# AC 2007-415: THE SOONER LUNAR SCHOONER: A COMMON PROJECT FOR MULTIPLE AEROSPACE CLASSES

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The Sooner Lunar Schooner: A Common Project for Multiple Aerospace Classes


## Abstract

The Sooner Lunar Schooner (SLS) mission is a robotic mission to perform material science experiments on the lunar remnants of the Apollo 17 and Lunakhod 2 spacecraft. We have been using the SLS mission scenario as a framework for a number of classes in several departments including the aerospace and mechanical engineering departments.

In this paper we will discuss, within the framework of the SLS project, the arrangement of projects within courses; give examples of the types of experiments and projects we are doing in these classes; and present current assessment results and future plans for assessment; plans for making SLS a coordinated multi-year theme through the curriculum; and the current state of the SLS mission.


## The Sooner Lunar Schooner Mission

The Sooner Lunar Schooner is a multi-disciplinary ongoing project at the University of Oklahoma to plan, design, prototype, cost and (when funds become available) build/contract and fly a robotic mission to the Moon.

The core of the SLS mission will be two robot rovers that will traverse the Moon's surface and observe its geology, as well as locating and studying artifacts of previous Lunar missions, including Apollo 17 and Luna 21 (Lunakhod 2). These rovers will be delivered to the surface by an innovative landing capsule designed to absorb the impact of a rough landing, rather than relying on a precision-guided powered descent. Upon arriving at the Moon, the spacecraft will fire a retrorocket, slowing its velocity to nearly zero approximately 100 meters above the surface. The capsule will then free-fall the rest of the way. After impact, the capsule will deploy the rovers. Additional details of the origin of the project are available in [5].

Most existing senior capstone projects, for example Big Blue [4], which are funded by industry or government agencies, try to address different problems each year. The SLS project is used every year with the same mission objectives, though the particular aspects of the mission under study do change. This allows students to build on the previous year's work while still exploring new problems and challenges.

The goal of the SLS mission is to explore a small section of the Moon; conduct a materials analysis of the materials left there by an Apollo mission thirty years earlier; and to perform a selenographic survey of areas that were too distant or considered too dangerous to be done by the Apollo crew. The goal of the Sooner Lunar Schooner Project is to improve the science and engineering educations of the hundreds of undergraduate and graduate students working on the project [5]. The participants, while primarily from engineering and physics, will also include representatives from business, art, journalism, law and education. This project ties together numerous existing research programs at the University of Oklahoma, and provides a framework for the creation of many new research proposals.

The Sooner Lunar Schooner concept was presented to the College of Engineering faculty at the University of Oklahoma. Discussions followed of the various roles that existing labs, capstones and faculty could fill. A number of courses were set up or reorganized to take advantage of the SLS domain. Additional details of the origin of the project are available in [5]. The remainder of this paper will review the results of a few of those classes.

## Space Robotics & the SLS Mission

Part of the graduate sequence in the robotics curriculum at the University of Oklahoma is a course on space robotics. In this course we cover the unique aspects of robot mechanics, electronics, software and design that are necessitated by the space environment. Recent versions of the course have used the SLS as the subject of the design study.

The initial SLS mission is to land at one of the Apollo landing sites and then to

