STUDENT DESIGN OF A MODULAR SOUNDING ROCKET

Submitted to the Oregon Space Grant Small Grants Program
April 10, 2000

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ABSTRACT

We propose to design, construct, and launch a medium-altitude modular sounding rocket. The rocket will deliver research payloads to altitudes in excess of 15 km (50,000 ft) and incorporate an advanced avionics system, including high speed RF communications (~1Mbps), a fault-tolerant arbitrated serial bus backbone, a prototype GPS-aided inertial navigation system, and real-time MPEG-encoded streaming video.

This will be the third in a series of sounding rockets successfully developed and launched by the Portland State Aerospace Society, a student group at Portland State University. The proposed launch vehicle will use inexpensive, off-the-shelf components to develop an electrically and physically modular, fault-tolerant, and adaptable vehicle that will serve as a valuable platform for future education and research projects.

The sounding rocket will be launched from a FAA-approved site in the Black Rock Desert of Nevada in the fall of 2001. As the project's coordinators, we feel that this will give undergraduate and graduate engineering students valuable experience in a hands-on, multi-disciplinary, team-based, systems-level project from concept through design and delivery.

PROJECT SIGNIFICANCE

The greatest significance of this educational engineering project is that it will engage students in multi-disciplinary systems-level engineering. Architectural and interface documents, design reviews, and team-based coordination are all critical skills that will be learned during the course of this project.

The vehicle will be a flexible and modular research platform that will enable new modules to be developed independently at minimal cost. Each component of the vehicle will be a self-contained unit (e.g., propulsion, avionics, payload, and recovery) that connects and communicates through a standardized electrical and mechanical interface. This rapid, snap-together modularity makes vehicle integration and assembly simple and will enable different configurations to be launched in a single day. It also allows the functional teams to work independently on their modules, decreasing design and development time, and it makes inter-university cooperation possible. For example, an atmospheric sampling payload could be designed and built at another institution and then integrated into the final vehicle just before launch.

The vehicle's payload bay will be capable of carrying research payloads of approximately 9 - 13 kg (20-30 lbs.) and 15 cm (6 in) in diameter to altitudes in excess of 15 km (50,000 ft). In addition to atmospheric sampling, the research applications of the rocket may include aerial imaging from altitudes inaccessible by conventional airplanes, the testing of high-speed or high-altitude aerodynamics (e.g. high-altitude wing sections), and astronomical observations only possible from above the lower atmosphere.

Off-the-shelf components help minimize the cost of this project. Most available sounding rockets are built by companies contracted by NASA who are not competing for lowest cost and which must support significant infrastructure at a few geographically remote launch centers (e.g., the Poker Flats Range in Alaska, or the Wallops Island Flight Facility far off the coast of North Carolina). The proposed launch vehicle requires only inexpensive, commercially available components such as small microcontrollers, low-cost silicon micro-machined inertial sensors, and inexpensive construction materials such as aluminum and fiberglass. This project requires a minimal amount of ground support equipment, including a portable launch tower that uses only a few sections of commercially available C-channel conduit, amateur-band radio equipment, and three laptop computers. Furthermore, this launch vehicle will satisfy FAA requirements allowing it to be launched from numerous sites around the country.

This project will also benefit other universities and amateur rocketry groups through the technical specifications, project planning, and collected data that will be published publicly on the project's web page.

PROJECT METHODS

We have already made considerable progress on the launch vehicle. A 1998-1999 senior project completed the specification of the fault-tolerant arbitrated serial bus architecture of the avionics system and much of the airframe has already been designed and is currently under construction. We have also started the construction of a GPS-guided steerable parafoil as a 1999-2000 senior project, which will be used as both the first research payload in the September 2001 launch and as a future recovery system. The functional specifications of the rocket have been completed and reviewed, including maximum expected acceleration loads, physical dimensions of the different airframe modules, and the physical and electrical properties of the connectors.

The project responsibilities have been assigned to six functional teams: airframe, avionics, ground systems, logistics, payload, propulsion, and public relations. The society meets monthly to coordinate activities, report team progress, and to informally review design decisions. The functional teams meet weekly. The project's web site has a critical role in project management and serves as the source of all project documentation, team communication, and public relations. Society communications, such as meeting times, special notices, and requests for engineering help, are announced through the society's mailing list.

We have divided the project into five stages and have specified three milestones.

Stage 1: Design (July 2000 - December 2000)

The Airframe, which has already been designed and is currently under construction, will be completed and the airframe modules will be tested (one destructively) for strength. The Avionics Team will begin converting the system architecture into a more detailed functional and interface-level design. Schematics, prototype PCB layouts, firmware flowcharts, power requirements and communication protocols will be completed. The Propulsion Team will validate the design of a ¼-scale motor during this stage.

Milestone 1: Airframe Test using ¼-scale motor in the Black Rock Desert (September 2000)

A year before the full vehicle launch, the airframe and an existing previous-generation payload will be launched using the ¼-scale motor. This will validate the single-stage recovery system, the behavior of the ¼-scale motor in-flight, and the strength and stability of the airframe.

Milestone 2: Final System Design Review (January 2001)

The teams will gather for a formal design review session, reviewing all designs completed in Stage 1.

