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Curriculum for Aerospace Architecture

With Emphasis on Lunar Base and Habitat Studies

Donna P. Duerk

September 2004

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Curriculum for Aerospace Architecture

With Emphasis on Lunar Base and Habitat Studies

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GLOSSARY

ALARA	as low as reasonably achievable—the standard for reducing radiation and other risks that are inevitable in spaceflight
APA	American Psychological Association
BFO	blood-forming organs; those organs where blood is formed that are used as an assumed average of the effects of a whole body radiation dose
DCI	decompression illness or “the bends”
ECLSS	environmental control and life support system
EMU	extravehicular maneuverability unit; space suits with power assists for astronaut movements
ESA	European Space Agency
EVA	extravehicular activity, whether in space or on a planetary surface
FTA	fault tree analysis
GCR	galactic cosmic radiation composed mostly of the nuclei of atoms from helium to iron, with the greatest preponderance being helium nuclei or alpha particles
GEO	geosynchronous Earth orbit
GPS	Global Positioning System
Gray (Gy)	a unit of measure for radiation equal to 1 joule/kilogram (J/kg)
Habot	habitable robot; a robotic entity that people live and/or work inside
HZE	heavy, high-energy cosmic rays; these particles do the most damage of all radiation because of the secondary radiation they generate as they crash into other atoms
Isovist	graph of regularity or irregularity in what is visible from a particular position in a room or space
ISRU	In-situ resource utilization
ISS	International Space Station; also called Space Station Alpha and Space Station Freedom in its earlier days
IVA	intravehicular activity or movement inside a space vehicle or habitat
JPL	Jet Propulsion Laboratory
JSC	NASA Johnson Space Center
KSC	NASA Kennedy Space Center
Lagrange points	any of five points between two planetary bodies where the gravity forces are equalized. L-1 in the Earth moon system is that point between the Earth and the moon such that the pull of the Earth is equal to the gravity pull of the moon. L-2 is equidistant on the other side of the moon from Earth, and L-3 is in the moon’s orbit exactly opposite the moon on the other side of the Earth. L-4 and L-5 are at points in the moon’s orbit 60° behind and 60° forward from the moon. There are Lagrange points for the sun/Earth system as well as relative to other planets and the sun.
LEO	low Earth orbit

LLO	low Lunar orbit
MEO	medium Earth orbit
MSFC	NASA Marshall Space Flight Center
microgravity	sometimes called zero gravity because even though there is a small amount of gravity, it feels as if there is none
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
OBPR	Office of Biological and Physical Research
OTV	orbital transfer vehicle
parti	an organizing idea for a design; i.e., a grid can be the organizing idea for a city
PERT	program evaluation review technique
PRA	probabilistic risk assessment
RBE	relative biological effectiveness; a measure of the damage potential of a particular type of radiation; also the Q or quality factor
rocket equation	$\Delta v = Isp \times g \times \ln[M_o/M_e]$, or Change in velocity is equal to specific impulse (in seconds) times force of gravity times natural log function times [mass before burn divided by mass at the end of the burn]
ROI	return on investment
SI	Standard International, metric system of units
Sievert (Sv)	a measure of the radiation dose equal to one Gray times Q, or quality factor
SPE	solar particle event; sometimes called solar proton event = the massive flux of protons, electrons, and atomic nuclei that the sun emits during a solar storm from sunspots
solar cycle	solar storms come and go on an 11-year cycle; in 2003 the cycle was on its way down from the peak in 2000, yet the solar flares of October and November 2003 were some of the largest x-ray emissions ever
SSP	space solar power
TMI	trans-Mars injection; the point in time at which the space vehicle leaves the Earth's or the moon's orbit and enters the Mars transit
USC	University of Southern California
Van Allen Belts	the radiation fields surrounding the Earth, held in doughnut shapes by the Earth's magnetic field; the inner doughnut is mostly protons and the outer one mostly electrons; they were discovered by James Van Allen from the Geiger counter readings of Explorer I and Explorer III satellites

Curriculum for Aerospace Architecture

Emphasis on Lunar Base and Habitat Studies

ABSTRACT

This curriculum for aerospace architecture is for a year-long study for fifth-year undergraduate students of architecture or masters of architecture. It is proposed as one option for students to choose as their capstone experience. Aerospace architecture is a topic within which graduating students can develop and enhance their architectural skills. The field has highly technical aspects that will develop in students a capacity to design in a highly regulated environment. Students will practice the rigors necessary to apply codes, specifications, and technological innovations to terrestrial architecture as well as to aerospace environments. The precision required in the discipline of designing for space will strengthen the abilities of architecture students to design to the less stringent requirements of “ordinary” architecture. This version of the Aerospace Architecture Curriculum is meant to be the foundation for a much richer version that is envisioned for the future when others have added their emphasis and special areas of expertise.

Aerospace architecture projects are exciting. They range from spaceports on Earth to human settlements on the moon or Mars. The students’ experiences in working through this curriculum should inspire them to become a part of the next generation of explorers of space, extreme terrestrial environments, or perhaps to design research facilities where the edges of knowledge are explored—from undersea habitats to biological laboratories.

The curriculum structure follows the precepts of Bloom’s (1956) Taxonomy of Educational Objectives for the cognitive domain. The curriculum takes the form of a framework of objectives, study guides for each objective, a workshop, and one possible schedule for organizing the year’s study to develop a specific aerospace architecture project to the design development phase. The goal is to encourage imaginations to soar.

1. INTRODUCTION

This curriculum aims to be a vehicle for teaching architecture as well as an instrument of inspiration in the tradition of NASA's vision and mission.

The NASA Vision

To improve life here,
To extend life to there,
To find life beyond.

The NASA Mission

To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers
... as only NASA can.
(emphasis added)

1.1. WHAT IS SPACE ARCHITECTURE?

The mission statement for space architecture, developed at the World Space Congress in Houston in 2002 by the American Institute of Aeronautics and Astronautics (AIAA) technical Aerospace Architecture Subcommittee, is as follows:

> *Space Architecture is the theory and practice of designing and building inhabited environments in outer space, responding to the deep human drive to explore and occupy new places. Architecture organizes and integrates the creation and enrichment of built environments.*
>
> *Designing for space requires specialized knowledge of orbital mechanics, propulsion, weightlessness, hard vacuum, psychology of hermetic environments, and other topics.*
>
> *Space Architecture has complementary relationships with diverse fields such as aerospace engineering, terrestrial architecture, transportation design, medicine, human factors, space science, law, and art. (Osburg et al., 2003)*

"***If*** one believes that Aerospace Architecture is an entirely new departure, untied to architectural history, ***then***, one tends to emphasize how different Space Architecture is from Earth Architecture.... ***If*** one believes that Space Architecture stands in a continuum of architectural history, ***then*** one tends to emphasize that human needs are essentially the same in space as on Earth." (Cohen, 2002a, p. 8) For this curriculum, aerospace architecture includes space architecture, which is conceived as an extension of terrestrial architecture, and includes all the terrestrial facilities that support the vehicles to explore and occupy far-distant environments. It includes the practice of the skills necessary to design terrestrial structures and moves beyond them to include the knowledge necessary to design for human survival in space as well as fostering an attitude of exceptional creativity and discovery.

1.2. PEDAGOGY

Bloom codified the basic "learning ladder" that has been used by teachers since the 1950's to track the progress of their students in the mastery of subject matter from the knowing of basic facts to the ability to discriminate between the finer points in the domain. Table 1 outlines the most generic skills in the six levels. The chart was developed from Bloom et al. (1956). The other domains (the affective domain, which emphasizes feeling and emotion; and the psychomotor domain, which emphasizes motor skills), are not emphasized in this curriculum structure, although they are important to the education of the whole person.

Table 1. Skills for mastering subject matter: from knowledge to evaluation.

Competence	Skills Demonstrated
Knowledge	observation and recall of information; knowledge of dates, events, places; knowledge of major ideas; mastery of subject matter
Comprehension	understand information; grasp meaning; translate knowledge into new context; interpret facts, compare, and contrast; order, group, infer causes; predict consequences
Application	use information; use methods, concepts, and theories in new situations; solve problems using required skills or knowledge
Analysis	see patterns; organize parts; recognize hidden meanings; identify components
Synthesis	use old ideas to create new ones; generalize from given facts; relate knowledge from several areas; predict, draw conclusions
Evaluation	compare and discriminate between ideas; assess value of theories, presentations; make choices based on reasoned argument; verify value of evidence; recognize subjectivity

For curriculum design in architecture, these levels of abstraction have been stacked into three levels of ability: ***to know***, which equals Bloom's knowledge competence; **to understand**, which is the equivalent of comprehension; and ***to be able to***, which wraps the three main competencies of design (analysis, synthesis and evaluation) into one category of application.

1.3. STUDENTS' PRIOR PREPARATION

A student arriving at the fifth year of an architectural education or a master's program should have grounding in the liberal arts, the basic sciences, math, computing, and the basics of architectural design and theory. Students come with a variety of skill levels and experiences. Instructors who use the curriculum should understand their students' levels of preparedness. The following are assumed topics of understanding and ability based on their prior years of study:

Architectural history	Basic psychology/sociology	Computer literacy
Architectural theory	Basic biology/physics/chemistry	Basic human physiology
Basic design skills	Critical thinking	Literature
Structural engineering	Mathematics	Principles of sustainability

Within the decade, parts of the data presented in this curriculum will be made obsolete by new discoveries. The structure is designed to set the stage for inquiry and innovation, for questioning and experimentation. Whereas the study guides introduce the main features of aerospace architecture, their content is only the tip of the proverbial iceberg, with pointers to resources for plumbing the depths.

The study guides have three main biases: 1. The *process of learning and discovery* is the most important lesson; 2. *Habitability* is the prime concern for architecture, especially in space; and 3. *Lunar habitats* are emphasized as focal lessons. It is not intended that student projects be limited by these biases, but that the information presented here is focused by them. Thus the order in which the study guides are listed is not the order in which they are to be taught. The syllabus at the end of the curriculum shows the order of introduction to students. Most of the "BE ABLE TO" guides are introduced at the beginning instead of the end so that the students might work steadily toward mastery. The "KNOW" guides are introduced to support project development by the students.

2. LEARNING OBJECTIVES

At the end of a year of study, in a capstone experience of a five-year program in architecture, students should have mastered the following objectives. The topics are those that are specifically addressed for aerospace architecture or are an expansion of design topics for a capstone experience. Many of the topics could be entire courses in their own right. As a result, the treatment of each topic is to denote the main issues rather than being an exhaustive treatise.

2.1. KNOW OBJECTIVES

2.1.1. Science and Exploration

2.1.1.1. Basic solar system science

Students should know the structure of the solar system in terms of the relationships between the objects in the solar system, the types of planets, and the comparative characteristics of the inner four planets and their moons.

2.1.1.2. Space exploration and aerospace history

Students should know the progression of discovery from early rockets and flight to today's launches and the major events and programs that have been the steps toward today's capacities.

2.1.2. Critical Threats to Safety

2.1.2.1. Radiation

Students should know the types of radiation that space travelers face, the countermeasures that are currently available, and the dangers of insufficient countermeasures.

2.1.2.2. Microgravity

Students should know the physiological changes induced by microgravity and the countermeasures necessary for crew health.

2.1.2.3. Safety hazards

Students should know the types of hazards, threats, and associated risks, which must be carefully considered in their designs so that their solutions will be developed to a higher standard of safety than in terrestrial architecture.

2.2. UNDERSTAND OBJECTIVES

2.2.1. Systems

2.2.1.1. Power systems

Students should understand the basics of solar power and nuclear power and their applications to space architecture.

2.2.1.2. Mission operations

Students should understand the difference between mission design and mission operation design and the impact that operations have on the systems that implement the purpose of the mission.

2.2.1.3. Structural systems and pneumatics

Students should understand the structural requirements of hard vacuum, reduced gravity, and various systems such as pneumatics that are currently being used and/or investigated for aerospace structures.

2.2.1.4. Environmental control and life support systems

Students should understand the importance and weight of various life support systems. including air quality and pressure, water quality, temperature and humidity, lighting, food, hygiene, recycling, and trash.

2.2.1.5. Mobility systems

Students should understand the implications of their choice of a mobility system on a planetary surface for rovers, habitat robots, or working machinery.

2.2.2. Concept Development

2.2.2.1. EVA

Students should understand the various concepts for airlocks, space suits, and the difficulties and hazards of extravehicular activity (EVA).

2.2.2.2. Site conditions

Students should understand the impacts on design of a site that has either no atmosphere or an unbreathable one, extreme temperatures, lower than Earth gravity, and high radiation exposure, as well as understanding such issues as topography and climate.

2.2.2.3. Habitability/human factors

Students should understand the impacts of environmental stressors and the associated habitability issues as well as applications at a level of detail that includes human factors for interior spaces.

2.3. BE ABLE TO OBJECTIVES

2.3.1. Design Methods

2.3.1.1. Architectural programming

Students should be able to develop a high-quality program document that is thorough and includes a robust mission statement, relevant issues and goals, practical performance requirements, and innovative concepts.

2.3.1.2. Research

Students should be able to search out, read, and understand the validity of research reports as well as be able to conduct small-scale primary research on their own using the basic scientific method, ethnographic methods, and/or good observation techniques.

2.3.1.3. Problem-solving methods

Students should be able to apply a wide range of design methods for analysis, synthesis, and evaluation in their design processes and be able to use advanced problem-solving skills, from computer analysis to brainstorming, to create innovative solutions to the myriad problems posed in aerospace architecture.

2.3.1.4. Collaboration

Students should be able to work together in various team roles to do research, to design, and/or to create a presentation to the class or to mentors.

2.3.1.5. Communication (write, speak, model, draw)

Students should be able to notice a great improvement in their abilities to communicate in all the modes, from writing a paper for a peer-reviewed journal to speaking before an audience, to modeling a three-dimensional (3-D) walk-through on the computer, to sketching by hand.

2.3.2. Design Framework

2.3.2.1. Mission design

Students should be able to develop coherent mission objectives; choose an appropriate number of people or robots for a mission; and determine its destination, length, and various phases.

2.3.2.2. Systems integration

Students should be able to use the tools of systems analysis to more deeply understand their projects and critically analyze them for quality; they should be able to integrate the wide variety of concerns from safety, habitability, and structure, to aesthetics into the design of facilities for aerospace.

2.3.2.3. Habitat/Habot concepts

Students should be able to develop the inner workings of a large variety of ideas for how to create habitable spaces on planetary surfaces, from "man cans" to habitable robots (Habots).

Note: This document was written in 2003. The web sites listed as references were retrieved as active in December 2003, and they may have moved or been discontinued in the interim. Please search for others that have similar or updated information to enrich the biography for use.

3. STUDY GUIDES INTRODUCTION

The study guides each follow the same basic outline:

Definition of terms and the basic set of concepts

Topics to be covered

Useful questions in the area—to provoke thought, research, and design concepts

Resources, including listed books first, then papers, then sites that were available in 2003 on the web

Activities that can be done by an individual or by the entire class

Activities are suggested as a means to have students dig deeper into the topics with their own research and to contribute their new understanding to the class as a whole; they can also be done in teams. It is not expected that every student will be an expert in each area at the end of the year, but that each student will develop breadth and a depth in several of the areas of understanding and ability. Questions are aimed at the class as a whole to discuss or for teams of students to investigate and report back to the class.

It is assumed that professors using this curriculum will modify the study guides by assigning specific readings, developing additional or alternative questions, and modeling specific activities to suit the significance of the topic for their own educational objectives. In the syllabus at the end of this curriculum is one possible model of the timing and order of the study units and the readings to be associated with each topic. Many of the topics are the subject of a whole course in other disciplines, so these study guides only direct the way toward the fundamental ideas within each topic. It is hoped that any professor or student who wants to go into greater depth can use these guides as a starting point.

None of the study guides stands alone. They are related to each other in the same manner that design issues are related: they often overlap, and a decision in one area will affect another area. For example, the size of the habitat is dictated by the mission design, which includes the decision on the number of crew and what they are to be doing, by the size and weight of the radiation shielding, by the size and weight of the life support system, etc. It is constrained by the lift capacity of the vehicle that moves it or its components out of Earth’s gravity well.

The constraints for making a system that is realistic should not inhibit one’s imagination. The only way to meet the challenges of spaceflight is with new ways of looking at things, new ways of putting things together, and new ways of thinking about how people live and move in the inhospitable environments in space or on planetary bodies.

3.1. SUGGESTED TEXTS FOR REQUIRED READING

Eckhart, Peter: Spaceflight Life Support and Biospherics. Microcosm Press, Torrance, Calif., 1996.

Larson, Wiley J.; and Pranke, Linda K.: Human Spaceflight: Mission Analysis and Design. Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

Connors, Mary M.; Harrison, Albert A.; and Akins, Faren R.: Living Aloft: Human Requirements for Extended Spaceflight. NASA Scientific and Technical Information Branch, Washington, D.C., 1985. Also available on line at http://www.hq.nasa.gov/office/pao/History/SP-483/cover.htm.

3.2. REFERENCES

Burroughs, William E.: This New Ocean. Random House, New York, N.Y., 1998.

Harrison, Albert A.: Spacefaring: the Human Dimension. University of California Press, Berkeley, Calif., 2001.

Mendell, Wendell W., ed.: Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Institute, Houston, Tex., 1985.

Stoker, Carol R.; and Emmart, Carter: Strategies for Mars: A Guide to Human Exploration. Science and Technology Series, vol. 86, American Astron. Soc., San Diego, Calif., Univelt, 1996.

The Design Guide Subcommittee of the AIAA Design Engineering Technical Committee: AIAA Aerospace Design Engineers Guide, Fifth ed., AIAA, Reston, Va., 2003.

Man-Systems Integration Standards. NASA-STD-3000, vols. VI and II, REV-B, NASA, Houston, Tex.,1995 (electronic version: http://msis.jsc.nasa.gov/).

Woodson, Wesley E.; Tillman, Barry; and Tillman, Peggy: Human Factors Design Handbook. Second ed., McGraw-Hill, New York, N.Y., 1992.

3.3. RESOURCES

A wide selection of topics in videos, educator briefs, and teachers' guides is available through:

NASA Educational Products, NASA Spacelink, http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EB.

NASA's Central Operation of Resources for Educators (CORE), http://core.nasa.gov/.

NASA Space Biology, An Educator's Resource, http://spacebio.net/modules/index.html (covers many topics of interest from the point of view of teaching undergraduate biology students).

4. KNOW STUDY GUIDES

4.1. SCIENCE AND EXPLORATION

4.1.1. Basic Solar System Science Study Guide

Students should know the structure of the solar system in terms of the relationships between the objects in the solar system, the types of planets, and the comparative characteristics of the inner four planets and their moons.

4.1.1.1. Definitions

For the purposes of aerospace architecture, the students' knowledge should concentrate on the sun and the terrestrial planets: Mercury, Venus, Earth, its moon, and Mars and its moons, Deimos and Phobos. Also of interrest are near earth orbits (NEOs), the main asteroid belt beyond Mars, and the Lagrange points.The outer, more gaseous planets and their moons are of interest for understanding and exploration, but not for human visitation in the near future.

4.1.1.2. Topics

Review the *structure* of the solar system—the distances from the sun of all nine planets, relative sizes of the planets, their orbital inclinations, axial tilts, asteroid locations, and trajectories.

How do the other *planets compare* to Earth—chemical compositions, mean densities, gravity relative to Earth's, atmospheric composition, surface temperatures, magnetic fields, and relative radiation exposure?

Determine timing for trips to the moon and to Mars.

4.1.1.3. Useful questions

Where does the solar system fit onto the galaxy? Are there likely to be other habitable planets?

What characteristics of the Earth and its place in the solar system make it habitable and why? Atmosphere, magnetic field, chemical composition, water availability, distance from the sun, etc.

Define LEO, MEO, and GEO and their current uses.

What is the utility of going to other planets? To the asteroids? What resources and data might be worth the expense?

What are the Lagrange points? How might they be useful to space travel, resource utilization, space colonization?

What are some of the orbital strategies that have been used to get probes and people to the moon and the rovers to Mars?

What are the easiest trajectories to get to the moon? To Mars? How often can launches be made economically?

4.1.1.4. Resources

Fraknoi, Andrew; Morrison, David; and Wolff, Sidney: Voyages to the Planets. Third ed. (with CD-ROM), Brooks/Cole, Florence, Ky., 2004, (plus others in the series).

There are many astronomy courses on the web. Some good sources that exist in 2003 are:

Hamilton, Calvin J.: The Solar System, http://www.solarviews.com/eng/solarsys.htm, 2001.

Erickson, Lance K.: Sp 200, Planetary and Space Exploration, http://faculty.erau.edu/ericksol/courses/sp200/sp200index.html, and http://faculty.erau.edu/ericksol/courses/sp200/text/ch4_space.htm, 2002 (good diagrams).

NASA, Goddard Space Flight Center: Imagine the Universe. http://imagine.gsfc.nasa.gov/docs/sitemap.html, (a good NASA site for information about the rest of the astronomical bodies from comets to black holes) (nd).

Tsarkon: Space Facts. http://www.geocities.com/CapeCanaveral/Launchpad/2978/facts.html, (good basic facts on the solar system) (nd).

4.1.1.5. Activities

Check out Boston's Museum of Science, Community Solar System, http://www.mos.org/sln/wtu/css.html, 1998, and plot similar objects and distances on your local map—to get the relative scale of the planetary distances from the sun to all nine planets.

Create charts that compare the terrestrial planets, their moons, and the asteroids on such dimensions as chemical composition of atmosphere (if any) and surface, gravity and mass, day and year length, etc.

Make a list of all the characteristics of the moon or of Mars that make it a place unlike the Earth such that it needs special design concepts to resolve the problems of human habitation.

Document the progress of the current satellites and/or rovers exploring the planets and/or moons, noting the latest photos and discoveries.

Diagram the relative distances of the terrestrial planets, the asteroids, the gaseous planets, Pluto, and the Kuiper belt.

Diagram the trajectories and orbits that have been used to get us to the moon and to Mars. Why do they that take form?

4.1.2. Space Exploration and Aerospace History Study Guide

Students should know the progression of discovery from early rockets and flight to today's launches and the major events and programs that have been the steps toward today's capacities.

4.1.2.1. Definitions

Space exploration started with what telescopes could show from Earth. The Montgolfier brothers developed the first feasible balloon flight. *Aerospace history* began with Orville and Wilbur Wright, although humans have longed to fly for most of known history. Exploration moved to satellites when rockets became powerful enough to escape the Earth's gravitational well and the technology of remote sensing came of age. Figure 1 shows the range of rocket types planned in Truman's time. Next came the robotic landers. Finally people went to the moon and to live on the International Space Station (ISS). They dream of going to Mars and the asteroids by combining concepts of rockets and airplanes. The longer-term dream is to inhabit the moon, Mars, and the asteroids and to be able to visit our further neighboring planets and eventually other star systems.

Figure 1. Truman receives rocket models. http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-001678.jpg.

4.1.2.2. Topics

Early rocketry—the basics from Chinese firecrackers to wartime ballistics

The rocket equation

Sputnik and Explorer

Vostok and Mercury

NASA

Gemini

Luna

Rocketry to move payloads further and further

Apollo and Soyuz

Skylab and Mir

Space Shuttle

Satellites: communications to the Hubble Space Telescope Global Positioning System (GPS)

International Space Station

Space probes and rovers

X-planes and the near future

Space and politics

4.1.2.3. Useful questions

What are the major milestones in the history of space exploration?

What are the available rockets/boosters for mission design today?

What are the proposed vehicles that could be used in the near future?

What is missing and needs to be designed for a Lunar habitat program? A Mars program?

What factors are most likely to delay a space project?

Given the rocket equation and known fuels, what are the speed limits for traveling to the moon or to Mars? The simplest version of the rocket equation is: Δv (change in velocity) = Isp (specific impulse in seconds) x g (gravity @ 9.805 meters/second/second (m/sec/sec)) x ln (natural log function)[M_o (mass before burn)/M_e (mass at end of burn), or $\Delta v = Isp \times g \times \ln (M_o/M_e)$.

