AC 2009-1818: PERSEUS LAUNCH VEHICLE: STUDENT-DESIGNED AEROSPACE ENGINEERING SENIOR CAPSTONE PROJECT

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Perseus Launch Vehicle: An Aerospace Engineering Senior Capstone Project

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Abstract

At the beginning of the Fall 2008/2009 school year, a group of four senior aerospace engineering students at Parks College, Saint Louis University founded the Earthrise Group. The purpose of this group was to participate in communal research projects, the first of which was the Perseus Launch Vehicle senior capstone project. The mission called for a rocket launch vehicle that was capable of placing a picosatellite or nanosatellite payload of mass no greater than fifteen kilograms into a circular earth orbit no greater than one thousand kilometers. A systems engineering approach ensured that the customers' constraints of economical pricing, the ability to tailor to the customer's particular needs, rapid response time, and long-term storage were met. The result was a two stage to orbit, hybrid-powered expendable launch vehicle which utilized commercial off the shelf components where possible. The team size was kept at a minimum to allow for focus and a free flow of ideas. Communal research and frequent idea meetings were a hallmark of the group organization, providing a holistic systems design on the part of each engineer. Specialization was a gradual process resulting in member dedication to fields that interested them. The educational construction of the senior capstone course brought the students a greater understanding of the unique challenges posed by a rocket system and the relative lack of coursework dedicated to these challenges. Group members were allowed a large amount of independence in their efforts, which proved both a blessing and challenge. Space technology education at the college was expanded by attempting a space systems design project, requesting additional space orientated classes, and encouraging the participation of underclassmen in space systems design. In the future, it is hoped that the efforts of the Earthrise Group, through the Perseus Project, will encourage future students to participate in the design of a rocket launch vehicle as a senior capstone project at Parks College.

Introduction

At the beginning of the Fall 2008/2009 school year, a group of four senior aerospace engineering students at Parks College, Saint Louis University founded the Earthrise Group. The purpose of this group was to participate in communal research projects, the first of which was the Perseus Launch Vehicle (PLV) senior capstone project, referred to as the Perseus Project. The Perseus Project was a rocket launch vehicle designed to deliver a picosatellite or nanosatellite of mass no greater than fifteen

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kilograms into an orbit of no greater than one thousand kilometers and meeting certain additional design constraints. The project was conceived of as a paper design which took into account diverse subjects including, but not limited to, marketing, legal regulations, and systems engineering.

As the culmination of four years of aerospace engineering education, the project was intended to test the students' abilities to manage a complex engineering design task. It was quickly realized that the project held many unique challenges specific to rocketry which had not been explicitly addressed in previous classes. Therefore, the project required much independent research on rocketry-specific concepts. With this realization, the members of the Earthrise Group intended the project as a way of promoting the expansion of space systems engineering within the college.

Project Description:

Market Considerations

Technology improvements in the field of space avionics over the last several decades have enabled the development of increasingly smaller yet still capable satellites. This has led to the rise of picosatellites and nanosatellites (spacecraft with masses less than 1 kg and between 1 and 10 kg respectively), most notably the CubeSat program increasingly used in university educational programs. At present no launch system exists tailored explicitly for untraditionally small satellites; these payloads have come to rely on either secondary payload opportunities or converted surplus ballistic missiles for access to orbit. Each of these options proves to be less than optimal for multiple programmatic and regulatory reasons.

At present, the majority of small satellite applications are dedicated to the academic and defense communities. The academic community has ongoing ventures in the fields of physics, cellular biology, and environmental science requiring experiments to be performed in the microgravity of space and its associated vacuum. Professors and researchers in the academic field depend on the advancement of their research for funding of their departments and individual programs. With this in mind, they are focused on achieving their research goals as quickly and effectively as possible, while operating at an optimum cost. Military communities demand a system which is rapidly deployable and reliable. In addition, they seek a transportable system capable of remaining in storage on site for extended periods of time.

The Perseus Launch Vehicle (PLV) was designed with this customer base in mind. The mission of the PLV is to place a picosatellite or nanosatellite payload having a mass of no greater than 15 kg into a circular Earth orbit of altitude no greater than 1,000 km. Keeping the needs of the customers in mind added the following constraints to the mission: economical pricing, the ability to tailor to the customer's particular needs, rapid response time, and long-term storage. These mission goals and constraints drove a systems approach to the vehicle design.

