NASA DESIGN PROJECTS AT UC BERKELEY FOR NASA'S HEDS-UP PROGRAM

Lawrence H. Kuznetz, PhD.
Instructor, Mars by 2012
University of California, Berkeley

INTRODUCTION	**Lawrence H. Kuznetz, Professor**
INTERACTIVE DESIGN ENVIRONMENT	**Sachin Shah**
SPACESUITS FOR MARS	**Sheyna Gifford/Tatiana Becker**
HYPOGRAVITY COUNTERMEASURES	**Franco Navazio/Connie Yu**
ELCSS	**Donald Beams**
SCIENCE HAB DESIGN	**Gordon Smith**
CREW SIZE	**Alexia Cooper**

BACKGROUND

Missions to Mars have been a topic for study since the advent of the space age. But funding has been largely reserved for the unmanned probes such as Viking, Pathfinder and Global Surveyer. Financial and political constraints have relegated human missions, on the other hand, to backroom efforts such as the Space Exploration Initiative (SEI) of 1989–1990. With the newfound enthusiasm from Pathfinder and the meteorite ALH84001, however, there is renewed interest in human exploration of Mars. This is manifest in the new Human Exploration and Development of Space (HEDS) program that NASA has recently initiated. This program, through its University Projects (HEDS-UP) office has taken the unusual step of soliciting creative solutions from universities.

DESIGN PROJECTS

For its part in the HEDS-UP program, the University of California at Berkeley was asked to study the issues of Habitat design, Space Suits for Mars, Environmental Control and Life Support Systems, Countermeasures to Hypogravity and Crew Size/Mix. These topics were investigated as design projects in "Mars by 2012", an ongoing class for undergraduates and graduate students. The methodology of study was deemed to be as important as the design projects themselves and for that, we were asked by Dr. Mike Duke of LPI to create an Interactive Design Environment. The Interactive Design Environment or IDE is an electronic "office" that allows scientists and engineers, as well as other interested parties, to interact with and critique engineering designs as they progress. It usually takes the form of a website (in our case, http://mars2012.berkeley.edu) that creates a "virtual office" environment. That environment is a place where NASA and others can interact with and critique the university designs for potential inclusion in the Mars Design Reference Mission.

PRESENTATION

UC Berkeley's presentation at the HEDS-UP conference at LPI started with a vision of how the IDE could be used to create a virtual organization tying together universities working on various Mars mission elements. The vision starts with the reasons for using universities to contribute to the design of the Mars reference mission, and continues by demonstrating the benefits of a large-scale space program such as Apollo to the economy, in terms of math/science graduates, patents and technology base. Figure 1 shows the breakdown of the Design Reference Mission into distinct elements that can be disseminated to universities or groups of unversities for study. These universities would have proven expertise in the mission element area. Figure 2 is a prototypical virtual organization chart that would tie the universities together under the auspices of a guiding NASA office such as HEDS-UP and the NASA University Affairs office for the purpose of distributing and critiquing the work on a semester by semester basis. In such an organization, each semester's work would be fed back to the next semester's group of students to provide continuity and improvement. The basis of this approach is that over the course of the months and years necessary for maturation of the design reference mission, these university studies could evolve to serious engineering designs, possibly even flight hardware, at a fraction of the cost associated with traditional government contracts. The talent, free labor, enthusiasm and facilities of universities would be the vehicle used to accomplish such a cost benefit.

Figure 3 displays the "Mars by 2012" demographics. Its purpose is to show how the large and disparate student makeup and design project philosophies provided an analog for the bigger organization. The intent here is to show that the organization created for the class could be used as a model to test the viability of the IDE concept for the larger university model.

In summary, the "Mars by 2012" class, with over 60 students working on 6 different design projects, was deemed a suitable testing ground for the IDE model to see if it could accelerate the design process. The IDE website provided information exchange, links to expert resources, documents, chat room meetings between groups and group leaders, archiving of data, mail and brainstorming sessions, and proposed solutions to the design projects as well as critiques, threaded by topic, date or author.