What have the tragedies (both Russian and U.S.) taught us about the need for safety and reliability?

Which countries have participated in space programs and what were their respective contributions?

What is the basic mission of NASA? What are the major different areas of ongoing research?

4.1.2.3-1. For reflection

Why might the Apollo program be called the largest scientific and technological undertaking in history?

What has the space program offered in terms of international cooperation? How does it work?

How did each of these programs inspire their constituents and change the education emphasis of their respective countries?

What can be learned from the past "man-in-space" programs to help us design moon habitats and other missions to advance the future of aerospace?

4.1.2.4. Resources

Burroughs, William E.: This New Ocean. Random House, New York, N.Y., 1998.

Harland, David M.: The Mir Space Station: Precursor to Space Colonization. John Wiley & Sons, Inc., New York, N.Y., 1997.

European Space Agency (ESA) Home page: http://www.esa.int/export/esaCP/index.html, 2003.

Goodman, Jason: Highest Speed for Human Space Travel. http://www.madsci.org/posts/archives/apr2001/988035420.Ph.r.html, 2001 (explains the rocket equation, etc.).

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4.1.2.5. Activities

4.1.2.5-1. Timelines

Develop an illustrated timeline for major rocket development from the ballistics of World War II to current technology, showing sizes, motor configurations, and lift capacity. Who were the people who made the major advances? Include failures in all timelines.

Develop an illustrated timeline of lunar exploration.

Develop an illustrated timeline of Mars exploration.

Develop an illustrated timeline of a particular type of satellite development (i.e., GPS, communications).

Develop an illustrated timeline of space stations/labs.

Develop an illustrated timeline of solar system probes for one area (i.e., Sun, outer planets).

Develop a timeline for the space race between the United States and the then USSR. What were the major events that sparked the competition? How has the incidence of discovery changed over time?

4.1.2.5-2. Reports

Create a report that documents the Gemini, Luna, Apollo, or Soyuz program in terms of what information was gained that is useful for future exploration and habitation. A map of landing sites would be useful for Apollo and Luna.

Create a report that documents the Mir, Skylab, Salyut, or ISS program in terms of what information was gained that is useful for future exploration and habitation. Focus on one aspect.

Diagram the design concepts that have proven successful for carrying humans into space, for landing them, or for moving them around on the moon's surface. Diagram as many hypothetical ones as you can find.

Apollo brought back samples of moon rocks and dust. Report on the advances in one aspect of the science of discovery or space transportation from one of the programs mentioned (do not include the chemical compositions of the air and soil of the moon or Mars).

4.2. CRITICAL THREATS TO SAFETY

4.2.1. Radiation Study Guide

Students should know the types of radiation that space travelers face, the countermeasures that are available, and the dangers of insufficient countermeasures.

4.2.1.1. Definitions

Radiation comes in two basic types, ionizing and nonionizing. Most of the radiation on Earth in our everyday lives is *nonionizing*: radio waves are longest, then come microwaves, infrared, visible light waves (which vary in length with color), and ultraviolet. These rays are damaging when they transfer their energy (usually in the form of heat) to living tissues or delicate electronics.

Ionizing radiation is "radiation that has enough energy to eject electrons from electrically neutral atoms, leaving behind charged atoms or ions. There are four basic types of ionizing radiation: alpha particles (helium nuclei), beta particles (electrons), neutrons, and gamma rays (high-frequency electromagnetic waves, x-rays are generally identical to gamma rays except for their place of origin). Neutrons are not themselves ionizing, but their collisions with nuclei lead to the ejection of other charged particles that do cause ionization." (Glossario, nd) This radiation does its damage by ionizing the atoms it hits as it passes through body tissue or some other material, in addition to giving off gamma rays. There are three major sources of ionizing radiation in space: the Van Allen Belts, the sun, and galactic cosmic radiation (GCR).

4.2.1.2. Topics

4.2.1.2-1. Sources of ionizing radiation

For space travelers ionizing radiation is the most dangerous.

The sun normally gives off electrons and protons in the solar wind, but in the 11-year solar cycle of sun spot activity it creates vast quantities of radiation in solar particle events (SPEs). These events are hard to predict accurately with more than a few hours' warning. The quantity of ionizing radiation is enough to kill an insufficiently shielded person. Most of the sun's radiation is trapped by the Earth's magnetic field or absorbed by its atmosphere and does not get to the ground. Sunburn comes from the ultraviolet rays that do get through.

The Van Allen Belts are doughnut-shaped fields of radiation particles that surround the Earth. The inner belt is mostly protons and the outer belt is mostly electrons. These charged particles are held away from the surface and trapped by the Earth's magnetic field so that orbits in low Earth orbit (LEO), up to approximately 400 kilometers (km), have low radiation exposures (Simonsen and Nealy, 1991). The Aurora Borealis and Australis are the visible light generated by the energy of the trapped particles from the solar wind or solar storms.

Galactic cosmic radiation (GCR) is made up of higher-density atomic nuclei starting with the lowest, helium (#2), to iron (#26), which is the highest that comes through with any frequency. Many of these particles are extremely high energy (HZE) and can do a great deal of damage. As GCRs pass through tissue they scatter atomic particles (electrons, protons, neutrons, gamma rays, etc.) with each collision, and the secondary radiation can be quite harmful. GCRs are at a consistent low level and are counted as background radiation on Earth's surface. In space, the levels are inversely proportional to the sun's storm activity due to the changing magnetic field of the sun (Simonsen and Nealy, 1991, and Wilson et al., 1997).

The effects of ionizing radiation on humans would be quite easy to measure if it were only a matter of measuring the energy of the particles, but different particles have different abilities to cause damage, and different parts of the body are more susceptible to radiation than others. Initially, the *rad* was the unit of measure (100 rads = 1 joule/kilogram (J/kg)) of radiation in terms of energy transferred per weight of material. The *rem* was used to signify the effect of radiation on a person. More recently, the standard international units have become the Gray (Gy) and the Seivert (Sv). Both sets of units show up in the literature.

Radiation Dose	1 Gray (Gy)	=100 rad	=1000 mGy	=1 J/kg	=10000 ergs/gram (ergs/g)
Biological Equivalent Dose	1 Sievert (Sv)	=100 rem	=1000 mSv	=100 cSv	=Gy X Q factor

(Eckhart, 1996)

Relative biological effectiveness (RBE) or Q (quality) factor is the relative damage done by a particular type of radiation (Setlow et al., 1996):

Type of Radiation	RBE
photons, all energies	1
gamma rays	1
electrons, muons, all energies	1
Neutrons < 10 kilo electron volts (keV)	5
10 keV to 100 keV	10
100 keV to 2 million eV (MeV)	20
2 MeV to 20 MeV	10
20 MeV	5
protons > 2 MeV	2–5
alpha particles, heavy nuclei	20

HZE rays are the most damaging. Some sources estimate that the Q factor for GCRs may be as much as 30.

It is estimated that in the U.S. the average *background radiation* is ±3.6 milliSieverts (mSv); the annual yearly whole-body limit for the average population is set at 5.0 mSv and for radiation workers at 50.0 mSv. Sometimes radiation to blood forming organs (BFO) is treated as equivalent to whole-body radiation.

Average Whole-Body Radiation Dose/Year	
Natural Sources:	
Cosmic	0.29 mSv
Terrestrial	0.29 mSv
Radon (varies by location)	2.00 mSv
Internal (K-40, C-14, etc.)	0.40 mSv
Man-made:	
Diagnostic x-ray	0.39 mSv
Nuclear medicine	0.14 mSv
Consumer products	0.11 mSv
All others (fallout, air travel)	0.02 mSv
Average annual total	3.6 mSv/year
For smokers, add 2.8 mSv/year (Zeitlin et al., 2003).	

Radiation sickness levels are caused by much higher doses than the prescribed limits for a healthy person because radiation effects build up over time and can cause delayed effects such as cancer, genetic abnormalities, and cataracts.

Dose	Probable Effects
0–500 mSv	≈ No obvious effects; possible minor blood changes
500–1000 mSv	≈ Radiation sickness in 5 to 10 percent of exposed personnel; no serious disability
1000–1500 mSv	≈ Radiation sickness in 25 percent of exposed personnel
1500–2000 mSv	≈ Radiation sickness in 50 percent of personnel; some deaths anticipated
2000–3500 mSv	≈ Radiation sickness in nearly all personnel; ±20 percent deaths
3500–5000 mSv	≈ Radiation sickness; about 50 percent deaths
10000 mSv	≈ Probably no survivors

An astronaut’s chance of fatal cancer is increased by ±2 to 5 percent for each 500-mSv dose of exposure (Eckhart, 1996).

The topic of radiation *dose* is further complicated by the fact that certain parts of the body are more sensitive to damage by radiation than others. Those organs of highest sensitivity are the lung, breast, stomach, and colon. Those of least sensitivity are the skin, gall bladder, bone, kidney, and spleen. The body heals itself relatively well, so that a series of small doses that accumulate over time are less life threatening than a massive dose all at once. Most of the data on the effects of massive radiation doses come from the aftereffects of the bombs dropped in Japan in World War II. Most of that radiation was composed of neutrons, so the translation to the effects of GCRs and SPEs is not equal.

A trip to the moon, similar in parameters to the Mars trip (following), would yield a dose of approximately 50 mSv.

Estimated doses for a 460-day trip to Mars in a craft with a shell of 0.75-centimeters (cm) aluminum, at solar minimum, would be:

Outbound through the Van Allen Belts	<20 mSv
Earth to Mars (205 days/GCR)	320 mSv
Thirty days on Martian surface (GCR)	23 mSv
Mars to Earth (225 days/GCR)	350 mSv
Inbound through Van Allen Belts	<20 mSv
Total	±730 mSv over 460 days

This level of radiation exposure could be expected to increase the risk of mortality from cancer for a 35-year-old male by 1 percent. Much more research needs to be done on the effects of GCRs (Eckhart, 1996). A more realistic journey to Mars would last 500 to 600 days on the surface instead of 30, and would give higher doses.

4.2.1.2-2. Shielding from radiation

Shielding from radiation in space is a serious enterprise, because the levels of radiation to which an astronaut is subjected could be harmful and, under the worst circumstances, fatal.

A typical *strategy* for shielding design would be: 1. Predict risk from a specific mission scenario. 2. Design architecture to accomplish mission. 3. Redesign until risk is acceptable at a reasonable cost (as low as reasonably achievable = ALARA) (Wilson, 1997).

New *materials* are being investigated all the time to develop a combination that shields well and does not have a high mass penalty. Using stored water or fuel as a radiation shield also has been proposed as a partial solution to the shielding problem. Safe havens are prescribed for SPEs if the flight is at the high solar storm part of the 11-year cycle. On a planetary surface, the strategies suggested are to bury a habitat or lab under the regolith by two or more meters or locate near the cliff wall of a crater (Simonsen, 1991).

Geometry plays an important part in radiation shielding. A spherical or cylindrical shape is very efficient for the surface-to-area ratio of materials use. One of the features of such shapes is that the secondary radiation is the maximum at the center of a sphere or a cube and at the axis of a cylinder, making those the areas where the highest doses of secondary radiation would be received.

Some *countermeasures* being investigated include certain drugs (such as vitamins A and E, and atropine) that block some of the effects of radiation.

4.2.1.3. Useful questions

Can you identify the sources of ionizing and nonionizing radiation in your daily life?

How many different ways can you think of to contribute to radiation shielding for the crew on a trip to the moon? On the surface? How might the two solutions differ?

How might you create a safe haven for a four-person crew on an orbital transfer vehicle (OTV) on its way to the moon?

What are the different methods of shielding for the different types of radiation in space?

How would orbits in LEO, medium Earth orbit (MEO) and geosynchronous Earth orbit (GEO) differ in their doses of radiation? What is the South Atlantic Anomaly, and how does it affect orbits in LEO?

4.2.1.4. Resources

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Eckart, Peter: Shielding Requirements and Concepts. Lunar Base Handbook, Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

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Stetlow, R. B.; Dicello, J. F.; Fry, R. J. M.; Little, J. B.; Preston, R. J.; Smathers, J. B.; and Ullrich, R. L.: Radiation Hazards to Crews of Interplanetary Missions: Biological Issues and Research Strategies. Space Studies Board, National Research Council, National Academy Press, Washington, D.C., 1996.

Wilson, J. W.; Miller, J.; Konradi, A.; and Cucinotta, F. A.: Shielding Strategies for Human Space Exploration. NASA Conference Publication 3360, 1997.

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Siddalingaiah, Madhu: Working with X-Ray Tubes Harmful? The Mad Scientist, http://www.madsci.org/posts/archives/aug98/899615850.Eg.r.html (the main web site (www.madsci.org) is good for questions to scientists on many different topics).

NASA: Hot Shots from SOHO. http://soho.nascom.nasa.gov/hotshots/ (images of the 2003 sunspot eruptions).

4.2.1.5. Activities

Locate the ISS and the satellites that are known to be still working in relationship to the Van Allen Belts. Predict the approximate radiation levels that would be experienced over a six-month period.

Diagram all the different concepts for shielding a habitat on the moon’s surface that you can think of on your own; then check to see what others have done.

There are many artists’ concepts for moon or Mars habitats. From what you have learned, rate the images for what you can learn about their level of radiation protection. How would you propose improvements?

Diagram the trip to the moon of one of the Apollo missions and show what type of radiation the crew was subjected to on each part of their trip. Your research should be able to find the official estimated doses.

Find as many different materials as you can that are used in making space transportation or habitats. Can you find out what their shielding capacity is for different types of radiation?

What are some of the basic shielding concepts for vehicles that will travel to Mars?

List as many different ways as you can think of to shield a crew from radiation on the way to the moon and on the moon’s surface. Think of every opportunity at every scale. What opportunities are there for having materials serve their function plus added radiation protection? What differences should there be for Mars?

4.2.2. *Microgravity Study Guide*

Students should know the physiological changes induced by microgravity and the countermeasures necessary for crew health.

4.2.2.1. Definitions

There are many *somatic* and *physiological effects* from microgravity on bodies that have evolved under the pressure of gravity. The first one that strikes astronauts is *space sickness*. It is very much like sea sickness in that it is brought on by the effects that weightlessness has on the inner ear and its correlates of visual perception. It usually lasts up to three days. Illusions are also attributed to the weightless state (Connors et al., 1985).

An immediate adaptation to microgravity is the "*neutral body position*," which is a very relaxed posture: the head is tilted forward, the back is gently curved, and the arms and legs are bent (NASA-STD-3000, 3.3.4.3-1). The spine elongates as much as 2 to 3 cm over the first few weeks of flight (Vogt, 1998). Notice the neutral body position in Figure 2.

Figure 2. Christa McAuliffe experiences weightlessness during KC-135 flight. http://grin.hq.nasa.gov/ABSTRACTS/GPN-2002-000149.html.

After being in microgravity for a short while, bodily *fluids start to pool* in the upper parts of the body because the circulatory system is designed to push fluids up—against gravity. Faces become puffy, and congestion and head colds become more of a nuisance. The body reacts to this state of affairs by increasing urine output and dehydrating (Eckhart, 1996).

Over a longer period of time one's *muscles start to weaken* because they do not have to work pushing against gravity. The heart muscles do not have to work as hard either, so they weaken as well. Muscles not pushing on bones leads to bone loss and weakening (osteoporosis). It has been estimated that astronauts loose about ±1.5 percent of the calcium in their bones per month of weightlessness. Because of this, there is a tendency toward kidney stones (Connors et al., 1985). It is not known whether this tapers off after a long period of time, or whether the loss rate is sustained indefinitely.

Lowered immune response is also a feature of living in weightlessness. T-lymphocytes have been found to behave differently in space: they do not multiply properly, they do not move or signal each other well, and they are less able to destroy invaders. Astronauts are thus more susceptible to viruses (Eckhart, 1996).

Over time one adapts to the microgravity environment and can almost swim through it like a fish in the ocean, but *returning to Earth* can be a problem with weakened muscles, bones, and a sluggish circulatory system. Another effect is called *orthostatic intolerance*, meaning that when one returns to gravity, one tends to lose one's balance easily and is unsteady and/or dizzy when upright (Connors et al., 1985). Readaptation to full gravity takes time commensurate with the amount of time spent in microgravity.

4.2.2.2. Topics

Artificial gravity is one countermeasure for microgravity. It can be generated by rotating the space vehicle: the larger the diameter, the slower the rotation needs to be to create 1 g. The faster the vehicle rotates, the more likely the crew is to become disoriented from the rotation (coriolis force) (Hall, 1999). Some options are to create a tether system (largest diameter spin circle), to have a rigid connection with a mass that rotates the system (smaller diameter), to create a centrifuge within the spacecraft (smallest diameter).

Exercise is also somewhat of a countermeasure to muscle weakening, but is insufficient to maintain full fitness. Research is being done on vibration machines that will stimulate bones to maintain their strength and calcium levels (Space Research, 2002). Many people in wheelchairs who suffer osteoporosis are also interested in the outcome of this research.

Drugs and *training* prior to flight seem to be ways to help lower the probability of space sickness.

Lower body negative pressure suits have been devised to help reverse the fluid pooling in the upper body. Spending time in a centrifuge also helps.

A strong sense of *local vertical* helps to mitigate the potential for visual illusions.

All work stations must be designed for the efficient use in *neutral body position*—considering the decreased reach, the visual angle, and the need to be stabilized in space.

4.2.2.3. Useful questions

What might you do in addition to spending time in a swimming pool to more completely visualize what it is like to be in microgravity?

How many ways can you think of to reinforce the local vertical on the ISS? On a trip to Mars?

Many astronauts create some fun by zooming through the space station like Peter Pan. What features can you think of that would enhance the joy of "flying"?

What training do astronauts go through to combat the effects of microgravity?

What practices on the ISS are designed to combat the negative effects of weightlessness?

What are the hypothesized effects of the moon's 1/6th gravity? Of Mars's 1/3rd gravity?

4.2.2.4. Resources

Connors, Mary M.; Harrison, Albert A.; and Akins, Faren R.: Living Aloft: Human Requirements for Extended Spaceflight. Chapter II. NASA Scientific and Technical Information Branch, Washington, D.C., 1985.

Vogt, Gregory L.: Suited for Spacewalking: A Teacher's Guide. NASA Office of Human Resources and Education, Washington, D.C., 1998.

Hall, Theodore W.: Inhabiting Artificial Gravity. AIAA Space Technology Conference, Albuquerque, New Mexico, 1999.

NASA Spacelink, http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html NASA Educational Products, 2003.

Space Research, OPBR, Bone Research, http://spaceresearch.nasa.gov/research_projects/shaken_lite.html, 2002.

NASA Aerospace Scholars: Life in Zero-G, http://aerospacescholars.jsc.nasa.gov/HAS/cirr/ss/2/8.cfm, Johnson Space Center, 2003.

*Note: NASA occasionally reorganizes its web sites, so you may have to search for topics of microgravity, etc.

4.2.2.5. Activities

Spend time in the swimming pool imagining the weightlessness of spaceflight. Imagine sleeping, working at a computer, eating. Ideally you will have diving gear on and can maintain neutral buoyancy.

Alternately, if you are ambitious, spend time lying down with your head slanted at –6°—this is the bed rest position used in weightlessness simulations. Document your experiences.

Numerous videos and online movies about weightlessness are available. Watch several and notice what designed elements are specifically for assisting weightless astronauts.

Find as many different solutions as you can to the problem of creating artificial gravity with a small centrifuge. Write a report about all the different circumstances you can think of where these ideas could be useful.

Write a report about the recovery from flight by the longest-term cosmonauts and astronauts. What were their physical reactions and how long did it take them to recover fully? What can you find out about their physical regime during that recovery period?

Write a scenario of what you might do in one day aboard the ISS? How would you get dressed in weightlessness? Take a bath? Fix a small machine? Use a computer?

How might you cope with the effects of weightlessness? Write an essay about your imaginings.

Diagram the different solutions you can find for creating artificial gravity. What is the range of scales?

4.2.3. Safety Hazards Study Guide

Students should know the types of hazards, threats, and associated risks that must be carefully considered in their designs so that their solutions will be developed to a higher standard of safety than in terrestrial architecture.

Figure 3. Saturn V Apollo preparations for launch with escape rocket tower. http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-000625.jpg.

4.2.3.1. Definition

The accidents of Gemini 8, Apollo (1 and 13), Soyuz (1, 11, and others), Challenger, and Columbia, as well as the Mir/Progress collision, have made it painfully clear that space travel is impossible to make perfectly safe and still fly. The framework for making spaceflight possible is *risk management*. The protocol is to assess the hazard; design to preclude; if unable to preclude, design to control; if unable to control, design a workaround; if unable to design an acceptable workaround, then ask if the residual risk is acceptable because the impact on health or mission is limited, or is there a high improbability of the hazard causing harm or mission degradation?

If worse comes to worst, and there is a catastrophic event, then how might the *crew survive*? The prevailing notions consist of creating safe havens with consumables available for survival for a certain period of time, and the mechanics and vehicles of escape and rescue. Because no vehicle is flawless, escape systems are necessary. The Apollo escape rocket is pictured prior to launch from Kennedy Space Center (KSC) in Figure 3.

4.2.3.2. Topics

Threats are situations that endanger the crew, the facility, or the mission.

Fires or explosions are probably the most dangerous and most probable accidents on board a spacecraft or contained habitat. Fire alarms and quick fire suppression are vital to the survival of the astronauts. Cleaning up the contamination of smoke or a toxic leak caused by an accident is also necessary for health. Protection of the astronauts until they can clean up after a fire plays a significant role as well. Numerous fires have occurred, so previous responses can be examined. If multiple modules are involved, isolation between modules is critical to fire recovery.

Leakage or sudden *loss of air pressure* can be fatal. One can live without oxygen for only four to six minutes. Slow leaks should be detectable by onboard sensors before they cause hazardous conditions.

Tumbling or *loss of control* of a spacecraft or space station is dangerous, not only because it can disorient the crew, but also because it may lead to a degraded orbit. A parallel situation would be an astronaut out of control in EVA or even in intravehicular activity (IVA). An internal crew member must take extraordinary measures to rescue an EVA astronaut in trouble.

Biological or toxic *contamination* can make the crew sick gradually or suddenly. A sick crew is unable to perform at full function. Cleanups from spills need to be designed with the given availability of cleaning equipment, air changes, and the efficiency of filtration.

Injury or illness may be serious enough to shorten the mission to return the crew member to Earth's medical care if the situation cannot be relieved by telemedicine. A Mars trip would preclude such a return after leaving Earth's gravity and entering the trans-Mars injection (TMI) stage.

Mechanical damage could require the crew to divert their energies to fixing the broken parts or may require that some equipment becomes unusable due to the degradation of the mission or habitability of the environment.

Vibrations from onboard equipment or from docking maneuvers or even crew activities may cause oscillations that are hazardous to the stability of a spacecraft. Long-term vibrations may compound problems with structural corrosion or erosion. The noise from mechanical vibrations can be detrimental to the crew's comfort and hearing.

Consumables depletion could happen if some freezer or bioregeneration plant failed such that there was not enough food or potable water available on a long-term mission. Amounts of consumables must be carefully balanced between the levels needed for use and their weights. Other consumables depend upon the mission and the types of chemical processes used.

Orbit decay to the point of an imminent fall to the planetary surface would require either a major boost to a suitable orbit or an escape and rescue for the crew.

Collision of vehicles, whether manned or unmanned, can cause mechanical failures, loss of air pressure, fire, or an explosion. Or a collision might dent the docking mechanism, making the hatch inaccessible so that supplies and/or crew cannot be transferred from one vehicle to another as scheduled.

Structural erosion is a long-term threat that must be managed. In a hard vacuum such as in LEO or on the moon, materials off-gas and become weaker over time. New materials are being developed and tested to discover how long they might be expected to last. The ISS is designed so that the structure can be inspected and tested at regular intervals.