Design Philosophy

The primary design philosophies behind the Perseus Project were systems engineering, simplicity, and holism. A focus on systems engineering was applied throughout the Perseus Project, with the primary concern being the customers' needs. All decisions on component and vehicle design were made with the mission and customer constraints in the forefront of thought. In the interest of simplicity, commercial off the shelf (COTS) components were projected to be used in as many applications as possible. It was anticipated that this would reduce costs, increase reliability, and decrease the design requirements of the team by reducing the amount of testing and validation required. Finally, a small and highly motivated group environment allowed members to specialize in one sub-discipline while maintaining intimate knowledge of the work of other group members, leading to a more holistic design approach.

Configuration:

The configuration of a rocket launch vehicle seeks to determine the optimum number of rocket stages and the amount of mass in each stage. Three basic designs were considered: Single Stage to Orbit (SSTO), Two Stage to Orbit (TTSO) and Boosted Stage to Orbit (BSTO). The chosen fuel combination yielded an I_{sp} of 247 seconds, which proved too low for a SSTO configuration. BSTO would require the use of solid fuels, making safe storability difficult. This left a TSTO or greater configuration. The design required an analysis of the rocket equation to determine the ideal number of stages and the mass of each stage.

The initial step was a design space analysis similar to that used in aircraft. Limiting curves were plotted to define a design space. This analysis determined that two stages would be optimum for the PLV. The second step used a MATLAB script to determine the optimum masses of the upper and lower stages. Finally the vehicle parameters defined by these analyses were run through a check script to verify that the vehicle met the mission requirements.

Propulsion:

The PLV was designed around hybrid rocket engines in both the upper and lower stages. In order to meet the needs of military customers, the vehicle would need to be stored on site for extended periods of time and then be rapidly deployed with little forewarning. Liquid fuelled engines are flexible in their capabilities but costly and complicated to operate on a budget. Solid fuelled motors are simple and storable but are not throttleable. A hybrid rocket engine combined the simplicity and storability of a solid system with the flexibility of a liquid one. A combination of solid polyethylene fuel and gaseous nitrous oxide oxidizer were chosen for their availability, safety, cost, and I_{sp}. Both of these substances are inert and harmless until combined and ignited within the engine, allowing for safe storage at normal room conditions. In this way, customer constraints were met while still fulfilling the mission.

Structures:

The structure of the PLV was designed around the upper and lower stage oxidizer tanks with additional structures supporting the engines, interstage, and payload adapter. The primary load-bearing structures in the PLV were the upper and lower stage oxidizer tanks. The secondary load-bearing structure, a stiffened outer skin, transmitted the loads from the various engine components, payload fairing, payload adapter, thrust structure, and engine mount to the tanks. The maximum axial acceleration anticipated during flight was ten g-loads, with the vehicle designed to withstand up to 12 g-loads before failure.

The payload to which the vehicle was tailored was the CubeSat, which would be deployed by the Poly Picosatellite Orbital Deployer (P-POD). The payload adapter designed for the PLV can accommodate up to six P-PODS; different payload adapters can be designed to accommodate single, larger payloads or multiple smaller ones.

Aerodynamics:

The aerodynamics of the PLV were not of greatest concern during the design process. As a result of the short time the launch vehicle spends within the atmosphere, approximately 1.5% of expended fuel was lost to combating aerodynamic forces. The greatest aerodynamic concerns were the design of the payload fairing to shield the satellite from the atmosphere during ascent and the lower stage fins to provide static stability to the launch vehicle. In order to minimize drag while maximizing internal volume, a HAACK series nosecone was chosen with a C value of 0.

Guidance, Navigation, and Control (GNC):

Guidance, Navigation, and Control of the PLV were simulated through a MATLAB script which solved the equations of motion of a rocket in flight. The script was used to predict the launch vehicle's trajectory. The actual GNC of the launch vehicle was studied primarily on a conceptual level due to time and manpower constraints on the project. It is theorized that guidance and navigation would be provided by an onboard inertial guidance system (IGS). This data would be checked for deviations against a predefined trajectory. The control system would then use the telemetry produced by the IGS to maintain the required trajectory by using thrust vectoring of the upper and lower stage nozzles. Fins on the lower stage will impart a degree of static stability while within the atmosphere. A slight spin imparted by cold-gas thrusters on the upper stage was considered to provide static stability to the upper stage. If deviations are uncorrectable, or if control of the vehicle is lost, oxidizer flow valves will seal, rendering the vehicle inert.