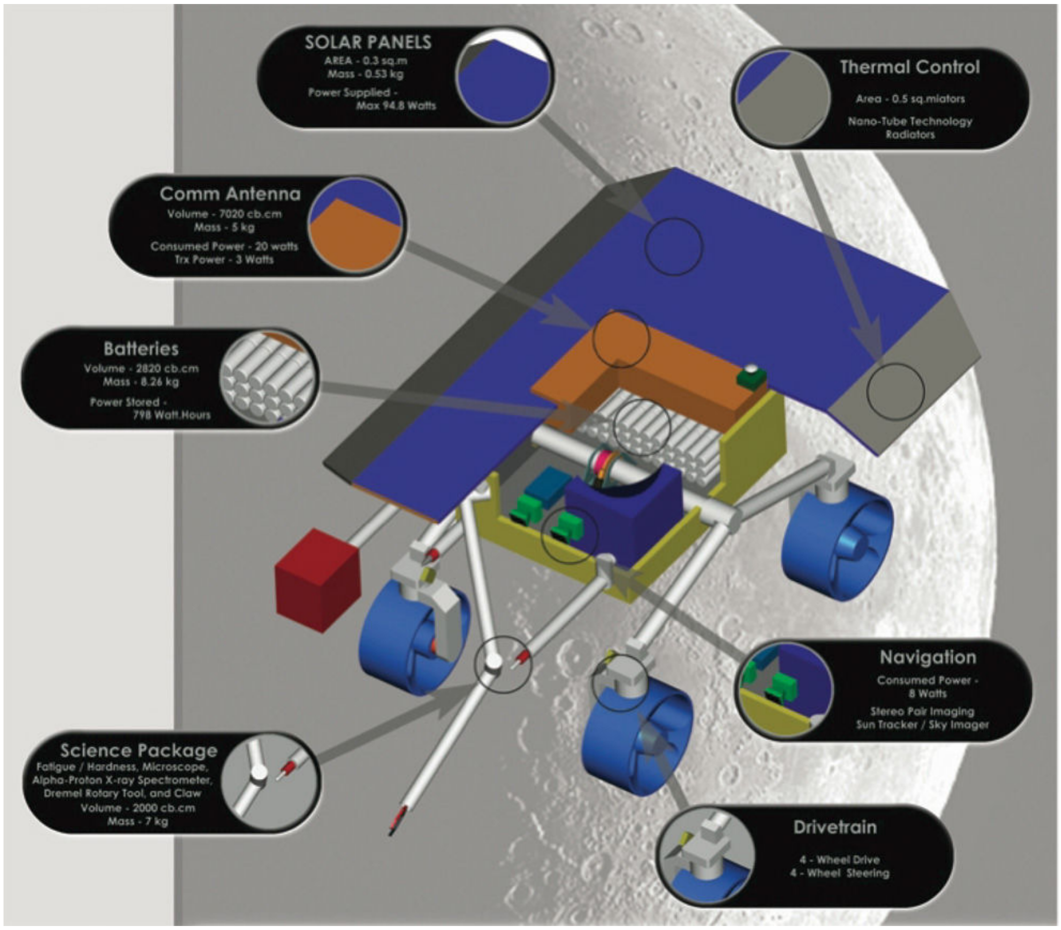


Figure 1: *Preliminary Design of Science Rover*

inspect the lower stage of the LEM (Lunar Excursion Module) and perform an analysis of the aging the materials of the LEM had experienced. The class created a preliminary design of a rover to travel from the SLS landing site a short distance to an Apollo landing site and perform a materials survey. (see Figure 1).

The only Apollo site that was formally with regards to materials and surface finish is Apollo 17. For those reasons, Apollo 17 is the primary site for the SLS exploration. This selection had the additional advantage that Lunakhod 2 is less than 150km almost due North of this site. The class decided that a secondary *sprint* rover (see Figure 2) should be created to try and reach the Lunakhod during the mission. Further details of the rovers are contained in [6].