Debris from satellites that have "died" in orbit, from the discarded early stages of some rockets, and other "space junk" can be dangerous for launch and any low orbits around Earth. As of June 2000, 8927 man-made objects are being officially tracked: some are satellites still working, some are probes that did not make it out of orbit, some are just pieces of stuff—from bolts to chips of paint. Other dangers from penetration come from micrometeoroids that are of a non-Earth origin (Britt, 2000).

Corrosion such as rust is part of the life cycle of many materials. It can be caused by interaction with the atmosphere (monoatomic oxygen in space), or by coming into contact with some other substance that chemically interacts. See http://setas-www.larc.nasa.gov/LDEF/ for information about the Long Duration Exposure Facility at Langley Research Center.

Radiation dangers to equipment should not be underestimated. See the Radiation Study Guide for more information.

Planet protection becomes important if there are biological or chemical hazards that may be brought back to Earth from Mars or the moon. None have yet been detected, but precautions are warranted. The reverse is also true. It is important to protect the moon and Mars from possible Earth contamination especially if we intend a long term human presence.

4.2.3.3. Useful questions

How many missions have been shortened or endangered by the incidence of one of the threats listed previously?

What design mitigation can you imagine for any of these threats? Which are not threats that could be "designed away"?

How are these dangers managed on the ISS?

4.2.3.3-1. For reflection

What levels of redundancy seem necessary for a very high probability of mission success?

4.2.3.4. Resources

Peercy, R. L., Jr.; Raasch, R. F.; and Rockoff, L. A.: Space Station Crew Safety Alternatives Study—Final Report. Vols. I–V, NASA CR-3854, 1985.

Foale, Colin: Waystation to the Stars. Trafalger Square Publishing, North Pomfret, Vermont, 2000.

Valentin, Vital Evich Lebedev: Diary of a Cosmonaut: 211 Days in Space. Phytoresource Research, 1988.

For other first-person accounts of life and safety issues in spaceflight, see the syllabus.

Britt, Robert Roy: Space.com, Space Junk: The Stuff Left Behind. http://www.space.com/spacewatch/space_junk.html, 2000.

4.2.3.5. Activities

Document how the Mir and ISS astronauts managed to deal with fires, collisions, and/or loss of air pressure.

List the components of a safe haven for an orbiting station, for a moon habitat, for an orbital transfer vehicle. Document the safest spots on the ISS.

Make a list of criteria for an escape vehicle for the ISS or for a moon colony.

Document the escape and rescue systems that have been used or considered.

Read a couple of the first-person accounts of the emergencies on Mir or Apollo and write your reflections and hypotheses on what might have been designed differently to make the environments safer.

Make a list of safety criteria for your own project.

5. UNDERSTAND STUDY GUIDES

5.1. SYSTEMS

5.1.1. Power Systems Study Guide

Students should understand the basics of solar power and nuclear power and their applications to space architecture.

5.1.1.1. Definitions

Great amounts of power are needed to move mass into orbit, another type of power is needed to run the life support systems and machinery of a spacecraft, and even more power is needed to run a habitat or laboratory on the surface of a planet. This unit explores a variety of options for power supply other than launch.

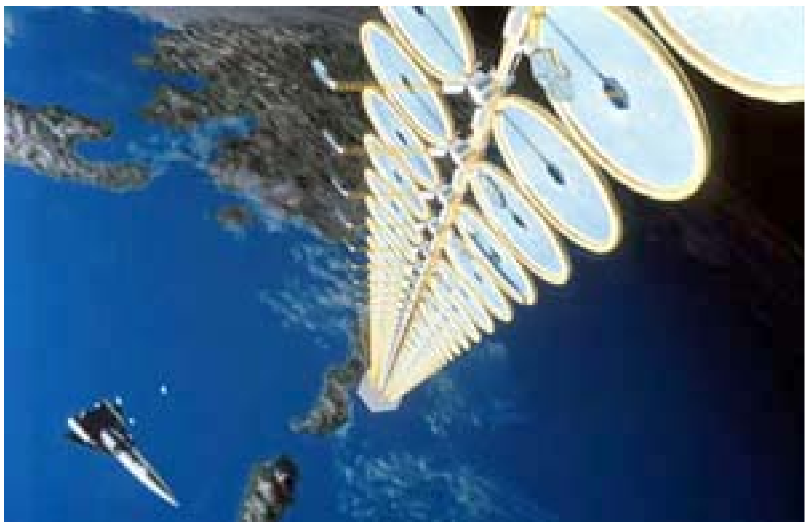

Figure 4. Space solar power (SSP) concept. http://www.grc.nasa.gov/WWW/tmsb/secondaryconc/doc/rsc_ssp.html.

5.1.1.2. Topics

Solar power has long been envisioned as a clean, cheap, almost-free energy source. That vision has not come to pass as yet because a system that efficiently converts the readily available solar energy into electric power has not yet been developed. The very best efficiency to date (2003) seems to be under 25 percent, but with every conversion to microwaves or other form, or beam to a distant source, more is lost. The structures to capture, convert, and beam solar-generated energy are as yet more expensive than conventional terrestrial sources, but are far more portable in terms of satellites and other space structures. Figure 4 shows a possible design for a solar power satellite.

Nuclear energy is very compact and more efficient than solar energy, and is envisioned as the type of energy plant used initially on the moon's surface because of the energy storage problem for the two-week long Lunar "night." The benefit of a small amount of mass for a large amount of power cannot be overestimated at this point in time. The disadvantages of adding to the radiation exposure of the crew, having to deal with the radioactive wastes, and having to deal with a potential accident make nuclear power a less-than-perfect energy source.

Unless there is a discovery that there are volcanic thermal resources on Mars, the choices for *long-term energy* supplies are between solar and nuclear. The questions then become where to position the power sources, how big to make them, and how to transfer the energy to its point of use.

Many of the concepts for rovers, robots, and habitats have solar power sources and radiators integrated into their structures. As long as the level of power generated is sufficient for the tasks at hand, this is a viable alternative. Storage of solar power is still an issue.

With the use of nuclear power, the power station is often placed at a safe distance from the inhabited portions and beamed to the point of use. Solar power might also be generated in large installations and beamed across the surface of a planet. One concept is to build a receiver at the Lunar south pole, where there is continuous sunlight, and beam the captured power (by microwave or laser) via transfer stations to habitats during the Lunar night.

Other *options* have been presented for establishing large power stations in space, either in orbit or at the Earth/moon Lagrange points and beaming power to the planetary surface, to vehicles in transit, or even to Earth. If power is beamed to Earth, it is assumed that solar power will be converted to microwaves and received in very large rectenna fields in unpopulated areas. The assumption is that the power at the receiving end will be low enough not to harm vegetation or herd animals and agriculture could thrive underneath.

5.1.1.3. Useful questions

Imagine your home or office as "off the grid." How would you supply affordable power for all the functions? What storage capacity would you need?

How would your choice of power systems influence your design for a colony, habitat, rover, or space transit vehicle?

What physical parts of a power system would need to be incorporated in a long-term colony for the moon or Mars? What are the relative sizes and weights of the parts that need to be considered?

5.1.1.4. Resources

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Larson, Wiley; and Pranke, Linda, eds.: Designing Power Systems. Human Spaceflight: Mission Analysis and Design. Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

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GRIN, Great Images In NASA, http://grin.hq.nasa.gov/ABSTRACTS/GPN-2003-00108.html.

5.1.1.5. Activities

Develop a set of diagrams that outline the different basic concepts for a solar-powered satellite.

Document the concepts using nuclear power in space colonies and the safety requirements.

Develop a graphic library of concepts for beamed power solutions.

List the criteria you would use for choosing a power system; how many are mission specific?

Investigate the latest research on power supplies. Graphically document the possible solutions.

If you could imagine a new way to create power for a Lunar expedition, what might it be? Obey the laws of physics.

5.1.2. Mission Operations Study Guide

Students should know the difference between mission design and mission operation design and the impact that operations have on the systems that implement the purpose of the mission.

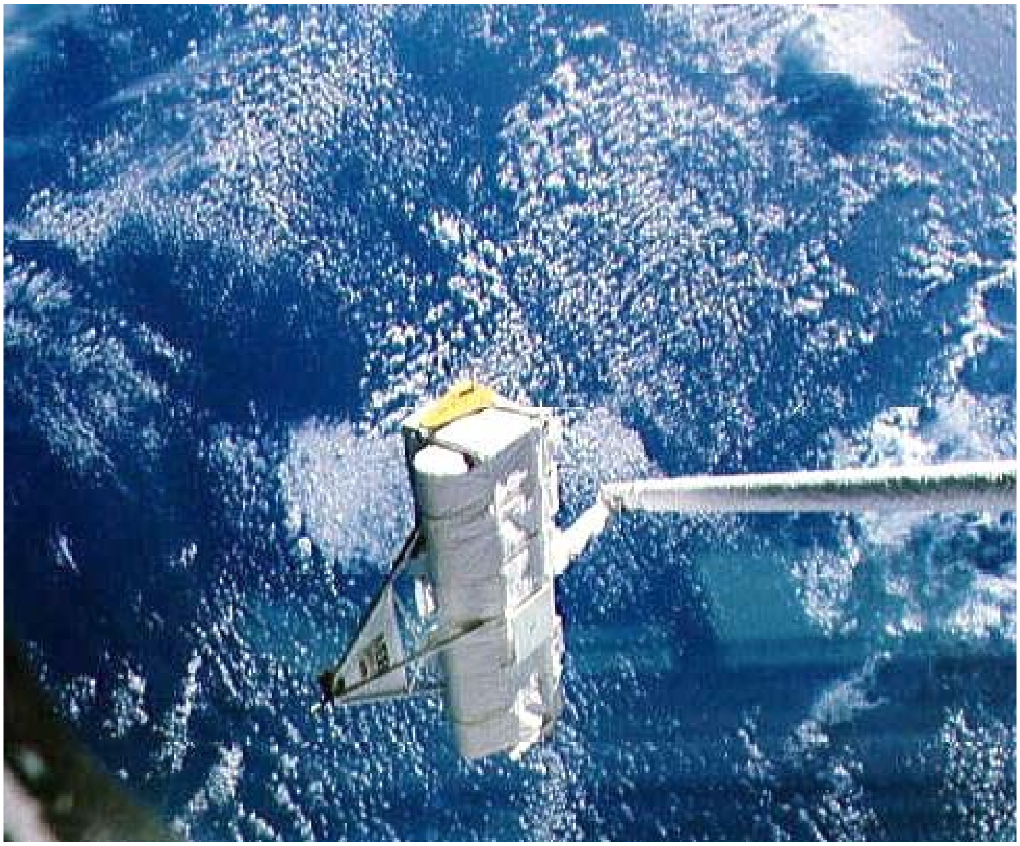

Figure 5. STS-7 Challenger's RMS arm grasps SPAS-01 during proximity operations. http://www.astronautix.com/craft/chaenger.htm.

5.1.2.1. Definitions

An *operations concept* is a reliable procedure for people and machinery to follow in achieving a specified goal. It is how the mission is accomplished in terms of activities, interactions, and operators.

An operations concept is really a *way of operating* that is developed after much thought and experience. It requires a detailed knowledge of the *tools*, *environment*, and *end goals*. Success depends closely on the ability to consider all the important factors and decide on a path of action. Success is more likely if one does not get bogged down in the details, trying to make everything as perfect as possible. It is easy to lose sight of the real issues that way. Also, success over the long term is more likely if there is some margin (or room for error) in planning (Cassini Mission, nd).

Mission operations are activities that prepare for launch, take place before and after launch, and maintain the infrastructure that supports space missions (Larson and Pranke, 1999). Proximity operations are one aspect of mission operations. See Figure 5.

5.1.2.2. Topics

Scenarios are very useful tools for developing operations. Scenarios are needed for what the crew does, what the ground crew has to do, what the users of the data produced by the flight must do, what the data systems must do, how each system works, and how all the systems must work together. A good scenario tells a detailed story of the events in a day or the story of a special event.

How a thing is done determines what *supporting facilities* are needed. Determinations must be made whether the item to be accomplished should be done by the flight crew, a robot, an onboard software system, a ground system, or by ground crew.

Mission operations include *procedures* for what to do in case of failures or equipment breakdown.

Phasing of the components of the mission and grouping of appropriate activities into the different phases may help to lower costs if the same equipment/software can do two different things at different times, such as having a habitat that also is a landing vehicle. It also helps to understand the mission in more detail to understand the parts and how the parts must flow together. "Simplicity tends to promote reliability" (Claque, Randall, personal communication, 12/15/2003).

5.1.2.3. Useful questions

How many different phases should be a part of the mission operations?

How much of the work of the mission should be automated or robotic, and how much must be done by the flight crew or the ground crew?

In long-duration missions to Mars, the communication time between a flight crew and a ground crew will be quite long. How might the autonomy that the flight crew needs from the ground change the mission operations? Should there be more or less automation? More or fewer robotic activities? Are there integration issues?

Should mission-control activities be centralized or distributed?

5.1.2.4. Resources

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Tullis, Thomas S.; and Bied, Barbra R.: Space Station Functional Relationships Analysis Final Technical Report. NASA CR-177497, 1988.

Cassini Mission, Operations Concepts, http://saturn.jpl.nasa.gov/cassini/Mission/ops.shtml (nd).

5.1.2.5. Activities

Develop a timeline for your mission, including the main activities to be performed and by whom.

Write a scenario for each phase of the mission, including the day-to-day activities of each "actor": flight crew, robots, automated systems, etc.

Make a list of all equipment needed to make the mission successful.

Diagram the different mission stages in terms of timing, vehicle(s), habitats, and major equipment needed for success. Are there any assumptions about new technology?

5.1.3. Structural Systems and Pneumatics Study Guide

Students should understand the structural requirements of hard vacuum, reduced gravity, and the various systems such as pneumatics that are currently being used and/or investigated for aerospace structures.

5.1.3.1. Definitions

Structures for space have to *resist forces* that Earth structures never do: launch, landing, radiation, high temperature differentials (inside/outside), vibrations, and gravity changes.

Pressure vessels are the first and foremost design consideration for space travel because no sites within reach have breathable atmospheres, and only Mars does not have a hard vacuum.

Air locks and *windows* are an important structural consideration, not only for the strength and integrity of the vessel, but also for the potential to connect two pressure vessels together.

A *landing apparatus* of some sort is required for all soft landings for people and supplies. Habitats may land in one mode and not return to orbit.

Materials choice and *fabrication processes* are important to understand because airtightness is not a normal factor in terrestrial architecture. A wide variety of materials are under consideration for pressure vessels besides the traditional aluminum. Corrosion and abrasion are two problems that a choice of materials must address.

Structures in *microgravity* are usually also in *hard vacuum*. Under these circumstances materials could evaporate/sublimate over time and reduce the structural strength. Materials in microgravity revert to a “pure” shape, not deformed by full gravity; i.e., a cylinder that sags into an ellipse on Earth will revert to a circular section in microgravity. Many large structures, such as the trusses that carry the solar panels for the ISS, would not be practical in a 1-g environment.

Structures in *reduced gravity* have less compressive load to bear because their mass weighs less in lower gravity, but the lateral loads and tipping forces are still substantial.

Inflatables are a type of structure that will allow a significant weight reduction for space construction. Generally they have multiple layers that are either stitched or laminated together. They have to withstand the same forces of any other pressure vessel in space: whether they come from internal pressure or from internal scuffing.

If *construction in space* could be done completely by robots, humanity’s path into space would be easier. With current space-suit designs it is very difficult for an astronaut to do construction work in microgravity and the vacuum of space. Construction processes are needed to expedite the structure type and maintain the safety of the construction crew. Most of the components are prefabricated so that few fastening movements are required to connect a new part in a stable configuration. Only the bundled sets of components need to be subjected to launch loads instead of the whole structure.

Construction on a surface such as the moon’s requires more than the usual loading considerations. There is a layer of fine abrasive dust on the surface that gets into everything and clings to most surfaces. Designing constructor robots and/or connections that will not be ruined by the dust is quite a challenge.

5.1.3.2. Topics

Primary structures are those that carry the main weight of the contents of the structure and the pressure of vacuum. *Secondary* structures are things such as equipment arms, solar-panel trusses, etc. that are attached to the primary structure. *Tertiary* structure is made up of small parts such as brackets for cameras, sensing equipment, etc.

Structural *configuration* and materials designed to dampen vibrations caused by equipment or crew activity help to keep the performance of the systems unaffected by these movements.

Where ever the construction takes place, the *construction methods* must be suited for that particular environment—from 0 g to 0.38 g on Mars, from hard vacuum to a thin carbon dioxide atmosphere.

Structural systems might be used in many different combinations to effect the desired result of a safe, comfortable, habitable environment. See Cohen, Marc, (1986) for a survey of space-station arrangements.

There are three *classes* of structures for use in space: 1. Preintegrated, ready for use; 2. Prefabricated, deployed, or assembled on site; and 3. In-situ resource construction, using materials available on site (Cohen, Marc, 2002b).

5.1.3.3. Useful questions

In the concepts for space structures, what are the traditional systems used for pressure vessels? For solar panels? For equipment arms?

What are some other structural systems that could prove to be useful? Materials being researched? What types of structures might be more suitable for each of the different uses: landing structure, habitable structure, launch vehicles, or power station?

What are some of the more advanced materials that are being considered today? Composites? Laminates? Alloys? Are any nanotechnology solutions on the horizon?

What computer programs can you access that will assist you in more complex structural analysis?

5.1.3.4. Resources

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Benaroya, Haym: Engineering, Design and Construction of Lunar Bases. J. Aerospace Eng., Apr. 2002, pp. 33-45.

Cohen, Marc M.: Lightweight Structures in Space Station Configurations. First International Conference on Lightweight Structures, vol. 1, Sydney, Australia, Aug. 24-29, 1986.

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Sarafin, Thomas P.; and Tagg, J. Malcolm: Structures. Human Spaceflight: Mission Analysis and Design, Wiley J. Larson and Linda Pranke, eds., Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

Otto, Frei: Tensile Structures: Design, structure, and calculation of buildings of cables, nets, and membranes. MIT Press, Cambridge, Mass., 1973.

Otto, Frei; and Bodo, Rasch: Finding Form: Towards an Architecture of the Minimal. Fellbach, Berlin, 1995.

5.1.3.5. Activities

Diagram the various structural system concepts that have been used in space programs so far: for space stations/labs, for rockets/capsules, and for reference missions to Mars and the moon.

Read Chapter 21 in Larson and Pranke (1999) and develop a preliminary set of structural diagrams to describe the types of facilities you are considering: pressure vessel, docking system, launch/landing vehicle, planetary habitat, power station, etc.

Consult with fellow students in structural engineering to brainstorm some ideas and/or verify your concepts for developing a structural system for your project. Work with them as the year progresses to do a thorough structural analysis of your systems.

Review as many different structural systems as you can find—which ones might have potential for space architecture? Which might function best in low-gravity situations? Which might best withstand the stresses of launch and landing?

5.1.4. Environmental Controls and Life Support Systems Study Guide

Students should understand the importance and weight of various life support systems, including air quality and pressure, water quality, temperature and humidity, lighting, food, hygiene, recycling, and trash: everything necessary to keep the crew alive, healthy, and functioning in good condition. Environmental control and life support systems (ECLSS) is the term most frequently used.

5.1.4.1. Definitions

Human beings can live without *oxygen* for only four to six minutes. In space vessels, people must have artificial *atmospheres* of the appropriate mix of oxygen and "neutral" gasses such as nitrogen without malodorous or dangerous contaminants such as wastes or CO_2. The air pressure and humidity must also be appropriate.

Water is the next most precious commodity for ongoing life. People need water for drinking, for food, and for washing their bodies and clothes. Safe, uncontaminated, good-tasting water is vital to any mission.

Food is the commodity a person can live longest without, but astronauts need a very nourishing diet with sufficient calories to support the exercise they must do and the high-energy EVAs. Food must be protected from spoilage and monitored for deterioration over a long mission. Figure 6 illustrates one type of food storage and access.

Figure 6. Eating in microgravity presents some special challenges. http://liftoff.msfc.nasa.gov/toc.asp?s=Living%20in%20Space.

The standard for the space station is a shirt-sleeves environment. *Temperatures* cannot be too hot or cold and should be variable and controllable in some areas for personal preferences.

Clothing is generally casual and needs to meet standards of being lint free and fire resistant, as well as comfortable and utilitarian. How to keep clothes clean is an issue to be resolved for long-duration missions.

Hygiene is important for health, comfort, and morale. If it is difficult to get one's body clean, then people tend to wash less frequently. If housekeeping is difficult, then it gets done less often as well.

Light is vital for vision as well as general health. Inappropriate light can keep one awake, too little light can make reading difficult or be harmful to one's vision. Light also has the potential for creating a mood and for aiding in creating a sense of local vertical.

Recycling can be part of the closed system for a long journey. Water and air are the most crucial items that need to be cleaned and reused because they take up so much volume.

Trash is compacted and stored on short missions that are easily resupplied, such as the ISS. On longer missions it should be recycled and made into useful material or objects for the trip, or decomposed using physicochemical systems (Larson and Pranke, 1999).

5.1.4.2. Topics

It is estimated that an average person needs ±0.85 kg of *oxygen* per day (Eckart, 1996). Carbon dioxide must be removed as a byproduct of respiration. People prefer fresh circulating air to stale, smelly air, especially if it could be damaging to their health. In a pressure vessel, maintaining the air pressure is a critical life-safety issue. There is an interesting question about whether it is more useful to maintain Earth normal pressure, or to have the habitat at a lower pressure to make transition into EVA suits easier, because they operate more comfortably at a lower internal pressure. There is almost no nitrogen on the moon, and very little on Mars. If nitrogen is to be used to create air pressure, it must be transported. Living in 100-percent oxygen can make fires far more dangerous.

Drinking *water* can total as much as 3 kg/day per person, depending upon activity level (Drysdale, 2005). Washing clothes can take as much as 24.75 kg of water (Eckart, 1996). Long-duration missions cannot afford not to wash clothes.

On a backpacking trip, dehydrated *food* is an interesting novelty, but probably not attractive for all meals on a two-month trip to the moon or a two+ year trip to Mars. Food storage is an issue that is under much research, so dehydration, freezing, irradiation, aeroponics, and hydroponics are all part of the investigation. Each method has its different weight/mass requirements.

The *thermal environment* is a system of power inputs, ventilation controls, and radiators to vent any extra heat. Clothing can be a part of thermal regulation as well. Clothing can also participate in a restraint system for working in microgravity.

In a closed system, cleanliness is vital for biological health, psychological health, and for aesthetics. Making the *housekeeping* chores easy, from cleaning the galley to keeping one's body clean, can make a space traveler's life much more agreeable than if these chores are seen as drudgery.

Sunlight is a source of vitamin D. Full-spectrum artificial light is healthier and more pleasant than cool white. Task lighting helps make work easier. Soft lights are more conducive to relaxing, and really low lights are good for sleeping. Within a small, closed system, lighting can make a big difference in how the place feels.

Trash handling and recycling are essential parts of a life support system for a long-duration flight. On short missions, the trash and biological wastes are stored and brought back to Earth, but this system cannot function for a really long trip. Oxygen must be generated for the air supply, possibly from the removed carbon dioxide, possibly from resources on the planet. Food packaging is the largest volume of trash, with no fully developed technology to recycle it into useful products. Waste-water recovery is in a better state with both chemical and biological processes available for reclaiming clean water. Fresh food might be generated using waste water and the biological human wastes for Mars missions. *Clothing* represents about 0.625 kg/day per person of waste if not washed, while food packaging is about 0.324 kg/day per person (Drysdale, 2005).

Fire alarms and fire suppression are sometimes thought of as life support, because a fire can be life threatening. Those issues are covered in the Safety Hazards Study Guide.

Monitoring and detection systems are also seen as a part of life support and protection.

5.1.4.3. Useful questions

What does the latest research that you can find say about ECLSS? Can you find out what the systems weigh?

How might you think of clothing as part of the ECLSS? How many functions can you design in to a clothing system? Look at the astronauts' wardrobes and see what has already been done.

What are the current levels of redundancy on the ISS?

What level of redundancy would be appropriate for ECLSS subsystems for a moon mission? For Mars?

What are the known systems for air cleaning? Oxygen regeneration? Nitrogen recovery?

