THE SATELLITE QUICK RESEARCH TESTBED (SQUIRT) PROGRAM

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21 May, 1994

Abstract

Stanford University's Department of Aeronautics and Astronautics has commenced full scale development of a new micro satellite initiative. Known as the Satellite Quick Research Testbed (SQUIRT) program, the project's goal is to produce student engineered satellites capable of servicing state-of-the-art research payloads on a yearly basis. This program is specifically designed to meet the education and research goals of the department's Satellite Systems Development Laboratory.

The first spacecraft in the SQUIRT series is the Stanford Audio Phonic Photographic Infrared Experiment (SAPPHIRE). The payloads for this mission include an experimental infrared (IR) sensor, a digital camera, and a voice synthesizer. The bus consists of a 25 pound, 9 inch tall, 16 inch diameter hexagonal structure with complete processor, communications, power, thermal, and attitude control subsystems. Through student participation, voluntary mentoring from the academic and industrial communities, and the extensive use of off-the-shelf components, the cash outlay target for SQUIRT class vehicles is $50,000.

This paper discusses the educational and research issues surrounding the development of Stanford's spacecraft design curriculum, the formulation of the SQUIRT program, and the progress of the current SAPPHIRE vehicle. Additionally, future payload concepts are outlined, and program expansion plans involving international academic partners are described.

1. Introduction

Modern engineering curricula tend to emphasize understanding, research, and optimization of specific technical disciplines. Although interdisciplinary engineering is fostered through system technology projects and courseware, these approaches traditionally conclude with a conceptual design report. Based on a vocal industry request for exposure to a more realistic systems engineering environment, many academic engineering programs have now initiated formalized methods to teach detailed system design, fabrication, integration, test, and operation. Successful programs provide students with authentic design education by introducing the real world issues of program management, system requirements formulation, and subsystem technology trades. The most fortunate students graduate with hands-on experience in all aspects of the system design life cycle and a technical grasp of the detailed design and operation of a variety of subsystems.

With respect to the satellite design field, the challenges to provide such an educational experience are magnified tremendously. This is due to the technically complex scope and multiyear timelines associated with most spacecraft projects. In addition, these factors greatly complicate the researcher's desire to use the rapid prototyping and iterative techniques employed in other scientific and technical fields.

In response to these issues, Stanford University's Department of Aeronautics and Astronautics has recently broadened the mission and expanded the scope of its traditional

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spacecraft design curriculum. The new center for these activities is the Satellite Systems Development Laboratory.

2. The Satellite Systems Development Laboratory

Officially inaugurated in January 1994, the Satellite Systems Development Laboratory (SSDL) is the focal point of Stanford University's spacecraft design program. The SSDL charter is to provide world class education and research in the field of spacecraft design, technology, and operation. Accordingly, its personnel create and instruct a comprehensive academic program as well as guide and manage a state-of-the-art research agenda. The specific execution of these tasks is accomplished through classroom instruction, research work, and project experience.

As a means of supporting these goals, the SSDL is actively engaged in a number of advanced satellite mission design projects. Scientific and engineering partners in these projects include a variety of academic research centers, government laboratories, and industrial corporations.

In order to prepare graduate degree students for these advanced Laboratory programs through a comprehensive educational experience, the SSDL has initiated development of a new micro satellite platform, the Satellite Quick Research Testbed.

3. The Satellite Quick Research Testbed (SQUIRT) Program

The goal of the SQUIRT program is to produce student engineered satellites capable of servicing state-of-the-art research payloads on a yearly basis.

To limit the scope of the program and to provide direction in the yearly academic setting, the following design guidelines are stressed. SQUIRT vehicle mission and environmental lifetimes are set at approximately one year, and relatively small cash budgets of $50,000 are targeted.

The SQUIRT physical requirement is loosely specified as a highly modular bus weighing 25 pounds and having a 9 inch high by 16 inch diameter hexagonal form as depicted in Figure 1. Continuous development of alternate processor, communications, power, thermal, attitude control, and detailed structural options serves to populate the satellite design toolbox available to future SQUIRT teams. Additionally, guidelines require that all employed design tools, facilities, and technologies be available within the Stanford community and its academic, governmental, and industrial affiliates.

Design teams are also urged to consider the use of amateur satellite radio standards in order to foster a cooperative and mutually beneficial relationship with that community. Current plans call for flight operations to commence with emphasis placed on payload research and educational activities. During this initial period, moderate access would be granted to satellite experimenters and would include command ability for the educational payloads. With research and educational activities finished, complete operational authority of the vehicles would be transferred to the amateur satellite community.