Testing and Verification:

Testing of the PLV was broken into aerodynamic testing and component testing. In order to gain experience with aerodynamic testing the team began constructing a supersonic wind tunnel model to validate the vehicle static stability predicted by calculations. Tests will be conducted for various angles of attack at various Mach numbers. The data from these tests will help refine the models used to predict the static stability derivatives of the vehicle. Testing on the various load-bearing structures of the rocket was performed by using ProMechanica to determine the failure loads of the various components and verify that they fell within the operating conditions. Due to a lack of sufficient time and manpower, investigation and selection of specific COTS components was not completed.

Team Management:

Team Formation

At the beginning of the Fall 2008/2009 school year, a group of four senior aerospace engineering students founded the Earthrise Group. The purpose of this group was to participate in communal research projects, the first of which was the Perseus

Launch Vehicle (PLV) senior capstone project. The philosophy of the group was to pool together the resources of highly motivated and ambitious students both academically and geographically.

Team Dynamics

Of the four group members, three chose to share an apartment on campus, while the fourth joined communal meals and events on an almost daily basis. This living arrangement allowed decisions and information to flow quickly and freely from person to person. For example, if the Propulsion Engineer needed to know the burn-time of the first stage engine, he simply walked to the Guidance, Navigation, and Control Engineer's room or wait until dinner to ask him. Textbooks and references were kept in a communal library, allowing easy and convenient access at any time of the day.

Group meetings were held often in order to share ideas and prepare for deadlines. The group gathered once a week for lunch and dinner. This time was advantageous as it allowed members to discuss their ideas and concerns in a relaxed setting.

One disadvantage encountered with the team arrangement was a decreased ability to find time away from the project as the barrier separating work and leisure time was eroded. At any given moment, there was usually one person in the apartment working on the project. Therefore, the potential for ones leisure time to being interrupted with a question always existed. On several occasions difficulties arose, and group members took time to discuss personal issues. This was necessary as not only the group dynamic was in question, but living arrangements as well. In spite of the difficulties, by living together, the Earthrise Group learned to put aside differences in the interest of preserving working and social relationships.

Educational Value:

Senior Capstone Course

The greatest challenge faced by the group was not in the calculations of the project but in the environment in which the project took place: the senior capstone course itself. The traditional focus of the course has been the development of atmospheric vehicles, with the supporting textbooks and requirements geared towards this goal. In addition, while various professors had experience in spacecraft systems, few had experience in rocket launch vehicles. This placed the group in a unique position of independence with its own disadvantages and advantages.

The primary disadvantage to the group was the lack of concrete deliverables. At the beginning of the project, a list of the expected vehicle design and performance parameters to calculate was not present. The search for this information consumed time and resulted in many dead ends. In the end, this proved to be an advantage to group members. While searching for what to deliver, members learned to judge which parameters were important in launch vehicle design, and which were of lesser concern. In addition, members learned to evaluate which resources, conferences, and software packages were most helpful to the design process.

Technical Electives

In addition to the required senior capstone course, group members enrolled in several technical electives which directly benefited the project. A course in satellite systems was taken by all group members, and individual members enrolled in courses on Orbital Mechanics, Numerical Methods, Computational Fluid Dynamics, and Finite Element Analysis. Classes explored but not taken due to lack of sufficient students included Hypersonics and Spacecraft Dynamics. The dropping of these two courses reminded group members of the relative lack of offerings in space technologies when compared with aviation technologies. Group members encouraged the offering of additional classes in spacecraft systems as well voting for prospective faculty who could teach space technology courses. It was hoped that by showing an interest in these classes, the college and current underclassmen would support more space systems education.

Underclassmen Involvement

Underclassmen involvement in the project was kept to a minimum in order to keep focus by group members. Despite this, underclassmen were routinely informed of the project's progress through question and answer sessions with the Parks College American Institute of Aeronautics and Astronautics (AIAA) club and the Saint Louis University Students for the Exploration and Development of Space (SEDS) club. In addition to discussing the project itself, these question and answer meetings also addressed the senior capstone course and the challenges posed to space technology projects.

The group was able to help two teams of underclassmen prepare their senior capstone projects. The first project, on hybrid rocket technologies, was an outgrowth of the AIAA club's experimentation with mid-powered rockets. The second project, an effort to develop a Google Lunar XPrize, was an outgrowth of the SEDS club. This was a concrete step forward in encouraging a greater interest in space technologies among underclassmen. It is hoped that with this head start and interest, these future senior capstone groups will have a better understanding of space technologies and the courses they will need to request in order to fulfill their projects.

