From the Earth to the Moon: A Freshman Seminar

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ABSTRACT

The seminar course for first-year undergraduate students, *From the Earth to the Moon*, deals with both technical and non-technical aspects of space flight, with particular reference to lunar voyages. The goals of the course are to establish a framework for understanding technology and its applications, to present fundamental principles of science and program management, and to motivate students to learn more about the many facets of engineering. As such, the course introduces numerous issues of systems engineering in a broad context, presenting not only science, technology, and mathematics but also the reasons that these subjects are important. Typically, all of the students in the course have studied physics and/or calculus in high school, though half plan to major in the humanities. Thus, the course has dual roles in exposing liberal arts students to details of technology and engineering students to societal impacts of technology.

I. INTRODUCTION

The dream that Jules Verne portrayed in 1865 became reality a century later when Project Apollo landed men on the moon and returned them safely to earth. In the 30 years that have passed since this stunning accomplishment, there has been no follow-up, giving the impression that this feat was an end in itself rather than the first chapter of a new human saga. Our society seems not only to have lost the momentum to build on its achievements in space but to have gone into reverse. The development of technology has continued at an ever-quickening pace, so it is clear that the reasons for this reversal must be found elsewhere. To re-establish human exploration and development beyond Earth orbit, our future leaders must have broad and detailed understanding of the societal, historical, and technical issues that govern space policy.

From the Earth to the Moon is a one-term freshman seminar (presented weekly) that reveals the freedoms and limitations of technology, with a focus on space flight. The course is presented along two parallel tracks. The first deals with the *science and technology* of space flight, including issues of systems engineering, with specific reference to the Apollo program. The seminar provides an introduction to orbital mechanics, launch, and re-entry, as well as to the principles of guidance, navigation, control, communication, space-vehicle design, and rocket propulsion, paying particular attention to lunar travel. The second track treats the *dreams, history, business, and policy* of space flight, beginning in the Second Millennium BC and extending into the foreseeable future. The space program is studied as portrayed in history and science fiction, and an understanding of the critical roles played by organizations, management principles, and budget is developed. In the process, the interplay between technological capabilities and social goals, between inward and outward thinking, between perception and actuality, and between baseness and nobility of purpose are addressed.

A basic philosophy of the course is that technical material must be presented in a context that is real and relevant to first-year students. At this early stage of their academic careers, measuring student performance is less of a concern than is introducing concepts that will reappear during the remainder of their stay in college. Thus, lectures and discussions are aimed at a high level, but students are not expected to respond beyond reasonable norms.

Assignments include problem sets, reading, short papers, and a term paper on the feasibility and rationale for and against future lunar operations. There are right answers to the problem sets but not to the papers. Students are encouraged to pick a point of view and to develop rationales that support it. Tools for symbolic computation

Week	Science & Technology	Dreams, History, Business, & Policy
1	Introductory Concepts	Early History & Fiction
2	Orbital Motion	Early History & Fiction
3	Orbital Motion	Precursors to Space Travel
4	Launch Dynamics & Staging	Early Space Age
5	Rocket Propulsion	Antecedents to Apollo
6	Interplanetary Travel	Apollo & the Space Race
7	Lunar Transfer	Apollo Missions, Astronauts, & Science
8	Spacecraft Attitude Dynamics	Social & Political Impacts of Apollo
9	Spacecraft Guidance & Control	Building the Apollo Vehicles
10	Atmospheric Re-Entry	Evolution of NASA
11	Communications & Tracking	International Cooperation on Space Projects
12	Space Vehicle Design	Business & Project Management

Table 1. Course Outline.