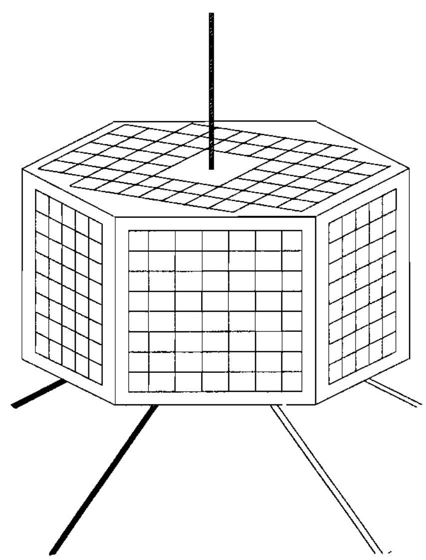

Figure 1 *- SQUIRT Physical Form.*

Because of the program's time and monetary considerations, much of the design process involves the modification of off-the-shelf non-space-rated consumer products. Once a particular component model has been selected, engineering studies are executed in order to determine the hardware, electronic, and software modifications required for space environment operation. These steps are documented in modification plans that are then submitted for review to the SSDL's mentors and the component's vendor. Once approved, the modifications are implemented and the components are interfaced and tested through hardware, software, and electrical diagnostic checks. Through cooperation with local industrial affiliates, these checks include structural vibration, acoustic, and thermal vacuum tests.

Educationally, the SQUIRT program exposes graduate engineering students to satellite design by providing hands-on technical and managerial experience in the following areas: conceptual design, requirements formulation, subsystem analysis, detailed design, fabrication, integration, test, launch, and operations. Geared specifically for Master's Degree students, participation emphasizes systems engineering practices and prepares potential advanced engineering and doctoral candidates for the Laboratory's more involved engineering and research activities. In particular, designs are technically comprehensive, challenging, and interesting.

With respect to research, SQUIRT vehicles serve as a generic space based platform for the variety of low power, volume, and mass experiments currently under development by the SSDL and its affiliates. Yearly cycles permit rapid access for state-of-the-art space research and unique opportunities for low cost payload iteration. Preliminary payload studies include component qualification, environmental monitoring, spacecraft technology, and satellite autonomy experiments.

Philosophically, SQUIRT satellites are intended to be excellent examples of simple, fast, cheap, flexible, and intelligent micro satellite design. Simplicity permits success in the allotted time and allows students to gain technical insight into the entire design and operation of the satellite. Speed allows the student to witness the entire life cycle of the satellite design process. It also provides rapid access to space and focuses efforts towards incremental and iterative technical upgrades. Low cost design satisfies the practical monetary constraints of the SSDL and provides an attractive platform alternative to potential researchers. Flexibility in the design allows the satellite to interface with a variety of potential payloads, to be launched on an assortment of launch vehicles, and to operate in a wide range of orbits. It also permits the design to withstand the uncertainties and technical evolution inherent in a student activity. Intelligence compensates for the operational inefficiencies that typically result from the above philosophical considerations.

Given this philosophical direction, the SQUIRT program accepts a number of characteristics typically denounced in commercial spacecraft development. These include acceptance of high risk, little component redundancy, low precision control, non-optimal designs, and inefficient spacecraft operations.

4. The Stanford Audio Phonic Photographic Infrared Experiment (SAPPHIRE)

Based on student interest and the capabilities of the SSDL's affiliated researchers, the selected missions for the SAPPHIRE spacecraft, the first SQUIRT vehicle, include 1) assessing the performance of experimental IR sensors, 2) performing digital space photography, and 3) broadcasting voice synthesized messages. The IR sensor package is the result of micro machinery research performed by Stanford Professor Tom Kenny and the Jet Propulsion Laboratory. Digital black and white photography is achieved through the modification of a Fotoman camera in cooperation with the engineering staff at Logitech. Digital voice synthesis is obtained through the modification of a commercially available synthesizer board. Broadcasts are transmitted so that they may be received on a hand held radio.

Given these objectives, as well as the SQUIRT program goals previously outlined, students commenced the formal design of the SAPPHIRE satellite by formulating the applicable system requirements and flowing them down to the respective subsystems. Design alternatives were then generated and analyzed through software simulation and hardware modeling. Finally, a series of formal trade-off studies led to the selection of a baseline spacecraft and component configuration.

An exploded view of the selected hardware configuration is displayed in Figure 2. The heart of the system is a four tray interior structure that carries the predominant launch loads and supports the satellite components. The majority of the power, communications, processing, and payload subsystems are housed in trays 1 through 4, respectively, numbered from the bottom to the top. Component wiring, attitude control magnets, and hysteresis rods are placed in the lateral spaces between the interior structure and the solar array panels. Attitude determination sensors, solar cells, and required antennae are mounted on the exterior panels.

