ALETRO
Undergraduate & Graduate Student
Engineering Learning Project Proposal

February 28, 2011

Aerospace Legacy Engineering and Technology Recovery Organization d/b/a (ALETRO)
http://www.aletro.org
A Not-For-Profit, 501(c)(3) Corporation
4514 E. Meadow Drive Phoenix, AZ 85032
Tel: (602) 795-3699 cell (602) 228-7260 Fax (602) 795-8536

1. Executive Summary

This proposal has evolved from a senior design capstone course developed by the Mechanical and Aerospace Engineering Department at Utah State University. During academic year 2009-2010, the Mechanical and Aerospace Engineering (MAE) Department at Utah State University (USU) completed the first phase of a Senior Design Capstone Course entitled "Design and Testing of a Prototype Lunar or Planetary Surface Landing Research Vehicle (LPSLRV)." Utah State University selected the Apollo-era Lunar Landing Research Vehicle (LLRV) and Lunar Landing Training Vehicle (LLTV) as the project models because the vehicles offered both inspiration and challenge to the students, yet still had relevance for future lunar and planetary missions. This project attracted great interest and participation by approximately1/4th of a senior class of 100 plus five graduate students. A prime focus of the design project was to revisit the key features of the LLRV design and to, whenever feasible, replace the 1960s era analog control technologies with modern computerized digital technologies.

A prime objective of the ALETRO learning project is to team those who engineered the previous generation's technology (a rapidly dwindling pool of experts) with academic institutions nationwide in an effort to "give back" and preserve some of their accumulated knowledge and wisdom. These experts offer lessons and inspiration not available in traditional academic discipline areas. Pending funding, the proposed project is scheduled to begin in calendar year 2011 with curriculum development and instruction to begin during academic year 2011-2012. The course is to be instructed by engineering departments of five western-state universities. Funding may also support graduate students to assist undergraduates in software and control system design tasks. The design course is to be instructed in a manner that emulates NASA and industry project teams, using systems engineering concepts to guide the design development, integration, and testing. This approach will provide essential "hands-on" skills not normally provided by in formal academic courses.

Classes for academic years 2011/2012 & 2012/2013 will design and flight test scale models of the Lunar Landing Research Vehicle, a gimbaled jet utilized in the Apollo program's astronaut training to develop lunar landing techniques simulating the lunar 1/6 gravity and absence of aerodynamic forces. Whenever possible, modern technology solutions will be applied, and these solutions will be contrasted and compared with legacy solutions that were actually used during the Apollo program. As an example, students will compare and contrast the effectiveness of digital flight control systems (modern) to the actual analog flight control systems (legacy) used during the Apollo era.

The choice of the five participating universities offers an opportunity to adapt the curriculum developed at USU to allow for the variances in academic course availabilities over one or two semesters, extra curricula activities such as rocket clubs, and grant funding business practices. This flexibility provides a more effective way to expand benefits to a broader spectrum of engineering and technology schools. Each academic team is expected to obtain additional support from regional professional societies, the local community, and other government or industry funding programs. In turn, the learning project participants will perform outreach with local high schools and elementary schools to promote Science, Technology, Engineering, and Mathematics (STEM) priorities outlined by the NASA office of education. The Accreditation Board for Engineering and Technology, Inc. (ABET) is recognized by the U.S. Government as the accreditation organization for higher-education programs in applied sciences, engineering, and technology. ABET requires a well-developed senior design curriculum for program certification and this learning project directly addresses the requirements for this certification.

The funding requirement to launch the program in early 2011 is estimated to be $980K and will cover the ALETRO administrative costs, five participating university teams, and a fly-off competition with a total competitive prize budget of $100K. The proposed project will last two years, with the fly-off occurring at the end of year two. Depending on the total level of funding received, each of the participating universities will receive $50K per year to cover expenses and allow for some minimal faculty salary compensation (approximately 1-month per year). As part of this project, all partners, including the Society of Experimental Test Pilots (SETP) Foundation will work together to develop potential follow-on projects that can benefit from this two-year design cycle, with the hope that a significant outcome will be dramatically improved quality of graduates entering the workforce.

Table of Contents

2. ALETRO Mission Statement

The ALETRO mission statement, found at [ALETRO Mission Statement PDF 269k] concludes: "*To inspire current and future generations of technologists through the old-timers (a vanishing resource) as docents providing the technological history of how aerospace challenges in the last half of the twentieth century were resolved.*"

3. Project Overview

The Apollo lunar program, and its incredible success culminating with the six successful human-crewed lunar landings and safe returns, represents a singular achievement that has perhaps never been rivaled in all of human history. It may be many decades before such a feat is accomplished again. Because of this indefinite delay, it is essential that the knowledge base and "lessons learned" from the Apollo era technology programs be preserved and archived for future reference, research, and application. The *Aerospace Legacy Engineering and Technology Recovery Organization* (ALETRO) was originally founded to identify, preserve, archive, and make Apollo-era artifacts and documents available for research. The non-profit organization is dedicated to locating, preserving, and archiving collections of non-archival aerospace technology documents and artifacts from the post World War II "space boom" during the latter half of the twentieth century. Of particular interest are personal collections of "old-timers," particularly those of deceased individuals where estate heirs may be unaware of the value of these collections. ALETRO provides collection owners and heirs services to digitize and archive these collections in the public domain for use by future generations. In addition to artifacts, one incredibly precious resource that cannot be preserved indefinitely is the human-capital from the Apollo-era programs – the generation of experts who worked on these projects. If the knowledge stored in these individuals is not "mined" soon, it will be lost forever.

ALETRO is currently pursuing a number of sources that can provide ALETRO and teaming academic partners with funding for document preservation, hardware, database and web-page management, and supplemental instructional materials. For more information regarding the ALETRO organization, please visit http://aletro.org & http://youtube.com/aletrospace.

The Society of Experimental Test Pilots (SETP) Foundation has joined ALETRO as a team member for this project as their charter and current activities in supporting higher education, STEM, and ABET bring significant additional resources and opportunities for integrating this learning project with their work with the Academic Bridge to the Aerospace Industry and their other education initiatives to accelerate the productivity of graduates as they enter the aerospace industry. This learning project will find ways to enhance the education and technology preservation missions of both ALETRO and the SETP Foundation.

The SETP Academic Bridge to the Aerospace Industry

This mentoring program involves naming and sponsoring awards for competitions at the universities between aerospace departments or student teams for excellence in aerospace related projects. These awards will be presented by a senior member of Society of Experimental Test Pilots (SETP). The Flight Test Safety Committee will participate in all areas related to Safety. The mentoring objective of this SETP program is to reach out to academia to encourage and stimulate interest in Aerospace careers with sponsorship of aeronautical activities, flight test evaluation and aerospace engineering developmental projects to motivate the students' technical and creative skills. SETP proposes to identify projects requiring techniques of multi-disciplinary team activity as well as technical workshop papers that make use of Aerospace Industry approaches to problem recognition, definition, issue resolution, requirements generation, solution development and lessons learned at all levels in aircraft design and other aerospace disciplines. Some level of exposure to these tools in the academic environment would hasten the productivity of recent graduates entering the Aerospace Industry. At present, the Aerospace Industry must train recent graduates in these processes and techniques. SETP would provide a Course Curriculum Advisory Panel to suggest areas of Aerospace Flight Safety, Flight Test Safety and Aircraft Design. This exposure would enhance and strengthen the student candidate's Aeronautical background. The panel would select technical papers from the SETP annual proceedings for case studies or background research information material. This selection activity would be updated each year to maintain currency with industry technologies. By providing these technical papers for case studies, it affords the students the opportunity to see how the Industry identifies the issues, resolves the issues and lessons learned. These technical papers will also demonstrate the current Aerospace Vocabulary, which is vital to multi-discipline team interaction.

The Senior Design Conundrum

The Accreditation Board for Engineering and Technology, Inc. (ABET) is recognized by the U.S. Government as the accreditation organization for higher-education programs in applied sciences, engineering, and technology. In 2000, ABET established a new program for accreditation review termed "Engineering Criteria 2000" (EC2000).[i] EC2000 changed the review perspective from qualitative evaluation to one based on program-defined missions, outcomes, and objectives. The primary EC2000 emphasis is on program "outcomes." One specific requirement stated by ABET is that "Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints."

As defined by ABET, "Engineering design is the multi-disciplinary process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs." This definition clearly delineates the differences between a *design project* and a *research project*. Here students are expected to engage in a culminating major design experience that requires cross-disciplinary efforts and a physical design realization. This broad-based comprehensive approach is not the objective of typical fundamental research efforts, which are directed and specific in nature.

Many university engineering programs satisfy this criterion to varying degrees of success by requiring a "capstone" senior design class or project. This capstone design project is often at odds with university promotion and tenure process (P&T) requirements for faculty. Capstone design projects are incredibly time consuming, and have the potential to detract from faculty time that would otherwise be dedicated to specific research projects. Senior tenured faculty with large research programs often "buy out" of class instruction, and undergraduate course instruction responsibilities often fall to untenured faculty. Since the university P&T process emphasizes publishable, funded research, faculty – especially untenured faculty who teach senior design capstone courses – put at risk promotion advancement and could potentially jeopardize tenure. Thus exists the "senior design conundrum". ABET requires a well-developed senior design curriculum for program certification, but general university P&T processes discount its relative importance. These conflicting demands lead many university departments to do a "minimal" job on senior design by substituting a senior year research project for a full-scale capstone course. Programs that *substitute* the capstone senior-year design with a senior year research project or a junior-year design course risk *losing* or not achieving accreditation.

ALETRO Undergraduate & Graduate Student Engineering Learning Project

The proposed learning project is designed to help circumvent this academic conundrum. Funding from this project *will only support student design activities* and will *not be used to support or augment sponsored faculty research programs*. This project extends the original ALETRO mission charter and attempts to partner with academic institutions to support academic program development in *senior design*, while at the same time transferring the personal recollections and experiences of Apollo-era experts to students. This project attempts to re-inspire students to seek careers in spaceflight and other aerospace industries using creative narratives and solutions from the halcyon days of the 1950s, 1960s, and 1970s, when it seemed that "anything was possible." If successful, the project will help to overcome some of the major challenges currently facing the country – including a diminishing pool of students seeking career paths in American aerospace, aeronautics, and defense industries. The proposed efforts directly support the Science, Technology, Engineering, and Mathematics (STEM) priorities outlined by the NASA office of education. Figure 1 shows the proposed NASA STEM activities and the relevance of the proposed ALETRO activities.[ii]

A key objective of the learning project is to develop a well-vetted collection of grand aerospace challenges from the 1950s through the 1970s, present the solutions that were achieved with the available "technologies of the day," and challenge students to find equal or better solutions using modern technologies. ALETRO strongly believes that in the process of reviewing and evaluating solutions to these "old problems," new and innovative solutions and technologies will result. These challenges and their solutions will be made available with the intent that they be used as the point of departure for junior and senior design projects. ALETRO learning modules will provide a historical perspective on the legacy problems and solutions, and academic partners will lead in the design of learning strategies that encourage students to answer the question: "How would this be solved today?"