Jerry Sellers, *Understanding Space: An Introduction to Astronautics*, McGraw-Hill, 1994.
Cyrano de Bergerac, excerpts from *A Voyage to the Moon*, 1649 [access from the Web].
Willy Ley, *Rockets, Missiles, and Men in Space*, Viking Press, 1968 [excerpts in course packet].
Jules Verne, *From the Earth to the Moon*, 1865 [access from the Web].
Jules Verne, selections from *Round the Moon*, 1870 [access from the Web].
Walter McDougall, *...The Heavens and the Earth*, Basic Books, 1985 [excerpts in course packet].
Roger Launius, *Apollo: A Retrospective Analysis*, NASA, 1994 [access from the Web].
Andrew Chaikin, *A Man on the Moon*, Penguin Books, 1994.
James Oberg, *Red Star in Orbit*, Random House, 1981 [excerpt in course packet].
Craig Covault, "Soviet Union Reveals Moon Rocket Design That Failed to Beat U.S. to Lunar Landing," *Aviation Week & Space Technology*, Feb. 18, 1991, pp. 58-59.
Theo Pirard, "The Cosmonauts Missed the Moon!" *Spaceflight*, Dec. 1993, pp. 410-414.
Luc van den Abeelen, "Soviet Lunar Landing Programme," *Spaceflight*, Mar 1994, pp. 90-92.
John M. Logsdon and Alain Dupas, "Was the Race to the Moon Real?" *Scientific American*, June 1994, pp. 36-43.
James R. Hansen, *Enchanted Rendezvous: John C. Houbolt and the Genesis of the Lunar-Orbit Rendezvous Concept*, NASA Headquarters, 1995.
Dave Dooling, "L + 25: A Quarter Century After the Apollo Landing," *IEEE Spectrum*, July 1994, pp. 16-29.
G. Jeffrey Taylor, "The Scientific Legacy of Apollo," *Scientific American*, July 1994, pp. 40-47.
Michael Gray, *Angle of Attack*, Penguin Books, 1992.
Joseph G. Gavin, Jr., "Fly Me to the Moon," *Technology Review*, July 1994, pp. 61-68.
Howard McCurdy, *Inside NASA*, Johns Hopkins Press, 1993.
James Oberg, "Russia's Space Program: Running on Empty," *IEEE Spectrum*, Dec 1995, pp. 18-35.
--, *U.S.-Russian Cooperation in Space*, OTA-ISS-618, April 1995.
--, *The National Space Transportation Policy: Issues for Congress*, OTA-ISS-620, May 1995.
Norman Augustine, *Augustine's Laws*, Viking Press, 1986 [excerpts in course packet].
Heinz Koelle, *Handbook of Astronautical Engineering*, McGraw-Hill, 1961 [excerpt in course packet].
Darren Burnham, "Return to the Moon?" *Spaceflight*, Nov 1991, pp. 370-376.
Heinz-Hermann Koelle, "Lunar Development, Past and Future: Part 1 - Apollo was a Race: Post-Apollo Studies," *Spaceflight*, Feb 1993, pp. 48-51.
Mark Hempsell, "A New Pattern for International Space Collaboration: Part 2 - Space Station and Lunar Base Development," *Spaceflight*, Feb 1993, pp. 52-53.
Darren L. Burnham, "Back to the Moon with Robots?", *Spaceflight*, Feb 1993, pp. 54-57.
Thomas J. Frieling, "Return to the Moon to Stay," *Spaceflight*, Dec 1993, pp. 398-401.
Thomas P. Stafford, excerpts from *America at the Threshold: America's Space Exploration Initiative*, Synthesis Group, Arlington, VA, 1991.
Dwayne A. Day, "Doomed to Fail: The Birth and Death of the Space Exploration Initiative," *Spaceflight*, Mar 1995, pp. 79-83.

Table 2. Course Reading List.

and computer-network search are presented and are used in the course.

The seminar is one of 55 freshman seminars offered by the university, and it was the first to be taught by an engineering faculty member. The freshman seminars are designed to enrich the first-year undergraduate experience by enabling students to work closely with a faculty member in small groups exploring significant ideas and documents. The seminar is conducted within a residential college of the university. Enrollment is limited to 15 students chosen for their interest in participating in a rigorous, intellectual endeavor. Approximately three times that number applied for the course in its first two offerings. The seminar counts as a regular university course for both Bachelor of Arts (AB) and Bachelor of Science in Engineering (BSE) students, and it satisfies Princeton's quantitative reasoning distributional requirement for students pursuing the AB degree.

II. Discussion

The course outline is presented in Table 1. The class meets for twelve weeks, with one three-hour session each week. Half of each session is devoted to science and technology, and half is devoted to the dreams, history, business, and policy of space flight. The technical material is presented in lecture format, and the instructor leads a roundtable discussion of the non-technical material.

As indicated by the reading list (Table 2), there are extensive reading assignments of both technical and non-technical material for each session. Students are expected (and eager) to participate in class discussions, and grading is partially based on their contributions. Reading materials are contained in individual books, a 468-page reprint packet, and the lecture notes described below.