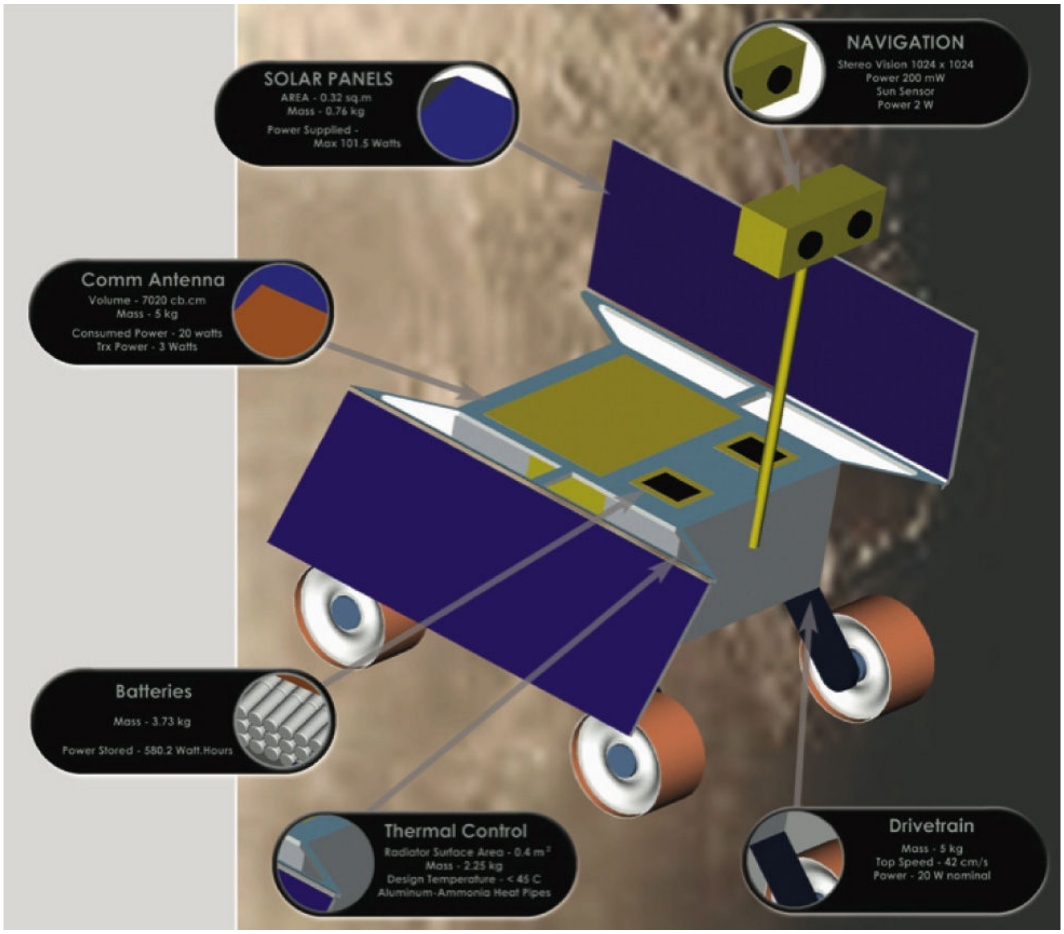


Figure 2: *Preliminary Design of Sprint Rover*

Subsequent iterations of the class have created prototypes of some of the rover navigation and science instruments. There is enough design and prototype work to be done for many classes to come.

## Design of a Lunar Landing Capsule

As part of the ME curriculum there is a design capstone class. Some of the projects for the class are provided by industry, others are generated internally. The SLS has generated some popular capstone projects, one of which was the Lunar landing capsule, described below.

The mission architecture chosen for SLS uses a simple but proven Lunar landing system modeled after that designed by *Ford Aeronutronic* and used by the Block II *Ranger* missions [2]. The original *Ranger* system used a landing radar to fire a solid motor that would kill most of the lander's velocity at an altitude of about 100m above the Lunar surface. A sphere of balsa wood was used to encase the payload and protect it from impact with the Lunar surface during that final fall of 100m or so.

During the Spring of 2003 a team of mechanical engineering seniors developed an updated version of the landing capsule for possible use in the Sooner Lunar Schooner. The capsule was designed to handle a one cubic meter payload massing 100kg (the projected size of the rovers designed a semester earlier). The landing system could be no more that two meters in diameter and two meters tall, in order to be able to fit in the launch shroud. The payload could not be subjected to more than 100 g's when falling from a dead stop 100m above the Lunar surface. The Lunar surface itself is assumed to be solid rock at the point of impact. For terrestrial test purposes, a drop height of 16.7m in Earth gravity onto a concrete slab was used to accelerate the capsule to the same impact velocity it would experience from a 100m drop on the Moon. Accelerometers in the payload compartment were used to measure the payloads deceleration.

During the initial research and planning phase, the team investigated previous attempts at delivering a science payload to a planetary surface. Specific strategies examined included a powered-descent, soft landing similar to *Surveyor*, an airbag system such as that used by Mars *Pathfinder*, or an impact-reducing capsule such as the *Ranger* 3-5 or the Soviet *Luna* 9, which returned the first pictures from the lunar surface. All the ideas fell into one of three preliminary conceptsa powered-descent using a rocket motor, an airbag system, or a capsule made of energy absorbing material. A rocket-powered descent was deemed too complex with its issues of guidance and control, and issues of cost and safety associated with testing a prototype. The Pathfinder-style airbag system was quite attractive based on its earlier high-profile success. However, an adequately strong and durable airbag material such as *Kevlar* or *Vectran* turned out to be prohibitively expensive. Furthermore, an airbag system would need to be tested in a vacuum chamber to replicate its behavior on the Lunar surface. As a final problem, the airbag systems bounce. The team was unable to determine any advantage to bouncing across the Lunar surface, and many disadvantages, so this strategy was abandoned.