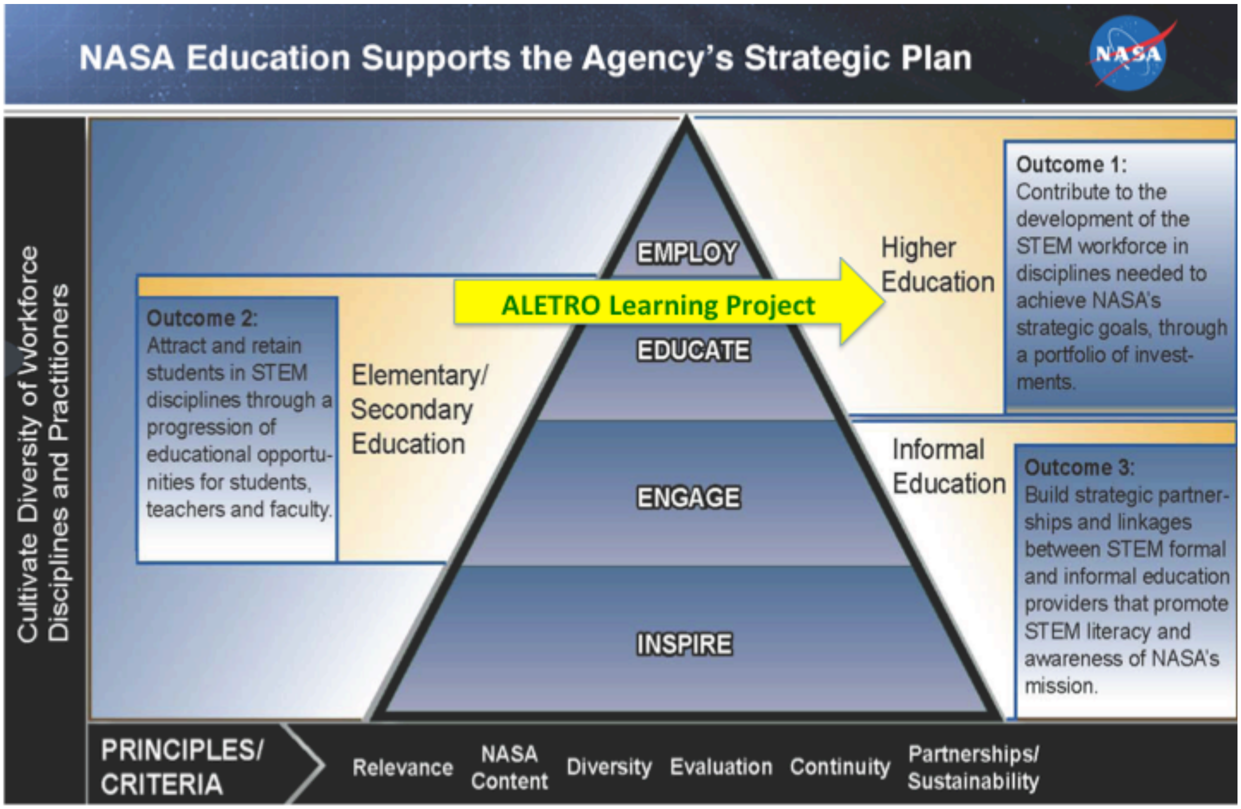


Figure 1. NASA's STEM Education Strategy

Participating Universities

Currently, four land-grant universities and one private institution from the western region have agreed to participate in the ALETRO learning project. These are

1. Arizona State University (ASU), Tempe AZ
2. California State Polytechnic University (CSU Pomona), Pomona CA
3. University of Colorado (CU), Boulder, CO
4. University of Southern California (USC), Los Angeles CA
5. Utah State University (USU), Logan UT

Each of these schools has a program in Mechanical and/or Aerospace Engineering, with the University of Colorado having a dedicated Aerospace Engineering department, and the University of Southern California having programs in Mechanical and Aerospace Engineering as well as Astronautical Engineering.

The choice of these initial five western universities lays a foundation for allowing broader expansion of the unique benefits of this learning project to many more schools, thus supporting the national goals of STEM education. For example, the variances in academic programs with senior design courses covering only one semester, such as ASU, compared to the USU two-semester senior design courses will require adaptation, which can be accomplished with this learning project. Utah State University has on campus a well-equipped test cell, which is used for testing the scale model jet engine, a real advantage for teaching hands-on skills required for teamwork and complex testing operations. Not all schools will have this type of facility, so the member schools of the learning project will be challenged to innovate within budget to provide the equivalent functions and comparable experiences for those students with fewer on-campus resources. The experience resulting from this project's execution will broaden the foundation for further expansion to other schools.

4. Background Information

Powered landings on the lunar surface presented several difficult situational awareness challenges to the Apollo astronauts. One such challenge was the significant difference in visual cues from terrestrial landings that would be very disorienting to the astronauts. Because of the lack of atmosphere, the surface lighting was very high in contrast, and astronauts had little or no ability to see into areas enveloped in surface shadows. To train astronauts to deal with this lighting effect, the NASA Langley Lunar Landing Training Facility (LLTF), which employed severe lighting and night training, was constructed.[iii] The LLTF modeled the $1/6^{th}$-g environment using a complex series of mechanical pulleys and cables. While providing a good visual simulation of the landing environment, the LLTF never successfully produced the required fidelity, and the piloting feel was described as "sluggish and artificial."[iv]

Most significantly, the LLTF was never able to satisfactorily reproduce the unusual physical orientation of the lunar landing vehicle during the approach and landing phase of the mission. Because of the $1/6^{th}$-g lunar environment (compared to a 1-g terrestrial environment), the lunar module required an extreme pitch angle for a given horizontal acceleration. Figure 2 demonstrates this reduced-g effect on pitch attitude. Here, the pitch angles required for an equivalent thrust to weight are illustrated. In Figure 2, W_0 refers to the weight at 1.0 standard earth-g's, T is the thrust required to hold the vehicle level, and θ is the tilt or negative pitch angle of the vehicle. The figure shows the required pitch angles for a helicopter, the Lunar Excursion Module (LEM), and the Apollo-era Lunar Landing Research Vehicle (LLRV).[v] Because a vehicle in $1/6^{th}$ g requires only a fraction of the vertical thrust component required to hold altitude as a terrestrial-based vehicle, the required pitch angle for a given amount of horizontal acceleration is significantly greater. A pitch angle of 5^{o} on earth is equivalent to 28^{o} on the moon.

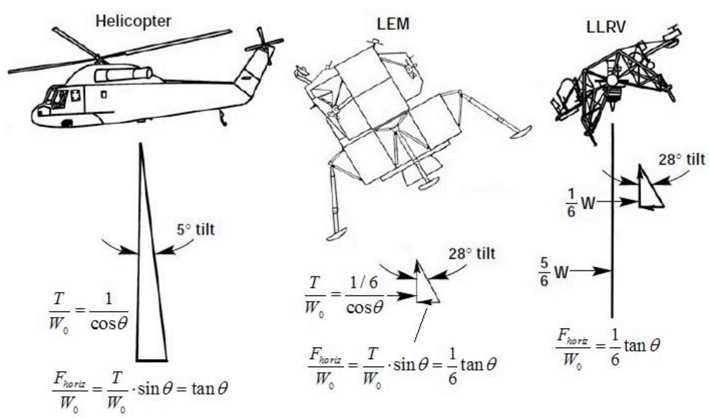


Figure 2. Pitch Angle Required by Terrestrial and Lunar Vehicles for Same Horizontal Acceleration.

A more risky, but higher fidelity free-flying, vehicle designed to simulate the $1/6^{th-}$g lunar environment was developed at the NASA Flight Research Center (FRC) (later to become NASA's Dryden Flight Research Center). This vehicle, the Lunar Landing Research Vehicle

(LLRV), used a single General Electric CF700-2V jet engine mounted on a gimbal. The engine was hydraulically driven to point in the vertical direction, and thrust was adjusted to offset 5/6th of the vehicle's weight. This gravity offset from the jet engine enabled the vehicle to respond in Earth's gravity field as it would on the moon. Hydrogen peroxide thrusters were used to maneuver an outer platform. Collectively, these apparatus presented a more accurate simulation of the lunar landing event to the pilots. Figure 3 depicts the original LLRV development platform on the tarmac at FRC. The jet engine, pilot cabin and maneuvering thrusters are clearly visible.

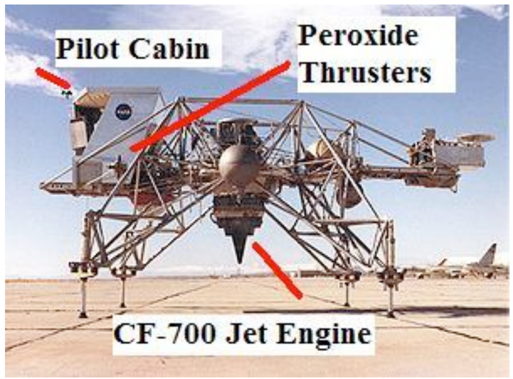


Figure 3. The Lunar Landing Research Vehicle.

The LLRV was originally built so that NASA scientists could evaluate the feasibility and accuracy of a lunar environment simulator. Once the LLRV became operational and proved to be an effective simulator, the vehicle was adapted for crew training. Ultimately, five simulators (two LLRVs and three Lunar Landing Training Vehicles-LLTVs) were delivered to the NASA Johnson Space Center (JSC); however, only one of the two LLRVs ever flew there. The LLTV was a difficult vehicle to fly if it was flown outside the operational envelope, which did occur on the first LLTV when it exceeded wind shear limits. Within the operating limits, it flew well even with the analog controls. Three of the five original vehicles were crashed before the end of the Apollo program, two due to human error and one due to an unanticipated design flaw in the emergency electrical switchover to battery during a generator failure. Emergency ejection and parachute systems prevented any significant injury to the pilots. There were also issues with hydrogen peroxide vapors burning the pilot's skin. Despite the sizeable risks involved in flying the LLTV, seven of the nine astronauts who trained for lunar landings using the LLTV testified that the vehicle was a key enabler for the lunar landing missions.[vi]

Neil Armstrong, on Apollo 11 was quite comfortable with his landing on the moon in spite of very low fuel reserves and significant maneuvering, as he had trained in the LLTV. This training was so valuable that it was sustained as a firm requirement for all six successful lunar landings (and the safe return of all 18 crew members) as well as the Apollo 13 mission, which never landed but returned all three crew members home safely.

5. ALETRO Learning Project Academic Course Details

The ultimate goal of the *ALETRO Learning Project* is for each university to produce a free flying research vehicle that reproduces many of the capabilities demonstrated by the 1960s-era LLRV and LLTV. It is expected that a wide variety of design solutions will be achieved. The proposed academic course will span two years. Year 1 will emphasize design and systems integration. Year 2 will emphasize flight-testing, envelope expansion, system identification, and any modifications required to make the vehicle "fly like a real surface lander."

For both academic years, all class work will directly satisfy the requirements for the specific university's capstone design course. For both years the senior class will lead the design efforts with the support of faculty and, as available, graduate research and teaching assistants. The course textbook will be at the discretion of the individual instructors; however, the text "*Understanding Space: An Introduction to Astronautics, 3rd ed.,*"[vii] by Jerry J. Sellers is highly recommended.

Year 1 will research existing concepts including the legacy LLRV and LLTV designs, flesh out the subsystem level requirements, develop concepts of operations (CONOPS), perform the requisite trade studies, and conduct preliminary and critical design reviews. The year 1 team will integrate the vehicle subsystems and assemble a vehicle that is at least marginally flight capable. Year 1 students will produce detailed mechanical and electrical drawing packages. The final design report will be of sufficient detail to allow the year-2 design team to completely understand and, if necessary, modify the vehicle systems to support flight testing. The final outcome of the year 1 design is a flight readiness review (FRR) for a tether hover flight. Whether an actual hover flight test is performed will depend on the team progress and readiness of the design at the end of the academic year.

Year 2 will start with an extensive review of the design documents from the previous year and preparation of flight test procedures and practices. It is expected (but not required) that some of the graduates from the previous year's team will be available for student consultation regarding the design features. Initial flight tests will be simple tethered hover tests and will eventually expand to untethered maneuvering flight. At each phase in the envelope expansion process, the year-2 student team must overcome design flaws and modify the vehicle as necessary to achieve stable flight. Multiple flight test reports will be prepared, and FRRs will be conducted whenever a new flight element is introduced. Adhering to NASA-developed flight rules will develop practices and procedures.

Once the envelope has been sufficiently expanded to safely allow for maneuvering flight, extensive parameter identification[viii] (PID) will be performed to identify the influence of aerodynamics on the vehicle's flying qualities. As feasible, the control systems will be modified to account for and remove these aerodynamic influences from the flight control loop. The year-2 student design team will define, install, and integrate all of the flight instrumentation necessary to perform the PID analysis. The PID flight maneuvers will also be student-defined.

The resulting flight mechanics data, including mass properties, effective moments of inertia, lift and drag coefficients, and "stability derivatives," will be compared to any existing LLRV and Apollo data. Detailed lunar lander flight simulations will also support the flight-testing. The collected flight and simulation data will be used to objectively assess just "how closely" the developed prototypes approximate the real lunar landing event. These numerical assessments, including "system identification" and digital flight simulations, were just in their "infant" stages of development during the Apollo era – subjective pilot observations were the only available assessments for the LLRV and LLTV designs.