Following this introduction of our vision for HEDS-UP and the concept of the IDE, each of the individual groups were called to the podium at LPI to present their findings in detail. The order of these presentations were as follows: The Interactive Design Environment, presented by Sachin Shah; Space Suits for Mars, presented by Sheyna Gifford and Tatiana Becker; Countermeasures to Hypogravity, presented by Connie Yu and Franco Navizio; Environmental Control and Life Support Systems, presented by Anthony Beams; Designs for the Mars Habitat, presented by Gordon Smith; and Crew Size and Mix Issues, presented by Alexia Cooper. Summary reports of these presentations, as well as recommendations for future work, are in the sections that follow.

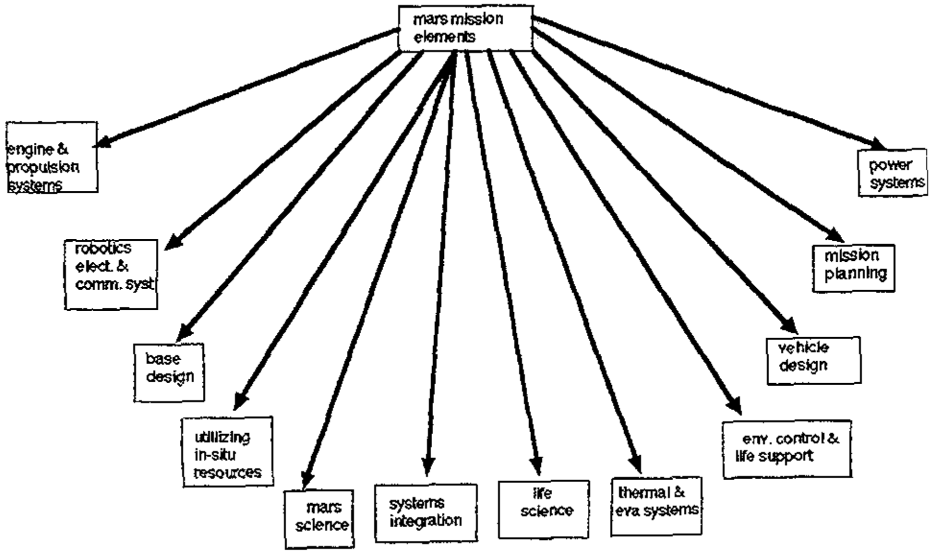


Fig. 1.

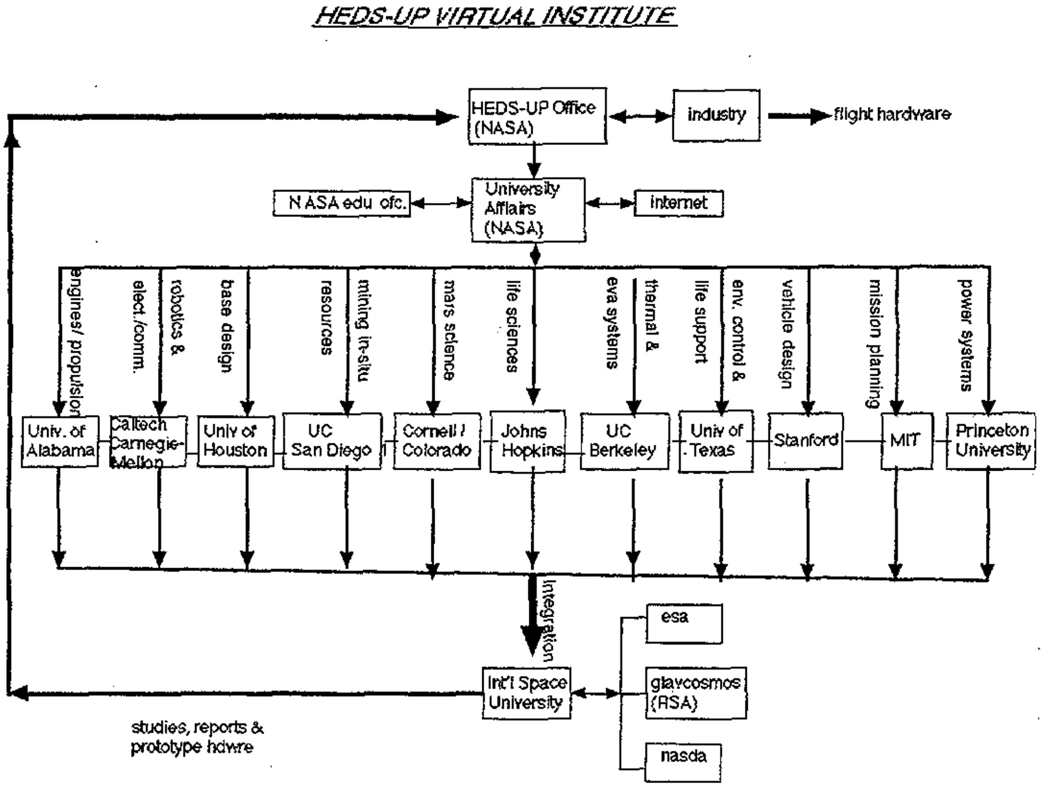


Fig. 2.