An energy-absorbing capsule presented several advantages. Its design and construction would be fairly straightforward. It presented few difficulties in testing – a simple drop test would suffice. Several viable materials were available at feasible prices, and these materials would not require any special handling. Finally, if the material was chosen correctly the capsule would “stick” its landing, limiting the payload to a single shock. This concept was selected by the team.

The landing capsule was based around a 1 meter tall octagonal frame with a 1 meter diameter. In the flight version, this frame would spilt lengthwise after landing, freeing the rovers to climb out and start their mission. For the tests purposes, the frame was made in part from steel box tube to give a rigid fixture for the accelerometers. Additional mass was added to the system to bring capsule mass to 100kg – the target mass of the rovers.

Research prior to the selection of the external cushion material revealed that viscoelastic polymer foams had quite complicated behavior under dynamic loading, strongly dependent on temperature and strain rate. Compared to polymer foams, honeycomb materials had several advantages. After the necessary properties were specified, the final selection was made based on properties, price, and availability. The result was a 33-wt paper honeycomb with 1/2 inch cells. The students performed an iterative design, adding the cardboard’s weight into the energy calculations and then re-calculating the amount of material needed.

Concurrent with the design and fabrication of the honeycomb cushion, the team designed an instrument package capable of measuring the decelerations to be experienced by the payload during impact. Accelerometers and a data-logger were procured. The sensors were rigidly mounted to the steel frame of the payload container.


Figure 3: *Drop Capsule Falling from a Great Height*

In order to test the prototype, students calculated the scale height on earth that would produce the same impact energy as the 100 meter free fall on the moon. They arranged to use a basket lift provided by the OU physical plant to hoist the capsule to the test height of 17m (see Figure 3).

The capsule was hoisted and dropped flawlessly, and the cushion performed as expected, deforming significantly in the impacted areas. Upon impact, the adhesive bonding the cushion material to the metal capsule failed, and the material came off. This was a desirable feature – lowering the deceleration shock and making exit from the capsule area easier for the rovers. The cushion material between the capsule and the ground of course was trapped in place. The honeycomb material exhibited no elastic properties and the capsule had absolutely no visible bounce, so the shed material was not needed, and has been removed in subsequent designs.

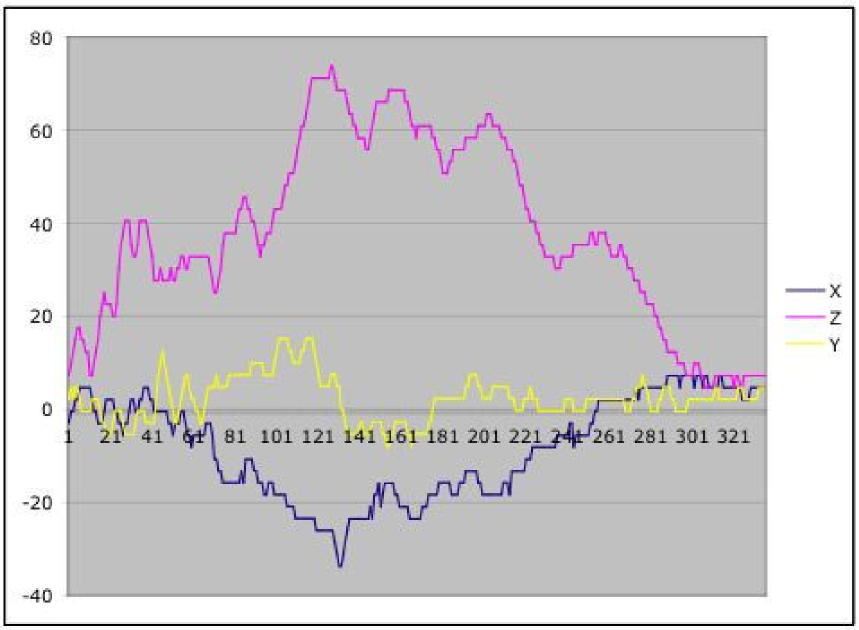


Figure 4: *Accelerometer Data from Drop Test (X-axis is time in ms, Y-axis is gees*

The landing shock was estimated by measuring the deformation of the cushion material. According to our measurement, the material was deformed by a maximum of 9 inches, corresponding to ≈73gs. This was confirmed by data from the accelerometers (see Figure 4). Additional drops, using cushion material only on the bottom of the capsule yielded similar results. This shock is within the survival specifications for standard hard drives, and consequently most electronics and mechanical systems.