Once the formal flight dynamics and handling assessments have been performed, it may be possible to modify the control systems or to add additional control actuators to make the vehicles fly more realistic approximates of true lunar descent profiles. Techniques developed during this second year of the design project will be incredibly valuable as guidance for larger scale LLTV-style trainers that would fly with human pilots onboard (i.e., for Mars missions). This parameter identification effort will be highly experimental, and is very likely to produce peer review quality, publishable results. Publishable results will go a long way to help resolve many of the P&T (university promotion and tenure process) conflicts described earlier in this proposal.

At the culmination of the two-year design period, it is anticipated that a student LLRV "mini-conference" and fly-off will be held at a site yet to be determined. This fly-off will allow each student team to demonstrate their vehicles' capabilities by flying a prescribed series of maneuvers. The championship will be awarded based on a weighted average of student written and oral briefings, and the ability to achieve the prescribed flight maneuvers.

Review of the USU LPLSRV Design Course

This learning project has evolved from a design capstone course instructed by the MAE Department at USU during academic year 2009-2010. This original two-semester design course sponsored by the NASA Office of Education, the Exploration Systems Mission Directorate (ESMD), and the NASA Space Grant Consortium, developed a packaged senior design course that can be readily incorporated into the instructional curriculum at universities across the country. The course materials adhere to ABET standards and are constructed to be relevant to key research areas identified by ESMD.[ix]

The Senior Design Capstone Course, entitled "*Design and Testing of a Prototype Lunar or Planetary Surface Landing Research Vehicle (LPSLRV),"* selected the LLRV as the project model because the vehicle offered both inspiration and challenge to the students. A prime focus of the design project was to revisit the key features of the LLRV design and to, whenever feasible, replace the 1960s era analog control technologies with modern computerized digital technologies. The design project challenged students to apply systems engineering concepts to define research and training requirements for a terrestrial-based lunar landing simulator. This project developed a flying prototype for a Lunar or Planetary Surface Landing Research Vehicle *(LPSRV).*

Detailed course notes and a course handbook are available online.[x] Student generated trade reports, design reports, briefings, and software, and final design reports are also available online.[xi] These documents were developed under contract NNK09Ol03P with NASA and are freely available in the public domain. The course handbook outlines the course materials and also describes the systems engineering processes developed to facilitate design fabrication, integration, and testing. This handbook presents sufficient details of the final design configuration to allow an independent group to reproduce the design. Details of the experimental apparatus used for system characterization may be found in Appendix A of the handbook available online. The project design and test results are formally documented in a technical paper presented at the 46th Joint Propulsion Conference.[xii]

Top-Level Design Requirements

Per NASA specifications the concept accounts for reduced lunar gravity, and allows the terminal stage of lunar descent to be flown either by remote pilot or autonomously. This free-flying platform was designed to be sufficiently flexible to allow both sensor evaluation and pilot training. Specific top-level design requirements levied by NASA ESMD for the LPLSRV program were:

i) *The vehicle must account for reduced lunar or planetary gravity.*
ii) *The vehicle must allow simulated terminal stage of lunar descent to be flown either by remote pilot or autonomously.*
iii) *The free-flying platform must allow for both sensor evaluation and pilot training.*
iv) *The project must include design, construction and flight testing of a small-scale prototype within the time and budget constraints of a university-based senior design project.*

These top-level requirements will be retained for the proposed ALETRO follow-on learning projects. Central to the design of a terrestrial based lunar or planetary landing simulator is accounting for the difference in gravity between Earth and the moon or other planetary body. For lunar landing training to be effective, as feasible, the simulator must duplicate conditions that a pilot or sensor-suite would experience during an actual lunar landing. Simulating a lunar landing means creating a situation where the trainee experiences the motion, vehicle attitudes, and translational time delays of the simulated $1/6^{th}$ of the gravity of that on Earth and experiences no aerodynamic resistance during flight. In both the LLRV and the LLTV designs, NASA accounted for the difference in gravity by means of a gravity-offset jet engine. This engine was positioned in a vertical orientation that produced a thrust level equal to $5/6^{th}$ the vehicle weight.

LPLSRV Design Overview and Concept of Operations

The USU LPLSRV design features a two-axis gimbal system that allows the inner gravity offset system on the inner platform to move independently in two degrees of freedom from the outer maneuvering platform. Stability of each platform is to be controlled independently by separate control systems. The final propulsion systems selected for the inner and outer platforms are the result of trade-study assessments. A decision was made very early in the program to eliminate the hydrogen peroxide maneuvering thrusters employed in the LLRV/LLTV design. Using a corrosive and hazardous mono-propellant would require extraordinary safety and handling procedures that are incompatible with an "open" university design project. Similarly, developing a state-of-the art "green-propellant" bi-propellant thruster system is far beyond the scope of what can be accomplished in a one-year senior design project. Cold-gas thrusters were quickly eliminated because there was insufficient lift requirement to meet project requirements for flight duration. Thus, the lift thrusters were replaced by a propeller-powered quadrotor system. Selecting the quadrotor system was a key programmatic design decision that drove many of the down-stream design decisions. Figure 4 compares the LPSLRV design features and concept of operations to the LLRV.

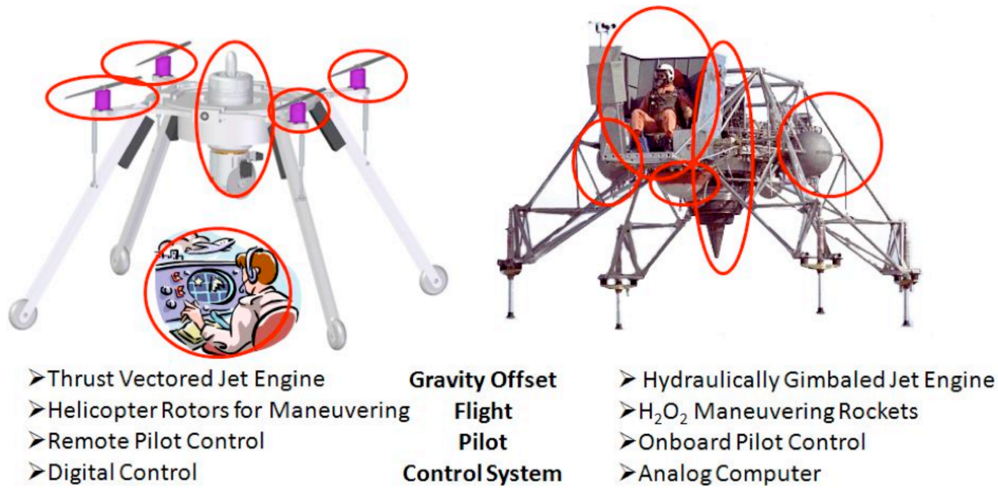


Figure 4. Comparison of LPSLRV and LLRV Concepts of Operations (CONOPS).

Because of their limited experience base, student design projects are especially susceptible to mission creep. A "tried and true" way to keep a program on track is adherence to a Design Reference Mission (DRM). A well-defined DRM accomplishes top-level program requirements but limits scope of design and restricts unnecessary requirement growth. The design reference mission for this vehicle attempts to reproduce as many elements of a lunar landing mission as is feasible within the schedule and budget constraints of a single year undergraduate student design project.

For this design project the DRM attempts to simulate the approach and landing phases of the mission (as did the LLRV and LLTV). To achieve a simulated lunar landing approach, the vehicle climbs, maneuvers horizontally to get onto the proper approach trajectory, then begins the powered descent before hovering for a vertical landing. An initial systems check is performed when the vehicle is at a 1-meter hover. Figure 5 depicts this design reference mission. Velocity and altitude markers were scaled from actual mission profile to keep the vehicle within the available testing range.

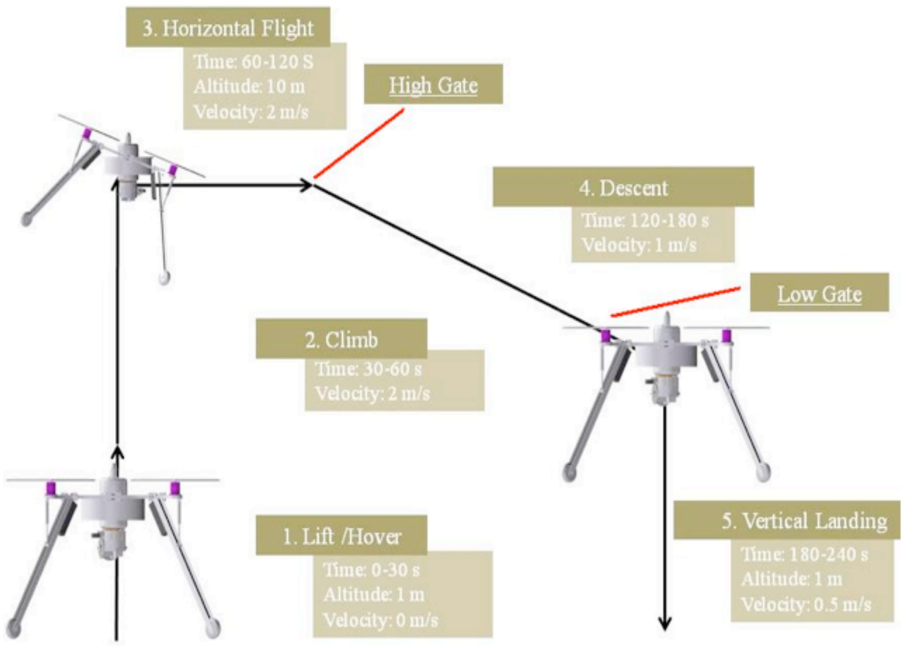


Figure 5. LPLSRV Design Reference Mission (DRM).

Figure 6 shows the design sequence that was used to close on the overall vehicle design. This approach is similar to the classical design process for spacecraft and starts with the power-plant selection. Since the gravity-offset system was a key factor in fulfilling the primary mission requirement, selection of the gravity offset system was the starting point for vehicle design. Once the available thrust is known, a maximum allowable vehicle mass can then be calculated as 6/5th of the lifting capacity of the jet engine. This total vehicle mass then determines the required thrust needed from the rotors. The lifting capacity of the rotors drives the power requirements for the battery systems, etc. Using subsystem simulations based on component performance testing, the process is iterated until an acceptable design is closed on.

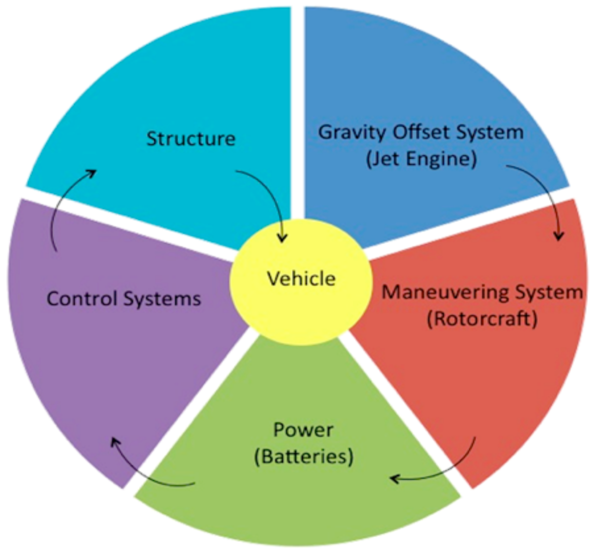
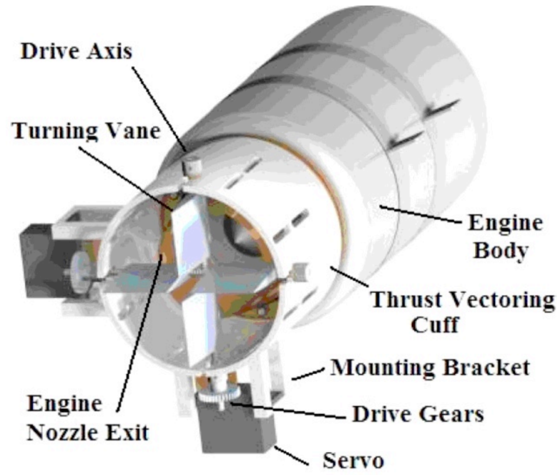


Figure 6. LPLSRV Design Process.

Figure 7 shows the solid 3-D model of the final design configuration for the LPSLRV. The vehicle features two gimbals designed to move independently about the pitch and roll axis. The gravity-offset system is attached to the inner of the two gimbals, and the maneuvering system is attached to the outer gimbal. The function of the gimbal platform is to decouple inner platform rotational dynamics from the outer platform. The outer gimbal-ring holds all of the maneuvering rotors and associated drive-train components, while the gimbal-inner ring holds the jet engine and associated equipment. The fuel tank for the jet engine is integrated into the structure of the inner ring. The inner platform pitch and roll angles are controlled by a thrust vectoring system featuring exhaust turning vanes.