UC Berkeley IDS 60...Mars by 2012

- Large class (60 students)
- Undergraduates
- Diverse majors
  - mechanical/civil/electrical engr
  - molecular/cell biology/physics/chem
  - computer science
  - economics
  - architecture
  - other
- Diverse mix
  - 1/3 women
  - 1/3 ethnic/international
- Lectures given by acknowledged experts in field
- Six design projects accompanying lectures
  - Six teams (approx 10 students/team)
    - Spacesuits
    - Countermeasures
    - ECLSS
    - Science Hab
    - Crew size
    - IDE

Fig. 3.

THE INTERACTIVE DESIGN ENVIRONMENT

IDE Team Members: Yuan-Juhn Chiao, Cora Estrada, Mike Goff, Billy Martin, and Sachin Shah

When we were assigned the task of creating the Interactive Design Environment at the beginning of the semester, the IDE team had one question: What is an IDE? After months of research we discovered the IDE is essentially the central processing plant of the virtual institute, a collection of tools designed to facilitate the exchange and development of ideas between and within the various groups. The IDE is, if you can imagine, the hub of a wheel, with each tool acting like a spoke, supporting the rim which consists of the various groups (e.g. Space Suit, Habitat, etc.). Once we figured out what the IDE is, we needed to figure out what it should do and what it needed to do. In order to help convey our vision of the IDE, I shall now take you on a metaphorical journey.

Pretend it is your first day at work. What are some essential questions you will have? Well, the first thing you are going to need to know is: who are your team members? Who are the people you are going to be working with? To find the answers to these questions, you turn to the IDE. Using the "Profiles" tool, you can easily find introductions and pictures of all of your team members, along with vital contact information and areas of expertise.

So you know who you are going to be working with; now it is time to get started. But what is it you are going to be doing? In the real world, your boss would now drop a stack of research material on your desk and say: catch-up. However, in our virtual world, you simply click on the link that leads you to the "Documents" section. Here you can find a variety of hyper-documents to update you on the history and current status of the project.

All right, you are now all caught-up. But what if you have questions? To whom can you turn to find answers? Who are the experts in your field? The "Contacts" page will reveal all. Here you can find the contact information for the various experts and third-party sources in your project area.

Now, what are your resources? Where can you turn to find primers and help researching your topic? You can find all of these sites under the "Links" page. From the "Links" page you can immediately leap across the web, going directly to supporting sites such as the HEDS-UP page.

Great, you are caught up and ready to start working. One problem: you have no idea what you are doing! That's when your boss comes in and tells you it is time for your section meeting. This is where you will be assigned your task, and find out how your team members are progressing. However, in the virtual world, you don't need to leave your desk. Your team members don't even have to be in the same state! You simply enter the "Chat" section, where you will enter a virtual conference room with your team members.