What is the level of technological readiness of food-growing systems for closed environments?

How might gray water be used?

How does the ISS incorporate all of its ECLSS?

How does monitoring of the quality of the air, water, and food occur on current missions?

5.1.4.4. Resources

Doll, Susan; and Eckart, Peter: Environmental Control and Life Support Systems (ECLSS). Human Spaceflight: Mission Analysis and Design, Wiley J. Larson and Linda K. Pranke, eds., Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

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Hanford, A. J.: Advanced Life Support Research and Technology Development Metric – Fiscal Year 2002. JSC 60313 (CTSD-ADV-510), Johnson Space Center, Houston, Tex., 2003.

Jones, Harry: Design Rules for Space Life Support Systems. SAE 2003-01-2356, 33rd ICES, 2003.

Stoker, Carol R.; and Emmart, Carter: Strategies for Mars: A Guide to Human Exploration. Science and Technology Series, vol. 86, American Astron. Soc., San Diego, Calif., Univelt, 1996.

5.1.4.5. Activities

Document the ECLSS for the Mars Reference Missions. List the mission design assumptions that drive a particular choice (i.e., length of mission).

Describe the basic components of the subsystems for ECLSS that are now used on the ISS. How might these systems be appropriate or inappropriate for a mission to the moon? To Mars?

Read Chapter 17 in Larson and Pranke (1999), and then chart the decisions you must make for your vehicles/ habitats. Also read Jones (2003).

Read several of the personal accounts of astronauts and their flights. Document the ways that they managed the life support systems to make their lives more comfortable or to overcome failures.

5.1.5. Mobility Systems Study Guide

Students should understand the implications of their choice of a mobility system on a planetary surface for rovers, habitat robots, or for working machinery.

5.1.5.1. Definitions

This unit focuses on the Lunar surface, but many of the concepts and principles will be useful for understanding mobility on the Martian surface. Rovers, robots, and Habots are the objects in question rather than the vehicles that get people and consumables to the surface from orbit. Figure 7 shows the configuration of the first rover on the moon.

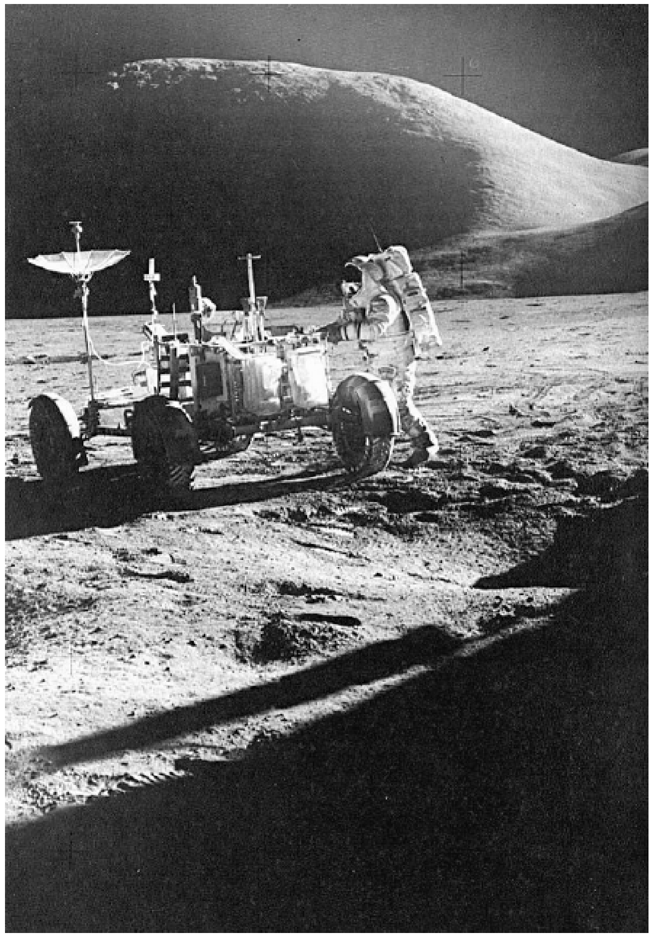

Figure 7. Astronaut Jim Irwin and the first Lunar Rover.
http://spaceplace.jpl.nasa.gov/teachers/images/moon/apollo_rover_L.jpg.

5.1.5.2. Topics

Lunar dust is very fine and the cover varies in thickness over a far more solid, compacted base. Numerous rocks of various sizes are seemingly scattered across the terrain. Traction does not seem to be a problem for most systems. *Wheels* have been the preferred system used so far. Lunar dust is extremely abrasive.

Treads have been used on tanks for years and have withstood rugged terrain, and sandy (dusty) soils; they have good traction up hills and through variable topographies.

Feet for a walking robot or Habot have been proposed as one possible alternative to allow movement through boulder fields and steady movement. The insect analogy seems relevant.

Combinations of some of the mobility systems are worth consideration if one solution does not overcome all the obstacles of dust, boulders, steep crater sides, and variable topography.

A mobility system cannot be complete without the consideration of its *power system*. Should the power systems be a part of the rover or habitat, beamed, nuclear, solar, solid fuel, liquid fuel, or other?

All systems have to work in a vacuum, in temperature extremes, and they have to resist abrasion by dust.

5.1.5.3. Useful questions

How many different ways can one move across the moon's surface? What are the most useful and efficient ways? What are the most outrageous ways? Can they be made to be practical?

How can mobility systems be durable enough to stand the launch and rugged terrain and yet be lightweight enough to have a small impact on the lift power needed to get them to the moon?

What are the advantages and disadvantages of carrying a power source along vs. having power beamed to the unit?

How does the mobility system relate to the landing system for the module?

Should mobility systems unfold from their landing configuration into their movement configuration? Look at the Mars rovers for unfolding examples.

Is a three-segment, six-wheeled concept (such as the Mars rovers Spirit and Opportunity) the best for rough terrain? What other concepts work well?

How might a rover/Habot mobility system be designed with the fewest moving parts?

How might a mobility system be protected from the dust of the moon's surface?

5.1.5.4. Resources

Arno, Roger: Planetary Surface Vehicles. Human Spaceflight: Mission Analysis and Design. Wiley J. Larson and Linda K. Pranke, eds., Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

Cohen, Marc M.: Pressurized Rover Airlocks. SAE 2000-01-2389, 30th ICES, 2000.

Cohen, Marc M.: Mobile Lunar and Planetary Bases. AIAA-2003-6280, Long Beach, Calif., 2003.

Athena, Mars Exploration Rovers, http://athena.cornell.edu/home/index.shtml, 2003 (details of the Mars rovers Spirit and Opportunity, which landed in 2004; movies, etc.).

Brick Vista: Size Does Matter. http://www.magneticpie.com/LEGO/roverHistory/roverSize.html#Size, 2003 (wide range of images of different rovers and concepts; the site has good technical information).

The Apollo Surface Journal, http://www.hq.nasa.gov/alsj/frame.html, 2003 (descriptions of rovers that were used on missions 15, 16, and 17).

5.1.5.5. Activities

Catalogue all the mobility systems that you can find for Lunar rovers, for mobile habitats, and for Habots.

Make a list of all the problems that a successful rover or mobile habitat must overcome on the Lunar surface. Are there any differences for the Martian surface?

Imagine as many different types of mobility as possible (analogies will do nicely). Develop a concept diagram for each, and indicate how it might solve a problem faced on the Lunar or Martian surface.

Make a list of criteria for a successful mobility system for a Habot or rover.

5.2. CONCEPT DEVELOPMENT

5.2.1. Extravehicular Activity (EVA) Study Guide

Students should understand the various concepts for pressure ports, air locks, space suits, and the difficulties and hazards of EVA.

5.2.1.1. Definitions

Going outside of the habitable volume of a spacecraft or habitat requires a great deal of equipment and preparation. Space suits, extravehicular maneuvering units (EMUs), and EVA suits consume a lot of volume and weight. They also require assistance and a lengthy time to don and prepare for EVA. The length of time to don the suit depends upon its design. The length of time that an astronaut must prebreathe an oxygen-rich mixture before going outside depends upon the air pressure at which the process was started and the air pressure within the suit. Doffing the suit also takes time and assistance. Figure 8 shows a view of an EVA from inside the space shuttle.

Air locks between the higher-pressure interior environment and the near vacuum of space or the Lunar surface must allow for pumping out air and repressurization that is completely isolated from both the habitat/spacecraft and the exterior. Some air locks must also function as hyperbaric chambers with possible pressures up to three atmospheres to treat astronauts with the bends if they develop decompression illness in the process of EVA (Flight Projects Directorate, nd). All that volume and plumbing take up a significant proportion of the mass of the airlock system.

Figure 8. Intelsat VI capture attempt. http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-001096.jpg.

On a planetary surface, another significant design problem is making it easy for the suited astronaut *to get to the ground surface* and to get back into the habitat or space vehicle. What is the height of the crew compartment/air lock? What is the decontamination regime? Is a ladder difficult to climb in an EVA suit?

Suit storage and maintenance are vital to the ongoing success of any mission, especially a lengthy one. Moon dust clings to the surface of the suits and will contaminate the interior of the habitat or spacecraft.

5.2.1.2. Topics

There are many *concepts* for how to manage EVA—from suitports, to separate EVA/hyperbaric modules. What are the most useful for the Moon? for Mars?

With the use of Habots on a Lunar mission, there will be a need to connect the different modules together with air locks/pressure ports that alternately could serve as EVA ports.

Concepts are being developed for an *inflatable* EVA module.

5.2.1.3. Useful questions

Is EVA in space similar to EVA on a planetary surface? In other words, is the same equipment required?

How might the time to don and doff a space suit be minimized?

What are the current concepts for emergency evacuation of the crew?

Should there be additional easy-to-don, lightweight EVA suits for emergencies?

How might the air-pressure differentials between the living/flying environment be balanced out for the most habitable environment and the most comfortable EVA suit environment?

What design concepts facilitate space-suit maintenance (cleaning, repair, preventing dust, or other contamination of the spacecraft interior)?

Can air locks/pressure ports be designed such that they can be mass produced and create uniform connections between habitat units, rovers, lab units, EVA modules, etc.?

What features need to be considered for samples brought back from EVA excursions?

5.2.1.4. Resources

Cohen, Marc M.; and Bussolari, Steven: Human Factors in Space Station Architecture II, EVA Access Facility. NASA TM-86856, 1987.

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5.2.1.5. Activities

Diagram all the concepts for EVA air locks. Include their mass and weight if possible.

Create concept drawings for Habots and their connecting configurations. Decide the number of EVA air locks/pressure ports needed.

Make a list of criteria for a successful EVA module, including suit storage and maintenance.

With your classmates, critique your designs in terms of ease of EVA, emergency egress, connectivity of modules, etc.

What innovative ways can you imagine that would make EVA easier from donning the suit to the exterior activities, to exit/entry, to doffing the suit? Could an EMU that functions as a rover be built into a suitport?

List the issues of integrating the EVA ports and suits into a habitat.

5.2.2. Site Conditions Study Guide

Students should be able to understand the impacts on design of a site that has either no atmosphere or an unbreathable one, extreme temperatures, lower than Earth gravity, and high radiation exposure.

5.2.2.1. Definitions

Site analysis is one of the standard tools of the terrestrial architect. This study guide focuses on the typical characteristics of site analysis as well as the characteristics vital only in space architecture. The three most likely spots for habitation in the near future are the moon and Mars or the moons of Mars. These bodies have far less gravity than the Earth, no atmosphere or one that is mostly carbon dioxide, and they are subject to a much higher level of ionizing radiation than the Earth's surface. It is vital to be able to use surface resources (ISRU) for long-term habitation because it is too expensive to haul everything from Earth. Consider also the potential for a habitat at the Lagrange points where one builds the site in hard vacuum.

5.2.2.2. Topics

The chemical composition of the *soil and air* (if any) is vital to the success of a long-term planetary mission. The moon's soil is 45-percent oxygen, 21-percent silicon, 13-percent iron, 8-percent calcium, 7-percent magnesium, and 3-percent other minerals such as aluminum and titanium. (Lunar soil composition, nd) With multiple missions to the same place, extracting oxygen becomes economically viable, and it can become part of an enclosed atmosphere or fuel (Larson and Pranke, 1999). Silicon can make ceramics and parts for solar collectors, etc. Mining and manufacturing processes need to be developed to take advantage of these chemicals.

Criteria for a *landing site* will be different for each distinct mission purpose. There may be interesting features to be explored, a specific mineral deposit, evidence of potential water, etc. The most important feature of the exact landing site will be its safety for landing—either for robots and supplies or for humans. Topography, obstacles, shadows, etc. will also be important.

A *permanent base* will need access to the resources it is to use for setup and maintenance: readily mined regolith for habitat shielding; adequate solar exposure for energy, or a suitable spot for a nuclear reactor; perhaps a crater's edge for shielding; or other features dictated by the mission design. A means to move from the landing zone to the base must be included in the design.

Mobile bases, on the other hand, can be landed in any relatively flat spot, assuming that the people to inhabit it will come via crew transfer vehicle and move to the habitat either by rover or on foot. The site would be chosen for its proximity to the sites of interest to the mission.

One of the realities of Lunar or Martian bases is that the *atmosphere* is either absent or unbreathable. People will be able to work outside only in space suits. Hard vacuum in the Lunar case makes any habitat a thermos jug for people to live inside. This has structural implications for vessel strength, air locks, and windows. Lack of atmosphere also has implications for vision: without air, light is not diffused or diffracted, so on the Lunar surface, contrasts are stark and shadows are very dark and glare is a big problem.

Dust is known to be a severe problem on the moon, and it is suspected that it will also be problematic on Mars.

On the moon, the day lasts for two weeks and temperatures can get up to 100°C (water boils) and at night (also two weeks) can go down to –147°C. On Mars the day is a bit longer than Earth's and temperatures are from –8°C to –112°C. Compare this to Earth's hottest spot at 58°C and its coldest spot at –89°C. This temperature range shows that the Antarctic in the winter is a fairly good analog to the Martian thermal conditions.

Comparative Surface Temperatures

Mean Surface Temperature			Minimum Surface Temperature			Maximum Surface Temperature		
	°C	K		°C	K		°C	K
Earth	15	288	Earth	–89	184	Earth	58	331
Moon	–23	250	Moon	–147	126	Moon	100	373
Mars	–60	213	Mars	–112	161	Mars	–8	265

From: http://www.asi.org/adb/02/05/01/surface-temperature.html.

Radiation is much more of a problem on the Lunar surface because of the lack of atmosphere or magnetic field. On Mars the CO_2 atmosphere protects somewhat, but not nearly as well as Earth's much denser air. The lack of a magnetic field also allows more radiation to reach the planetary surface. Ultraviolet radiation is also more intense because of the lack of atmosphere on the Moon and the CO_2 of Mars. See the Radiation Study Guide A.2.1. for more information.

The gravity of the moon is 0.16 g. Gravity on Mars is 0.38 g. Earth's gravity is 1 g.

5.2.2.3. Useful question

Because the Lunar and Martian surfaces are so very different from the Earth's, how would you evaluate the site conditions as impacts on the design of habitats and other structures? On site selection?

How might you design for the wide thermal swings on the moon? The cold of Mars?

What considerations should you have for designing in lower than Earth gravity?

From your research on precedents, what site factors seem to be prominent in the choices of sites in artists' conceptions of Lunar or Martian bases?

Given the different surface conditions, where would you rather be a colonist—on the Moon or Mars? Why?

5.2.2.4. Resources

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5.2.2.5. Activities

Choose a site (even if just to practice), and begin a graphic library (site analysis diagrams) of the site circumstances to which you must respond as a designer.

If you have chosen a Martian site, find out more about the Martian atmosphere: composition, pressure, winds, dust storms, etc.

For a Lunar site, find out as much as you can about the surface conditions: dust, hardpan, etc.

Add to your concept diagram library of different approaches to building on a planetary surface. What are the arguments for a compact site vs. a dispersed one, a mobile base vs. a permanent one?

Record any new "city planning" concepts shown in artists' conceptions.

5.2.3. Basic Habitability Study Guide

Students should be able to incorporate solutions to stressors and habitability issues as well as design at a level of detail that includes human factors for interior spaces.

5.2.3.1. Definitions

Human factors can be broken down into three different areas of concern: human/human interaction, human/technology interaction, and human/environment interaction. Components of human/human interaction range from communication to team culture. Components of the human/technology interaction include hardware ergonomics, software utility, visual/perceptual issues, and automation integration. Human/environment interactions cover issues such as color and décor, illumination, spaciousness, individual control, variety, and the ergonomics of the neutral body position. The focus is on habitat design (including workspaces), but many of the issues relate to other environments that are a part of the wide range of aerospace architecture. Habitability is defined as:

> *"...a measure of the degree to which an environment promotes the productivity, well-being, and situationally desirable behavior of its occupants."*

(Yvonne Clearwater, quoted in: Cohen, Marc, 1990)

When ergonomics are wrong, the temperature is too hot, and getting away from it all is impossible, stress is very likely. It is the misfits that turn into stressors.

5.2.3.2. Topics

5.2.3.2-1. Human/human interaction

Isolation: Much study has been done about the isolation (from friends and family) of space travel and life in other extreme environments such as Antarctica, submarines, and underwater habitats and the tendencies toward conflict or withdrawal.

Communication: Microgravity allows fluids to pool in the body's upper portions instead of the lower. As a result, people tend to have bloated faces that mask their expressions and tend toward miscommunication, especially when a face is viewed upside down and the noise level is high (Cohen, Malcolm, 2000).

Teamwork: Teamwork is vitally important to the success of the crew's work, and their safety depends upon it during times of emergency. Social relationships become as important as working relationships.

Recreation opportunities are restricted, given the spatial constraints. Opportunities for group recreation should be encouraged as well as private, individual amusements.

5.2.3.2-2. Human/technology interaction

Workstation ergonomics: All workstations need to be efficient and easy to use, whether it is command and control for a Mars station or a lab workbench in the ISS. Anthropometrics are different for weightlessness than they are for 1 g or 0.16 g. Under microgravity conditions, the body elongates up to three inches and takes on a neutral body position (STS-57 (56), 2001).

Displays: Visual and auditory displays need to have readily discernable, useful information—especially for warnings and alarms.

Ease of use: All hardware and software needs to be as easy to use as possible by all crew members.

Automation: The greatest leaps in technology that need to be developed are those that integrate the best of human judgment with the best of the quick computations of automated systems. Problems arise when automation and human action must duplicate each other in order to know what is happening within a particular layer of information (Connors, Mary, personal communication, 12/9/2003).

Figure 9. Commander Brian Duffy adds STS-92 patch to growing collection. http://spaceflight.nasa.gov/gallery/images/shuttle/sts-92/html/sts092-372-035.html.

5.2.3.2-3. Human/environment interaction

Sleep: A disturbed sleep cycle leads to fatigue and potentially dangerous inattention. Some causes in a microgravity environment are noise (plus vibrations of equipment), lighting, proximity of other people who are awake, job stress, temperature extremes, and space sickness (Connors et al., 1985).

Available volume: Because it costs so much to move mass into space, there are major restrictions on just how much space is available. Such small spaces can give rise to a sense of confinement and restriction. A sense of spaciousness can be developed by emphasizing the longest view, varying the distance from the viewer to the extent of the spatial volume; i.e., irregularly shaped volumes, and putting the volume where it needs to be for functionality (Wise, 1988).

Privacy (control of interactions with other people) becomes a great concern when there is not much space to "get away from it all." Control of visual, audial, and olfactory stimuli becomes very important. Having a personal territory (control) leads to a sense of ownership and belonging (Connors et al., 1985).

Personalization: Personal belongings help people bolster their sense of identity and sense of territory. Stowage of such items can be problematic in microgravity when a group of items floats away as one retrieves an item out of the bunch. In Figure 9 Commander Duffy adds his crew's patch as an identity marker.

Circulation in most gravity situations takes up a lot of floor space, and in microgravity it takes up a lot of volume. Yet efficient circulation is vital to the working of the environment. The ISS has handholds along the walls to aid in movement and in maintaining position. Restraints for maintaining a working position are also necessary for success in microgravity.

Circadian rhythm on Earth is a 24-hour day/night cycle. People manage their schedules in relationship to the light/dark changes. When these cycles are seriously disturbed, fatigue and illness can be a result.

Local vertical: In a microgravity environment, one can position one's body in any orientation without major difficulty. Humans, who evolved in gravity, work much better with a consistent local vertical.

Visual quality of the environment is also important. A monotonous visual environment can lead to boredom and a sense of tiredness. Just as spaciousness can be enhanced by irregularly shaped spaces, so can visual variety. Windows, artwork, patterns, and textures can all contribute to visual variety and quality. The ability to change configuration, color, pattern, or artwork would be useful for long-duration spaceflights. People tend to prefer greater visual complexity over time (Connors et al., 1985).

Color and texture are important visual and tactile stimuli—a boring environment leads to understimulation, and a visually chaotic environment leads to overstimulation—neither of which are good. Color contrasts in the appropriate context are probably the most powerful tool a designer can use (Wise and Wise, 1988).

Illumination greatly affects the mood and ambience of a space habitat as well as the sense of spaciousness and the local vertical. Rhythms of day and night can be simulated with lighting. Full-spectrum light is better for color discrimination than cool white or other partial-spectrum lighting. People who are under partial-spectrum lighting all day, every day, tend to lose their vitamin D without the ultraviolet component (Spivack, 1983).

Exercise has proven to be vital to maintaining one's health and strength in space, even though it is not sufficient to mitigate all the deconditioning effects of microgravity.

Hygiene is especially important for good health and for controlling odors in a confined environment. If being clean is difficult, people tend to avoid the chore.

Temperature is critical to physical comfort. The norm for space habitation is a "shirt-sleeves" thermal environment.

Noise: Imagine living in an environment that sounds louder than a trip across the country in a jet plane. To date, the ISS and other environments such as the Space Shuttle are very noisy compared to terrestrial environments.

Odors are more of a problem in a hermetically sealed environment than they are on Earth where one can "air out" a stuffy room. Volatiles, body odors, and food odors are all much more problematic in small enclosed spaces.

Air composition and pressure, food, and hygiene are covered in the Environmental Controls and Life Support Systems Study Unit.

5.2.3.2-4. Biomedical issues

Deconditioning (bone loss, lowered muscle and cardiac strength, immune system depression, fluid pooling, and temporary space sickness) is an integral part of living in weightlessness. Many countermeasures (such as exercise) exist but none are perfect at this time.

A very high percentage of ISS astronauts get *space sickness*, which feels similar to being seasick. Typically it comes on within the first day or two and is gone by the third or fourth day. Most astronauts just work through it, even though they don't really feel like it.

Decompression illness (DCI, or the "bends") could occur when an astronaut goes EVA and moves too quickly from a higher pressure to a lower pressure, or if internal cabin pressure changes too fast. It is caused by gasses, which are dissolved in the blood, making bubbles as the pressure is lowered—much like opening a soft drink bottle. The symptoms can range from mild pain to a fatal embolism. With recompression, DCI is rarely fatal and full recovery is usually assured. The potential for DCI is one reason that some air locks should also act as hyperbaric chambers.

Lowered physical endurance and deconditioning are unavoidable aspects of a microgravity environment. Muscle strength decreases as the result of having no gravity to resist. Bones loose calcium, heart muscles shrink, fluids pool in the upper body, and the body becomes dehydrated because of increased urine output.

5.2.3.2-5. Potential stressors

When the human factors issues discussed previously are not dealt with properly, the effects can be stressful to long-duration space travelers. If the design of the spacecraft or habitat is wrong, then some features cannot be changed and the stressors may become *consistent or continuous*. "Spaceflight subjects people to a wide range of physical, psychological, and social stressors. A recurrent concern is that these stressors could add up in such a way as to undermine a spacefarer's performance" (Harrison, 2001, p. 118). Stress can lead to anxiety, depression, and lowered performance as well as physiological symptoms such as headaches, insomnia, and stomach upsets.