The gravity offset system features a Jet-Central® JF-170 Rhino[xiii] centrifugal turbine jet engine. The engine features a single shaft turbojet with an annular combustor. A single stage axial flow turbine drives a single stage centrifugal compressor. The shaft is supported by two fuel/oil lubricated, annular contact bearings. The turbine speed is controlled by the amount of fuel received from the fuel pump, which is controlled by a full-authority digital engine control system (FADEC). The turbine runs on both jet-A fuel and K-1 grade kerosene.

Inner and Outer Platform Gimbals



Solid Model of Thrust Vectoring Components

Figure 7. Inner and Outer Platform Gimbals and Gravity Offset System.

LPLSRV Flight Tests

The LPSLRV has successfully performed free flights in a 1-g configuration – without jet engine gravity offset, and 1/6th-g (with gravity offset) tethered hover flights. The vehicle has not yet achieved free-maneuvering flights with both the maneuvering and gravity offset propulsion and flight control systems active. Total system free flights required extensive retuning of the flight control laws, and successful free flights are anticipated before the end of academic year 2010-2011. Figure 8 shows the LPLSRV in 1-g free flight.

Figure 8. LPLSRV in 1-g Free Flight.

Figure 9 shows the integrated vehicle with the inner platform maneuvering using the gravity offset system during ground evaluation tests. Detailed flight test videos and images can be found at the LPLSRV YouTube™ video site.[xiv,xv]

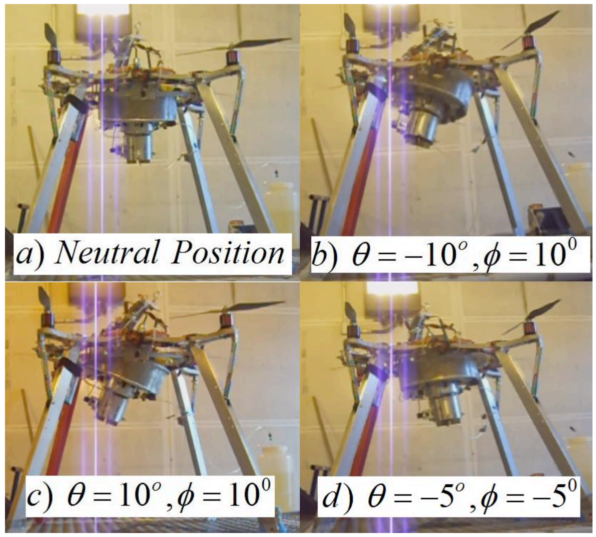


Figure 9. LPLSRV Inner Platform Closed-Loop Maneuvering Using Thrust vectoring Control System.

6. Lessons Learned and Proposed Design Enhancements for the ALETRO Learning Project

The USU LPLSRV project is an excellent "point of departure" for the proposed follow-on projects, and "lessons learned" during this design experience may aid the other participants to converge on a closed and workable design more quickly. The lessons learned from the LPLDSRV project will be itemized first, followed by suggested project enhancements for the ALETRO learning project.

Schedule Lessons Learned

The USU LPLSRV project was extremely ambitious, and achieving all of the design and test objectives within the one-year time and budget constraints of a university-based senior-design project was a major challenge. The schedule ran slightly longer than a single academic year with the complete design closure not occurring until early April. Integration and verification testing spilled over into late May and the first flight did not occur until mid to late June. Clearly, stretching the schedule to two years and leveraging the existing USU work will allow a greater chance of success for the five individual design teams.

Budget Lessons Learned

The USU team consumed slightly more than $70,000 on its LPLSRV project. Expenditures associated with the project include 1.0 months faculty salary compensation, funding for three full time research/teaching assistants, student travel for training, faculty travel associated with the project and course material development, administrative overhead, and the hardware components necessary to fabricate the vehicle. All undergraduate team members taking the class for design credit were unpaid. The USU team was fairly thrifty with its expenditures, so this cost figure may be relatively conservative. Even so, the final expenditures were $4,011 larger than the budget originally allocated for the project. This overage was primarily a result of higher hardware and materials expenditures ($22,146) than was originally anticipated ($18,000). The deficit was back-filled using discretionary funds from the faculty mentor for the project and course instructor. Table 1 itemizes the USU budget for the LPLSRV project.

Table 1. LPLSRV Budget Itemization.

Receipts	
From	**Total Amount**
NASA ESMD	$55,000
SDL	$5,000
USU College of Engineering	$5,000
Utah Section of AIAA	$1,500
Total	***$66,000***
Expenditures	
Item	**Amount**
Faculty Salary and Student Salaries	$23,738
Fringe benefits and Insurance	$8800
Travel and Training	$7400
Facilities and Administration (11.9%) of ESMD funds	$5477
Hardware and Materials	$22,146
Software and Licenses	$2450
Total	***$70,011***

The administrative overhead for the LPLSRV project was restricted to 11.8% by the primary sponsor, NASA ESMD, and it is suggested that ALETRO impose a similar restriction somewhere in the 12-20% range. As long as this project is tied to “student assistance” or “curriculum development” and not “sponsored research,” most of the participating partners will accept this restriction. With this lowered overhead in mind, a minimum of $100k for each team is recommended for a two-year project. This figure will be reflected in the proposed ALETRO budget for the learning program.

Proposed Design Enhancements

The items listed below are suggested areas for improvement and would be excellent topics of research for each of the individual design teams.

- Replace the quadrotors USU used for attitude and fractional g (earth gravity) lift landing maneuvering with a cold gas jet system for more accurate simulations
- Replace the Rhino-170 jet engine with a higher thrust, more reliable unit
- Divide research-engineering tasks among the five teams to achieve the following technical investigations to contribute to the design of a Mars Lander (See attachment for quote from Augustine Commission report)
- Eventually replace cold gas jets with new non-hazardous monopropellants
- Use aerospike nozzles for maneuvering jet thrusters to enhance specific impulse and reduce nozzle weight
- Determine specific impulse threshold for aerospike nozzle design to perform both the attitude control and fractional g lift with a single rocket system

- Replace the Apollo jet engine hydraulic attitude control system with Thrust Vectoring
- Conduct fly-off competition at a facility to be determined in both the 1st (tether tests) and 2nd year for landing performance (accuracy, maneuverability to specified targets, fuel reserve margins)

7. Proposed Budget and Schedule

ALETRO Total: $480K*

$240K Yr 1, $240K Yr 2

*This total includes $50K to competitive prizes for fly-off competition, administration, legal, accounting, travel, website, preservation outreach, and SETP Foundation expenses such as directly related travel.

Universities Total: $500K*

$50K/Yr, 2 yrs, 5 schools

*$10K per year will come from each institution as a real money match (from internal sources or raised from local industry and professional organizations) to the ALETRO $50K donation for the fly-off competition, for a total competitive prize budget of $100K.

ALETRO will request each participating university to accept a 15% overhead rate for this undergraduate student support project in lieu of standard sponsored research rates. There may be a need for variances between the universities in the allocation of funding between the two academic years (e.g., early needs for test equipment).

Prospective Funding Sources

1. Philanthropists
2. Foundations
3. NASA
4. Department of Defense (DoD)
5. Department of Energy (DoE)
6. Professional Societies

Figure 10 shows the proposed schedule for the ALETRO Learning Project. As required, this draft schedule will be expanded and modified when the curriculum is more fully developed at each of the teaming universities.

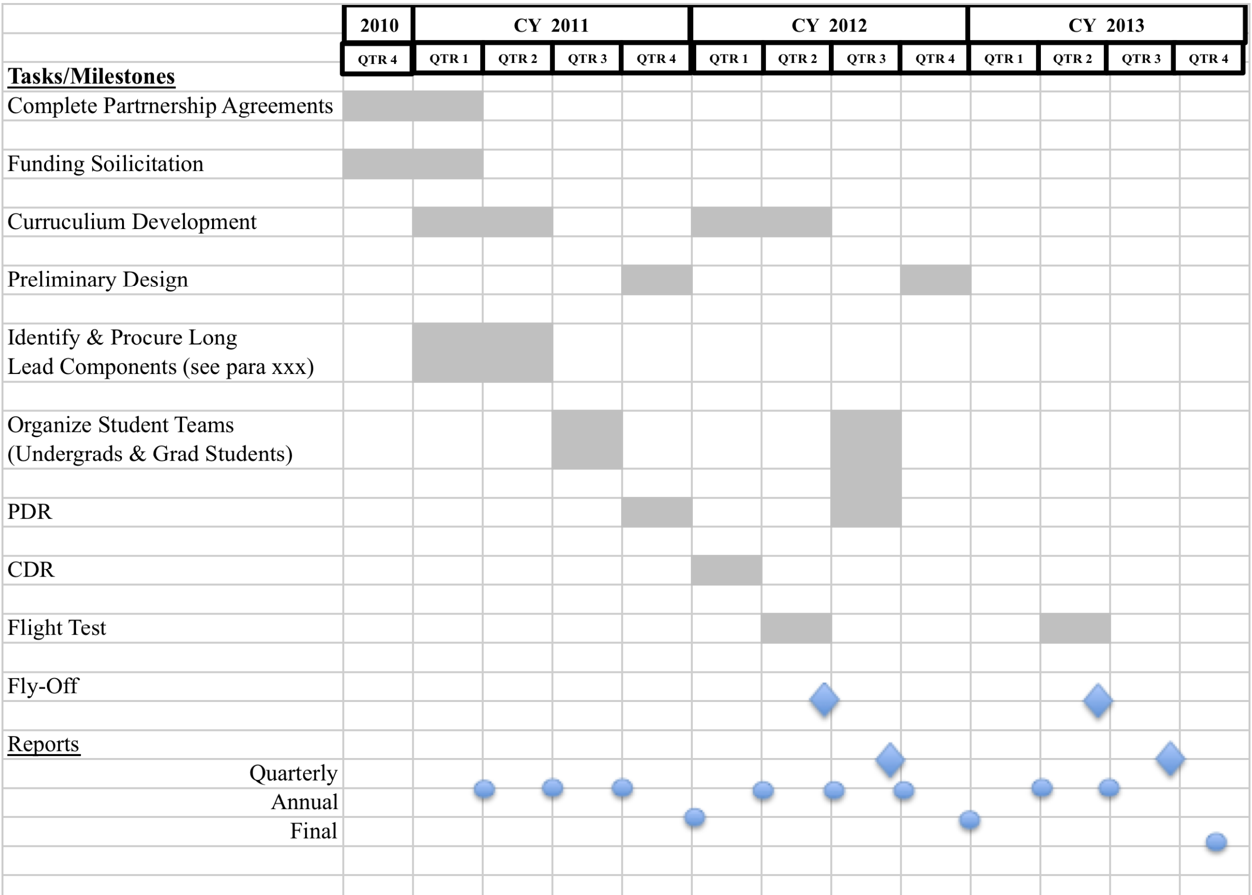


Figure 10. Senior Engineering/Graduate Student Learning Project Schedule.

8. Programmatic Risks

Three primary risks are associated with this project: Administrative, Technical, and Financial. The following paragraphs summarize each of these associated risks.

Administrative Risks

This project is very ambitious and will require two academic years to complete the design and flight-testing. The intent is for the first year to complete the systems engineering and design trade studies to allow the construction and integration of "workable" prototypes. The goal is to have vehicles capable of tethered hover by the end of the first academic year. The project documentation will be sufficiently detailed to allow "hand off" to a follow-on senior design team. It is anticipated that some team members from the first year will be retained as graduate research assistants to guide the development and testing efforts of the second year team. Difference in curriculum requirements, numbers of participating students, and faculty support are risks that will be addressed and mitigated on an individual basis for each school. Funding instruments between ALETRO and the participating universities may be adjusted to keep the administrative overhead costs to an acceptable level. It is unlikely that universities requiring full administrative overhead costs will be able to successfully complete this project.

Technical Risks

Minimizing the technical risks, both with regards to design features and physical hazards, will be the responsibility of each of the participating teams. The LPLSRV project leveraged NASA and USU safety guidelines to conduct all testing activities successfully with no safety related incidents. Technical risks with respect to achieving the design goals are identified and managed with NASA guidelines for preliminary and critical design reviews. Inherent to the proposed research work there are technical risks to be taken as part of the engineering exploratory work, and identifying and managing these risks are an essential part of the education and teamwork experience that makes this project valuable to the senior and graduate student participants.