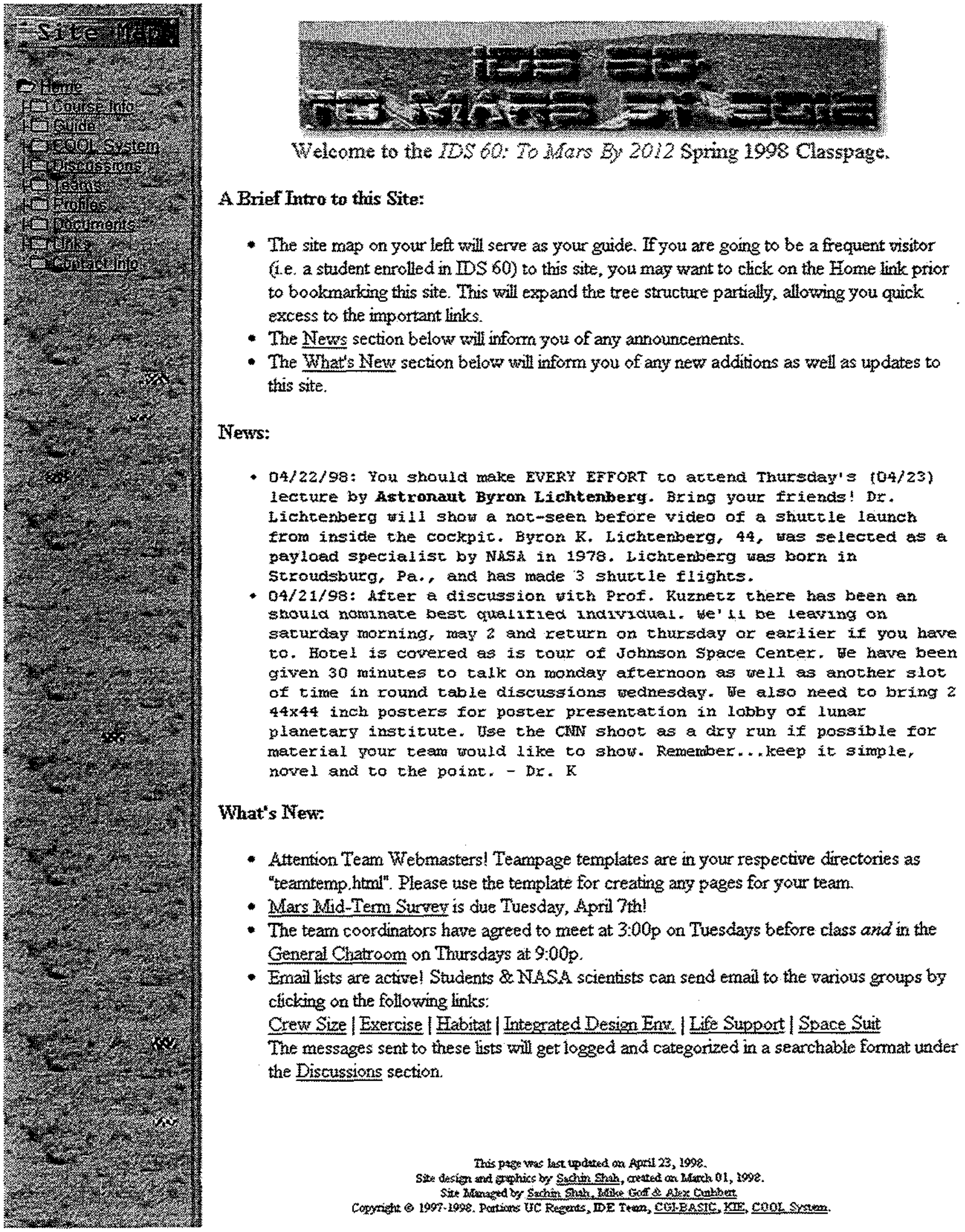
You've met your team members and you now know your share of the project. But what has already been done? You wouldn't want to repeat what others have already accomplished. So you enter your team's section of the IDE and read about the problem definition and what progress has been made in your area. Here you can also retrieve data posted by other team members or invited third-party support groups.

Now you start thinking: what are some possible solutions to my task? In the real world, you would head to the library, and begin research on possible solutions. However, in our virtual world, you head for "The Collaborative Digital Library." Here you can search for sites with information on your topic, and read reviews of the site by other team members. This way you can get a basic idea of how valuable the site will be to your research without having to load each site.

Wow! Only your first day at work and you have already come up with a solution. But you need feedback from your team members. You need to find out what other people think. So you send out an email with your proposed idea to your team address, where it will get distributed to all interested parties. They in return will provide you with feedback. And this entire exchange of ideas can be tracked from within the "Mail Archives" where you can search by subject, date or author, and follow a virtual paper trail of ideas as they develop into tangible solutions.

At this point I would like you to imagine the IDE not as a wheel, but a ship's wheel. And this wheel is what you will use to navigate the virtual institute, through the choppy waters of budget cuts and bureaucracy, and into the wide, open seas of a cheaper, faster, better way.

The purpose of IDE is to help you answer the following questions: Who are my team members? What is the background of the project? Who are the experts in this field? What are my resources? What is my task? What work has been done on my topic? What are some possible solutions? What do other people think?