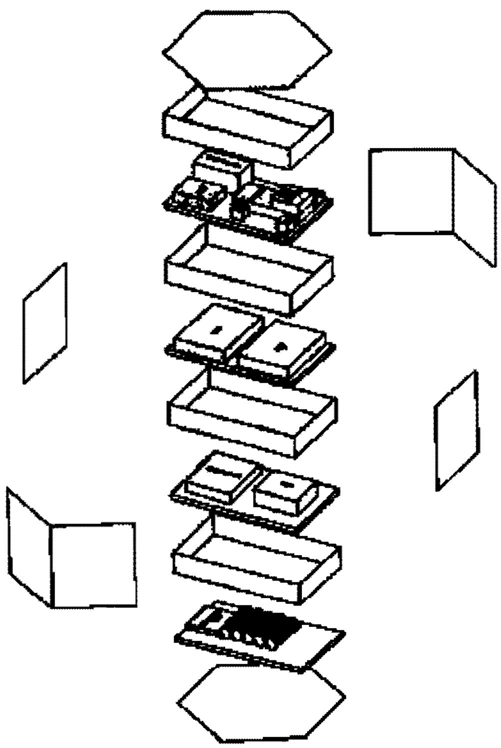

***Figure 2** - SAPPHIRE Structural Configuration*

With respect to the spacecraft subsystems, the selected baseline consists of a Motorola 68332 based computer board that monitors and controls component activity, processes command inputs, and formats telemetry outputs. The communications subsystem is composed of a 1200 baud, Mode J, AFSK packet data system employing both a hardware and software terminal node controller. Voice synthesizer and beacon outputs are transmitted via a separate FM link. The power subsystem generates over eight watts of average power via the exterior solar panels. It is augmented by battery storage capability and regulated to provide both 5 and 12 volt lines. Orbit and attitude determination are provided by a GPS receiver, student manufactured Earth sensors, and a virtual sun sensor based upon relative solar panel current magnitudes. Passive attitude control is achieved with stationary magnets and radiometers. This orients the slowly spinning spacecraft for northern hemispheric imaging and smooths the radiant load on the passive thermal subsystem. Figure 3 displays the functional electrical interfacing of the active components.

Managerial and systems level control is established through weekly student organized design reviews and subsystem manager meetings. System and subsystem specifications are maintained in a formal requirements document, and all component hardware, electrical, and software interfaces are published and reviewed on a weekly basis. Additionally, students regularly update a computerized design log that documents all relevant design information including trade-off justifications, component modification plans, and subsystem continuity data.

Without question, as the first SSDL mission and SQUIRT vehicle, the SAPPHIRE design project is challenged with considerations above and beyond the scope of what is planned for future SQUIRT design efforts. These challenges include the nonexistence of a formulated design toolbox, the lack of startup funding, and the difficulty of developing a suitable laboratory environment in parallel with the satellite design effort. Accordingly, SSDL personnel are prepared to delay the first vehicle's one year time line as necessary in order to produce a suitable technical design and academic experience.

5. Future Missions and Initiatives

In addition to developing the SAPPHIRE spacecraft, the SSDL has commenced with preliminary mission conceptualization and payload feasibility studies for future SQUIRT vehicles. In the category of student interest, payloads include higher resolution color digital cameras, analog television transmitters, micro meteorite sensors,