Financial Risks

Although the lessons learned by the USU team may reduce the risk of unexpected cost, financial risk cannot be altogether eliminated. It is highly likely that one or more of the participating teams will experience cost over-runs during this project. Each school and faculty advisor should be prepared to seek additional funding sources to offset these cost overruns. The USU LPLSRV team overcame financial overruns resulting from unexpected technical problems with supplemental fund raising to complete the project. A likely outcome of such a cutting edge student project is that new technological research opportunities will be identified and additional funding sources will become readily available.

9. Partner Roles within the ALETRO Collaboration

ALETRO's Roles (The SETP Foundation to support ALETRO for common mission elements of the two nonprofits)

- Identification, collection, and processing of personal collections
- Development of candidate technical challenges to be used by the universities
- Managing the indexed data base of the historical documents
- Supporting the universities in their learning stimulus developments (telling the creative stories from the last half of the last century – for this project the Apollo Lunar Landing Research Vehicle)
- Procurement assistance to the university partners for bulk purchase of long-lead and high-value hardware components
- Preparation and delivery of interim and final reports
- Lead the web-based conferences necessary to conduct the execution of the proposed work
- Preparation of Memorandums of Understanding (MOUs) for all partners including Statements of Work (SOW) and deliverables
- Provide overall financial management for the project

Roles of the Academic Teams

- Develop and manage the classroom curriculum
- Manage and lead the student teams
- Manage and lead the test operations
- Prepare and deliver the required reports/deliverables
- Manage the university financial proceeds from this grant
- Participate in the web-based conferences necessary to conduct the execution of the proposed work
- Review and Execution of MOUs

Collaborators and Academic Mentors

- ALETRO, C. Wayne Ottinger, President, former NASA LLRV Project Engineer and Bell Aerosystems LLTV Technical Director, 602-795-3699, cell 602-228-7260, wottinger@cox.net
- SETP Foundation, Capt. Bill Connor, Ph.D., Member of the Board, cell 706-809-0490, Bill Connor <captconnor@aol.com>
- Arizona State University (ASU), Valana L. Wells, Ph.D., Program Chair, Aerospace Engineering and Mechanical Engineering Arizona State University 480-965-4777, valana@asu.edu
- Praveen Shankar, Ph.D. in Aerospace Engineering, Lecturer, 480-965-5859, Praveen.Shankar@asu.edu
- California State Polytechnic University (CSU Pomona), Edberg, Donald L., Ph.D., Professor, Aerospace Engineering, Director, Uninhabited Aerial Vehicle Laboratory, Director, Spacecraft & Launch Vehicle Laboratory, 909-869-2618, dedberg@csupomona.edu
- University of Colorado (CU), Joe Tanner, Senior Instructor, Retired NASA Astronaut & Space Shuttle Training Aircraft Instructor Pilot, 303-492-1486, joe.tanner@colorado.edu
- University of Southern California (USC), Daniel A. Erwin, Ph.D., Professor of Astronautics and chair of the Department of Astronautical Engineering, 213-740-5358 erwin@usc.edu
- Utah State University (USU), Stephen A. Whitmore, (retired NASA scientist) Ph.D., Assistant Professor, Mechanical and Aerospace Engineering Department, Utah State University ENGR 419F, 4130 Old Main Hill MAIL CODE: UMC 4130 Logan Utah, 84322-4130 435-797-2951 swhitmore@engineering.usu.edu

10. Management Plan

The Internet will be the main vehicle for communication for the ALETRO Learning Project. Online conferencing using tools such as WebEx, Adobe Connect, or Skype will be used for periodic technical interchange meetings and design reviews. It is anticipated that faculty members from the member teams and ALETRO members will serve as members of the design review peer review boards. The proposed budget will provide for semi-annual face to face conferences at alternating host sites, or at times to be determined, as the project progresses. Each university team will maintain a dedicated web site for this project, and these sites will be used, along with ALETRO's web site, to organize and disseminate design information to each of the member teams. Each individual team will be allowed to patent and copyright intellectual property generated by the project; however, a c*ooperative* as opposed to *a competitive* environment will be encouraged.

11. Biographical Sketches of Key Participants

C. Wayne Ottinger (ALETRO)

President and founder of ALETRO, formed in June 2008. NASA SAGES (Shuttle and Apollo Generation Expert Services) consultant on NASA DRFC Trade Study for Lunar Landing Training Vehicle (LLTV) Options on the Constellation program: 2008 & 2009. Co-authored NASA DFRC report (2010) "A Toolset for an Advanced Landing Technology Development and Training Program," promoted and participated in a conference in December, 2008 at the NASA Johnson Space Center, Apollo astronauts Neil Armstrong, Apollo 11 Commander, John Young, Apollo 16 Commander, Gene Cernan, Apollo 17 Commander, Harrison (Jack) Schmitt, Apollo 17 LM Pilot, briefed the Constellation Lunar Landing Project Office about the LLTV training program with recommendations for future missions: Conceived and Co-Chaired Go For Lunar Landing Conference, Tempe, AZ March 4/5 2008 http://www.lunarlanding.info. Founder and Managing Director of PAT Projects, Inc., a non-profit support in NASA DFRC's education and strategic planning initiatives: 1993 – 2002. Garret Engine Division, controls engineer, OV-10 turboprop: 1990 – 1993. Synervision, industrial (nuclear power plants & manufacturing operations) imaging services for motion analysis and articulating endoscopes: 1988 – 1990. AiResearch Manufacturing Co., Manager, Advanced Imaging and Motion analysis developed first use of copper vapor laser and high speed video for spin tank diagnostics of failure modes of high speed rotating parts, video production of classified training operations for testing and assembly of gas centrifuges for uranium enrichment, Gas Centrifuge Project: 1979 – 1987. Owner/developer/occupier of a passive solar house in Oceanside, California, featuring Trombe walls providing all of the heating and a total energy cost of $35/mo for a 2,400 square foot house featured in Sunset Magazine (1981). California Energy Commission, Project Engineer, energy conservation and renewables, wrote and produced the film "Phantom City" promoting energy conservation, ran workshops for local and state government agencies: 1978 – 1979. Engineering Consultant for the U.S. Navy Surface Effect Ship and Air Cushion Vehicle (ACV) programs and Engineering/Marketing Consultant for Aerojet and Rohr, produced project film reports for the U.S. Navy on the 100 ton Surface Effect Ship test program, developed contoured hull appendage for optimizing air cushion interface with the hydrodynamic environment throughout the speed range to 100 knots, designed hybrid wheeled air cushion vehicles for operation over the arctic tundra, awarded U.S. patent for controlling traction selectively on hybrid wheeled ACV: 1970 – 78. Bell Aerosystems: Technical Director LLTV, West Coast Marketing Representative, 1966 – 1970. NASA FRC: X-15 operations engineer for main propulsion system, developed field repair of XLR-99 Rocket Engine thrust chamber ceramic coating dramatically improving engine availability for the three X-15 hypersonic research aircraft to "keep them flying", Lunar Landing Research Vehicle (LLRV) Project Engineer, Flight Operations, served as NASA Plant Representative for the Bell LLRV design/fabrication, directed final assembly, systems testing, developed test fixtures for closed loop flight control system testing in lieu of tether tests, directed first 132 flights of the LLRV: 1960 – 1966. Rocket Power Talco: Rocket Test Engineer, Ejection Seats, B-58 capsule, sounding rockets, 1959 – 1960. General Electric and Chance Vought, J79 jet engine flight test engineer for F-104, B-58, F-11-1F, Regulus II, all Mach 2 aircraft, 1955 – 1959. University of Arizona, BSME (1955), USC graduate school 1956/57.

Captain C. W. “Bill” Connor, Ph.D.

U.S. Naval Flight Training, Pensacola Naval Air Station, single and multi-engine land airplane plus helicopter. Designated a Naval Aviator and received commission in the United States Marine Corps. Tours of duty Far East, Europe, and the Caribbean. Awarded Chinese Air Force Wings for meritorious contributions to the joint efforts with the Chinese Air Force in taking air rescue action during Operation Hunger (1 of only 26 ever awarded in the United States Military); Congress approved wearing these wings in conjunction with our Naval Wings on our uniform. **Selected as a Recovery Pilot – Project Mercury and participated in the primary recovery for Astronauts Glenn & Carpenter and training pilot for Schirra and Cooper.** Doctorate degrees in Aeronautical Science and Human Factors Behavioral Psychology (Columbia Pacific University). Master degrees Aeronautical Science and Business Administration in Aviation both with distinction (Embry-Riddle Aeronautical University). ERAU Graduate School Adjunct Professor and Curriculum Advisor to the University. Currently, pursuing a Ph.D. in Aviation Human Factors/Engineering Laser Technologies.

Experimental Test Pilot with Boeing-Vertol Company (4 years) expanding the flight envelope of experimental test aircraft (CH-46A and CH-47A). Contract Administrator for the Lockheed Georgia Aircraft Corp on the C5-A Program. **Delta Airlines line pilot and Captain for 30 years. Retiring in 1995 as an L-1011 Captain. During my career with Delta I flew (DC-6, DC-7, C-130, DC-8, DC-9, DC-10, B-727 and L-1011 aircraft) also served as Delta Check Airman, FAA Aircrew Program Designee/APD/ATP, B-727 and L-1011. TOTAL FLIGHT HOURS - 20,526. After retirement, requested by Delta and returned as an L-1011 Flight Simulator Instructor and Delta Pilot Interviewer of potential new-hires (1996-1999) In 1992, I founded the SAE G-10 Airborne Laser Hazards Subcommittee. I am currently Chairman of the Operational Laser Hazards and Flight Deck Procedures Subcommittee. Former ALPA Laser Safety Chairman and US Representative to ICAO on Airborne Laser Safety Standards.** Aviation Human Factors Consultant for the FAA and U.S. Air Force and ICAO (International Civil Aviation Organization). A principal investigator for the Joint FAA and USAF Laser Research Program for visual interference to flight crew members**.** Assisted in the development of a Operational Outdoor Laser Technology Safety Program. Resulted in laser containment and establishing of flight safety exposure levels of outdoor lasers around airports.

Developed and instructed the Introduction to Risk Analysis-Air Space Human Factors, and Human Factors In flight Laser Exposures/pilot concerns regarding distraction, disruption, disorientation, and incapacitation. . Also, developed Operational Flight Deck Laser Procedures to recognize and respond to startle effect due to Laser Flash Blindness. Chaired and developed SAE Aerospace Standard (4970) “Human Factors Considerations for Outdoor LASER Operations In Navigable Airspace”. This document is the core reference for ICAO Laser Safety, and is the Standard World Wide for “Outdoor Laser Safety for the ICAO 184 member countries. The USAF has praised the document and stated “It has prevented at least 1 AF accident so Far”. Consultant to Jeppesen as “Human Factors Expert on Information Transfer and Symbology Recognition for the EFB (electronic flight bag development)”.

Associate Fellow, The Society of Experimental Test Pilots (SETP) , SETP Foundation Board of Directors. Chairman of the Academic Bridge to the Aerospace Industry. Founder of the First 2 Human Factors Safety Committees of SAE: the SAE G-10 Committee “Aviation Behavioral Engineering Technology” in (1982) and the SAE HBT Committee “Human Behavioral Technology” (1982) and wrote their Charters. Current Chairman of the SAE G-10 Executive Board and Chairman of the SAE G-10 Operational Laser Procedures, Protocols and Educational

Program Development, Co-Chairman of the SAE G-10 Flight Deck Design Processes for Current, Future and Modified Flight Decks. Past Laser Project Chairman for the Air Line Pilots Association (ALPA), and ALPA National Spokesperson (elected Board of Directors – 3 terms) Past member of the American Institute of Aeronautics and Astronautics, Institute of Navigation, Human Factors Society, Association of Aviation Psychologists & National Aviation Club. Authored articles on "High Altitude-Low Level Ionizing Radiation Exposure Levels" and two articles on " Laser Visual Interference of Information Transfer during Critical Phases of Flight for Flight Crews" , one for International Airport Security and the other for the Air Line Pilots Magazine. Received numerous Human Factors Technical Awards from the SAE Technical Board in recognition of outstanding leadership and service for Human Factors Contributions and advancing Air Transportation Safety and Technology. Recipient of ALPA's 1995 "Presidential Citation" for Outstanding Service for Air Safety**". FAA Administration Award from the FAA Administrator, Jane F. Garvey: "In Recognition of Outstanding Contributions to Aviation Safety and Standardization as Founder and Chair of the SAE G-10 "Aviation Behavioral Engineering Technology Committee" for over 18 years, the documents developed have served as the reference documents for most of the FAA and Industry Standards and Practices that have followed. Captain Connor continues a legacy of hard work, effective government/industry cooperation and much improved Air Safety."** Advisor to Florida Institute of Technology (FIT) for SETP Academic Bridge to the Aerospace Industry Projects to stimulate and motivate students for Aerospace Careers and shorten the bridge to Industry productivity and assist in the development of a Bachelor of Science in Flight Test Evaluation with NATC and NGC.