Welcome to the *IDS 60: To Mars By 2012* Spring 1998 Classpage.

A Brief Intro to this Site:

- The site map on your left will serve as your guide. If you are going to be a frequent visitor (i.e. a student enrolled in IDS 60) to this site, you may want to click on the Home link prior to bookmarking this site. This will expand the tree structure partially, allowing you quick excess to the important links.
- The News section below will inform you of any announcements.
- The What's New section below will inform you of any new additions as well as updates to this site.

News:

- 04/22/98: You should make EVERY EFFORT to attend Thursday's (04/23) lecture by **Astronaut Byron Lichtenberg**. Bring your friends! Dr. Lichtenberg will show a not-seen before video of a shuttle launch from inside the cockpit. Byron K. Lichtenberg, 44, was selected as a payload specialist by NASA in 1978. Lichtenberg was born in Stroudsburg, Pa., and has made 3 shuttle flights.
- 04/21/98: After a discussion with Prof. Kuznetz there has been an should nominate best qualified individual. We'll be leaving on saturday morning, may 2 and return on thursday or earlier if you have to. Hotel is covered as is tour of Johnson Space Center. We have been given 30 minutes to talk on monday afternoon as well as another slot of time in round table discussions wednesday. We also need to bring 2 44x44 inch posters for poster presentation in lobby of lunar planetary institute. Use the CNN shoot as a dry run if possible for material your team would like to show. Remember...keep it simple, novel and to the point. - Dr. K

What's New:

- Attention Team Webmasters! Teampage templates are in your respective directories as "teamtemp.html". Please use the template for creating any pages for your team.
- Mars Mid-Term Survey is due Tuesday, April 7th!
- The team coordinators have agreed to meet at 3:00p on Tuesdays before class *and* in the General Chatroom on Thursdays at 9:00p.
- Email lists are active! Students & NASA scientists can send email to the various groups by clicking on the following links:
  Crew Size | Exercise | Habitat | Integrated Design Env. | Life Support | Space Suit
  The messages sent to these lists will get logged and categorized in a searchable format under the Discussions section.

This page was last updated on April 23, 1998.
Site design and graphics by Sachin Shah, created on March 01, 1998.
Site Managed by Sachin Shah, Mike Goff & Alex Cuthbert
Copyright © 1997-1998. Portions UC Regents, IDE Team, CGI-BASIC, KIE, COOL System.

Example home page from UC Berkeley NASA design project showing the interactive design environment.

MARS SUIT DESIGN PROJECT

Mars Suit Design Group Team Members: Sheyna Gifford (team lead), Jamaica Lambie, Tatiana Becker, Minka Ludwig, Elizabeth Yale, Pete Dorman, Chris Spitzer, John Chang, Benjamin Hartshorne, Jeff Marx

In Spring 1998, our research team at UC Berkeley examined new technologies for a space suit to be used in a future Mars mission. Using the Interactive Design Environment created by our IDE group (http://www.mars2012.berkeley.edu), we formulated requirements for this EVA suit and hypothesized design solutions. Our research eventually led us to dense monolithic membranes and the Polymer Technology Group in Emeryville, California. Mr. Robert Ward, the company president, discussed the properties of these membranes with our group for their possible inclusion in spacesuits.

The attractiveness of these membranes is rooted in the fact that they can serve as a pressure bladder, thermal control system and biological contaminant barrier, we believe. If this proves to be the case, they would have great potential for substantive weight reduction of a Mars suit, thereby significantly enhancing the conduct, efficiency and productivity of EVAs on the martian surface.

It is our strong recommendation that these dense monolithic membranes be studied further and that a prototype suit be built to test their merits in the field.

BACKGROUND/RELEVANCE

To date, NASA's space suits have been built for earth orbit's zero (micro) gravity and the Moon's 1/6 gravity. These suits, extremely heavy, thick with insulation and relatively unmaneuverable, perform well in the hostile environments for which they were intended.

It is unlikely, however, that a space shuttle suit or any close relative will prove satisfactory on Mars. The environment of Mars presents a new set of challenges and advantages, radically unlike those for which Shuttle and Apollo suits were designed. In addition, the Mars Design Reference Mission states that important scientific research is one of the two main goals of any human mission to Mars.