Academic Competitions and Conferences:

While much of the work on the Perseus project was conducted in isolation at Parks College, academic competitions and conferences proved to be a treasure trove of helpful advice and encouragement from the outside world. Over the course of the year, three conferences and one competition were entered into or attended.

The first conference attended was the SEDS Space Vision conference in College Station, Texas. This conference brought together notable individuals and organizations involved in the development of the private space industry. The conference provided an opportunity for the group to exchange ideas and draw inspiration from the founders of the private space movement. Armadillo Aerospace provided advice on procuring COTS equipment and testing engine components. The Federal Aviation Administration provided paperwork on the regulations concerning commercial space launch vehicles. Students form the various universities in attendance provided information on their research in hybrid rockets, rocket design, and other related fields.

The second conference entered into was the American Institute of Aeronautics and Astronautics (AIAA) Region V Student Paper Conference. At the time of this paper, the conference had not yet occurred. However, in writing the abstract and preparing the materials, the group was developing the mindset and skills necessary to write a technical conference paper. This will be of great benefit to the students in their professional careers.

The third conference entered was the American Society for Engineering Education (ASEE). The value of this conference was in helping the group to understand the scope and place of their design project. Reflecting on the project's educational value helped cement the importance of the work being undertaken.

The only official competition entered was the Idea to Product (I2P) competition for seeking out innovative products with marketing potential. This competition proved to be of tremendous importance to the group. By presenting the capstone project as a business proposal, the group became more familiar with its customer base, and thus the constraints and requirements imposed on the vehicle. In addition, the feedback from judges helped students become more aware of the regulations governing space technologies, particularly ITAR and export control.

Improvements in Education

Education is an evolving discipline, and the group encountered several situations which it could be improved.

The first suggestion is with regard to the format of the senior capstone course. Currently, the class meets once a week for an hour lecture and twice a week for a three hour design lab. This arrangement gave the lecture little legitimacy for students and faculty. It is suggested that less time be given for lab and more to the lecture. The additional time devoted to lecture will allow professors to better prepare students in systems engineering and team management during the first semester and paper writing and presentation skills during the second semester.

The second suggestion is in regards to interuniversity communication. More emphasis and assistance should be provided to students on seeking out other university programs working on similar projects. If lasting relationships can be established between several universities, then students will gain not only a greater knowledge base to work with, but also a sense of the collaboration existing between contractors in the professional world.

The third suggestion is to encourage a greater participation in student conferences. Group members attending the SEDS Space Vision conference gained a wealth of information on practical design of space systems that was useful throughout the project. Ideas not previously fathomed as being of interest were brought up in each of the conferences, and the group moved to address them. Conferences also help students fulfill the second suggestion of networking and sharing project ideas.

The fourth suggestion is to provide students with a more diverse course selection. In addition to courses on space technology, courses in business practices, aerospace law, entrepreneurship, systems engineering, and project management are also desirable. The end result is hoped to be senior capstone projects which are better rounded and holistic in their approach.

The final suggestion is to involve more underclassmen. The Perseus Project did not tap the full potential of undergraduates, thus depriving the group of resources and the students of an opportunity to learn. Underclassmen are ideally suited to work on physical and CAD models since shop and CAD classes are normally taught early on. This helps them practice their developing skills while freeing seniors to perform more complicated tasks. The assistance of underclassmen in this way would have been helpful to the Perseus Project, but was not employed.

Conclusion

The Perseus Project was a learning experience on many different levels for the students involved. Group members learned to work with high independence on a complicated design project. Concepts of systems engineering, team management, business practices, and regulations were utilized at various times during the project. Through the design philosophies of systems engineering, simplicity, and holism, a vehicle design was produced which met the mission requirements and customer constraints. The project was the first design effort of a small and dedicated team of four students who formed the Earthrise Group. What had initially started as a senior capstone project quickly grew into an effort to promote sustainable space systems education throughout the college. The choice of working on a project fundamentally different from the norm, requesting specialty classes to support the project, and sharing progress with underclassmen represented a dedication to the expansion of space systems education at Parks College. In the future, it is hoped that the efforts of the Earthrise Group, through the Perseus Project, will encourage future students to participate in the design of a rocket launch vehicle as a senior capstone project.

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