Stephen A. Whitmore, Ph.D. (Utah State University)

Dr. Stephen A. Whitmore is an assistant professor of mechanical and aerospace engineering at Utah State University (USU) in Logan, Utah. He joined USU after more than 28 years working as a civil servant for NASA. He accepted early retirement from NASA in April 2005. Prior to his retirement , Dr. Whitmore was an original member of the team selected to formulate the Constellations Systems Program at NASA Headquarters. For the previous 15 years before accepting the USU position, Dr. Whitmore worked in various aspects of NASA's "space-access" program, including work on seven "X-vehicles." Dr. Whitmore served multiple roles within NASA including research engineer, technical lead, group leader, principal investigator, chief engineer, and branch chief. From 2000-2002 Dr. Whitmore completed a two-year tenure as the Michael J. Smith Space Systems (NASA Chair) Professor at the Naval Postgraduate School (NPS), Monterey CA. The position is a NASA-funded academic chair in the Space Systems Academic Group at NPS, and was created in honor of the late astronaut CAPT Michael J. Smith, an alumnus of NPS. The chair position is a competitive appointment with candidates coming from a pool of highly qualified NASA managers, scientists, and engineers. During his tenure at NPS, Dr. Whitmore instructed multiple classes in orbital mechanics, spacecraft and launch-systems, and served as thesis advisor to five students.

Dr. Whitmore attended undergraduate school at the University of Illinois, Urbana IL, where he graduated cum laude with a BS in aerospace engineering (1980). He attended graduate school at the University of California, Los Angeles CA, where he received MS (1983), engineer (1987), and doctoral (1989) degrees in aerospace engineering. Dr. Whitmore has published over 100 technical monographs including NASA technical memoranda and technical reports, conference papers, book chapters, and peer-reviewed journal publications. He has four awarded patents and has received multiple national and international awards including Outstanding Scientist at both NASA Ames and NASA Dryden research centers, and the NASA Engineering Achievement Medal. Dr. Whitmore is an Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA), is a member of the AIAA Space Systems and Hybrid Rocket Systems Technical Committees. He was a finalist for the Astronaut class of 2000.

Dr. Whitmore is director of the Chimaera Hybrid and High-Powered Rocketry program at USU. For two successive academic years, 2007-2008 & 2008-2009, the USU senior design team lead by Dr. Whitmore won the NASA-sponsored University Student Launch Initiative (USLI) Competition at Huntsville Alabama. The rocket used a closed loop energy management system to deploy drag devices to modulate the rocket energy to achieve precisely 5280 ft altitude above the local ground level, a primary objective of the USLI competition. At the 2009 competition launch, the rocket missed the one-mile target altitude by approximately 0.8-meter. This result was an amazing accomplishment for a group of inexperienced student-engineers. He has advised student teams on 14 ground-based rocket motor firings and seven test launches while at USU. During Academic year 2009-2010 Dr. Whitmore lead a NASA-funded senior design project that challenged students to apply systems engineering concepts to define research and training requirements for a terrestrial-based lunar landing simulator. The project designed, built, and tested a free flying research vehicle that reproduced many of the capabilities demonstrated by the 1960s-era Lunar Landing Research Vehicle. This sub-scale (~1/10th scale) vehicle produced by this work simulates the reduced-gravity (i.e., lunar or planetary surface environment) using a vertically-thrusting jet engine to partially offset the vehicle weight. Although this vehicle is remotely piloted, the design is intended as a scalable configuration.

Experience gained with the Chimaera rocket program has recently spun off a series of research topics focusing on the characterization and modeling of medium-scale experimental hybrid rocket motors, and a NASA EPSCOR-funded aerospike nozzle project. The aerospike project seeks to develop quasi-passive, non-gimbaled thrust vectoring techniques using flow-manipulation on the nozzle surface. Because the flow is unconstrained on one side, it is believed that these techniques will allow the generation of very significant side forces to develop via surface flow injection. This experiment seeks to characterize the fidelity of these forces and to develop algorithms for precisely controlling the generated thrust moments.

Dr. Whitmore teaches classes in compressible fluids, propulsion systems, mechanical measurements, and the aerospace section of the capstone senior design course at USU. During the previous five years, Dr. Whitmore has received research grants, awards, and contracts with a total funded value equaling $1,286,320. Dr. Whitmore has published more than 100 technical monographs, including 24 peer reviewed journal publications. He has written three book chapters and has four awarded USA patents, and one pending.

Joseph R. Tanner (University of Colorado)

Joe Tanner is a Senior Instructor in the Aerospace Engineering Sciences Department at the University of Colorado in Boulder. He teaches a two-semester Graduate Projects course to students at Masters and PhD levels. The students work design projects in the areas of human spacecraft, small satellites, and unmanned aerial vehicles. Prior to joining the faculty at the University of Colorado in 2008, he was employed by NASA at Johnson Space Center for eight years as an instructor and research pilot and 16 years as an astronaut. Joe flew four missions on the space shuttle with one being to the Hubble Space Telescope and two to the International Space Station. During his four missions he performed seven spacewalks or EVAs totaling more than forty-six hours. His primary duty as an instructor pilot was to train the astronaut pilots landing techniques in the Shuttle Training Aircraft. Joe started his flying career as a U.S. Navy jet aircraft pilot. Tanner flew aboard the Space Shuttle Atlantis on the STS-66, November 3–14, 1994, performing the Atmospheric Laboratory for Applications and Science-3 (ATLAS-3) mission. ATLAS-3 was the third in a series of flights to study the Earth's atmosphere composition and solar effects at several points during the Sun's 11-year cycle. The mission also carried the CRISTA-SPAS satellite that was deployed to study the chemical composition of the middle atmosphere and then was retrieved later in the mission. Tanner logged 262 hours and 34 minutes in space and 175 orbits of the Earth.

Tanner performed two space walks as a member of the STS-82 crew to service the Hubble Space Telescope (HST) in February, 1997. The STS-82 crew of seven launched aboard Space Shuttle Discovery on February 11 and returned to a night landing at Kennedy Space Center on February 21. During the flight the crew completed a total of five space walks to improve the science capability of the telescope and replace aging support equipment, restoring HST to near perfect working condition. The crew boosted HST's orbit by eight nautical miles (15 km) before releasing it to once again study the universe. Tanner's two space walks totaled 14 hours and 01 minutes. The flight orbited the earth 150 times covering 4.1 million miles (6,600,000 km) in 9 days, 23 hours, 37 minutes.

Tanner's third mission was STS-97 aboard Space Shuttle Endeavour (November 30 to December 11, 2000), the fifth Space Shuttle mission dedicated to the assembly of the International Space Station. While docked to the station, the crew installed the first set of U.S. solar arrays, in addition to delivering supplies and equipment to the station's first resident crew. Tanner performed three space walks totaling 19 hours 20 minutes. Mission duration was 10 days, 19 hours, 57 minutes, and covered 4.47 million miles (7,190,000 km).

Tanner's fourth mission, STS-115 aboard Space Shuttle Atlantis launched on September 9, 2006. On September 13, he participated in the 5 hour 26 minute spacewalk to connect the P3/4 truss to the ISS. STS-115 returned to Earth on September 21, 2006.

Daniel A. Erwin, Ph.D. (University of Southern California)

Dan Erwin is Professor of Astronautics and chair of the Department of Astronautical Engineering at the University of Southern California, Los Angeles, California. He joined USC in 1986. Prof. Erwin's research areas include dynamics of rarefied gases and plasmas; electric spacecraft propulsion; optics and optical instrumentation; and space situational awareness.

Dr. Erwin is a founding member of the Department of Astronautical Engineering and the principal developer of the undergraduate curriculum. He is the faculty mentor for the student Rocket Propulsion Laboratory and is one of several faculty advisors for the microsatellite group and the Lunar Lander prototype (LEAPFROG) project. He teaches courses in introductory astronautics; spacecraft systems; rocket propulsion; and computational rarefied gas dynamics.

Dr. Erwin earned his B.S. in applied physics from Caltech and his Ph.D. in electrical engineering at USC. Since 1986, he has been on the USC faculty where he is currently Professor of Astronautics and Chair of the Department of Astronautical Engineering. He has held positions at Lockheed California Company, the Aerospace Corporation, California Scientific Software, and Sierra Online. He is a senior member of the American Institute of Aeronautics and Astronautics and a member of the Institute of Electrical and Electronics Engineers, the American Physical Society, and the Optical Society of America. He has served on the Science and Technology Advisory Board of Intelligent Optical Systems, Inc. and the AIAA Plasmadynamics and Lasers Technical Committee.

Donald L. Edberg, Ph.D. (California Polytechnic University, Pomona)

Don Edberg is a Professor in the Department of Aerospace Engineering at California State Polytechnic University, Pomona, California, where he is responsible for the astronautics and aerospace vehicle design curriculum. He joined Cal Poly in 2001 after a career of 17 years in the aerospace industry, working at General Dynamics Convair Division, Jet Propulsion Lab, AeroVironment Inc., McDonnell Douglas Aerospace, and Boeing Space and Defense Systems. During this time, he performed research and development in UAV development and structural dynamics in launch vehicles and spacecraft, as well as consulting to several small businesses. Dr. Edberg is also a Lecturer for the University of California Los Angeles Extension, California where he teaches a short course in spacecraft design and systems engineering. He has also taught at the Departments of Mechanical and Aerospace Engineering, in the University of California San Diego, University of California, Los Angeles, and the University of California, Irvine.

Dr. Edberg was a Boeing Technical Fellow in Smart Structures at the Phantom Works at Boeing (formerly McDonnell Douglas), Huntington Beach, CA, from 1989 to 2009. During this period, he directed and performed research on Independent Research & Development (IRAD) projects supporting shock suppression and whole spacecraft vibration isolation on expendable launch vehicles. He served as the Principal Investigator for Launch Vibration Isolation System (LVIS) program under contract to Air Force Research Lab during 1996-97. He also invented and was the chief engineer for McDonnell Douglas' patented STABLE (Suppression of Transient Acceleration by Levitation Evaluation) microgravity vibration isolation system, which was successfully demonstrated on-orbit during the flight of shuttle STS-73/USML-2 in 1995.

During 1998 to 2000, Dr. Edberg was a consultant to Rotometrics Inc. and investigated prognostic health evaluation techniques to be applied to turbojet engines under a Small Business Innovative Research contract to U.S. Navy, Patuxent River, MD. He also served as Senior Scientist at AeroVironment Inc. during 1987 to 1989 where he performed design, performance optimization studies, and system integration tasks on the electric-powered AV Pointer® FQM-151 UAV.

Dr. Edberg was a Member of the Technical Staff, Structures & Dynamics Technology, Jet Propulsion Laboratory during 1985 to 1987, where he performed research in the dynamics and control of large space structures, including "smart member" control and optical pointing accuracy. He served as a Dynamics Engineer at General Dynamics Convair Division during 1979-1980, where he performed dynamic analyses on cruise missiles and carriers, and Atlas launch vehicles in various configurations. Analyses included transportation loads, blast loading, and launch loads.

Dr. Edberg holds a B.A. in Applied Mechanics and Engineering Sciences from the University of California, San Diego; a M.S. in Aeronautical and Astronautical Engineering, Stanford University; and a Ph.D. in Aeronautical and Astronautical Sciences from Stanford University in December 1984. Dr. Edberg is an Associate Fellow of the American Institute of Aeronautics and Astronautics and a Life Member of the Academy of Model Aeronautics. He has been awarded the *Silver Eagle* award from McDonnell Douglas (1996) and is the holder of ten U.S. patents.