Research on Mars will involve a human presence outside the habitat. However, current suit designs will not allow the planetary explorer to be productive in the field. Martian gravity presents the first barrier to the suit designer. The one-third earth g loading, would make the nearly four hundred pound shuttle suits too heavy and unwieldy to "get down in the dirt and work", as NASA-Ames astrogeologist, Chris McKay puts it. The thick layers of the current mechanically pressurized suits are an impediment to meaningful scientific work. They limit joint motion and make small finger manipulations all but impossible. Finally, cross contamination is an issue with them. The suit designer must include a biological barrier in a Mars suit, a feature not required in the sterile environments of the Moon and low earth orbit.

Countering these challenges, the designer has the martian environment working to his or her benefit. Temperatures are more moderate on Mars. Thermal modeling indicates fewer layers of insulation need be used. Mars has seasons so the thickness of suits can be tailored to match them. Astronauts could wear thinner suits in summer, thicker suits in winter. Finally, the designer can allow the martian environment to absorb some of the heat created by the astronaut's activities. It may well be that the suit need not be burdened with the excess mass of a closed loop system.

We believe that a dense monolithic membrane of the type developed by the Polymer Technology Group is a potential solution to the Mars suit conundrum. This membrane, called Biospan, is a dense, non-porous polymer that retains pressures in excess of 8 psi while allowing water vapor to diffuse across the pressure gradient by an active transport process. When combined with an appropriate restraint layer (the nature of which remains a topic for future study), Biospan could serve as a passive, lightweight pressure and thermal control system that maintains biological isolation. The resultant benefits in weight reduction, mobility, dexterity and performance would contribute to more meaningful scientific research, one of the two primary objectives stated in the Mars Design Reference Mission.

OBJECTIVES

The goal of suit design is identical to the goal of the Mars Design Reference Mission: the properly designed suit should make it possible for humans to conduct scientific exploration on the martian surface. Indeed, without functional EVA equipment, exploration will be impossible. *If suits are too heavy, if they don't allow a range of movement for walking, bending, kneeling, and climbing in 1/3 g, a human mission to Mars will be defeated before it begins.*

The objectives in designing Mars EVA suits are very different from the objectives behind the Apollo program. In Apollo, the goal was to get to the moon and back. Engineering was the primary driver, then science. As for suit design, the question of what kind of science can be done was asked after the suit had been built. Those priorities are reversed for a Mars suit. The first question is, what kind of science do we need, the second, how will that influence suit design.

Unlike Apollo, there is no Cold War to compel us to go to Mars today simply because we can. Consequently, we cannot afford to waste the scientific opportunities that wait in the martian deserts. If and when they present themselves, we must take advantage of these opportunities by having an EVA suit that will enhance research.

REQUIREMENTS

Over the course of this semester, our group brainstormed a number of requirements for the Mars EVA suit. Some of these requirements are addressed by the dense polymer technology; others are not. This list follows.

A MARS EVA SUIT MUST:

1. Weigh less than 140 pounds, earth weight, including the PLSS and all accessories
2. Be durable enough to withstand radiation and dust as well as occasional falls to the surface.
3. Be cost effective
4,. Be easy to don/doff
5. Be flexible, especially at the joints, to promote the fullest range of natural movement.
6. Keep the astronaut at a comfortable body temperature, regardless of the martian season or the kind of metabolic workload.
7. Form an effective cross contamination barrier.
8. Be easy to clean, maintain and repair.
9. Integrate with the habitat and the rover

CONCLUSIONS/RECOMMENDATIONS

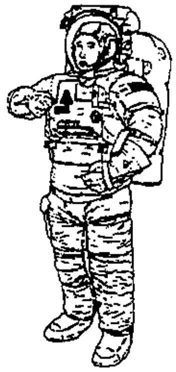
The Suit Design Team has concluded that the internal garment of the EVA suit represents the best source of potential weight savings/ performance gains. The use of the Biospan membrane, supported by a polypropylene insulating layer internally and a silicone rubber-coated heavy duty nylon externally is our choice for that internal garment. Research and testing should be done in several related areas to validate this design.

First we must ensure that the polymer will perform as advertised. We plan to do this in upcoming semesters by contructing an actual suit component such as a torso that can be put through pressure, durability and permeability testing in a lab setting. We would also like to build a glove component so that mobility and dexterity testing can be performed.