The conclusions from this class' project were that significant mass savings can be achieved by stabilizing the capsule so only one end needs full padding, the rest of the capsule can have lower levels of padding should the capsule capsize after the initial impact, or roll from landing on an incline or rock. Additional design work is need to determine the best way to stabilize the capsule for landing (e.g., an RCS, or spinning), should this approach be used.

| Method | Typical Accuracy | Remarks |
|---|---|---|
| Spin Stabilized | 0.1 deg | Passive, simple; single axis inertial, low cost, need slip rings |
| Gravity Gradient | 1-3 deg | Passive, simple; central body oriented; low cost |
| Jets | 0.1 deg | Consumables required, fast; high cost |
| Magnetic | 1 deg | Near Earth; slow ; low weight, low cost |
| Reaction Wheels | 0.01 deg | Internal torque; requires other momentum control; high power, cost |

Figure 5: *Accelerometer Data from Drop Test (ADCS Performance Comparison*

## SLS Systems and Mission Design

AME 4593 (Space System and Mission Design, every Spring Semester) needs to provide students a much needed big picture perspective that can be used by managers, engineers, and students to integrate the myriad of elements associated with human/robotic space flight. After this course, students should be able to acquire enough knowledge and skills to understand and design a conceptual space mission.

The SLS mission, as an integrated project [3], covers a variety of aerospace topics in materials, propulsion, robotics, space environment, structure, astrodynamics, sensors, and even project management. Therefore, this concept is a good option for the course project. In the spring of 2005, a team of seven senior aerospace engineering students studied mission profile for the transfer from the Earths surface

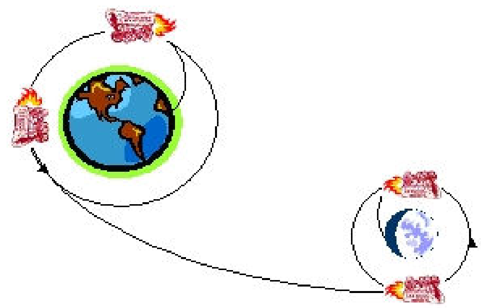

Figure 6: *Sooner Lunar Schooner transfer*

to the Moons surface with modest operating budget. This project ended being the judges choice award for the aerospace capstone projects. In the spring of 2006, three mission options with detailed solicitations are provided: the SLS mission, a HTHL (horizontal takeoff and landing) RLV (reusable launch vehicle) mission for space tourism, and a low earth orbit (LEO) formation flying satellites for forest fire monitoring. Almost all students (21 students in the class) choose the SLS project (over 90%).

## Course Organization and Project Evaluation

The main challenge of the application of SLS concept as a course project in this class is: how to organize the project team, layout a proper lecture material, and give students fair grades.

In order to mimicking professional team arrangement and peer competition among general industries, students are allocated to two groups. Before these two groups are finalized, a survey will be taken in order to form a fair competition.

In each group, there will be a Chief Engineer and a Design Engineer. The other students will be separated to four teams dealing with one of the four areas of designs according to their interests. The Chief Engineer will be in charge of management and timeline and also specialized in one area of designs. The Design Engineer will be in charge of the overall design and make sure the design is reasonable and s/he will also be involved in one area of designs. Four teams in each group are in charge of mission analysis, launch vehicle, structure/weight/payload, and onboard subsystems separately.