Number	Title
1	Getting Started
2	Understanding Orbits
3	Describing Orbits
4	Rocket Performance and Staging
5	Rocket Propulsion
6	Interplanetary Travel
7	Lunar Mission Planning
8	Spacecraft Orientation and Attitude Dynamics
9	Spacecraft Guidance, Navigation, and Control
10	Atmospheric Re-Entry
11	Communication and Tracking
12	Structural Design of Space Vehicles

Table 3. Mathematica™ Notebooks (available at http://www.princeton.edu/~stengel/FRSOut.html).

With the need to present some fairly deep technical concepts in an understandable fashion, it was apparent that using a laptop computer and projector in class would be an important feature. Furthermore, preparing visuals that could be easily modified and used again was attractive. I wanted to be able to present symbolic equations, solve them, and graph them in class, leading me to adopt *Mathematica*™ as a presentation tool. Having made that decision, I could use the notebook feature to provide my own explanations of the material. Twelve notebooks (Table 3) that contain text, executable code, and 2-D and 3-D graphs were prepared. The Mathematica™ notebooks are available on the Internet, and they can be accessed without restriction. (Copies continue to be accessed on the web, even though the course is not in session.) As students generally feel the need for a "real" textbook, we also refer to Sellers's *Understanding Space*, whose workbook format is suitable for freshmen.

Mathematica™ must be resident on the student's computer to execute the code contained in the notebooks; however, the text and code can be read from any PC or Macintosh by downloading *The MathReader* from the Wolfram Research site (http://www. wri.com/). Literal names are assigned to the variables in all equations, as shown in Figure 1. Although cumbersome for number crunching or heavy analysis, this approach makes the meaning of each equation more obvious, and it allows the student to track the roles played by the physical quantities in the algorithm. The notebook sequence also serves as an applications-oriented Mathematica™ tutorial. The power and versatility of Mathematica™ are apparent in the illustration of the

```
EarthGravity = UniversalGravityConstant EarthMass;
MoonGravity = UniversalGravityConstant MoonMass;
EarthPosition = -Barycenter;
MoonPosition = MoonSemiMajorAxis - Barycenter;
RadiusToEarth = Sqrt[(x - EarthPosition)^2 + y^2];
RadiusToMoon = Sqrt[(x - MoonPosition)^2 + y^2];
MeanMotion = N[1 / (Sqrt[MoonSemiMajorAxis^3 /
   GravitationalParameter])];
EffectiveEnergy =
2 (EarthGravity / RadiusToEarth + MoonGravity / RadiusToMoon) +
MeanMotion^2 (x^2 + y^2);
Plot3D[-EffectiveEnergy,{x,-5*10^5,5*10^5},{y,-5*10^5,5*10^5},
PlotPoints -> 60]
```

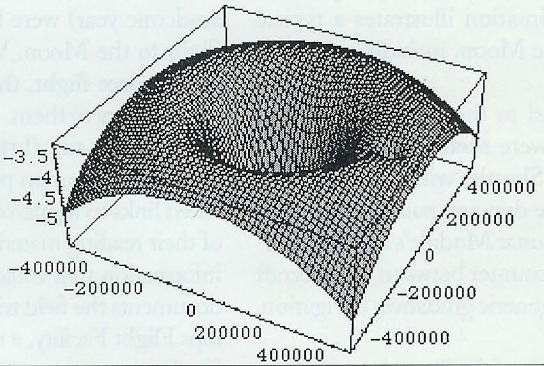

Figure 1. Jacobi Potential Surface for the Earth-Moon system.

```
Signal = Sin[CarrierFrequency  (0.5 InformationWave + 1) Time +
   PhaseAngle];
Plot[Signal, {Time, 0, 100}, PlotPoints -> 80]
```

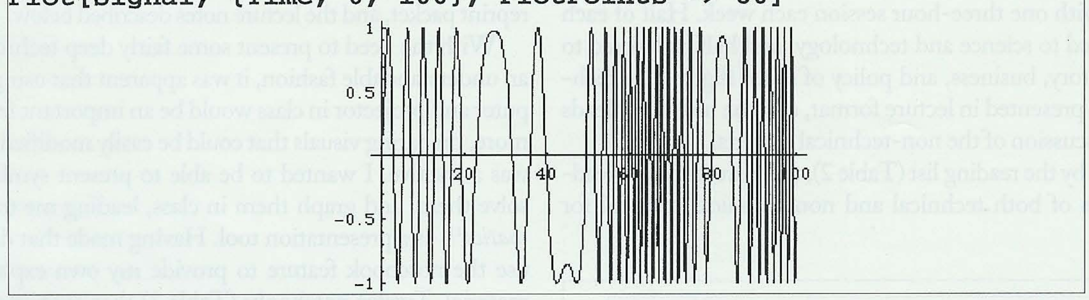

Figure 2. Frequency Modulation Example.