Isolation and separation from family, friends, and Earth are the most stressful aspects of long-duration spaceflight. Even in training, astronauts find that the separation from their social supports is very troublesome—for some even more so than when they were in the military (Harrison, 2001).

Boredom and monotony caused by a repetitive job that must be done or by a bland environment relate to increased fatigue (Harrison, 2001).

In a *closed atmosphere*, air regeneration is vitally important for health and safety as well as comfort. If temperature and humidity are not at the appropriate levels and odors are unpleasant, it becomes uncomfortable and stressful and eventually interferes with performance.

Artificial lighting at its best mimics sunlight, sets a mood, and sets off spaces from each other; at its worst it can render colors poorly and seem uniform or "unnatural." Task lighting should be bright enough to do the job, even if general lighting needs to be lowered to accommodate the power supply. Light levels that are too low cause eye strain and glare (too much contrast) and can become a stressor as well.

Clothing that is ill-fitting, a rough texture, or inefficient can cause irritation and stress. Astronauts' clothing usually has pockets or attachments for tools or objects necessary for the job at hand in order to keep the items conveniently located and from floating away in microgravity. Features of clothing might also be a part of a restraint system for holding a working position in microgravity.

Ergonomics in microgravity are quite different from ergonomics in 1 g because of weightlessness and the neutral body position. If an astronaut has to struggle to maintain a working position (inappropriate restraints) or to see the work surface, then the consequences of muscle strain, eye strain, or excess fatigue are highly likely.

Housekeeping is considered a burden by almost everyone. If the chore is unpleasant or difficult, the crew will likely do housekeeping less often. Unpleasant chores can be stressful, as can the resulting soiled environment.

Hygiene standards for the U.S. are very high, yet in space the activities of bathing and elimination are complicated by microgravity. As with housekeeping, the more difficult the bathing becomes, the less likely an astronaut is to do it. This leads to people with potentially offensive body odors that become quite stressful in a closed environment.

Noise and vibration can be a great source of sleep disturbances, they can interfere with communications, and they can be irritating. Having to operate with too little sleep and to strain to be understood can undermine a spacefarer's performance.

Confinement to small spaces is necessitated by the fact that it costs so much to lift mass off the Earth's surface. The consequence of such small space allocation is that there is very little personal territory, and one shares the same spaces with the same few people day after day. "Cabin fever" is a well-known reaction to confinement.

Lack of privacy and the inability to get away from being "on stage" can lead to withdrawal and antisocial behavior. Even a small crew cabin in which astronauts have a place that is their own, where astronauts can put up personal mementos, communicate privately with family, or just be alone, helps to maintain appropriate control of boundaries and reinforce a sense of individuality.

Crew incompatibilities such as very different eating or cooking habits, an argumentative nature, or rudeness can become quite wearing over long missions. As the missions last longer than a couple of weeks or months, the choice of a compatible team becomes more important.

Some stressors such as space sickness are only *temporal* in nature and seldom are constant or continuous.

Scheduling overload has been a complaint of many space crews. Everyone has felt the pressure of too little time and too much to do and how that scenario takes its toll. Normally, scheduling overload is temporary. Conflict with ground control is often over workload.

Many stressors *never happen* or are *infrequent*. The fear of the improbable accident or emergency can be stressful, as well as the event itself.

Emotional problems that result from the accumulation of stress are far more likely on a mission to Mars of more than two and a half years than on a six-month mission to the ISS. Yet, several Russian missions to Mir were reportedly shortened because of emotional issues.

With *illness or injury* comes the uncertainty of treatment in space. If just first aid is needed, then it's not much of a problem, but with increasing severity there will be a need for telemedicine or for the affected crew member to be evacuated back to Earth. An evacuation is all but impossible for a Mars mission.

A *failure of the life support system* could be fixed if there is sufficient redundancy or enough warning, but an immediate catastrophic failure could lead to loss of the mission.

Death of a crew member is the most difficult acute emotional stress to bear. Even though it is highly unlikely, procedures and emotional support should be in place for such an event.

Not all stress is bad. The excitement of a new adventure, while stressful, usually heightens the experience and sharpens the wits. Many people who work in isolated and confined environments such as Antarctica report that their experience was the best of their lives. Russian cosmonauts report improved coping abilities and greater self-confidence after their space experiences. The job of the designer is to mitigate stress where possible so that it does not impair performance (Suedfeld, 1998).

Designers should endeavor to make the space-faring environment a place where people can thrive, rather than just survive the hazards and privations.

5.2.3.3. Useful questions

What design features and strategies can mitigate the sense of isolation from friends and family that is so often a part of a space habitat?

Do physical features of the environment contribute to teamwork going well or not?

How might equipment, furniture, and workstation designs and configurations be different in microgravity, 0.16 g, 0.38 g and 1 g?

What architectural features might assist in a crewmember's getting a good night's sleep in microgravity? Can you imagine how it might be different on the moon?

How are spaces designed to seem more spacious? Are windows worth the extra radiation risk? Will videos make an acceptable substitute?

What are the aspects of a habitat design that make it more social than not?

What features would make keeping one's body clean easy in minimum space? How would this differ from microgravity to the 0.16 gravity of the moon?

How might a designer maximize personal stowage and make retrieval of small items easy in microgravity?

What are the existing circulation aids on the ISS (for movement and restraint)? How might you organize the functions of sleep, hygiene, exercise, eating, lab experiments, communication with Earth, and EVA for the most efficient and easiest circulation? What are the existing ISS modules and how are they now organized?

How might the interior design of a space station reinforce a sense of "up and down"?

How might vibration and noise control be effected in a space station? In a Lunar habitat?

How might a designer use lighting to enhance the sense of a 24-hour day/night cycle? In what other ways might one use lighting to increase the habitability of a space station or planetary habitat?

What are the aspects under an aerospace architect's control that will contribute to a healthy sense of privacy and territoriality within the limited space of a habitat?

What countermeasures are available to designers for combating the deconditioning effects of weightlessness?

How might color and texture contribute to a space crew's sense of well-being?

What role might aesthetics play in a space habitat? Proportion? Visual variety?

What design features and strategies can improve communication in microgravity?

What aspects of habitability should be under the control of each individual crew member?

How might designers maximize personal choice in control of the environment and the habitability features?

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5.2.3.5. Activities

Design a crew cabin that includes appropriate personal stowage and facilitates sound sleep. First read some accounts of life on a space station or habitat. Validate the design based on your research.

Go to a pool with your class. Float (using a flotation device between your knees if necessary) in as close an approximation of neutral body position as you can. Observe yourself: What motions are the most difficult to do and maintain control of your body position? Can you design movements that would allow you to test movements that might be required for working in microgravity? What props might you make to test your movements? If possible, use scuba gear to maintain neutral buoyancy.

Read Wise (1988) and generate the basic Isovists for your bedroom and your design lab space. What might you do to make these spaces seem roomier? See http://www.vr.ucl.ac.uk/depthmap/ for the University College of London's VR Centre software to calculate visibility graphs.

Use the human factors research to design our own group workspace so that each person has a sense of privacy and of belonging to the group. What could we do in this class that would make our spaces more sociable?

Examine the existing hygiene facilities for use on the ISS. What would be some of your reasons for not using it very often? What might you do to make using the facility more likely?

Use your own body measurements and the NASA-STD-3000 to determine the absolute minimum requirement for a volume of space for a crew cabin in which you would feel comfortable in microgravity. How would the dimensions change with the addition of gravity?

Given the dimensions of the ISS, design a color scheme for a lab module that would reinforce the local vertical, aid in the legibility of the racks, assist in circulation, and be pleasing to the eye.

Review existing exercise apparatus types and research, and then develop a minimum suite of machines/activities for maintaining the best possible physical conditioning at the current level of technology. Why did you make your choices?

Draw a concept map of the interactions of the habitability issues for designing a crew quarters. Also try one for the stressors. Which designed aspects affect several aspects of habitability?

Program the interior of a Habot on the moon's surface to house two crew members and their workstations using habitability issues as the main criteria for success.

After reading Sturgeon (1992), make a list of design guidelines you would want followed for designing a habitat if you were to be on a space mission to the moon or Mars (two months to two years).

List all the concepts you can think of to decrease the noise levels or to make them tolerable to astronauts in flight and on a planetary surface.

List and diagram the design features and strategies you would recommend for creating a sense of privacy in a habitat module.

Boredom from a monotonous routine, food, environment, or the same group of people can lower morale. List those items/concepts that you would consider to assist in creating a changeable visual environment that would help keep the crew stimulated.

Create a list of all the opportunities you would want to include in a Lunar habitat for personalization by the crew as a group and by individuals. How much do the items weigh?

6. BE ABLE TO STUDY GUIDES

6.1. DESIGN METHODS

6.1.1. Architectural Programming Study Guide

Students should be able to develop a high-quality program document that is thorough and includes a robust mission statement, relevant issues and goals, practical performance requirements, and innovative concepts.

6.1.1.1. Definitions

Architectural programming is the orderly management of information relevant to design such that the right information is available at the appropriate time in the process in order that the best possible decisions might be made in a timely manner. It is the process that fulfills the hopes, dreams, wishes, and the pragmatic realities of the client/user. It is the problem-definition stage of the design process.

6.1.1.2. Topics

Design is a cyclical, *iterative* process, even though the easiest way to describe the parts of the process is as though it were linear. The description of the process here will go from the more general to the more specific—even though it may take research into the specifics to uncover the general ideas.

The most general statement of the problem definition is the *mission statement*. This is the purpose of the project, the "why" of the whole effort. Mission design in aerospace architecture is a subset of the overall mission statement in that it outlines the tasks and the stages required to accomplish the purpose of the facility being designed. A mission statement should clearly explain, in one sentence, the overall purpose of the project. It should inspire the designers to do their best work.

Each design problem has a set of subproblems called design *issues*. An issue is an area of the problem that requires a design response. Safety, circulation, privacy, isolation, and confinement are a few of the many design issues.

For each issue there should be a *goal* statement in order to set the level of aspiration for the project. Goals speak to the quality of solution required for each issue. Goals answer the question, "How good does it have to be to be successful in this area?" Different design problems have different sets of priorities and thus may have different goals/quality requirements for the same issue.

Each goal will have numerous *performance requirements* in order to describe the level of function required to implement each goal. Performance requirements answer the question, "How must the facility behave in order to create the desired quality of outcome?" Performance requirements can be measured: binary (yes/no), a range (size, light levels, weight, energy output, etc.), and judgment (is this more comfortable than that?)

Each performance requirement will have a set of implementing *concepts*, which are relationships that make the performance levels possible. Concepts answer the question, "How should components be arranged so that the function is best implemented?" Concepts can also be at higher levels of generality—a parti is an organizing concept for the whole problem, and there may be concepts that function at the level of a goal. A concept diagram is composed of a graphic set of relationships and a verbal caption to make it specific.

A *program document* is the narrative story of the project, including the background, the mission, the site analysis, the issues and goals, the performance requirements, concepts, space, size and weight summaries, budget, and a summary of any other analysis or research that had to be done to fully understand and design the project. The document may also include a parti, adjacency diagrams, and an appendix with material such as return on investment (ROI), raw research data, etc. Appendix materials are items that are too large to go into the body of the document. The program document is a record of the decisions made about the scope and definition of the project, as well as a documentation of the research that went into the decision process.

6.1.1.3. Useful questions

What qualities does a mission statement need to have to inspire you to do your best work?

What are the design issues you can identify for your project? What five issues are the most important to the success of the design outcome?

How do you distinguish between a goal and a performance requirement?

How can you tell the difference between a concept and a performance requirement?

How much research do you need to do to understand the problem well enough to create a mission statement? See the Research Study Guide for techniques.

What information are you missing that you need to uncover?

What format suits your audience so that they can best understand your program document?

Should you do primary research to help you understand the parameters of this project?

6.1.1.4. Resources

Duerk, Donna P.: Architectural Programming: Information Management for Design. John Wiley & Sons, New York, N.Y., 1993.

Kelly, John; Moreledge, Roy; and Wilkinson, Sara: Best Value in Construction. RICS Foundation, Blackwell Publishing, Oxford, UK, 2002.

There are various other books on programming with different points of emphasis, but the process is generally the same.

6.1.1.5. Activities

Write a mission statement for your project that inspires you to put your full energy into the design process.

Write out a list of issues and their definitions. Keep them in priority order and revisit them occasionally to ensure that you have not discovered the need to change your priorities and that you are spending most of your time on the top-priority issues.

Write goal statements for each issue, making sure that they are clear statements of the quality required of your solution.

Write at least three performance requirements for each goal, making sure that they are specific, measurable, and operational.

Diagram at least three concepts for each performance requirement. You may, as you go along, discover higher-order concepts that you will want to include. Make sure each diagram has a concise caption.

A full program document also includes a project description, a site analysis, a budget, a mass/weight analysis, and other pieces of information that fill out the full story of your project. Just how the document comes together depends upon your audience—who will receive the information? You as the designer? Your client? Keep a careful record as you go along and the final document will be far easier to put together.

Make a list of all the information that should go into your program document and check each item off as you compile the document.

6.1.2. Research Methods Study Guide

Students should be able to search out, read, and understand the validity of research reports as well as be able to conduct small-scale primary research on their own using the basic scientific method, ethnographic methods, and/or good observation techniques.

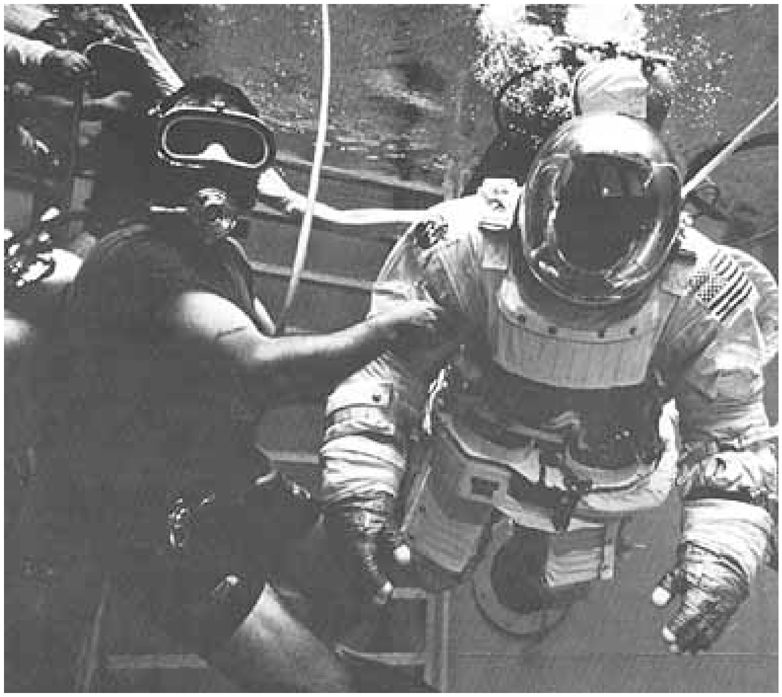

Figure 10. Two astronauts selected for the Skylab mission are assisted by scuba divers during a Neutral Buoyancy Simulator test. http://history.nasa.gov/SP-4213/ch3.htm.

6.1.2.1. Definitions

Research comes in three basic types: *primary* (you saw it yourself), *secondary* (you read what somebody said they saw), and *tertiary* (you read someone's summary of what they read).

The basic scientific method is to observe, record, hypothesize, test, and conclude. When reading research, it is necessary to be aware of good methodology for collecting data, carefully kept records, appropriate analysis tools, and logical conclusions that lead from the data instead of justifying a position. Neutral buoyancy simulations such as those at USC and MSFC have the conditions that most closely approximate microgravity for tests and research on Earth (Figure 10).

6.1.2.2. Topics

Research tools for designers vary from casual observation to rigorous primary research. The following is a sequence of research activities that will be useful as a protocol or a checklist.

Literature Review Basics:

Find an *expert* for a starting point.

Develop a *list of topics* for search (i.e., king = regent = monarch).

Research books and periodicals in the library: word search, subject search, and references given the same catalogue numbers close to a good resource.

Find bibliographies, authors, and *new topics* for subject and word search.

Research government documents.

Research conference proceedings.

Perform a web search: organizations, people, and topics.

Keep accurate *records* of topics and sources that are useful, as well as bibliographic information.

If primary research is required, the following is a useful sequence:

1. *Casual observation* asks "What is the story of this place?" It is done by just hanging out in a place that has the population or the type of activities that need to be understood more clearly. Data collected might be: a list of the types of activities, a list of the types of people, a list of physical characteristics that seem to support certain behavior, or a sequence of what several people do in the place. Its main purpose is to get a feel for the place to help develop a question or an hypothesis.
2. To *develop an hypothesis* or a research question, ask these questions: "What will I know about how to design when I know the answer to my (forming) question? What do I think makes this place work? How can I prove my guesses to be right or wrong?" A question such as, "How do I make a small space seem larger?" is far too general. One question such as, "Do windows make a small space seem larger?" is too narrow and has already been answered with a "Yes." A decent question to ask and test might be, "Could a video scene serve the same function as a window in this place? If so, how well?"
3. *Design the research study* as carefully as if you were designing a room. Choose the methods carefully to answer the question. Just asking people if they would spend time looking at a video screen instead of a window does not get to the heart of the matter. Know who should be the research subjects and where to do the research work.
4. An important concept in research is "*units of analysis*"—Choose the "what" to be studied so that one can compare apples to apples. It does no good to have one person watching a crackling fire on the video and another watching an action movie and a third watching an underwater scene instead of looking out a window. Unless all subjects watch the same video, the comparison is not valid.
5. After choosing the methods, the first thing to do is a *pilot study*. This is a trial run where one will, hopefully, make all the major mistakes. Ask for a generous set of volunteers to be the first subjects. Carefully define what to look for, when the event happens or person appears, and how to record it. Methods are usually best carried out in groups of three so that one can verify or negate initial assumptions from one method by cross-checking it with another.

Data-gathering methods are vitally important to your success. The following group of tools has proven to be very useful to architects:

1. The *focused interview* is a technique that requires that a consistent set of questions be asked of each subject. Start with general questions and move to more specific ones as the interview progresses. Practice encouraging a quiet respondent to elaborate and to steer a verbose one back on topic. Choose informants carefully and be careful not to waste their time.
2. *Observation techniques* are what architects seem to find most useful. After having done a casual observation, it is time to set up some *systematic observations* where it is possible to count things that are meaningful to the study. Most people will not need to use observational methods that are rigorous enough for statistical validity, but Whyte (1980, 1990) has done so in New York.
3. A favorite technique is the *behavior map*. Make a drawing of the place to be observed. Make enough copies so that there is one for every five minutes of observation time. Note the date, time, weather, where the observer is in the scene, and any other important information. Alternate between mapping where people go (*traffic*) and what people do (*activity*). If the "who" is important, mark that on the map. Be sure to operationalize the differences between faculty and students or whomever you are trying to observe, if those differences are important to design. Operationalize means that there are

objective criteria for putting an observation into one category or another, such as making a list of all those behaviors that will count as "social interaction."

4. *Participant observation* is another great observation technique. Taken from anthropological work, it involves being a part of the group being observed, and letting them know exactly what the purpose is. Do the same homework one would do for any other observation (units of analysis, pilot study, etc.) but take notes after the events.
5. If testing the effectiveness of a certain arrangement or object, an *experiment of the A-B-A design* may be warranted. "A" is the original observed condition. "B" is the rearranged situation, observed in the same manner as the first. The second "A" means that you return the environment to its original condition and observe again. If the condition "B" has different behaviors, then check to be sure that it was the intervention and not the "Hawthorne effect" (look up if unknown).
6. *User diaries* work well when there is a long series of events to be recorded and the researcher is unable to observe them. The instructions must be the same for each person and be specifically targeted toward units of analysis or the wrong information will be generated.
7. Sometimes *drawings and maps* made by subjects are illuminating. Choose or devise methods in a manner that will best answer the questions, not "do an observation experiment."
8. *Case studies* are also good for design research. They generally use numerous methods with a smaller set of subjects. Some of the isolation and confinement studies use each person as a "case" and use many measures to gather data. The books by astronauts and cosmonauts and their experiences may be useful as case studies if you read with some clear units of analysis in mind and they give comparable information.

Data analyses/testing are vitally important for scientists needing to prove their theories. In subjective design it is appropriate to verify validity by using multiple methods; i.e., if sufficient observations and interviews give the same information, there is a good chance that the direction is appropriate. For more vital processes such as life support systems, a more rigorous, empirical testing is required.

Every good research report draws *conclusions and design implications*. State the information that confirms that the answers to the question asked are "X, Y, and Z." If conclusions are uncertain, then it is appropriate to outline future research. If the hypothesis turns out to be false, then "No," is a good answer, and useful for design.

Most of these methods are called "quasi-experimental" because the subjects and conditions studied are not randomly assigned to one condition or the other, but are chosen because they exhibit the specific characteristics under consideration.

6.1.2.3. Useful questions

Which methods will best help answer the questions?

Are there any facilities on Earth comparable to the facility to be designed?

What facilities has the space program used on Earth to facilitate use and understanding of the space environment?

Are people available who might be very much like the people for whom the design is intended? Are there some things that can be tested on classmates?

6.1.2.4. Resources

Duerk, Donna P.: Architectural Programming: Information Management for Design. John Wiley & Sons, New York, N.Y., 1993.

Groat, Linda; and Wang, David: Architectural Research Methods. John Wiley & Sons, New York, N.Y., 2001.

Whyte, W. H.: The Social Life of Small Urban Spaces. Conservation Foundation, New York, N.Y., 1980.

Whyte, W. H.: The Social Life of Small Urban Spaces. [video] Municipal Art Society of New York, New York, N.Y., 1990 (many useful research techniques for architects and planners).

Yin, Robert: Case Study Research: Design and Methods. Sage Publishing, Thousand Oaks, Calif., 1989.

6.1.3. Problem-Solving Methods Study Guide

Students should be able to use a wide variety of design methods and more advanced problem-solving skills, from detailed analyses to graphic concept maps, to create innovative solutions to the myriad problems posed in aerospace architecture.

6.1.3.1. Definitions

Advanced design and problem-solving techniques generally go into greater detail and become similar to systems engineering. Functional analysis, systems analysis, prototype modeling, pattern language, and mission simulations all lead to understanding the problem at hand at multiple levels: from the overall system characteristics to the functionality of the smallest designed module.

6.1.3.2. Topics

6.1.3.2-1. Analysis techniques

Pragmatic principles for *systems engineering* do very well for advanced design in aerospace.

Know the problem, the customer, and the consumer.
Use effectiveness criteria based on needs to make system decisions.
Establish and manage requirements.
Identify and assess alternatives so as to converge on a solution.
Verify and validate requirements and solution performance.
Maintain the integrity of the system.
Use an articulated and documented process.
Manage against a plan (DeFoe, 1993).

Systems analysis leads to an understanding of the parts of a system and the interactions that make it function as it does. Tools from organization charts to objective and fault trees, from rich picture concept maps to “House of Quality” diagrams (Lowe, 2000) serve to organize data and show relationships that illuminate the design. See the Systems Integration Study Guide. House of Quality diagrams plot performance requirements against each other to ascertain the enabling and inhibiting interactions between the requirements and use weighted values in judging the importance of solution components. A good system diagram shows how the system works: from inputs to outputs and all the interacting elements and forces in between (Senge, 1990).

Safety analysis is one of the most important aspects of designing for space because it is an environment that is not hospitable to human survival. See the Critical Threats to Safety Study Guide.

With regard to *proximity analysis*, functionality depends upon minimizing conflicts and maximizing efficient circulation. A matrix of all spaces/activity areas can be developed to uncover audial, visual, and olfactory conflicts as well as diagrams for person trips between spaces.

With regard to *ergonomic analysis*, Man Systems Integration Standard NASA-STD-3000, Rev B (plus web updates, http://msis.jsc.nasa.gov/) gives detailed ergonomic measurements of many aspects of space architecture. Check the designs for use by a person in neutral body position in microgravity.