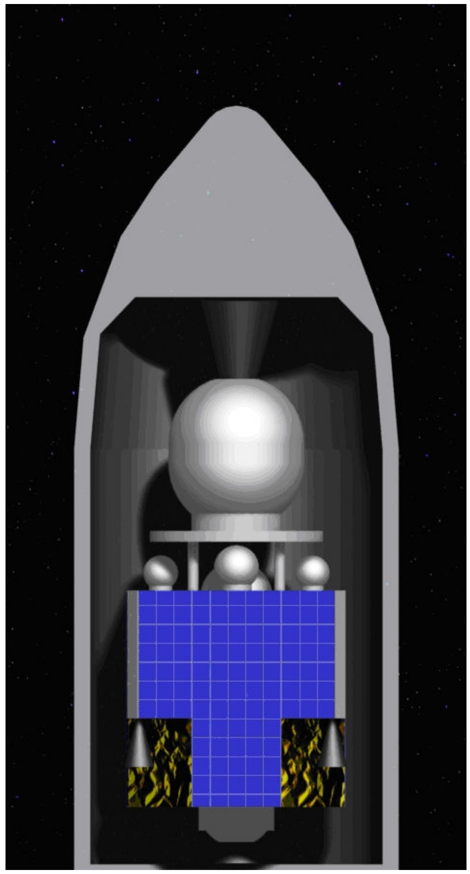

Figure 7: *CAD model shown loaded in Space Head Module*

During the first week of the class, the lecturer and the students go over previous years' SLS mission design reports. Then within 3 weeks, two groups will send in small project proposals in which initial ideas of the mission objective, mission analysis, payload design, structure, and onboard subsystems will be described. Every other week, each team gives a 10-minute presentation for the project update. In late march, a midterm presentation is given. The instructor gives comments and suggestions to students' design. Experts from industries are invited to give talks on specific topic areas each year. Final reports and presentations are due at the end of the semester.

The whole course is organized according to these tasks. In each topics covered during the lecture time, the lecturer will give students background information, mathematic and simulation illustrations, general design tools, as well as different design options.

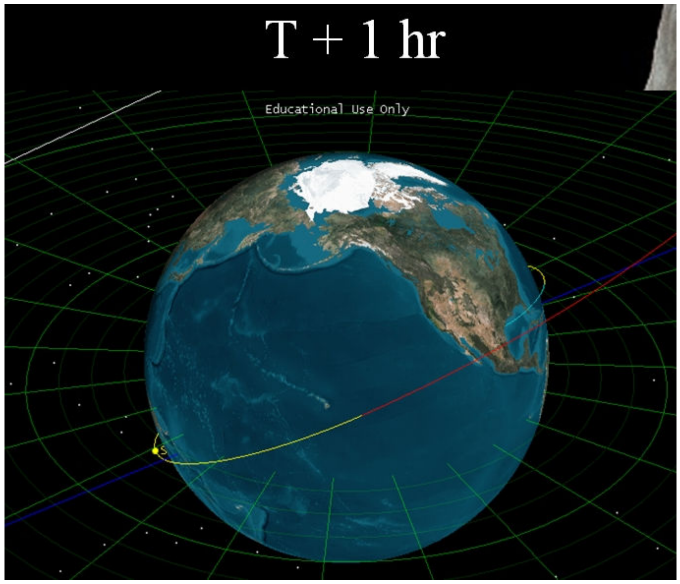


Figure 8: *Trajectory Design Using STK [1]*

For example, in the attitude determination and control subsystem (ADCS) lectures (three lectures), the following topics will be taught. Why do we need ADCS? Common definitions and terminologies, different attitude representations, passive attitude controls, active attitude controls, often used attitude estimation methods, and several commercial actuators and sensors used in ADCS. Also, a list of references and websites will be provided. Students should be able to figure out which methods to be used in the SLS mission and when should the ADCS work during the mission. It is impossible to cover all these topics in three lectures time. However, due to the conceptual design nature, students only need to understand advantages and disadvantages of different design options. The lecturer will provide some quality comparisons and an example is shown in Figure 5.

Also experts from industry will be invited to give guest lectures related to the space mission design. In 2006 class, Mr. Nasrullah from Boeing Space Exploration Systems gave a talk titled payload cargo integration.

Students grades will depend on comparisons between these two groups (approximately 10 students in each group). Two groups will response to the solicitation with a proposal within two weeks after the project description (solicitation) is posted. In the middle of the semester, there will be a group presentation for project updates. In the end of the semester, two groups will present their design as well as submitting