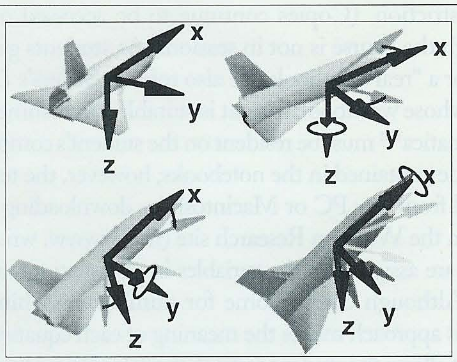

Figure 3. Illustrations of Sequential Yaw-Pitch-Roll Euler-Angle Rotations.

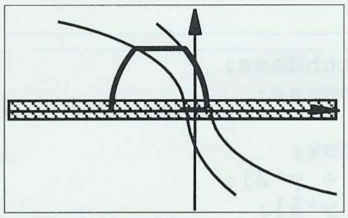

Figure 4. Phase-Plane Logic for Manual Attitude Control of the Apollo Lunar Module showing on-off switching curves and dual-mode rate-command deadband for reaction thrusters.[1]

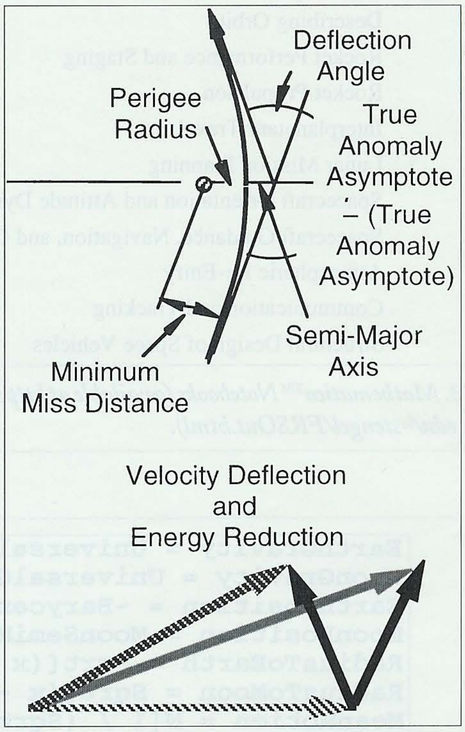

Figure 5. Example of Hyperbolic Encounter showing deflection of the velocity vector produced by a swingby maneuver.

potential wells of the Earth-Moon gravitational system (Figure 1, from Notebook 7) and the effect of frequency modulation of a carrier signal (Figure 2, from Notebook 11).

Working Model ™ was used to simulate three-body trajectories in the Earth-Moon system. This animation illustrates a typical Apollo trajectory from the Earth to the Moon, including the relative motion of the two major bodies.

Computer graphics also contributed to the depiction of other concepts. The Euler attitude angles were sketched using *Swivel 3D*™ to rotate a model of the Space Shuttle, with axes superimposed in *ClarisDraw*™ (Figure 3). The drawing package was used to show the phase-plane logic for the Lunar Module's reaction control system (Figure 4),[1] a hyperbolic encounter between a spacecraft and a planetary body (Figure 5), and a generic guidance, navigation, and control system (Figure 6).

The laptop computer proved to be a useful adjunct in presenting the historic material that tied the course together. An example of the *Timeline of Events Critical to Space Travel* is given in Table 4. The table shows information about concurrent events in science fact, science fiction, and the development of the world. Keep in mind that the first students to take this course (in the 1995–1996 academic year) were born in 1977, five years *after* the last Apollo flight to the Moon. While many of them are keenly interested in future space flight, the actual events of the lunar program are ancient history to them.