Christopher Alexander and his colleagues at the University of California, Berkeley, developed *Pattern Language* for architects and planners. It is a hierarchical set of patterns that respond to performance requirements for everything from city form to paving stones. There is no comparable set of patterns for aerospace architecture, and it would be an excellent learning opportunity for students to develop an analytical catalog of design concepts that solve problems specific to the space environment. Make innovation a goal for using this system.

6.1.3.2-2. Synthesis

Concept mapping (also called mind mapping or mess mapping), invented by Joseph D. Novak, is a great tool to lay out what is known already and find where the gaps are, where the connections are, what the relationships are, and even to begin to develop a system analysis. Start with an idea and put it in the center. Draw lines to the subsidiary ideas that come next. Each line may have a verb or descriptor that explains just how the item is related to the central topic. Each subsidiary idea may also have lower-level ideas connected to it. Some ideas may be related to more than one subsidiary idea, so lots of loops may form. See Figure 11 for a concept map for exploring Mars. It is a map that gives us an index for many other concept maps.

It is the action of filling in the gaps that makes this a really good synthesis tool and brainstorming helper. If a problem, issue, or idea is known, then finding a solution is more likely. A concept map is a good way to begin to get a handle on what Horst Rittel calls the "wicked problems" of design (Keep, 2000). Organization charts, tree diagrams, spider diagrams, etc. are all specific versions of the same idea. Concept maps become "rich pictures" when they are embellished with graphics for the ideas that the map communicates.

The *participatory design* technique allows the users to be involved in the process instead of having designers guessing. Many techniques are available, from having the users look over the shoulder of the designers as they work to having the users manipulate models or diagrams or criteria for success. For students of aerospace architecture, the use of first-hand accounts by astronauts and cosmonauts will be of value as a substitute, because most will not be able to interview active participants in the space program.

The *Morphological or Zwicky Box* tool, designed by Fritz Zwicky, is for creating a force fit among different aspects of a design. Imagine a box divided into smaller boxes and on each axis is a set of ideas. For example: X-axis = fuel: gasoline, nuclear power, solar power, solid fuels, electric battery power, mag-lev (all possible power sources); Y-axis = sling, chair, box, bubble, bed (all possible carrying devices); and Z-axis = rail, hard surface, water, vacuum, air, oiled surface (all possible surfaces/media to move upon). Now pick one from each axis and try to design a method of conveyance that uses the three aspects together, no matter how crazy it seems on the surface (Ritchey, 2003).

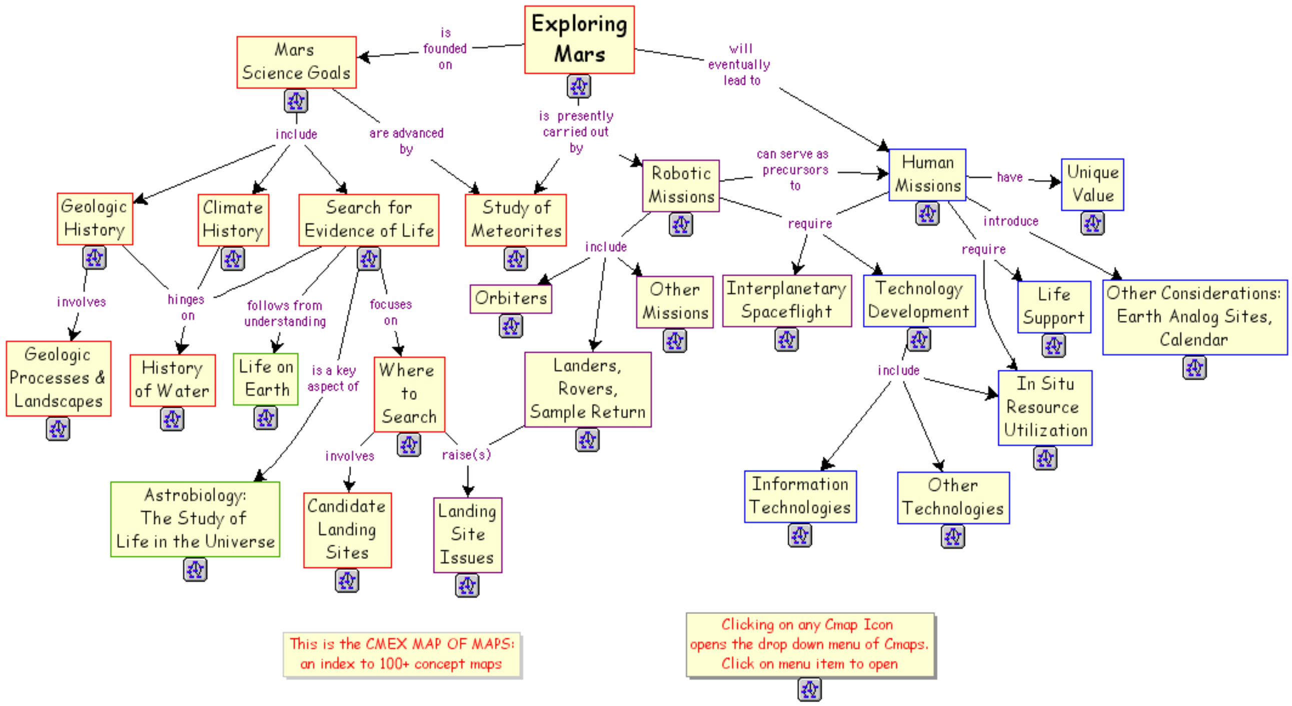

Figure 11. Concept map for exploring Mars. http://cmex-www.arc.nasa.gov/CMEX/Map%20of%20Maps.html.

6.1.3.2-3. Evaluation

Decision trees can show all possible outcomes from several levels of decisions. They can take the form of simple trees or networks of decisions. Each outcome can be compared on a set of values such as dollars, weight, mass, ease of use, or a multitude of performance or risk criteria. A fault tree analysis is useful in documenting risk factors and design weaknesses (Stamatelatos and Vesely, 2002).

The *binary matrix* device plots alternatives against each other and judges them two at a time as to which is best, based on a set of criteria. This technique is useful if there are a large number of alternatives to evaluate. Matrices can also be used to plot and score a variety of alternatives against an array of criteria. Under these circumstances, the criteria are usually given a weight to indicate their importance for success.

Computer graphics—three-dimensional (3-D) simulations/animations—have become important tools in the development of prototypes, walk-throughs, and modeling of various processes such as sun movement and heat loss. If available, use the various programs for modeling air flow, mission design, and other features of an aerospace design. These tools should be useful in testing the more outlandish design concepts for utility. Mission simulations take high degrees of animation skill that are appropriate for this level of architectural design. If the students do not already possess fundamental rendering and modeling skills, then it may not be appropriate for them to learn the software and the rigors of aerospace architecture at the same time.

6.1.3.3. Useful questions

What is your current design process? Can you name all the activities you do when you design?

If reading the personal accounts of astronauts is the only substitute for participatory design, is it sufficient? Who might be surrogate users? How else might you discover criteria for suitability for space?

How might you combine these methods to create for yourself a more powerful design methodology?

Which of these methods do you already use unsystematically?

Which of these methods are new to you or offer refinements that you can use?

How might you use the principles of system engineering to assist you to create a plan and to organize a timeline for your project?

From the analysis you have done on the precedents of your project type, can you discern any patterns that are worthy of documenting in the same form as in a Pattern Language?

What 3-D computer programs are available to you? Which of them do you have skill in using?

What mission simulations can you do without a computer program?

6.1.3.4. Resources

Adams, J. L.: Conceptual Blockbusting. Fourth ed., Perseus Publishing, Boulder, Colo., 2001.

Alexander, C.; Ishikawa, S.; Silverstein, M.; Jacobson, M.; Fiksdahl, I.,; and Angel, S.: A Pattern Language: Towns, Buildings, and Construction. Oxford University Press, Oxford, 1997.

Broadbent, G.: Design in Architecture: Architecture and the Human Sciences. John Wiley & Sons, New York, N.Y., 1973.

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Koberg, D.; and Bagnall, J.: Universal Traveler. Fourth ed., Crisp Publications, Menlo Park, Calif., 2003.

System Engineering Handbook, NASA SP-610S, 1995.

Man-Systems Integration Standards. Vols. I & II, REV-B NASA, Houston, Tex., 1995 (electronic version: http://msis.jsc.nasa.gov/).

Fault Tree Handbook with Aerospace Applications. NASA, Washington, D.C., 2002.

Peercy, R. L. Jr.; Raasch, R. F.; and Rockoff, L. A.: Space Station Crew Safety Alternatives Study—Final Report. Vols. I–V, NASA CR-3854, 1985.

Rowe, Peter G.: Design Thinking. MIT Press, Cambridge, Mass., 1991.

Ritchey, Tom: General Morphological Analysis: A General Method for Non-Quantified Modeling. Adapted from a paper presented at the 16th EURO Conference on Operational Analysis, Brussels, 1998.

Senge, Peter: The Fifth Discipline: The Art & Practice of the Learning Organization. Doubleday, New York, N.Y., 1990.

Zeisel, John: Inquiry by Design. Cambridge University Press, Cambridge, 1984.

University of Queensland, Design Surfer's Paradise, http://www.catalyst.uq.edu.au/designsurfer/, 2002 (Australian engineering website with interesting method).

Lowe, A. J.: Quality Function Deployment. House of Quality Diagrams Tutorial, 2000. http://www.shef.ac.uk/~ibberson/QFD-Introduction.html.

Defoe, J. C.: INCOSE, Pragmatic Principles. http://www.incose.org/workgrps/practice/pragprin.html, 1993.

Novak, John D.: Theory Underlying Concept Maps and How to Construct Them. http://cmap.coginst.uwf.edu/info/, Cornell University (also software for constructing maps) (nd).

Keep, Christopher; McLaughlin, Tim; and Parmar, Robin: The Electronic Labyrinth. IBIS, http://www.iath.virginia.edu/elab/hfl0104.html, 2000.

6.1.3.5. Activities

Develop a list of topics for literature research that will help you more carefully define your project. Keep an expanded ongoing list as you learn more about your topics.

Develop a noise/odor/vision conflict matrix for Lunar base functions. Develop a person/trip diagram for a day-in-the-life scenario. Derive a proximity bubble diagram that solves the conflicts and enhances activity adjacencies.

Measure your own body and compare to the NASA-3000-STD. What are the critical dimensions for a hatch/port between modules? Other critical dimensions?

Develop a timeline for your year's work quarter by quarter or semester by semester. Mark the evaluative milestones and all the activities you plan to carry out. Develop a week-by-week plan of action.

Draw a concept map of what you have learned so far about the requirements for a Moon habitat that are above and beyond the requirements for a terrestrial home.

Develop a pictorial typology of space habitats. Then develop a concept library of those good patterns that you have observed, including the performance requirements and links to other patterns. Make some judgment as to the validity of acceptability of the pattern—either by documented research or by the problem it solves.

Create a mission simulation in the most appropriate form. Evaluate it using your performance requirements.

Develop 3-D physical or digital models of your concepts. How do they stand up to a safety analysis? A habitability analysis? Do they meet your performance requirements? Is there a virtual reality program you can use to more thoroughly experience your models?

Develop a House of Quality matrix for your project facility using your performance requirements from your architectural program document. See the Architectural Programming Study Guide for more on performance requirements.

Start a concept map of your project. Update it as you go along. Redraw/rearrange the diagram as your organization of your knowledge space changes.

Choose a promising method that you have never used before and try it out on a part of your problem. If it proves useful to you, use it on the whole problem.

6.1.4. Collaboration Study Guide

Students should be able to work together in various team roles to do research, to design, and/or to create a presentation to the class or to mentors.

6.1.4.1. Definitions

It is often said that two heads are better than one. In design, often teams must take advantage of the various skills that different team members have. A good team member can lead or follow as the situation allows. In the world of aerospace architecture, no projects are assumed by an individual—it all takes teamwork, and often a team of many, many people. Cooperative learning has proven itself to be far more effective as student-centered learning rather than teacher-centered learning, and it serves as a model for teamwork as a professional.

6.1.4.2. Topics

Team size is important for smooth functioning. Three to five people on a team make for the best results because beyond that the teams tend to break up into factions and have difficulty keeping everyone attentive (University of St. Thomas, nd).

Goal setting should be the first order of business for any group. When students clearly understand assignments and a group sets its goals for a high-quality product, then the learning outcome is much more likely to be a higher level of attainment than if the work were done individually.

Shared rules and procedures are vital to the smooth operation of a team. Showing up at meetings on time, making sure everyone contributes, being polite, rotating leadership roles, etc. are all useful normative rules. Each team needs to agree on how they will manage to re-inspire a team member who does not abide by the functional rules set by the group.

Making sure that all team members *communicate* their ideas, their needs for support, and the resources they want to contribute should be important to everyone on the team. Listening is more than 50 percent of communication. Students who feel they have been heard will participate more fully than those who feel they have been ignored. People with different learning styles communicate in a variety of ways, and each team member should be open to listening to those forms that are not the same as their own. A different approach may be just what is needed.

Contribution is the measure of the responsibility for the project carried by each individual. It is as important for team members to value and encourage other members' proposals as it is for them to produce their own work. If teams operate by first having each individual set up the problem and then getting together as a group to solve it, each person has something to contribute. The final product is usually better when everyone has an even stake in the project than when one or two dominate or take up the slack and complain about having to do all the work. The weaker student learns by following the stronger student's lead, and the stronger student learns more deeply by teaching the weaker student. A good team is made up of people who have different strengths and weaknesses and who will sometimes teach and sometimes be taught.

Woody Allen is credited with saying that, "Eighty percent of life is just showing up." *Commitment* is the underpinning of all good work. It is the stubbornness that sees students through the rough spots of teamwork, that has them try just a little bit harder to come up with a great solution. People with moderate talent often do great projects because of their commitment and drive to do good work.

In a smoothly working group, members take on the following *roles*: convenor/agenda maker, recorder, and facilitator (who makes sure everyone contributes). These roles may rotate or gravitate to those who do the job best or who like that role the best. Individuals keep their own process record or sketchbook, but a record of the group's decision-making process is important for the collective memory of the team.

6.1.4.3. Useful questions

Students should ask themselves how teams have worked for them in the past. What worked well? What did not work?

If past experience with group work has been bad, why was that? Because one person did most of the work? Because the group did not take time to get to know each other? Because the group goals or norms were unclear?

What actions can each individual take to ensure that this design studio and the smaller teams within it work well as groups?

What role does the instructor have in facilitating good group work?

What team-building exercises can you find that will be fun and useful?

What preparation should team members have for times when the going gets tough and things are not going smoothly? What actions should the team take?

6.1.4.4. Resources

Kagan, S.: Cooperative Learning. Kagan Cooperative Learning, Inc., San Juan Capistrano, Calif., 1992.

Linder, Darwyn E.; and Ledlow, Susan: Five Issues to Be Considered in Teambuilding. http://www.public.asu.edu/~ledlow/sledlow/teambuilding.htm 1999.

University of St. Thomas, Cooperative & Collaborative Learning, http://www.iss.stthomas.edu/studyguides/cooplearn.htm (nd).

6.1.4.5. Activities

Create a "Mission Patch" for the class in groups of three or four, practicing the principles of teambuilding. Each person keeps a log of how the team operated and at the end of the exercise, the group discusses how they could develop into a better team. Then the class as a whole chooses the direction for the design and puts on the finishing details.

Each team should find three or four different team-building exercises to present to the class. Members of the whole class choose one exercise from each group to implement as a class or as small groups.

The class takes a learning-style inventory, the MBTI, or some other analysis of problem-solving or learning approach. They then form teams with the widest possible variety within the team. The team takes on one of the team assignments, from doing a history report to planning a reference mission. Part of their grade is a report on team process.

Astronauts train in teams that will be the mission team. Treat each team in the class as a mission team. Plan the studio space for the team, the project display space, and how to manage computing facilities, food facilities, and property security.

Each project team member should have an opportunity to practice all the roles of team managers: facilitator, convenor, and recorder.

6.1.5. Communication Study Guide

Students should be able to notice a great improvement in their abilities to communicate in all the modes from writing a paper for a peer-reviewed journal, to speaking before an audience, to 3-D walk-throughs on the computer, to sketching by hand.

6.1.5.1. Definitions

Communication is the basis for human relationships. It is the most important part of architecture. If the idea is not acquired for use, it makes no difference how great it might be. Architects are used to drawing, making models, and making presentations to juries. For aerospace architecture, conferences and journals are generally used as the main vehicles for communication. Therefore, it is important for a student to be able to produce a paper that will be accepted at a conference or for a peer-reviewed journal. Published papers are great vehicles, but most of the presentations to conferences are made with graphics that capture the attention of the audience—generally PowerPoint presentations. The combination of a well-written paper and a dynamite visual presentation is difficult to beat.

6.1.5.2. Topics

The American Psychological Association (APA) has developed the standard *format* that has been adopted for peer-reviewed papers. The association's handbook should be available in any library. The basic format of the paper is Title, Abstract, Introduction and Literature Review, Methods, Results, Conclusions/Further Study, and References. A design paper includes inspiring precedents, research that led to the design decisions, the basic design challenges, diagrams, model photos, etc. It is important that the references be consistent and easily found by people reading the paper. Use only Standard International (SI) units.

Knowing the *audience* is the key to the best presentation. The level and amount of technical detail, the number and detail of the illustrations, the use of acronyms and jargon, etc. all depend on how well the audience can readily follow the information presented. The final distribution of your work will also influence its content. For example, if a paper is to be Xeroxed, the illustrations need to account for the high contrast of this medium.

Drawings imbedded into papers need to be clear and simpler than the normal full-size drawings for a poster presentation. They should be legible when reduced. Contrast is also an important consideration because most reproduction is still black and white unless a computer format is readily available. It may be useful to include a more realistic reduced drawing and add a diagram to explain the relationships. All architectural drawings should have a graphic scale and planet-based plans should have a north arrow. Include dates and names as appropriate.

Photographs of models need to have an appropriate level of contrast so that the 3-D quality presents itself in a reduced format in a paper that is reproduced in a high-contrast medium. Labeling should be done at the final scale of the image.

PowerPoint presentations are the typical mode for paper presentation to large groups. The following guidelines are of value to people presenting with overheads or slides. Make sure the text is legible to people in the back row. This usually means a maximum of 10 to 12 lines for text per slide; 5 to 6 lines are better, normally 18 point (pt) type. Colors should have a sufficient contrast to make images, diagrams, and text clear. It is a good idea to practice with a projector for a PowerPoint presentation, because colors on the screen do not always translate well through a projector. Do not read the contents of the slides to the audience. Do not read a paper to an audience. Speak from note cards if necessary, but speak instead of reading.

People will remember only *three points* from a presentation. Most presentations are limited to 20 to 30 minutes, so keep it simple. Presenting three ideas clearly, and speaking reasonably slowly, will aid the audience in understanding and remembering. Good graphics are better than lists or matrices of numbers. Combine drawings and charts to make points clear and keep the audience interested.

For *poster presentations* or for traditional architectural presentations, drawings and computer graphics take on a larger role. The designer can control, to some extent, how the audience's eyes move over the presentation. They generally start at the point of highest contrast and move along strong lines in the presentation, or to sequentially lower levels of contrast, or left to right and back (if that is their normal reading style). One of the best tools for planning a project display is a scale drawing of the layout (called a cartoon, story board, or dummy). The cartoon allows the designer to decide the sizes of drawings, the relationships needed to tell the story of the project, the levels of contrast and simplicity required for legibility, and the interaction of the variety of ways to guide audience eye movements. Storyboards are also great tools for developing a PowerPoint presentation. The conceptual graphic layout of a presentation is the key to audience understanding and serves as the vehicle to tie together the charts and diagrams, line drawings and photos, sketches and computer perspectives, as well as any tables or graphs needed to convey the message.

Often a computer screen is included in such presentations to show animations and fly-throughs. As in speaking, a relatively slow speed for an animation is critical to audience understanding and appreciation.

6.1.5.3. Useful questions

What are the most important things for the audience to understand about the presentation? How can those ideas be most clearly communicated? What form? What medium?

In writing a paper, what is the level of detail appropriate for the reader? How should a paper be simplified for a 20-minute presentation?

How much of the data can best be communicated with graphics? Charts? Diagrams?

How might one compensate for graphics developed in full color yet presented in a black-and-white format so that the graphic is highly legible?

How much of a PowerPoint presentation can be illustrated? How can one reduce the number of words on each slide to images?

6.1.5.4. Resources

University of Wisconsin, Madison, Writing Center, APA Documentation, http://www.wisc.edu/writing/Handbook/DocAPA.html, 2003.

APA Style.org, http://www.apastyle.org/, 2003 (buy the handbook on line).

6.1.5.5. Activities

Write an outline for a paper that you might give at a conference using APA format.

Observe yourself looking at other people's presentations. How do your eyes move and why? What do you see as examples of legible, interesting work? What do you see that needs improvement? Use your observations to improve your own work.

Set up a storyboard for a presentation to the class to explain your mission design scenario.

For each presentation write down the three points that you want your audience to remember.

Practice your presentations so that your speaking is natural and you can keep your eye contact with the audience and leave time for questions at the end.

Make copies of your paper so that you can see the final outcome in terms of layout, contrast, legibility, etc. and make any necessary changes early.

Do the final printing a week before it is due to allow time for solving printing problems and correcting mistakes.

6.2. DESIGN FRAMEWORK

6.2.1. Mission Design Study Guide

Students should understand the consequences for their designs of mission objectives, numbers of people or robots on a mission, the destination, and the length of the mission.

6.2.1.1. Definitions

Mission design makes the basic decisions of what sorts of spacecraft and habitats will be deployed into what sorts of orbits/trajectories to achieve the objectives of the mission (see fig. 12). Objectives usually fall into the following categories: demonstrations, exploration, physical science, life science, tests for habitation (life support, mining, ISRU, etc.), or maintaining a presence. Mission operations and the day-to-day activities will also shape the design.

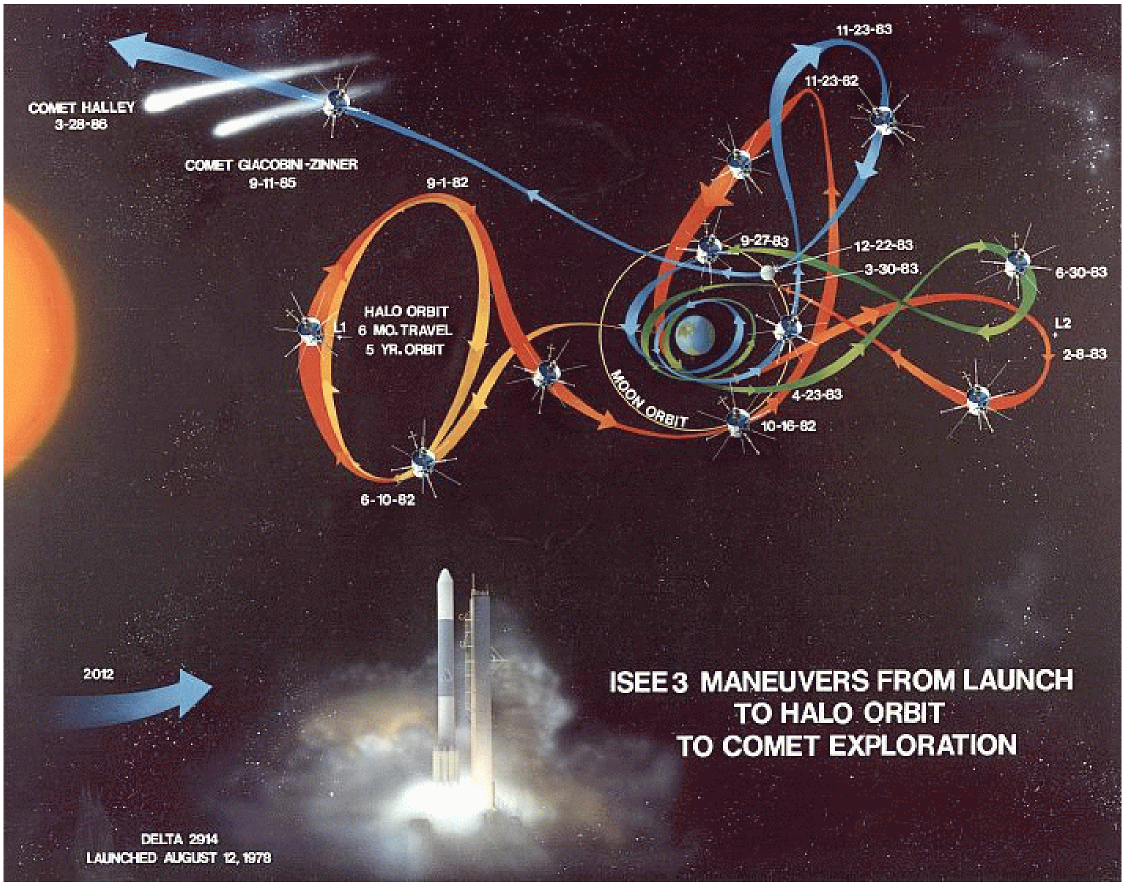

Figure 12. ISEE3 Mission. http://heasarc.gsfc.nasa.gov/limages/misc_missions/isee3_traj.gif.

