level) requirements definition, allocation, validation and verification.
- **Describe** the **purpose and scope of key documents** required in the validation and verification processes, and describe typical errors committed.
- **Describe** various **methods of verification**, when they are appropriate. and how they are used as part of a **verification plan for a system of interest**
- **Determine** appropriate circumstances and applicability of verification methods to **prototype and proto-flight systems**.
- **Analyze** representative **verification plans, test sequences and activities** for an example system of interest (spacecraft).
- **Develop, evaluate and implement a master verification plan** for a space system including hardware, software and associated ground support equipment (GSE).

- **Apply** processes and techniques **in a hands-on workshop** associated with a system of interest.
- **Describe** applicable **NASA, ECSS, DoD and Industry Standards and lessons learned** to support system verification decisions and activities

It became immediately clear that three days of lecture on V&V principles without an opportunity for hands-on experience and application would have little value (and little fun). The EyasSAT, which had already been developed under a Cooperative Research and Development Agreement between the US Air Force Academy and a local small company, was an obvious choice to fill this need.

Power point charts and lecture are not adequate ways to teach the practical aspects of testing, requirements check-off, modeling approximations and anomaly resolution. The real hardware and software in the EyasSAT enable students to see the process "come to life" as they pass each stage successfully or decide how to deal with less-than-perfect requirements and verification failures. About two hundred EyasSAT requirements are captured in a Verification Requirement Matrix and then "closed" over three days of exercises integrated with lecture and discussion. During these exercises, students:

- Verify subsystem-level requirements for Structure, Power, Communications, Data Handling, ADCS and Thermal Control using standard lab equipment
- Verify software at the code-level via requirements testing, code review and stress testing
- Verify and Validate system-level performance against requirements and stakeholder expectations
- Decide how to deal with ambiguities and anomalies associated with real hardware and software
- Perform a series Acceptance Reviews as EyasSAT integration progresses from boards to a complete satellite

This combination of lecture and hands-on experience with the EyasSAT satellite simulator provides insight into how requirements flow to design and how V&V activities close the loop between what the customers want and what the system actually delivers. Since its original debut at NASA, the TSTI Space Systems Verification and Validation course has been adopted by ESA and a number of commercial space companies in the US and Europe. In partnership with the Stevens Institute of Technology, the course has been bundled with several other Stevens and TSTI courses to form a unique Graduate Certificate in Space Systems Engineering. More information is available at www.stevens.edu/sse/academics/graduate/Space_SysEng.html or www.TSTI.net.

CONCLUSIONS

This paper has introduced the five V&V activities that make up a space systems verification and validation campaign: requirements validation, model validation, product verification, product validation and flight certification. The paper then described the EyasSAT desktop satellite simulator that is used to provide practical applications of these activities during a three day Space System Verification and Validation course which was developed for NASA and has since been adopted by ESA and a number of commercial companies in the US and Europe.

Most of what we know as an industry about space system verification and validation has been learned through hard-won lessons over the last 60 years. To prevent a new generation of engineers from relearning those lessons the hard and expensive way, it is important that we capture this knowledge and experience and pass it on the classroom effectively.

REFERENCES

1. Applied Space Systems Engineering, Larson, Kirkpatrick, Sellers, Thomas and Verma, McGraw-Hill, 2009
2. ECSS-E-ST-10C, “Space Engineering – Testing”, March 2009
3. “EyasSAT: Transforming the Way Students Experience Systems Engineering” Barnhart, Ritchey, Sellers, White and Clark, American Society for Engineering Education Annual Conference, 2004
4. NASA Procedural Requirements, NPR 7123.1A, March 2007
5. “Redefining Space System Verification & Validation”, Sellers, Larson, Kirkpatrick and White, USAF T&E Days Conference, 2008.
6. “Space Systems Verification and Validation” , APPEL-SSVV, Rev 9, Nov 2011 (copyright © Teaching Science and Technology, 2011)