The web site (http://www.princeton.edu/~stengel/FRS.html) provided a common point of reference for communication, with updated links to numerous space flight resources. Students found some of their reading material on the web, as well as pointers to additional information that could be used in their assignments. The web page documents the field trip that two classes took to see the NASA Wallops Flight Facility, a rocket launch site on the east coast of Virginia. Furthermore, the web page is an adjunct to informal "distance learning." While the web resources were prepared to support a for-credit

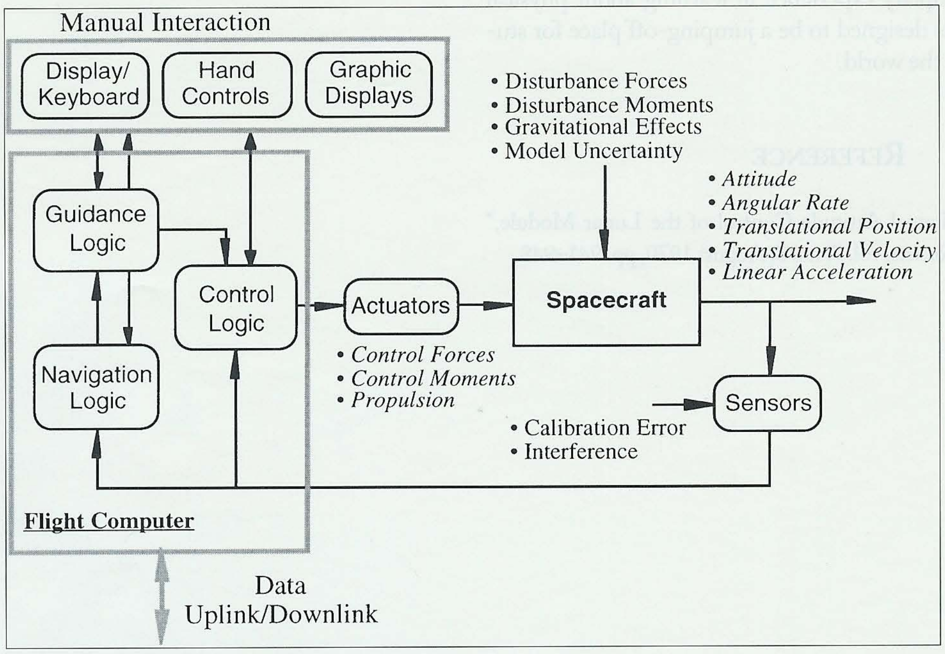

Figure 6. Generic Spacecraft Guidance, Navigation, and Control System.

Date	Science Fact	Science Fiction	World Scene
March 1926	Flight of Goddard's First Liquid-Fueled Rocket		Post WWI
1930-1941	Succeeding Goddard Flights (w/turbopumps)	*Frau im Mond* (1929); BIS Spaceship (1937)	Beginning of WWII; Flight control systems
October 1942	First A4 (V2) Flight		WWII; RMI; JPL
1943-1945	Me-163, Me-263 Rocket Aircraft		Development of radar, computers, telemetry
October 1947	X-1 Rocket Aircraft exceeds Speed of Sound (Mach 1); RMI	Arthur C. Clarke, *Extra-Terrestrial Relays* (1945)	Post WWII
February 1949	V2-WAC Corporal (Bumper) to 393 km	Ray Bradbury, *Martian Chronicles* (1950)	Berlin Blockade
1952	Aerobee-Hi Sounding Rocket in service	Arthur C. Clarke, *The Sentinel* (1951) *[2001]*	Korean War; *Collier's* articles, von Braun *et al*
December 1955	First *Atlas* Flight		Inertial guidance
August 1957	First R7 ICBM Flight (USSR)		Cold War
October 1957	Sputnik 1 launch to orbit		
November 1957	Sputnik 2 launch to orbit (w/Laika)		International Geophysical Year
December 1957	Vanguard rocket failure		

Table 4. A timeline of events critical to space travel—VIII.

course at Princeton, they are available around the world as an introduction to space flight engineering. Positive outcomes include not only the dissemination of knowledge but also increased public awareness of educational programs at the university.

III. Conclusion

Space vehicles are the archetypal "systems" requiring decision and control; they contain many of the elements of science and mathematics that must go into the education of budding engineers and technologically literate leaders. They are important in their own right and as analogs to other dynamic systems. While control systems provide an important component of the entire vehicle, and numerous control systems contribute to the overall mission as well, they must be portrayed in a way that makes their purpose clear, especially for first-year college students.

Freshman seminars provide an excellent opportunity to help students choose career paths, to prepare for advanced courses, and to broaden their perspectives. *From the Earth to the Moon* strives to be more than an exemplary experience in learning about physical and social systems: it is designed to be a jumping-off place for students who will change the world.

Reference

1. Stengel, R.F., "Manual Attitude Control of the Lunar Module," *Journal of Spacecraft and Rockets*, vol. 7, no. 8, August 1970, pp. 941–948.