6.2.1.2. Topics

What is the *purpose* of the mission? Exploration, habitation, settlement? Can multiple purposes be implemented with quality, or are there conflicts? What are the operations and crew time allocations?

What is the *lift capacity*? How much should land? Vehicle types and sizes?

Sequence of events: Who/what goes first, what are the first activities? How many types of vehicles? What allocations of functions are necessary among the different parts of the mission facilities?

What is the *human/robot interface*? Robots as scouts? Robots as constructors? As habitats? How to tell when something goes wrong and needs to be fixed? Integration issues?

What is the *size* of pressure vessel, and for how many people?

Open vs. closed system—level and frequency of *resupply*? Weight of consumables? Length of mission?

Destinations/trip segments:

Earth to LEO; LEO to low Lunar orbit (LLO); LEO to moon surface; Moon surface to LLO or back to Earth; Mars, Mars moons, asteroids

Construction:

On Earth; In LEO; At L-2 (Sun-Earth), L-5 (Earth-moon), or other Lagrange points

Costs: Fuel, time in orbit, mass to target? Mass, volume, power budgets?

Are life support systems *central* or *distributed*?

For long-term bases—how to *move payloads* away from the landing zone?

6.2.1.3. Useful questions

What is the difference between a mission for pure exploration and one that is for human settlements? Between a mission for mining and one for establishing a presence? What are the critical requirements?

How can you decide what is best for robots and what is best for humans to do on planetary missions?

What are the different types of vehicles possible and their uses in an overall mission strategy? Which are already under development and which still need to be designed?

For each phase of the mission, what are the best components to do the job?

What are the constraints for sizes and numbers of components and length of mission?

6.2.1.4. Resources

Cohen, Marc M.: First Mars Outpost Habitation Strategy. In Strategies for Mars: A guide to human exploration, Stoker, Carol R. and Emmart, Carter, eds., vol. 86, Science and Technology Series, American Astron. Soc., San Diego, Calif., 1996a.

Hoffman, S. J.; and Kaplan, D. I., eds.: Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team. NASA SP-6107, 1997.

Larson, Wiley J.; and Pranke, Linda K.: Human Spaceflight: Mission Analysis and Design. Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

Mankins, John C.: Human Exploration and Development of Space (HEDS) Technology/Commercialization Initiative, for the Space Resources Roundtable (II). NASA, Golden, Tex., 2000.

Zubrin, R. M.; Baker, D. A.; and Qwon, G.: Mars Direct: A Simple, Robust, and Cost-Effective Architecture for the Space Exploration Initiative. AIAA-91-0328, 1991.

Lampson, N.: Space Exploration Act of 2003. http://www.house.gov/lampson/pr09-10-03.htm, 2003 (Texas Congressman).

Center for Mars Exploration, Mars Reference Mission Summary, Mission Design, http://cmex.arc.nasa.gov/marsnews/missions/human_missions/links/Human_Mars_Mission3.html#3.3.1; Mars missions, http://mars.caltech.edu/links.html (nd).

The Artemis Project, http://www.asi.org/adb/05/, 2002 (privately funded lunar research and mission plans).

6.2.1.5. Activities

Research various reference missions to see how they are designed. Diagram the steps.

Document the arguments for the mission design of the Apollo missions that debated between the Earth-orbit-rendevous vs. the Lunar-orbit-rendezvous design.

Make a list of all the options that you want to consider in your mission design. Develop a decision tree. Keep a journal of the arguments pro and con for each decision along the way.

Develop a list of criteria that will help you decide how large your spacecraft(s) needs to be and what the constraints are.

Develop a mission statement—the big picture. What is your mission purpose? A good mission statement is the start of architectural programming.

Develop a concept map of those areas you think deserve your primary attention, because you cannot learn everything all at once. Keep a record of your discoveries and decisions.

List the arguments for a crew of three versus a crew of eight or more for a mission to the moon or Mars.

Start to develop alternative mission configurations so that as you learn more, you can critique them effectively in greater detail.

6.2.2. <u>Systems Integration Study Guide</u>

Students should be able to use the tools of architecture and systems analysis to integrate the wide variety of concerns from safety, habitability, and structure, to functionality and aesthetics into the design of facilities for aerospace and critically analyze them for quality.

6.2.2.1. Definitions

Systems are basically things in *relationship* to each other—a set of elements that interact to produce a behavior. Systems thinking and systems analysis are ways of understanding the sets of interactions and how they produce the behaviors.

Space architecture has many issues that are not critical in terrestrial architecture. It is the *integration* of all the issues from life support to EVA to habitability that will make a space vehicle or habitat successful. All the tools and perspectives described in the following paragraphs are useful and can be used in combination to develop a path toward integration and/or to assess how well the integration was achieved.

6.2.2.2. Topics

6.2.2.2-1. Understanding the System—Analysis

Fault tree analysis (FTA) is a tool used for risk assessment and failure analysis. It is a systematic way to list all failures thought to be possible (probabilistic risk assessment, or PRA) and to track all the known ways that a failure could occur. It starts with a known failure and tracks all possible contributors to that failure in a binary decision tree using gates that are "and" or "or" circumstances. In the "and" circumstance, both A and B must happen for the fault to occur. In the "or" circumstance, the occurrence of either A or B will result in the occurrence of the fault. Then the tree goes on to investigate what the sources of A or B might be—similar to the classic chain of events, "For want of a nail the shoe was lost, for want of a shoe the horse was lost, for want of a horse the rider was lost, etc.....until the war was lost." At essence a fault tree analysis is looking for the nails (base events) that could lose the war (top event). The minimum cut set is the set of those base events, both mechanical and human, that are the minimum necessary to produce the fault (top event). The main drawback to FTA is that the fault tree works only as well as the list of possible events that contribute to failure. It does not uncover unsuspected events. FTA can also be used for planning, prevention, and for reducing the complexity of systems (NASA, 2002).

House of Quality diagrams are useful tools for rating and comparing different aspects of the problem with each other and for comparing and rating different solutions. In Figure 13, the factors listed in the square on the left side (middle, "whats") are quality goals, the factors in the square at the top are performance requirements ("hows"), and the "roof" of the house is the rating of the interaction of the performance requirements from strong negative to strong positive. At the bottom is an assessment of how the solution is rated in performance terms, and the right side rates the solution in terms of how it stacks up against others in meeting the goals. Using this tool, designers must look at the interactions of the parts.

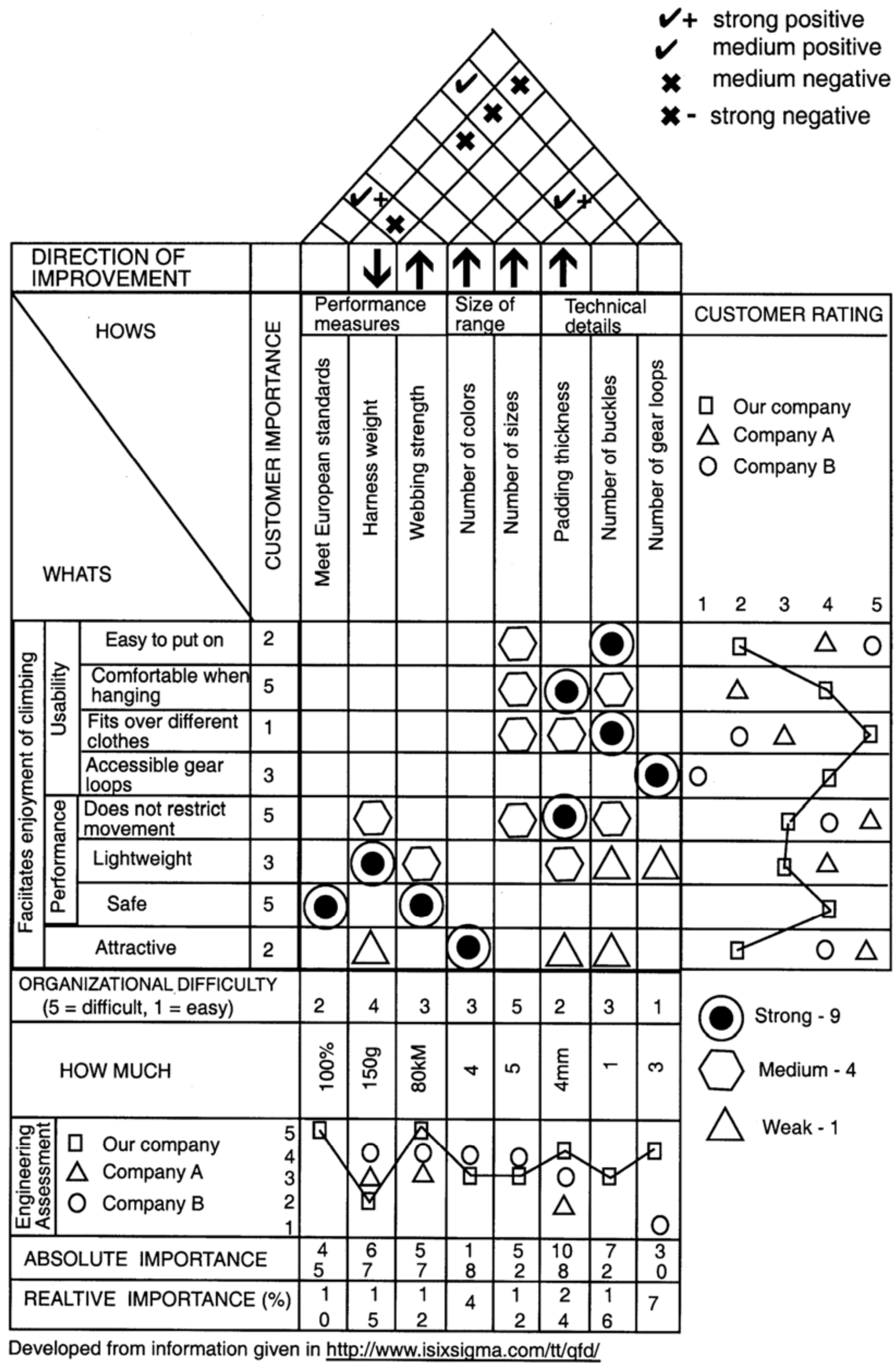

Figure 13. House of quality diagram for a backpacking product. http://www.isixsigma.com/tt/qfd/.

Causal loops are the classic systems analysis diagrams that plot the elements of the system being studied with the loops that indicate their interactions: there are elements, inputs, actions, and outputs. These are often reduced to "stocks" (resources, whether human or material) and "flows" (actions, movements of resources). Figure 14 shows flow of "interest earned" into the resource of "cash on deposit," which as it grows impacts the amount of interest earned, leading to the compounding of interest. The external factor of interest rate also impacts the flow amount. Causal loops can become very complex, depending on the level of detail and the numbers of flows and stocks to be related (Boucher, 1995).

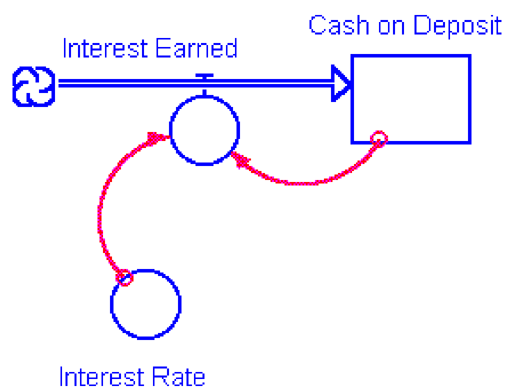

Figure 14. A simple causal loop. http://www.economics.ltsn.ac.uk/cheer/ch9_2/ch9_2p03.htm.

Project management time flows are recorded in *Gantt charts*, PERT charts, and other critical path tools. Much software is available for creating these tools for managing the different parts of the system design.

Concept maps are also great tools for understanding system interactions. See the Problem-Solving Methods Study Guide.

6.2.2.2-2. Integrating the systems

Architecture has long used the *geometry* of form and proportion as integrators. From the Greeks and Romans to Corbu to Bucky Fuller, the systems of relationships between the parts of the buildings governed the overall design. Much of the logic of aerospace architecture is governed by the functional anthropometrics of the people working in space within a minimal weight and volume budget.

Patterns and meta patterns are ways of looking for the systems within systems that create easily useable and buildable facilities. The truss within the span within the bridge, the post and beam system, and the geodesic dome are all structural patterns in architecture that have some use within aerospace. Other patterns need to be recognized or developed for a more efficient aerospace architecture.

A *functional* matrix helps the designer to see how to group or distribute functions most appropriately. In missions such as those to the moon, current technology gives small launch loads a greater cost efficiency and implies distributed functionality and mass production. A large lift load would allow for centralized functionality and a greater efficiency in surface-to-volume ratio. There must be a balance between centralized versus distributed functions within the cost parameters of the system.

Modularization has come into its own in the shipping industry, but not yet in the realm of architecture. Moshe Safdie's Habitat was visionary, but the precedent was not followed in any significant way. In aerospace, standardization and "plug-and-play" modular components will make internationalization of the space program much easier than the implementation of the ISS which has not all standard interfaces or modules.

Hardware commonality is another aspect of the need for standardization. Chases for electrical conduits, plumbing, and data transfer all need to be thoroughly integrated, not only for space saving, but also for ease of maintenance and repair. The position and number of airlocks and docking ports should be functional for interior equipment deployment as well as on the exterior for connecting to other modules and access for EVA.

Information/data systems, although not form generators, are a substantial portion of the functional integration of the work of a space facility—whether it is a vehicle or a habitat. Avionics (aviation electronics) include guidance, navigation, and control. Communication to ground and to families of the space flyers is also important.

6.2.2.3. Useful questions

What are the components of the system in the facility you are designing? How many of the components are systems in their own right?

How should the systems that you are designing interact?

How many of the tools discussed previously can you use to improve your understanding of the integration issues in your design?

6.2.2.4. Resources

Senge, Peter: The Fifth Discipline: The Art & Practice of The Learning Organization. Doubleday, New York, N.Y., 1990.

Shishko, R.: NASA Systems Engineering Handbook. NASA SP-6105, Washington D.C., 1995.

Fault tree Handbook with Aerospace Applications. NASA, Washington, D.C., 2002.

House of Quality or "Quality Function Deployment." http://www.isixsigma.com/tt/qfd/, QFD diagrams, 2003 (includes tutorial and examples).

Shibley, John J.: Primer on Systems Thinking. http://www.systemsprimer.com/index.html, 2003.

6.2.2.5. Activities

Start to develop a "House of Quality" matrix. Start with architectural programming goals (the hows) and the technical performance requirements (the whats) you have developed in your research. Start with the top five goals and the top five performance requirements. Continue to develop it as you go for each system and subsystem, documenting your priorities, actions, and evaluations. If the matrix gets too big, break it into parts and create another matrix of higher-order/simpler comparisons.

What is a simple enough fault tree analysis to do as a part of your design planning? Draw it out.

Develop a concept map for all the systems and system components—nest them if necessary. Nesting means that the overall map may be a map of maps and many items have their own maps on other pages.

Write a set of performance requirements for how the systems should work together.

Develop a timeline using the Gantt method, a program evaluation review technique (PERT) chart, or other critical path method (CPM) that works for you.

6.2.3. ***Habitat/Habot Concepts Study Guide***

Students should understand the workings of the large variety of ideas for how to create habitable spaces on planetary surfaces, from "man cans" to habitable robots (Habots). See Figure 15.

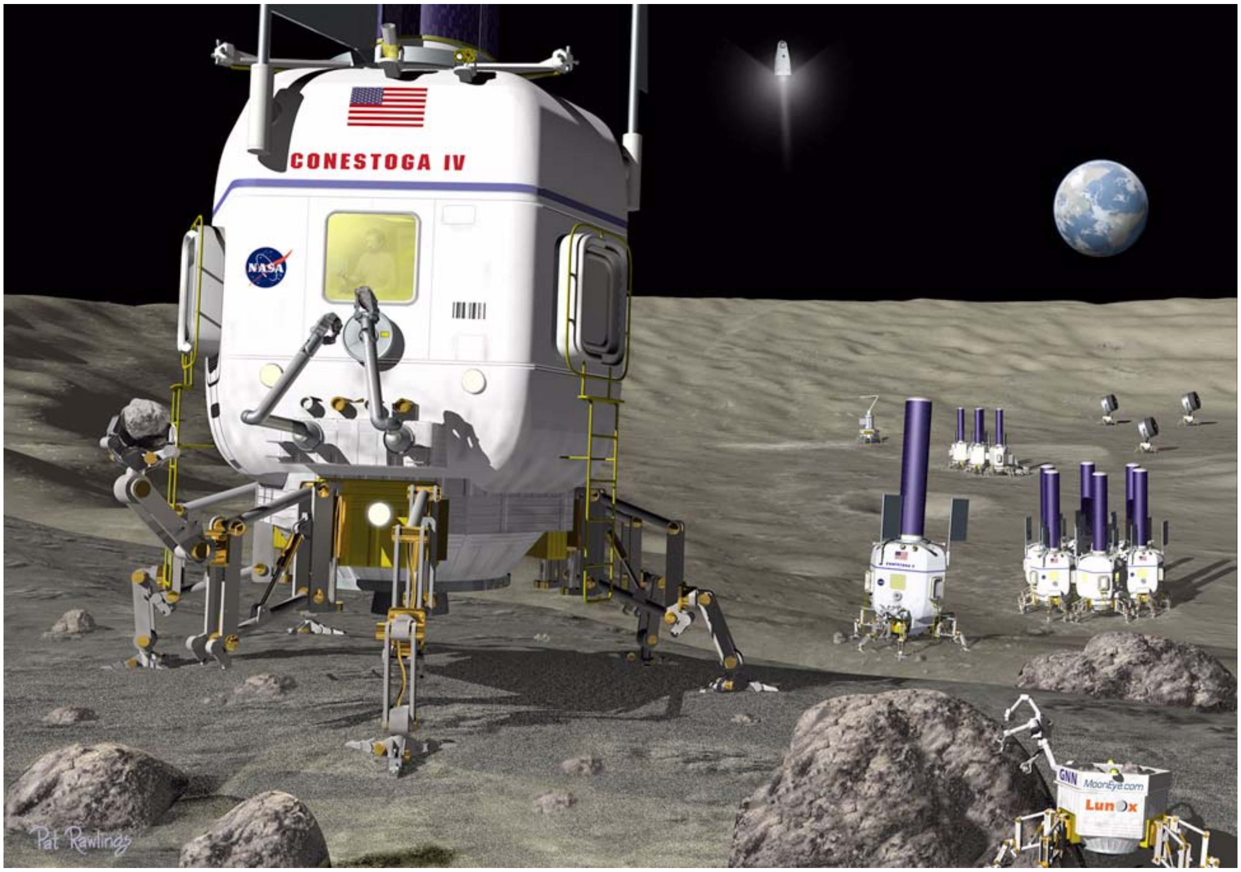

Figure 15. "Habot" Mobile Lunar Base concept. Pat Rawling's rendering, courtesy John Mankins, NASA Headquarters, and Neville Marzwell, Jet Propulsion Laboratory.

6.2.3.1. Definitions

To date, visits to the surface of the moon have lasted only a few days. The future vision of *living on the moon* for months or years needs a lot of technological and design advances to become a reality. A habitat is the place/container where people live and often work. This unit explores those visionary and more realistic concepts for further development in this course. The learnings from the human factors and habitability study units are vital to development of habitats.

6.2.3.2. Topics

Visionary concepts for the future *utilization of space* come from many sources. Gerard K. O'Neill envisioned very large habitats at the Lagrange points that would eventually house 10,000 people in each habitat. The Mars Society is actively pursuing habitat, mission simulations, and public education so that, "This time we stay!"

Space stations from SkyLab to Mir, and the ISS, have been useful for discoveries, especially about the effects of microgravity on people. They have also been laboratories for the study of humans living in isolated and confined environments in LEO. Most of the missions have been short (± 6 months) with a few Russian exceptions (about 2 years, maximum). Much more understanding about the long-duration effects on people in space is needed before a Mars mission can be realistically attempted.

Mars habitat concepts range from a habitat as lander to inflatables, to robotic placement and configuration before the arrival of humans. Some are surface oriented, and some are dug into the surface and covered with regolith. Some are consolidated and some are spread out. Much work and design needs to be done to determine the best way to start our missions on the red planet.

Lunar habitat concepts have as much or more variety than the Martian ones. Besides the configuration of the habitat, there are considerations for power source, in-situ resource utilization (ISRU), dust, radiation protection, and mission-specific scientific analysis. Lunar bases will be good research for Martian habitation.

6.2.3.2-1. Lunar bases and Habots

The argument as to whether to make a base *stationary* or *mobile* may depend upon the development of relatively lightweight radiation shielding. The many ideas for how to organize a mobile Lunar base include the following: the big habitat where everything to live and do research is in one structure, small modules that hook together, a train concept, or a "wagon train" approach.

Habitats that are also robots are called *Habots*. The concept is that the habitats can be sent ahead of the crew and they will move to the appropriate site and set themselves up in readiness for the crew's arrival. They will also have robotic capabilities that can be controlled by the crew for research and travel as necessary. Several Habots hooked together will make a small community of astronauts.

Habitats may be one of *three classes*: 1. Premanufactured and sent whole to the surface, ready to be inhabited; 2. Prefabricated and assembled in space or on the surface; and 3. Made entirely on the surface of available resources (Cohen, Marc, 2002b).

6.2.3.3. Useful questions

What do all the habitat concepts have in common?

What do the space habitats need that terrestrial homes do not? Are there patterns that are useful to notice?

What are the most important issues that have not yet been solved to full satisfaction?

What are the smallest spaces that would serve as appropriate living spaces for long-duration spaceflight or planetary habitats? How do you find out the measurements?

How might a set of habitats be connected together for maximum efficiency and sociability?

6.2.3.4. Resources

Eckart, Peter: The Lunar Base Handbook. Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

Hoffman, Stephen J.; and Kaplan, David I.; eds.: Human Exploration of Mars: The Reference Mission of the NASA Mars Exploration Study Team. NASA SP-6107, 1997.

O'Neill, G. K.: The High Frontier. Apogee Books, Burlington, Ontario, reissued 2002 (a visionary look at living in space).

Stoker, Carol R.; and Emmart, Carter: Strategies for Mars: A Guide to Human Exploration. Science and Technology Series, vol. 86, American Astron. Soc., San Diego, Calif., Univelt, 1996 (plus others in the series).

Benaroya, Hyam: Reliability of Structures on the Moon. Structural Safety, vol. 15, 1994.

Cohen, Marc M.: Designing Space Habitats for Human Productivity. SAE Technical Paper 901204, 1990.

Cohen, Marc M.: Space Habitat Design Integration Issues. SAE Technical Paper 981800, 1998.

Cohen, Marc M.: Pressurized Rover Airlocks. SAE 2000-01-2389. 30th International Conference on Environmental Sciences (ICES), Toulouse, France, 2000. Society of Automotive Engineers, Warrendale, Pennsylvania.