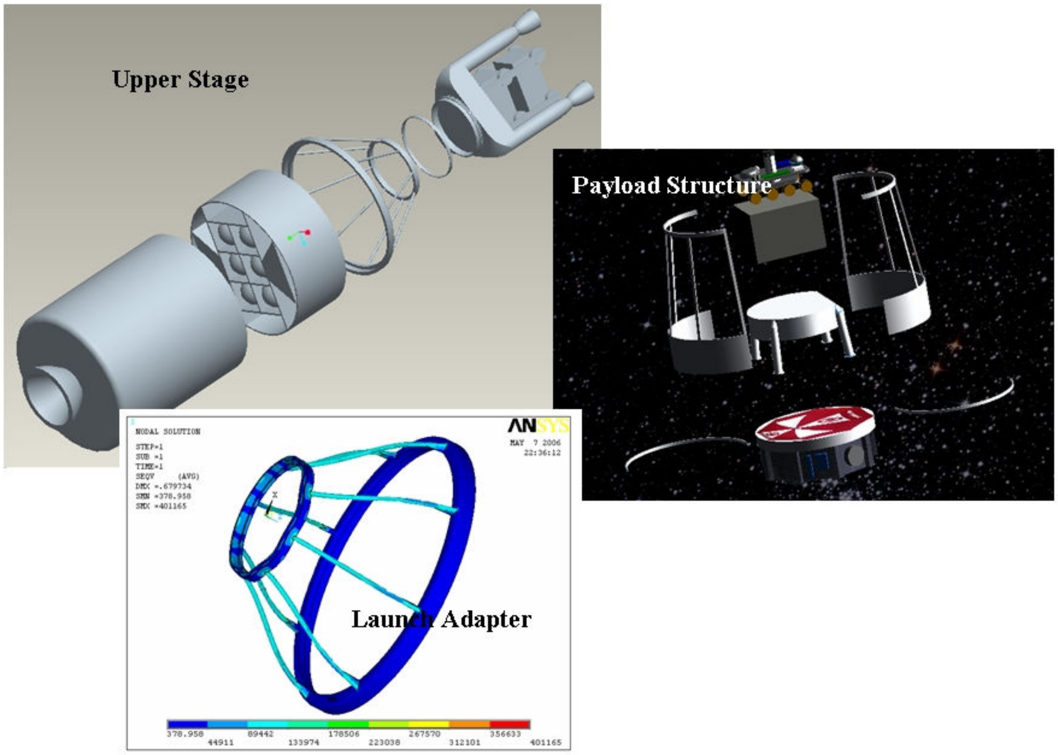


Figure 9: *Structure Design*

a CD with all the required documents. After each lecture module, individual team will present a topic relating to SLS. For example, after the lecture of the astrodynamics, students will present their design of the transfer trajectory from the Earth surface to the Lunar surface and calculate the fuel budge for their designs. Fair evaluation is crucial in these presentations and a detailed break down points system is used for this project. Overall, only one student out of 21 has complained once for this grading system.

## Course Project Demonstration

It has been shown that the SLS will not only benefit students learning, they can bring in enthusiasm, significant innovations, and imagination into this project. Has a type of heritage project, students in the class of 2006 improved the quality of the design achieved by the class of 2005. In 2005, students studied a conceptual trajectory design (basic Hohmann transfer) (as shown in Figure 6), launch vehicle selection, CAD structure design [7] (Figure 7). In 2006, students not only refined the 2005 design (Figure 8), they also investigated different structure (Figure 9) and ADCS subsystem design (Figure 10). For quick comparison, both teams handed in a 2-page quick fact which briefly discussed mission introduction, mission objectives, team members, launch vehicle, launch site, launch options, approximate cost, payload module, and major technologies.