Stage 2: Prototype and Test (January 2001 - April 2001)

The Avionics Team will build prototype modules and begin crude integration and calibration tests. The RF Communications, GPS Position and Attitude Determination and 3D Magnetometer Modules will be validated for accuracy. The Recovery Team will integrate a 2-stage recovery system into the airframe and conduct simulations (ground tests) of deployment. The Propulsion Team will design and validate a ½-scale motor.

Stage 3: Integration and Test (May 2001 - August 2001)

The Avionics Team will integrate all modules into the airframe and perform the first full systems tests and analyses. Individual modules will be improved to increase system performance if necessary. At this point, the Logistics Team will begin planning the transportation, lodging, food and other logistical issues for the upcoming launch in Black Rock Desert. Although distant from Portland State, the Black Rock Desert is an ideal location for this launch because of its distance from population centers, its recognition by the FAA as an amateur launch site, and the ease of recovering the vehicle on the flat, dry lake bed.

Milestone 3: Full System Integration Test Week (August 2001)

The completed vehicle will be thoroughly tested, including a simulated launch using all ground and rocket systems except the motor. The launch station will be fully set up and tested to simulate all aspects of the launch. Checklists and scripts will be created to facilitate rapid deployment at the launch site.

Stage 4: Launch in the Black Rock Desert (September 2001)

The entire team will make the trip out to the Black Rock Desert in September 2001 for a nation-wide experimental amateur rocketry event. The rocket will be launched and all data will be recorded for later analysis. The launch will be extensively documented by video and photographs, all of which will be posted on the web site. Members of the local and national media will be invited to observe the event.

Stage 5: Analysis and Documentation (September 2001 - November 2001)

After returning from the launch, we will synchronize the acquired data into a single data set for analysis. This data set will include: the six degree-of-freedom inertial measurement data, differential GPS position data, GPS phase attitude data, atmospheric data (pressure and temperature), 3D magnetometer data, mechanical data (strain gauges in the composite skin), and the digital video. This data will allow us to characterize the rocket's in-flight dynamics and to assess the feasibility of an active guidance system for future flights. We will document the findings of the analysis and post both the analysis report and raw data on the web site. Shortened versions of the document will be published as articles in various periodicals and journals.

EXPECTED OUTCOMES

During the year of intensive development preceding the launch, we will document all aspects of the vehicle's design and post it on the project's web site. Schematics, CAD drawings, PCB layouts, functional specifications, detailed firmware listings, and an introductory white paper of the vehicle's architecture will allow other groups, both amateur and educational, to replicate our results. To encourage the design of research payloads by other groups, the detailed specifications for the payload module have already been posted on the project's web page.

We expect to successfully launch the vehicle in the Black Rocket Desert of Nevada in the early fall of 2001. We hypothesize that the data gathered from this launch will prove four critical points. First, the rocket design is a flexible, low cost platform that can be used in other educational and research projects. Second, the data from the inertial measurement unit, differential GPS, GPS phase attitude determination, 3D magnetometer, atmospheric sensors and digital video are sufficient to characterize the vehicle's dynamics with enough accuracy and precision to validate existing models of flight dynamics and improve future modeling. Third, the same data set is sufficient to model real-time, fault-tolerant position and attitude determination algorithms for future flights using an autonomous guidance system. Finally, engineering students, especially undergraduates, can complete a real-world engineering project when given an exciting, hands-on application and the necessary resources.

After the launch, the full report of the successes and problems of the launch vehicle, along with the raw data and analysis results, will be posted on the web site and published as articles in various amateur rocketry and technical periodicals such as Test & Measurement Design and the Journal of the IEEE Aerospace and Electronics Systems Society.

On an institutional level, we expect that this project will benefit Portland State University's School of Engineering and Applied Science by being one of the first in a series of multi-disciplinary engineering projects with student participation and responsibilities in all aspects of the project. This will, in turn, improve recruiting and retention in the school of engineering.

The most rewarding outcome of this project will be the experience gained by the participating students. In the year they work on this project, we expect them to learn an array of technical skills, including the use of EDA tools to design electrical and mechanical systems, system-level debugging, and electrical and mechanical construction techniques such as machining and soldering. We also expect students to acquire a number of skills that will help them become successful engineers including project management, methods of communication, team-based cooperation, and a systems level, multi-disciplinary approach to engineering problems.

TIMELINE

Sept. 1998 - July 2000	**Stage 0: Preliminary Design & Specification**
	Airframe design, ¼-scale motor design, and avionics system architecture specifications.
July 2000 - Dec. 2000	**Stage 1: Design**
	Detailed design of modules and system. Completion of design documentation & first airframe (by August 2000).
Sept. 2000	**Milestone 1: Airframe Test using ¼-scale motor and existing avionics package.**

Jan. 2001 **Milestone 2: Final System Design Review**

Jan. 2001 - April 2001 **Stage 2: Prototype and Test**

Completion of module prototypes, testing and initial verification.

May 2001 - Aug. 2001 **Stage 3: Integration and Test**

Test modules as a system, including ground systems. Improve modules, if necessary.

Aug. 2001 **Milestone 3: Full System Integration Test Week**

Test the entire system, including a "dry run" of the launch. Prepare for launch in Nevada.

Sept. 2001 **Stage 4: Launch in the Black Rock Desert**

Launch. Document activities, capture data.

Sept. 2001 - Nov. 2001 **Stage 5: Analysis and Documentation**

Complete documentation. Complete data analysis. Publish results on web site.

KEY PERSONNEL

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