Cohen, Marc M.: Selected Precepts in Lunar Architecture. IAC-02-Q.4.3.08, 53rd International Astronautical Congress, World Space Congress AST, International Astronautical Federation, Houston, Tex., 2002.

Cohen, Marc M.: Mobile Lunar and Planetary Bases. AIAA Paper 2003-6280, AIAA Long Beach, Calif., 2003.

Howe, Scott: The Ultimate Construction Toy: Applying Kit-of-Parts Theory to Habitat and Vehicle Design. AIAA Paper 2002-6116, AIAA Space Architecture Symposium, World Space Congress, Houston, Tex., 2002.

Kennedy, Kriss J.: The Vernacular of Space Architecture. AIAA Paper 2002-6102, AIAA Space Architecture Symposium, World Space Congress, Houston, Tex., 2002.

Kitmacher, Gary H.: Design of the Space Station Habitable Modules. IAC-02-IAA.8.2.04, World Space Congress, Houston, Tex., 2002.

Mankins, John: Modular Architecture Options of Lunar Exploration and Development. Space Technology, vol. 21, no. 1–2, 2001.

Tullis, Thomas S.; and Bied, Barbra R.: Space Station Functional Relationships Analysis Final Technical Report. NASA CR-177497, 1988.

Vogler, Andreas: Modular Inflatable Space Habitats. First European Workshop on Inflatable Space Structures, ESA/ESTEC, 2002.

The Mars Society: http://www.marssociety.org/, 2001.

6.2.3.5. Activities

Diagram the basic concepts for habitats in LEO or in deep space from small to large.

Diagram the variety of Lunar habitat vessel concepts—you might include radiation protection, configuration, composition, and size. Evaluate their relative effectiveness within what you know of criteria for safe design. As you learn more, you may want to revisit this exercise.

Diagram the different concepts for Mars habitats. How different are they from the Lunar ones?

Diagram the “city planning” of a variety of Lunar or Martian bases. Evaluate their effectiveness for efficiency, habitability, and safety—given what criteria you know at the present. Any noticeable patterns?

List/diagram the advantages and disadvantages of different concepts for grouping Habots together for extended work periods. How might the various functions be distributed? How would you want to live during the two-week-long Lunar night? Would there be any difference for a permanent settlement?

Devise a scenario of what the astronauts might do in their Habots over one Earth day on the moon.

Investigate the various shapes that a Habot might take. Which are the most efficient for surface/volume ratios? For human habitation? For equipment? For connecting together? For structure? For a variety of internal functions? For a permanent settlement?

Habots add the dimension of mobility to the Lunar habitat equation. Diagram the different concepts for mobility. List the positive and negative aspects of each. Can you imagine other concepts not shown in the literature you have searched? Another study guide more fully covers the mobility aspects.

How might Habots and a permanent settlement complement each other best? Design an interface between the two.

7. PRESTUDIO WORKSHOP

The purpose of a workshop is to start students off on a path of research and discovery that they can begin over the summer, before they begin their final year of study. It sets out some readings, lays the groundwork for a variety of project types, and focuses on habitat options.

A brief introductory presentation (±1/2 hour (hr)) outlining the purpose of the workshop introduces the field of aerospace architecture and helps students gain some insight into which portion of the problem they would like to develop in more depth as their year-long design project.

Divide participants into groups of three.

Give each group a set of 4–6 readings (±10 pages each—may be study guides or other papers). Give them an hour to read, digest, and discuss their topics and to develop a report to the whole group. Encourage concept mapping.

Present group reports. (±1 hr)

After group reports, have each group design a potential mission scenario and discuss the areas of design that they want to tackle. Use butcher paper on the walls or flip charts. (±1 hr)

The group of three will come to a consensus on one part to investigate. (±1/2 hr)

Break for lunch.

The groups then will brainstorm diverse design concepts (diagramming exercise) showing the positive aspects plus potential problems of each—that they either do not know how to handle or need further research to refine. (±1 hr)

The groups will choose one concept to develop into sketches for presentation. (±1 hr)

Each group presents a concept with plus and minus evaluations. (±1 hr)

The success of the workshop depends upon the choice of readings. The readings should cover topics that include innovative ideas, basics of mission components, and information about the human-factors challenges of living in space or on a planetary surface.

8. PROPOSED SYLLABUS FOR A YEAR-LONG PROGRAM

The studio meets three times per week for 4 hours. Professor presentations last about one hour. The rest of the class time is devoted to discussions, research, critiques, presentations, and the usual design studio activities of computing, writing, drawing, and model making. Field trips and visits take more time for a class meeting and attendance is expected. The process is to introduce the topics of aerospace architecture and some background material, have the students choose their particular project, start them off in architectural programming, design methods, and the design framework, introducing other topics along the way so as to enrich their individual projects.

Required Texts

Connors, Mary M.; Harrison, Albert A.; and Akins, Faren R.: Living Aloft: Human Requirements for Extended Spaceflight. NASA SP-483, 1985 (also available at: http://www.hq.nasa.gov/office/pao/History/SP-483/cover.htm).

Eckhart, Peter: Spaceflight Life Support and Biospherics. Microcosm Press, Torrance, Calif., 1996.

Larson, Wiley, J.; and Pranke, Linda K.: Human Spaceflight: Mission Analysis and Design. Space Technology Series, McGraw-Hill, New York, N.Y., 1999.

References

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Mendell, Wendell W., ed.: Lunar Bases and Space Activities of the 21st Century. Lunar and Planetary Inst., Houston, Tex., 1985.

Man-Systems Integration Standards. Vols. VI & II, REV-B, NASA-STD-3000, Houston, Tex., 1995 (also: http://msis.jsc.nasa.gov/).

O'Neill, Gerard K.: The High Frontier. Third ed., Apogee Books, Ontario, Canada, revised 2002.

Stoker, Carol R.; and Emmart, Carter: Strategies for Mars: A Guide to Human Exploration. Science and Technology Series, vol. 86, American Astron. Soc., San Diego, Calif., Univelt, 1996.

The Design Guide Subcommittee of the AIAA Design Engineering Technical Committee. AIAA Aerospace Design Engineers Guide. Fifth ed., AIAA, Reston, Va., 2003.

Woodson, Wesley E.; Tillman, Barry; and Tillman, Peggy: Human Factors Design Handbook. Second ed., McGraw-Hill, New York, N.Y., 1992.

Zubrin, Robert: The Case for Mars: The Plan to Settle the Red Planet and Why We Must. Touchstone, New York, N.Y., 1996.

Resources

A wide selection of topics in videos, educator briefs, and teacher's guides is available through:

NASA Educational Products http://spacelink.nasa.gov/Instructional.Materials/NASA.Educational.Products/.index.html#EB.

NASA's Central Operation of Resources for Educators, http://core.nasa.gov/.

NASA Space Biology, http://spacebio.net/modules/index.html, which covers many topics of interest from the point of view of teaching undergraduate biology students.

Astronauts' Stories (an incomplete list):

Aldrin, Buzz: Men From Earth. Bantam, New York, N.Y., 1989.

Armstrong, Neil: First on the Moon. William S. Konecky Associates, New York, N.Y., 2002.

Burrough, Bryan: Dragonfly: An Epic Adventure of Survival in Outer Space. Harper Perennial Publishers, New York, N.Y., 2000.

Carpenter, Scott M.; Glenn, John H., Jr.; Cooper, Gordon L., Jr.; Grissom, Virgil I., Jr.; Schirra, Walter M., Jr.; Shepard, Alan B.; and Slayton, Donald K.: We Seven. Pocketbooks, New York, N.Y., 1963.

Carpenter, Scott M.; and Stoever, Kris: For Spacious Skies: The Uncommon Journey of a Mercury Astronaut. Harcourt, New York, N.Y., 2003.

Chaikin, Andrew L.; and Hanks, Tom: A Man on the Moon: The Voyages of the Apollo Astronauts. Viking Press, New York, N.Y., 1994.

Collins, Michael; and Lindberg, Charles A.: Carrying the Fire: An Astronaut's Journey. Farrar Straus & Giroux, New York, N.Y., 2001.

Davis, Don: The Last Man on the Moon: Astronaut Eugene Cernan and America's Race in Space. St. Martin's Press, New York, N.Y., 1999.

Foale, Colin: Waystation to the Stars: Michael, Mir, and Me. Trafalger Square Publishing, London, 2000.

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RESEARCH AND PROGRAMMING QUARTER

Each student is required to keep a process record/sketchbook. This document will be the chronological record of the research and design process—from the organization of the information search to the sudden inspiration, to the development of details in a specific design. Because the topic of aerospace architecture is broad, students will be required to read about 200 pages per week—a graduate-student-level effort. Readings will be discussed in class and additional papers from the study guides will be emphasized for further investigation.

September

Week 1—

Day 1: Introductions to the topic: What is aerospace architecture? What do we need to know beyond terrestrial architecture?

Research Methods Study Guide (6.1.2.)

Space Exploration and Aerospace History Study Guide (4.1.2.)

Assign: history reports to class for greater depth (teams)

Readings: Burroughs, William E., (1998) From the Earth to the Moon, Chapter 11 in: This New Ocean; The Story of the First Space Age, pp. 387–443 (46 pp.)

Day 2: Basic Solar System Astronomy Study Guide (4.1.1.)

Safety Hazards Study Guide (4.2.3.)

Readings: Eckart (1996), Spaceflight Life Support and Biospherics, Chap. III, The Extraterrestrial Environment. pp. 39–78 (39 pp.).

Larson & Pranke (1999), Human Spaceflight: Mission Analysis and Design, Chap. 3, The Space Environment—Hazards and Effects, pp. 53–76 (23 pp.)

Day 3: Mission Operations Study Guide (5.1.2.)

Mission Design Study Guide (6.2.1.)

Potential NASA Ames Research Center guest (Murbach, history of aerospace)

Readings: Larson & Pranke (1999), Chap. 2, Human Space Missions, pp. 17–52 (35 pp.)

Larson & Pranke (1999), Chap. 26, Mission Operations for Crewed Spaceflight, pp. 811–868 (57 pp.)

Week 2—

Day 1: Architectural Programming Study Guide (6.1.1.)

Assign: Architectural programming and mission design (number of people, type of launch vehicles, destinations, etc.—individual). Choose basic project type.

Present: history reports

Readings: Duerk (1993), Architectural Programming: Information Management for Design, Chap. 1–5, pp. 5–76 (69 pp.)

Day 2: Basic Habitability Study Guide (5.2.3.)

Assign: life support system research (teams)

Visit: Rocket launch facilities at Vandenberg Air Force Base; check with California Polytechnic and State University Aerospace Engineering Department.

Readings: Connors, et al. (1985), Living Aloft: Human Requirements for Extended Spaceflight, Chap. I and III, pp. 1–15 and 59–106 (61 pp.)

Eckart (1999), The Lunar Base Handbook, Chap 8: Lunar Base Development, pp. 225-240 (15 pp.)

Day 3: Environmental Controls and Life Support Systems Study Guide (5.1.4.)

Potential NASA Ames Research Center guest (Cohen, ECLSS and Human Factors)

Readings: Larson & Pranke (1999), Chap. 17, ECLSS, pp. 539–574 (35 pp.)

Reference: Eckart (1996), Chap. IV, Fundamentals of Life Support Systems, pp. 79–169 and Chap. VIII, Future Life Support in Space, pp. 397–412 (105 pp. total)

Week 3—

Day 1: Assign: Site research (teams), **Site Conditions Study Guide (5.2.2.)**

Readings: Larson & Pranke (1999), Chap. 4, Surface Environments, pp. 77–102; skim Chap. 15, In-situ Resources, pp. 477–510 (25 and 33 pp.)

Connors, et al. (1985), Chap. II, Behavioral and Selection Implications of Biomedical Changes, pp. 19–58 and Chap. IV, Performance, pp. 107–144 (39 and 37 pp.)

Day 2: Review programming progress.

First cut at mission design scenarios presented.

Readings: Review Duerk (1993)

Day 3: Visit NASA Ames Research Center if paperwork is all done.

Week 4—

Day 1: Life support system research reports presented.

Radiation Study Guide (4.2.1.) and Microgravity Study Guide (4.2.2.)

Review: readings from Week 1 **(4.2.3.)**

Visit: the swimming pool

Day 2: Research Methods Study Guide (6.1.2.) and **Problem-Solving Methods Study Guide (6.1.3.)**

Habitat/Habot Concepts Study Guide (6.2.3.)

Assign: programming research project/review methods (individual)

Movie: Whyte, W. H.: The Social Life of Small Urban Spaces. Video, Municipal Art Society of New York, New York, N.Y., 1990.

Readings: Connors, et al. (1985), Chap. V, Small Groups, and Chap. VI, Communication, pp. 145–216 (71 pp.)

Cohen, Marc M.: Mobile Lunar and Planetary Bases. AIAA-2003-6280, Long Beach, Calif., 2003.

Day 3: Visit Boeing, Jet Propulsion Lab (JPL) or other?

Week 5—

Day 1: Assign: Precedent research.

Review architectural programs and mission designs.

Review research study designs and methods proposed.

Readings: Center for Mars Exploration, NASA, Ames, Mars Reference Mission Summary, http://cmex.arc.nasa.gov/marsnews/missions/human_missions/links/Human_Mars_Mission3.html#3.3.1.

References: Alred; Bufkin; Kenned; Roberts; Petro; Stecklein; and Sturm: Lunar Outpost. Systems Definition Branch, Advanced Programs Office, NASA/Johnson Space Center (JSC), Houston, Tex., 1989.

The Artemis Project, Reference Mission Development, http://www.asi.org/adb/04.

Cal Tech, Mars Mission Links, http://mars.caltech.edu/links.html.

Zubrin, R.: The Case for Mars. Free Press, New York, N.Y., 1996.

Day 2: Present site conditions research.

Collaboration Study Guide (6.1.4)

Readings: Connors, et al. (1985), Chap. VII, Crises, and Chap. VIII, Organization and Management, pp. 217–258 (41 pp.)

Day 3: Work day—**Review** readings as necessary.

Week 6—

Day 1: What does it take to develop a design presentation worthy of presentation at a conference?

Communication Study Guide (6.1.5.)

Readings: APA Handbook.

Day 2: Do we want to plan a trip to Houston, SICSA, and JSC?

Readings: Connors, et al. (1985), Chap. IX, Summary and Conclusions, pp. 305–332 (27 pp.)

Day 3: Review research study designs and data-collection progress.

Systems Integration Study Guide (6.2.2.)

Larson & Pranke (1999), Chap. 31, Mars Design Example, pp. 981–1002 (21 pp.)

Week 7—

Day 1: Discuss preliminary project concepts, integration issues, how to focus the design

Structural Systems and Pneumatics Study Guide (5.1.3.)

Readings: Larson & Pranke (1999), Chap. 21, Structures, pp. 665–706 (41 pp.)

Day 2: Mobility Systems Study Guide (5.1.5.)

Readings: Wallace, Brian E. and Rao, Niranjan S.: Engineering Elements for Transportation on the Lunar Surface. In Applied Mechanics of a Lunar Base, Applied Mechanics Reviews, vol. 46, no. 6, American Soc. of Mechanical Engineers, June 1993, pp. 301–312 (12 pp.)

Review: Cohen, Marc M., Mobile Lunar and Planetary Bases. Space 2003, AIAA Paper 2003-6280, 2003.

Day 3: Write programming research study report.

Invite industry **mentor** for project presentation.

Week 8—

Day 1: Present programming research project.

Power Systems Study Guide (5.1.1.)

Readings: Larson & Pranke (1999), Chap. 20, Designing Power Systems, pp. 643–664 (21 pp.)

Day 2: Present formats for architectural program document, mission design, etc.

Extravehicular Activity Study Guide (5.2.1.)

Readings: Larson & Pranke (1999), Chap. 22, Extravehicular Activity (EVA) Systems, pp. 707–738 (31 pp.)

Day 3: Work day

Week 9—

Work on presentations for 10th week.

Week 10—

Day 1: Presentations: architectural program, mission design (includes site), preliminary project concepts (including precedent research). Assume at this point that most of the work is done electronically, with drawings, reports, and verbal presentations. Some study models may be appropriate.

Day 2: Class evaluations

Day 3: Professor evaluations

Quarter Break

SCHEMATIC DESIGN QUARTER

January

Week 11—

Day 1: Review project concepts, analyze positive and negative aspects, check all aspects that need to be integrated, places where more research is necessary.

Day 2: Lay out a plan of work for the quarter (or until the end of the semester).

Day 3: Readings: Wilson, J. W.; Miller, J.; Konradi, A.; Cucinotta, F. A.: Shielding Strategies for Human Space Exploration. NASA Conference Publication 3360, 1997, (pdf) (highly technical; read for understanding basic concepts). Class to divide and report.

Week 12—

Day 1: Review structural concepts with engineering cohort.

Day 2: Report on Wilson, et al. (1997)

Day 3: Readings: Mead, George H.; Peercy, Robert L., Jr.; and Raasch, Robert F.: Space Station Crew Safety Alternatives Study—Final Report: Vol. V—Space Station Safety Plan, NASA CR-3858, 1985 (highly technical; read for understanding basic concepts). Class to divide and report.

Peercy, R. L., Jr.; Raasch, R. F.; and Rockoff, L. A.: Space Station Crew Safety Alternatives Study—Final Report: Vol. I—Final Summary Report, NASA CR-3854, 1985 (highly technical; read for understanding basic concepts). Class to divide and report.

Peercy, R. L., Jr.; Raasch, R. F.; and Rockoff, L. A.: Space Station Crew Safety Alternatives Study—Final Report: Vol. IV—Appendices, NASA CR-3857, 1985 (highly technical; read for understanding basic concepts). Class to divide and report.

Raasch, R. F.; Peercy, R. L., Jr.; and Rockoff, L. A.: Space Station Crew Safety Alternative Study—Final Report: Vol. II—Threat Development, NASA CR-3855, 1985 (highly technical; read for understanding basic concepts). Class to divide and report.

Rockoff, L. A.; Raasch, R. F.; and Peercy, R. L., Jr.: Space Station Crew Safety Alternatives Study—Final Report: Vol. III—Safety Impact of Human Factors, NASA CR-3856, 1985 (highly technical; read for understanding basic concepts). Class to divide and report.

Week 13—

Day 1: Work day; finalize plans for trip. Plan for March application for KC-135 summer flight if projects warrant.

Day 2: Report on Peercy, et al. (1985)

Day 3: Visit Houston and JSC/Sasakawa International Center for Space Architecture (SICSA) if we go.

Week 14—

Day 1: Work on presentations for midquarter (semester end) reviews.

Invite industry mentor **for project presentation.**

Day 2: Reading: Peacock, Brian; Blume, Jennifer Novak; and Vallance, Susan: Index of Habitability, SAE 2002-01-2501, 32nd ICES, 2002.

Adams, Constance; and McCurdy, Matthew R.: Habitability as a Tier One Criterion in Advanced Space Vehicle Design: Part One—Habitability. SAE 1999-01-2137, 29th ICES, 1999.

Cohen, Malcolm M.: Perception of Facial Features and Face-to-Face Communication in Space. Aviation, Space and Environmental Medicine, vol. 71, no. 9, section II, Sept. 2000.

Other short habitability papers.

Day 3: Work day

Week 15—

Day 1: Present conceptual designs for review—includes study models.

Day 2: Class evaluations

Day 3: Revise calendar work flow for the rest of the quarter/next semester.

Semester end

Week 16—

Day 1: Start House of Quality matrix and systems analysis.

Day 2: Reading: Benaroya, Haym; Bernhold, Leonhard; and Chua, Koon Meng: Engineering, Design and Construction of Lunar Bases. J. Aerosp. Eng., Apr. 2002, pp. 33–45.

Cohen, Marc M.: Lightweight Structures in Space Station Configurations. The First International Conference on Lightweight Structures in Architecture, vol. 1, Australia, Aug. 1986, pp. 507–541.

Day 3: Potential NASA Ames Research Center guest.

Week 17—

Day 1: Structural critiques

Day 2: Reading: Jones, Harry: Design Rules for Life Support Systems. SAE 2003-01-2356, 33rd ICES, 2003.

Day 3: Work day

Week 18—

Day 1: Human Factors/Habitability Critiques

Invite industry **mentor** for quarter-end project presentation.

Day 2: Reading: Cohen, Marc M: Mobile Lunar and Planetary Bases. AIAA Paper 2003-6280, AIAA Space 2003, Long Beach, Calif., 2003.

Mankins, John C.: Modular Architecture Options for Lunar Exploration and Development. Space Technology, vol. 21, no. 1–2, 2001, pp. 54–64.

Day 3: Work day

Week 19—

Day 1: Power/Mobility/EVA critiques

Day 2: Work day

Day 3: Work day

Week 20—

Day 1: Quarter end—Integration presentations

Day 2: Class evaluations

Day 3: Professor evaluations

Quarter Break

DESIGN and PRESENTATION QUARTER

March

The final quarter is mostly a working quarter. Papers will be available to any student wanting to deepen understanding in a particular area. Any visits or guests will be based upon discoveries made in the first two quarters. Most days are scheduled as work days—desk critiques by the professor and cross critiques between students are an active part of the quarter's work.

Week 21—

Day 1: Review project concepts; make schedule for refining, making study, scale, and full-scale models; do computer modeling; format presentations.

Apply for KC-135 flight if appropriate.

Day 2: Work day

Day 3: Work day

Week 22—

Day 1: Revise program to update any conceptual changes made during winter quarter.

Day 2: Work day

Day 3: Work day

Week 23—

Day 1: Solicit donations for materials for any full-scale models.

Day 2: Work day

Day 3: Work day

Week 24—

Day 1: Finish accurate drawings, scale models of project.

Day 2: Work day

Day 3: Work day

Week 25—

Day 1: Midquarter progress reviews

Day 2: Develop final schedule for finishing and refining presentation drawings and models.

Day 3: Work day

Week 26—

Day 1: Finalize computer drawings, fly-throughs, etc.

Day 2: Design a paper to explain concept and design to a technical conference.

Day 3: Class teams critique each other's paper outline.

Week 27—

Day 1: Develop paper.

Day 2: Work day

Day 3: Work day

Week 28—

Day 1: Practice presentations.

Invite industry **mentor** for project presentation.

Day 2: Work day

Day 3: Print program, drawings, paper, etc. and prepare to present at the last class.

Week 29—

Day 1: Work day

Day 2: Work day

Day 3: Presentation: mini symposium on aerospace architecture—paper presentations with architectural presentation posters as background.

Week 30—

Day 1: Class evaluations

Day 2: Professor evaluations

Day 3: Year-end: tie up loose ends, exit interviews, celebrate!

Evaluation modes

Each time a report or presentation is given, there will be an evaluation. Criteria are based upon the quality of the product produced, the student's process, and developmental progress. Many criteria in architectural design are subjective, but in aerospace architecture, the technical accuracy becomes far more important because of issues of survival in an extreme environment.

Quality product: accuracy of information, meets requirements, concept quality, craft, visual quality, verbal presentation.

Quality of process: thorough research, alternative generation, critical thinking, concept development, and process record.

Quality of progress: improvement in the criteria given for success in product and process.

Part of the pedagogy is to teach self-evaluation. At many points there will be cross-critiques between individual students or groups of students. A group of students who can critique each other and teach each other learns a great deal more than those who depend upon the professor.

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Adams, J. L.: Conceptual Blockbusting. Fourth ed., Perseus Publishing, Boulder, Colo., 2001.

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Aldrin, Buzz: Men From Earth. Bantam, New York, N.Y., 1989.

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Carpenter, Scott M.; and Stoever, Kris: For Spacious Skies: The Uncommon Journey of a Mercury Astronaut. Harcourt, New York, N.Y., 2003.

Cassini Mission, Operations Concepts, http://saturn.jpl.nasa.gov/cassini/Mission/ops.shtml (nd).

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14. ABSTRACT
Curriculum for a year-long study of aerospace architecture by 5th year or Masters architecture students. Students will practice the rigors necessary to apply codes, specifications, and technological innovations to terrestrial architecture as well as to aerospace environments. The curriculum is composed of study guides at three levels: "know," "understand," and "be able to." Its modularity invites expansion into other topics.

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