Valana L. Wells, Ph.D. (Arizona State University)

Dr. Valana Wells is an associate professor in the School for Engineering of Matter, Transport and Energy at Arizona State University. Since arriving at ASU in 1987, Dr. Wells' research has focused on the areas of rotorcraft aero-acoustic prediction, hybrid rotorcraft design, numerical aero-acoustics, noise suppression and the study of stringed musical instruments.

As the program chair for Mechanical and Aerospace Engineering, Dr. Wells oversees all curriculum matters for both Aerospace and Mechanical Engineering. She teaches courses in Aerodynamics, Aircraft Design, Rotary-Wing Aerodynamics, Numerical Methods, Aircraft Dynamics and Control, Vibrations and Introduction to Mechanical and Aerospace Engineering. Dr. Wells designed and supervised the implementation of substantial revisions to both Mechanical and Aerospace Engineering programs in 2006. She designed the Astronautics concentration in the Aerospace Engineering major (2006) as well as two new concentrations in the Mechanical Engineering major (2007). She has developed and taught several new courses. She played an instrumental role in establishing the innovative, senior-level MAE 400 Engineering Profession course. Dr. Wells helped to develop the department's novel outcomes assessment and continuous improvement process (Assessment Fair) to meet ABET accreditation criteria, and she is an experienced ABET program evaluator for Aerospace, Aeronautical and Astronautical Engineering programs. She is the principal investigator on a grant funded by the NASA Innovation in Aeronautics Instruction Program to transform the junior level aeronautics curriculum at Arizona State University.

Dr. Wells is a member of the American Institute of Aeronautics and Astronautics and the American Society for Engineering Education. She has served on and chaired numerous committees at the local and national levels, including the AIAA Aero-acoustics Technical Committee, the University Standards Committee and the Faculty Women's Association Executive Board.

Praveen Shankar, Ph.D. (Arizona State University)

Dr. Praveen Shankar is a lecturer of Mechanical and Aerospace Engineering in the School for Engineering of Matter, Transport and Energy at Arizona State University. He obtained a M.S. and Ph.D. in Aerospace Engineering from the Ohio State University, Columbus, OH and a Bachelor's degree in Mechanical Engineering from Bangalore University, India. Dr. Shankar is the recipient of the prestigious AIAA Orville and Wilbur Wright Graduate Award (2006-2007).

Dr. Shankar's teaching experience encompasses several fundamental courses in mechanical and aerospace engineering including engineering mechanics, aircraft and spacecraft dynamics and control and control system design. In addition he has developed two new courses: Structures in a Space Environment and Space Systems Design required for the ABET certification of the astronautics concentration that has been offered since 2006.

Dr. Shankar is a faculty advisor for undergraduate student clubs such as Daedalus Astronautics and AIAA Design Build Fly and is a mentor for undergraduate researchers through the Fulton Undergraduate Research Initiative and NASA Space Grant. He was the faculty mentor for senior astronautics students that recently won 2nd place in the 2010 AIAA Space Transportation Design competition.

Dr. Shankar's research interests broadly include adaptive algorithms for complex aerospace systems, development of novel aircraft control effectors and enhancement of the undergraduate engineering curriculum. He is currently a co-investigator on a grant funded by the NASA Innovation in Aeronautics Instruction Program to transform the junior level aeronautics curriculum at Arizona State University.

Dr. Shankar is a senior member of the American Institute of Aeronautics and Astronautics and a member of the American Society for Engineering Education.

12. ALETRO Accomplishments

ALETRO was formed in 2008 and three months later received its 501(c)(3) certification from the IRS (assisted by the Ira G. Ross Aerospace Museum). It has acquired personal collections from three key technologists experienced in the early 1950s supersonic aircraft, hypersonic research aircraft (the X-15), Lifting Bodies, and the projects Mercury, Gemini, Apollo, Skylab, and Space Shuttle. ALETRO has also identified a substantial number of additional sources. These collections contain technical documents, program management memos and reports, films, photos, and some hardware artifacts. Several gigabytes of scanned (and processed as searchable) data are currently being catalogued. The presently identified materials available present several times the volume of those already processed (scanned) and offer an opportunity to preserve significant key technology lessons learned.

ALETRO appreciates the endorsement received in 2009 from the NASA Constellation Lunar Landing Project Office and, through its encouragement, is committed to preserve the legacy of Human Space Flight during this rapidly closing window of opportunity. As human space exploration continues, the legacy of the last half of the twentieth century will be vital.

To accept the risk resulting from the permanent loss of personal collections of this diminishing community of space pioneers is not tolerable. To do nothing ensures that loss. The collections are often latent, and some of the key players are still able to provide personal details—that record should be preserved. Most heirs have no means for judging the value or the need for preservation and, if action does not take place during this limited opportunity, the loss will be beyond measure. ALETRO offers a solution! See: ALETRO Vision ALETRO Vision Statement .

Figures 11 and 12 represent the initial concept development for the learning projects "Leveraging Education and Preservation (LEAP).

Figures 13 and 14 shows the challenges to students to learn from the Apollo LLRV story and other sample projects.

Background for the Learning Project

All Partners ALETRO, Education, Industry, Professional/Non-Profits, Gov't	Education Partners	ALETRO
Baseline Data	**Learning Stimulus**	**Historical Data Base**
Define the Challenge & Ask *How would this be solved today?*	Develop Investigative & Innovative Design Skills	Indexed PDF Content With Refined Keywords
ALETRO generates candidate list of challenges/solutions. All partners to prioritize and complement a living list targeted at education needs. All partners assist ALETRO in developing the story telling templates.	Education partners lead in the design of learning strategies that encourage students to answer "***How would this be solved today?"*** and then progressing to discover the historical solutions.	All Partners contribute data base management inputs targeted at maximizing support for both students and professional technologists.

Figure 11. Partnerships

Leveraging Education and Preservation (LEAP)

Through Creative Storytelling of Technology Solutions to the Challenges of the Last Half of the Twentieth Century

All Partners ALETRO, Education, Industry, Professional/ Nonprofits, Gov't.	Education Partners	ALETRO
Project Selection Typical Prototype Projects	**Learning Stimulus**	**Historical Data Base**
1950s – Development of supersonic military aircraft and the X-series rocket aircraft **1960s** – Mercury, Gemini, Apollo, Lifting Bodies, X-15, Jet Air Transport **1970s** – Skylab, Apollo-Soyuz, MIR Space Station, F-8 Supercritical Wing **1980s** – Space Shuttle, Stealth Aircraft, Fly-By- Wire Adopted, X-29, SR-71, Large Bypass Jets **1990s** – International Space Station, Global Positioning System, Regional Jets, Solar Powered Aircraft, X-34, X-36, X-38	Methodology appropriate for curriculum stimulating investigative and innovative design skills.	ALETRO supplies key words for search engine & selection/access controlled by educators in accordance with curriculum.

For each project, a one-page set of input data will be provided plus the story/background for each project. As ALETRO's collections expand, there will be an abundance of candidate projects to choose from, perhaps by voting via the web site.

Figure 12. Leveraging Education and Preservation (LEAP)

13. ALETRO's Apollo LLRV Story

ALETRO's Apollo LLRV Story

<u>1960s Apollo Earthbound Free-Flight Simulation of Lunar Landings</u>

– for spacecraft systems development and astronaut training –

<u>Baseline Data</u>

• What **<u>three types of sensors</u>** provided the *gimbaled-jet* VTOL the capability to simulate the lunar 1/6 g (gravity offset) to a less than +/- 3% accuracy or +/- .005 g's and simultaneously offsetting aerodynamic drag forces experienced on the earth that are not present on the lunar surface?

<u>Learning Stimulus</u>

• Students should be encouraged to use their innovative design skills to develop force diagrams and list the potential motion, attitude, and other sensors that would meet this flight control system challenge for the earth-bound lunar landing research and training vehicles (LLRV & LLTV). Is this a candidate for an educational video game?

<u>Historical Data Base (The Ingenious Design of Walt Rusnak, Bell Aerosystems)</u>

• The NASA DFRC website provides a monograph (NASA-SP-2004-4535) with the answer, though it is in terms of +/- 3% accuracy or +/- .02 earth g's.

• ALETRO's database contains the detailed design documents for this analog system showing the goal of +/-.005 g accuracy was met by sensor selections.

Figure 13. ALETRO's Apollo LLRV Story

ALETRO Vision – Other Sample Projects

• 1950s

Development of supersonic military aircraft and the X-series rocket aircraft

• 1960s

Mercury, Gemini, Apollo, Lifting Bodies, X-15, Jet Air Transport
(i.e., Dean Grimm's solutions to the early failures of the first attempts to rendezvous two Gemini spacecraft in orbit)

•1970s

Skylab, Apollo-Soyuz, MIR Space Station, F-8 Supercritical Wing

•1980s

Space Shuttle, Stealth Aircraft, Fly-By- Wire Adopted, X-29, SR-71, Large Bypass Jets

•1990s

Global Positioning System, Regional Jets, Solar Powered Aircraft, X-34, X-36, X-38

Figure 14. ALETRO Vision – Other Sample Projects

14. Attachments

Quote from Augustine Report

Page 102 of the Augustine Commission Final Report, "SEEKING A HUMAN SPACEFLIGHT PROGRAM WORTHY OF A GREAT NATION"—Section 7.4, MARS ORBIT TO SURFACE TRANSPORTATION

"The entry, descent and landing of cargo on Mars is difficult because Mars has sufficient atmosphere to drive the design of landing systems, but inadequate atmosphere for feasible parachutes or wings to safely land astronauts on the surface. Scientific probes landing on Mars have used a complex mix of aerodynamic braking and rocket propulsion. These techniques will have to be improved before larger robotic or crewed missions can be sent to Mars. *This research and technology development program needs to be started soon, because it will require many iterations and increasingly larger missions before NASA is ready to demonstrate a safe, crewed Mars landing. Meanwhile, the intermediate results would greatly benefit future robotic missions."*
[Emphasis added]

Answers to The LLRV Challenge

Answers to the ALETRO Sample One

These will be available at aletro.org with password access for teachers in the future.

1. http://www.nasa.gov/centers/dryden/pdf/187516main_LLRV_Monograph2.pdf
   Pages 52-56, 92-95 27.5 mb

Page 52 label on photo, change "gimbal frame" to "just outside the gimbal – was known as the main frame"

2. http://www.nasa.gov/centers/dryden/pdf/87724main_H-436.pdf
   Pages 36-40 2.6 mb

3. Bell Jet Engine Stabilization System Memo dated 4/22/1963 (attached as a PDF file)
   Pages 1-9 1.3 mb

The motion sensor locations are shown on the following slides, they are all mounted on the outer body of the vehicle, just outside the gimbals, resolvers are used to control the jet engine position.

1

The Three Types of Sensors Used to Provide Earth g Offset and Aero Compensation

Motion

(1) Vertical Gyro

(4) Accelerometers

Rocket Thrust

(1) Pressure transducer

Position

Pitch & Roll Jet Engine
Angular Position Resolvers

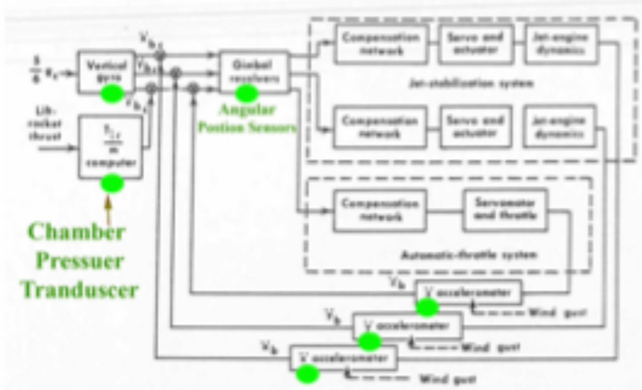


Figure 4.– Simplified block diagram of the LLRV lunar-simulation system.

two separate subsystems: the jet-stabilization system (JSS) and the automatic-throttle system (ATS). The JSS controls the jet-engine pitch- and roll-gimbal position to compensate for aerodynamic disturbances. The ATS automatically controls the jet-engine thrust for the five-sixths vehicle-weight compensation.

Also incorporated in the lunar-simulation system is a thrust-to-weight $\left(\frac{T_{LR}}{W}\right)$ computer that determines the initial weight of the vehicle when the system is activated and computes the acceleration of the vehicle resulting from lift-rocket operation during a lunar-simulation maneuver. The computer is also mechanized to compensate for the change in vehicle mass resulting from fuel burnoff.