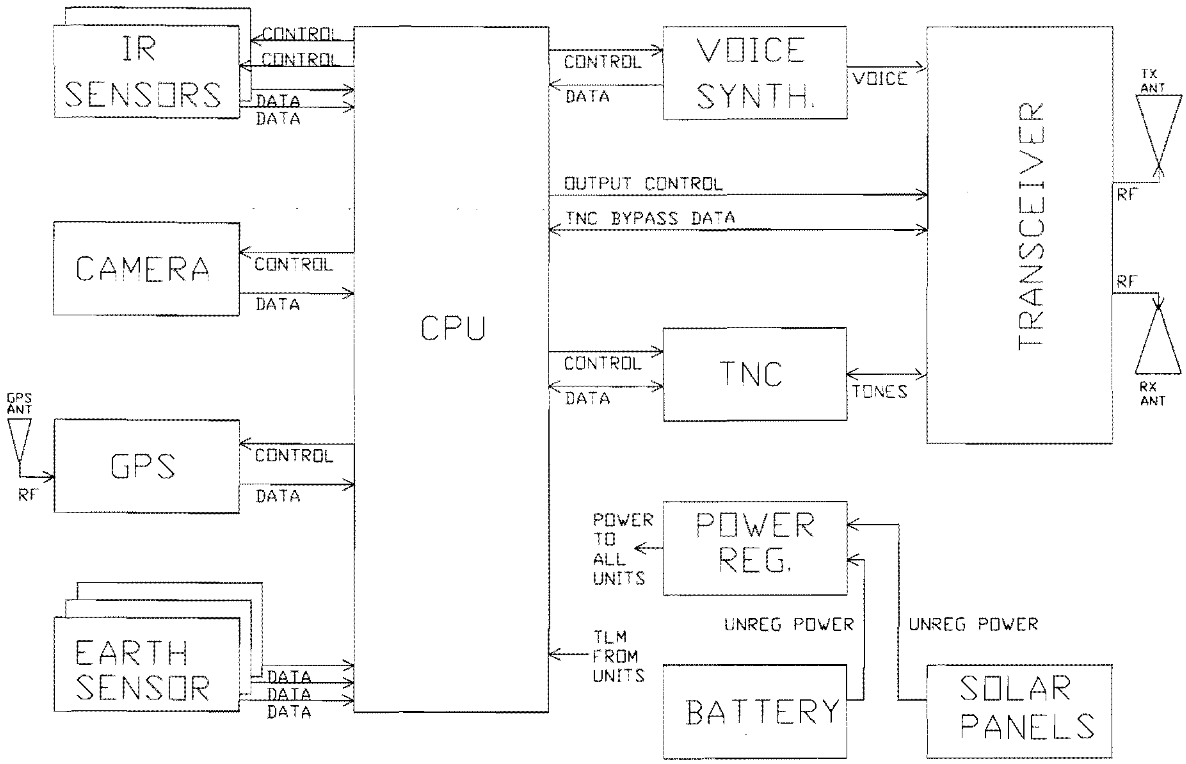

***Figure 3** - SAPPHIRE Functional Interfaces*

and radiation sensors. Research payload studies include a miniaturized arc jet thruster, a space environment plasma analysis package, an autonomously coordinated constellation experiment involving multiple SQUIRT vehicles, a number of spacecraft navigation and attitude control investigations, a spectroscopic imagery package, and a series of component space qualification tests.

In order to broaden the organizational scope of the SQUIRT program, the SSDL is promoting the formation of an international academic SQUIRT community geared specifically towards the rapid production of SQUIRT class micro satellites for the purposes of education and research. Along these lines, design cooperation and discussions have commenced with the University of Umea in Sweden and with Weber State University. To promote this cause and to further overall educational objectives, the SSDL plans to make all SAPPHIRE and future SQUIRT design information available to the public via an Internet Mosaic link and through specific requests for documentation.

6. Conclusions

Stanford's Satellite Systems Development Laboratory was formed due to an increasing demand for graduate students with a mature background in satellite systems engineering. As the focal point for Stanford's spacecraft design program, the SSDL provides a world class education by teaching a comprehensive sequence of courses covering system design methodologies and satellite technologies. The SSDL fosters world class research through doctoral student investigations and by designing and integrating space based research platforms.

The SQUIRT program specifically caters to the educational needs of graduate students through a judicious blend of systems engineering exposure and hands-on technical experience with a limited size, scope, and timeline. It appeals to researchers with low power, volume, and mass payloads as an inexpensive and rapid access flight opportunity. As the first SQUIRT project, the SAPPHIRE vehicle meets both of these educational and research goals. Additionally, the SAPPHIRE design team has built a strong foundation for the future of the SQUIRT program by developing a flexible structural configuration, by investigating and developing a range of viable bus components, and by establishing a sound operational relationship with the amateur satellite community.

Finally, through a strong advisory program, the SSDL has been able to tap the strengths and abilities of a wide variety of engineering and design specialists in the academic and industrial communities. These relationships serve to enhance the educational experience of the program's students, and it reinvests the skills and experiences of mentors in a new generation of engineering designers.

Acknowledgments

The authors wish to acknowledge the outstanding work and commitment of the current SAPPHIRE student design team: Eric Abbott, Sung Ahn, Birdy Amrutur, Raj Batra, Jeff Chan, Helene Cochelin, Louie Demmel, Michel Iagolnitzer, Beth Kader, Will Kim, Sangho Kim, Dave Lauben, Rick Lu, Alex Luebke, Mori Ohara, Jeff Ota, Kevin Stattenfield, and Michael Swartwout.

In addition, special thanks is given to all of the individuals and companies that have donated their time and resources to this design effort. Particular gratitude is expressed to the following design mentors for their dedicated assistance: Mr. John Ellis, Mr. Kitt Blanke, Mr. Tim Panczak, Mr. Kevin Freund, Dr. Frank McLaughlin, Mr. Bill Rausch, Professor Tom Kenny, and Mr. Kevin Mackey.

Finally, appreciation is extended to Professor George Springer and Professor Daniel DeBra of Stanford's Department of Aeronautics and Astronautics for their support and guidance concerning the development of the SSDL and the SQUIRT program.