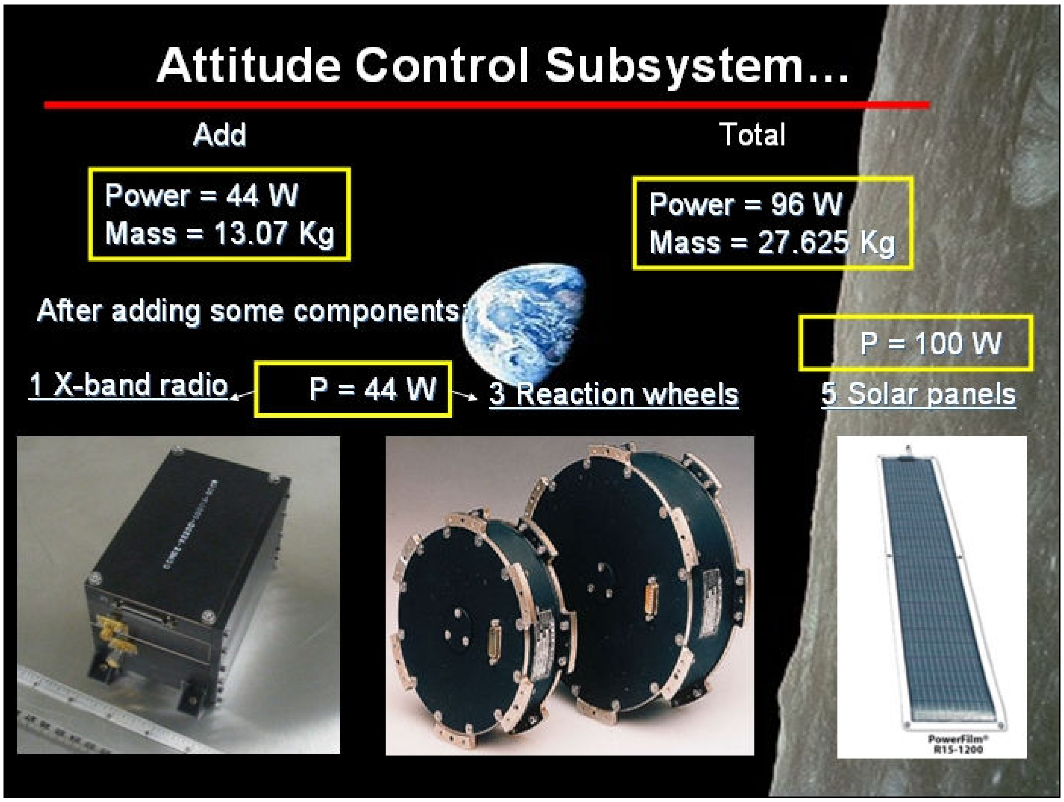


Figure 10: *ADCS Design*

**Project Outcome**

Real mission related research and design projects give them the opportunity to apply knowledge learned in fundamental courses. The students can explore areas in more depth because the project is larger, and they will have more time to explore the design boundaries to meet the mission objectives with the minimum budget in creative ways. The SLS mission gives students a dedicated project where they can refresh their skills of using different design tools such as Pro-E, Matlab, and ANSYS which is critical for aerospace related career. Because of the nature, size and scope of the project, student enthusiasm for working on it is much higher than on other paper projects. Specifically, mimicking professional team arrangement and peer competition in the SLS project gives students a reality feeling.

Up to this point, there is no enough information to draw a conclusion on how SLS project affect students learning. But just as an example, the following items have obtained a high ranking as compared with other courses (according to students evaluation): (1) The course increased students ability to speak effectively; (2) The course increased students ability to function effectively as part of a team; and (3) the course increased students ability to use modern engineering tools.

## Evaluation

There are two ways to evaluate this project. The most obvious is to see what impact this project has on future Lunar missions. If ten years from now the OU flag is on the Moon then a certain level of project success has occurred.

From an educational standpoint, we will evaluate this project based on exit surveys of students who have participated in the SLS classes and compare them to similarly qualified students who have not. We will be looking at their academic performance their evaluations of courses as to utility and enjoyment and their future career goals – along with their ability to achieve those goals. To date we do not yet have enough information to make any conclusions about the educational benefits of the SLS project. However, we can state that the project has been enthusiastically embraced by students in all of the classes where it has been used. For example, in the space system and mission design course, students could use the SLS, a formation flying satellite project, and a HTHL RLV for space quick access as the framework for the exercises and reports. Almost all students choose the SLS project (over 90%). Surveys reveal that there are several major reasons for this: 1) There is heritage – not only are they building on previous work, but they are building on work done by their classmates – and their improvements are easily visible to them; 2) they love the idea of the project and want to make it happen; 3) Because the SLS project is a framework for a number of courses, they can easily see the connection of what they have done in other courses, in which SLS concept was used as projects (such as rover mechanical design and orbit design etc.); and 4) mimicking professional team arrangement and peer competition in the SLS project gives students a feeling of reality.

SLS is fundamentally different than other projects that bear some surface similarity such as Stanford on the Moon [8]. Stanfords project is not a single project, but an initiative by a group of alumni to have Stanford do more lunar related activities. The SLS project, on the other hand, is being done by students (who are trying to convince the alumni to pony up the funds) and they are working on and refining a single mission concept. We believe that this single mission focus keeps the students interest focused. The project itself is certainly big enough to cover a wide variety of interests and skills. The SLS will not only benefit students learning, the enthusiasm and connections it makes beyond their specific class will help them throughout their careers and make eventual implementation of the SLS mission a reality.

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