The lunar-simulation system and associated subsystems are described in detail in appendix C.

2

The Automatic Throttle System for the Jet Engine Providing Earth g Offset

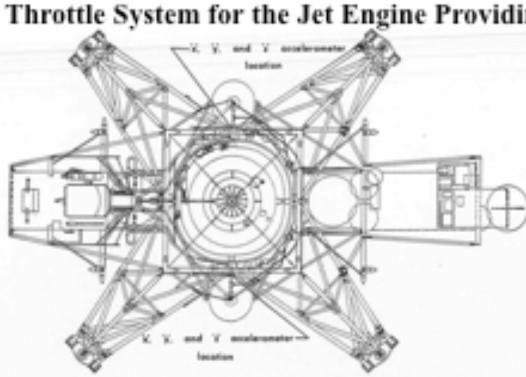


Figure 32.– Jet-stabilization-system accelerometer locations.

Automatic-Throttle System (ATS)

A simplified block diagram of the automatic-throttle system is presented in figure 33. The earth-referenced $\frac{5}{6}$ g command signal is resolved into body-axis coordinates as in the jet-engine stabilization system. The resultant signal is compared to the actual z-axis acceleration of the vehicle which is obtained from the body-mounted accelerometer (fig. 32).

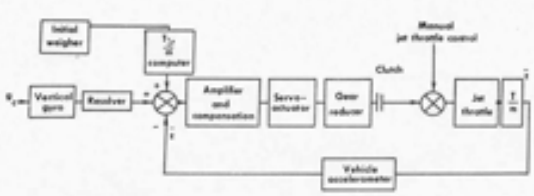


Figure 33.– Block diagram of lunar-gravity automatic-throttle system.

37

3

LLRV Accelerometer Installation for the Jet Stabilization and Lunar Simulations Systems (Outside the Gimbals)

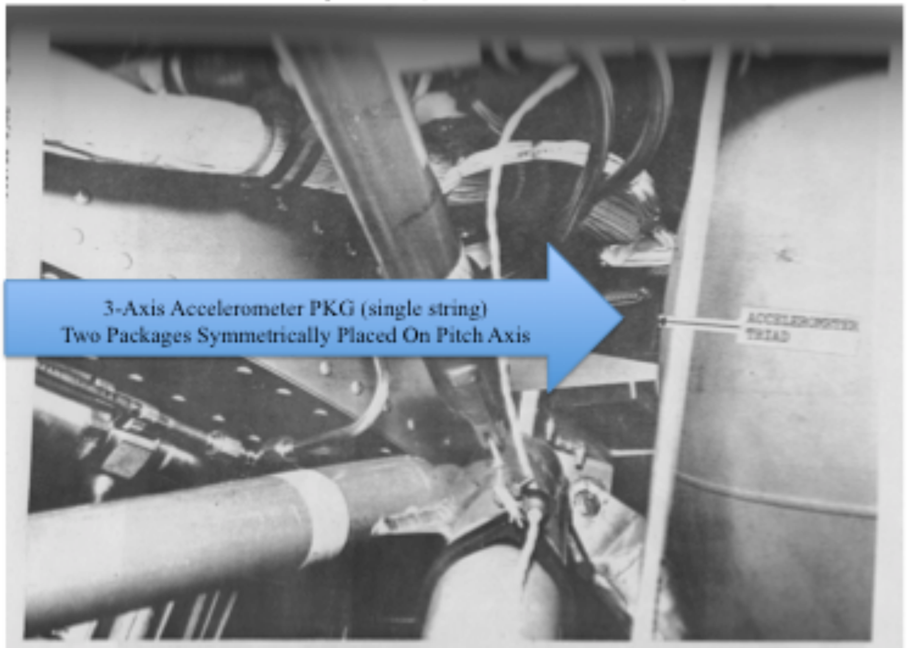
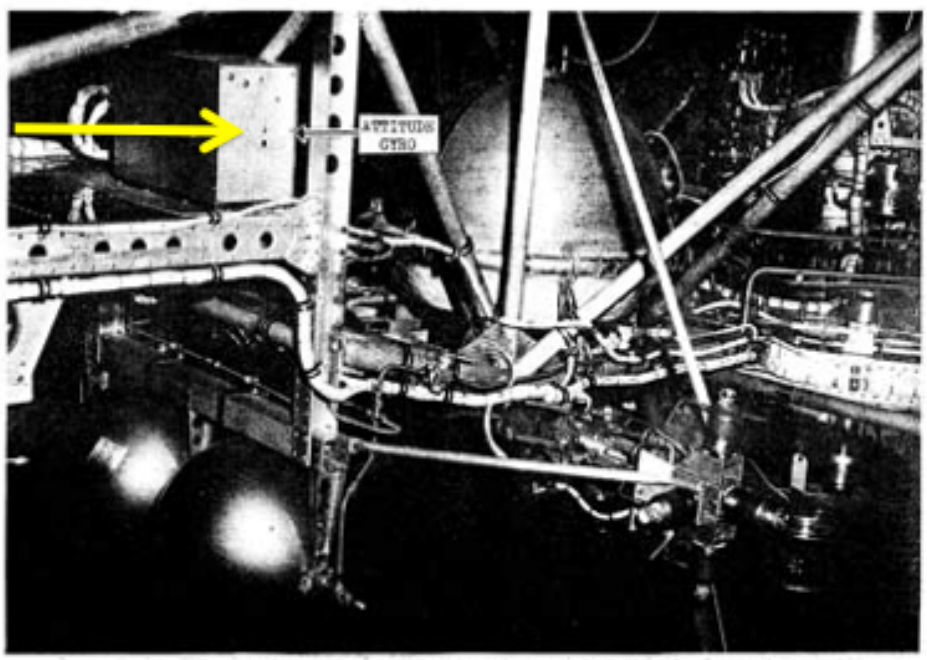


Figure 11-4. Avionics System Accelerometer Triad

4

LLRV Vertical (Attitude) Gyro Location on the Aft Equipment Platform

Report No. 7260-954002



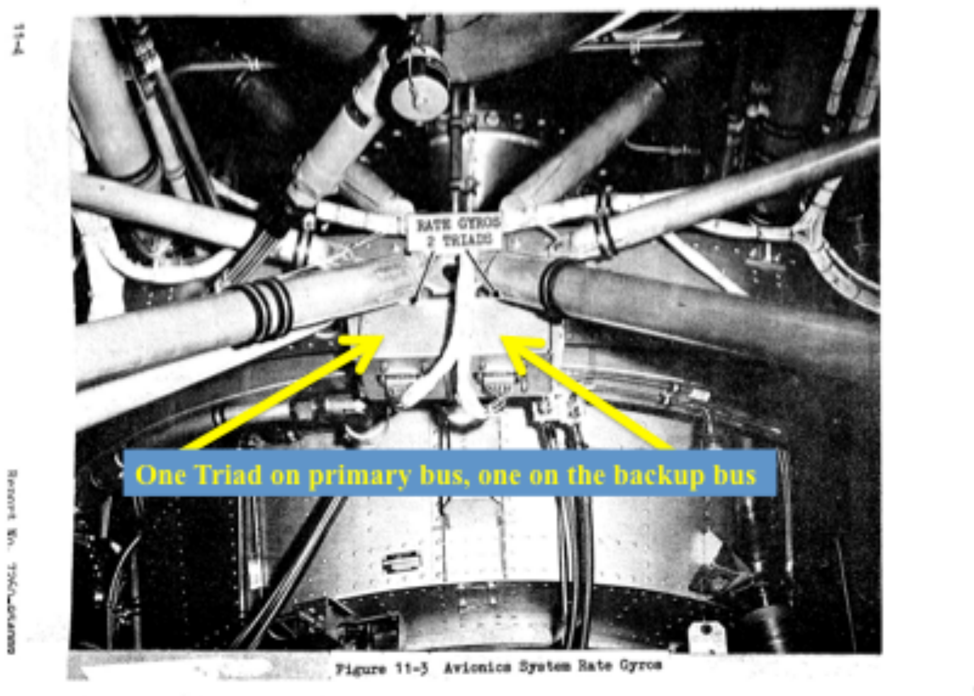
11-5

Figure 11-2. Avionics System Attitude Gyro Unit

5

LLRV Rate Gyro Locations on the Vehicle Pitch Axis Outside the Gimbals

(Used for the Redundant Attitude Control System)



15. Online References and Resources

USU Proposed Budget Straw-Man Document 34.5K

USU Proposed Budget Template Spreadsheet 148K

USU Email LLRV Flies Again Document 806K

USU Video Clip LLRV Flies Again mp4 3.73mb

USU Handbook, for Senior Design Capstone Course PDF 2.77mb

NASA ESMD Workshop July 2010 Document 36k

NASA ESMD Workshop July 2010 Attendees Spreadsheet 81.5k

ALETRO Mission Statement PDF 269k

ALETRO Vision Statement

NASA Monograph SP-2004-4535 Unconventional, Contrary and Ugly (LLRV) PDF 26.4mb

NASA DFRC Advanced Landing Technology Report PDF 6.63mb

NASA DFRC Advanced Landing Technology Appendix, Volume 1 PDF 7.3mb

Proposed ALETRO Budget 12/21/10

Lunar Landing Conference March 4th & 5th 2008

ALETRO Videos on YouTube ™

Society of Experimental Test Pilots Foundation

16. Cited References

i "Criteria for Accrediting Engineering Programs, 2008-2009, ABET Engineering Accreditation Commission," http://www.abet.org/Linked Documents-UPDATE/Criteria and PP/E001 0809 EAC Criteria 12-04-07.pdf, [Retrieved September 4, 2008].

ii Hartman, Jerry, Murphy, Gloria, " Exploration Systems Mission Directorate: Higher Education", NASA Office of Education, URL: http://www.nasa.gov/education, [Cited November 30, 2010].

iii O'Bryan, T. C., and Hewes, D. E., "Operational Features of the Langley Lunar Landing Research Facility," NASA TN D-3828, 1967.

iv Nassiff, S. H., and Armstrong, N. A., "Apollo Flight Crew training in Lunar landing Simulators", AIAA Paper 68-254, Presented at the AIAA 2nd Flight Test, Simulation, and Support Conference, Los Angeles, CA, March 25-27, 1968.

vMatranga, G. J., Ottinger, C. W., Jarvis, C. R., and Gelzer, D. C., "Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle," NASA SP-2004-4535, 2005.

vi Ottinger, D/. W., ed., "Go For Lunar Landing Conference: From Terminal Descent to Touchdown," March 4th and 5th, 2008 Tempe, AZ, http://ser.sese.asu.edu/GO/, [cited 14 June 2010].

vii Sellers, J., J., Understanding Space: An Introduction to Astronautics, 3rd Ed, McGraw-Hill, 2005.

viii Maine, Richard E., and Iliff, Kenneth W., "Application of Parameter Estimation to Aircraft Stability and Control," NASA RP-1168, Washington DC, 1986.

ix "Education in the Exploration Systems Mission Directorate," http://www.nasa.gov/directorates/esmd/aboutesmd/education/index.html, [Retrieved 1 December 2010].

1. x "Design and Testing of a Demonstration Prototype for Lunar/Planetary Surface Landing Research Vehicle *(LPLSRV)*," http://www.neng.usu.edu/classes/mae/5900/frameset_for_design_class_webpage.html, [Retrieved 1 December 2010].
2. xi LPLSRV Student website, http://www.engr.usu.edu/classes/mae/5900/Lunar/Index.html, [Retrieved 1 December 2010].

xii Schaeffermeyer, Whitmore, S. A., and C. B. Wright,C. B., "Maneuvering and Gravity Offset Flight Controls for an Extraterrestrial Surface Landing Research Vehicle," AIAA-2010-6936, *46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Nashville, TN, 25-28 July 2010.*

xiii "Rhino Turbine," Jet Central Inc., http://www.jetcentral.com.mx/english/rhino.html, [Retrieved 10 April 2010].

xiv Quadrotor testing, You Tube, http://www.youtube-nocookie.com/watch?v=_b7XLsUqqXs, [Retrieved 1 December 2010].

xv Jon_high_fly, You Tube, http://www.youtube.com/watch?v=m0cewfVfijg&feature=channel, [Retrieved 1 December 2010].