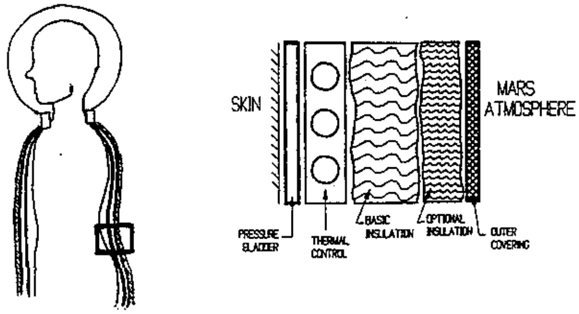
The liquid collection and storage system must also be researched. Once moisture permeates through the polymer membrane layer, it must either be rejected to the atmosphere or collected and stored in the suit. Persistant concerns over the risk of contaminaton make the preferred method liquid storage. However routing perspiration and other moisture (in vapor form) to a central location for condening and storage presents a unique set of problems of their own.

Once the above concerns have been addressed, a prototype thermal control and restraint layer system can be constructed. This work should illuminate any remaining design issues and allow testing of the system as a whole. With proper encouragement from NASA, the university community and industry, we would like to perform that work.

WOULD YOU RATHER GO HIKING



IN THIS SUIT OR THIS SUIT?



SUIT CROSS-SECTION

Biospan

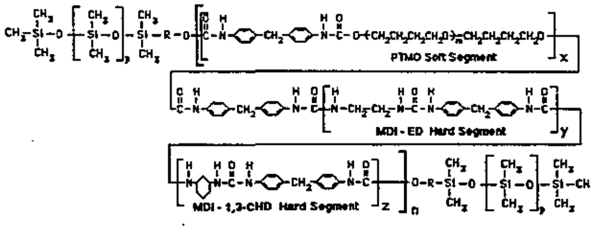
1. Hydrophilic
2. Dense
3. High tensile strength

Physical Property Comparison: PTG vs Conventional Polyurethane

	PTG-PU	Typical PU
Tensile Strength [psi]	4300	5000
Initial Modulus [psi]	500	2200
Ultimate Elongation [%]	1100	800
MVTR [g/M²/24 hr]$^{1.}$	18000	2700

---

1. 0.5 mil unsupported film /Inverted Cup MVTR



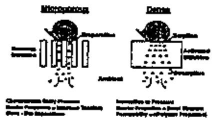
Chemical structure of BioSpan-S segmented polyurethane showing polydimethylsiloxane surface-modifying end groups on BioSpan base polymer. From "Development of a New Family of Polyurethaneurea Biomaterials," by Robert S. Ward and Kathleen A. White, The Polymer Technology Group Incorporated, 4561-A Horton Street, Emeryville, California, USA.

How Biospan Could Replace
LCG & Sublimation System

1. It's hydrophilicity makes this polymer an excellent "sweating suit".
2. Density = "unquestionable" biological
3. Strength = Maintaining structural integrity in the face of all the motion a Martian EVA would require.

Microporous vs Nonporous (Dense) Semi-Permeable Membranes

(Condensed/Liquid Phase Not Necessary for Transport)



Effect of Pressure and Contamination on Liquid Barrier Properties of BBFs

EXERCISE COUNTERMEASURES

Exercise Countermeasures Team Members: Crispin Barker, Brett Bondi, Sian Geraghty, Anoop Ghuman, Jason Kintner, Dr. Franco Navazio, Lanny Rudner, Connie Yu

NOTE: Countermeasures based on rotational devices to implement artificial gravity were considered but were not the focus of our research since we did not want to reinvent the wheel. Significant work has already been done in this area pointing to the complexity and expense of implementing such systems, and their potential safety concerns.

There are many physiological problems associated with space travel. Our responsibility in the Exercise Countermeasures Group of the Mars by 2012 class at the University of California, Berkeley, was to research and brainstorm solutions to them. Perhaps the most insidious problem facing astronauts on a mission to Mars will be bone demineralization. Most bone loss occurs in the weight bearing bones, especially the heel and legs. Paradoxically, there is actually an increase in bone mass in the head and hands! One prospective solution we investigated was to increase overall bone mass through an increase in vitamin D. Vitamin D is important in bone formation. It has been found that whales maintain a hypervitaminosis D condition that may help to maintain an adequate skeletal system in the sea. The sea is a neutrally buoyant environment and whales are mammels living in what amounts to a zero gravity world. They have a human-like skeletel structure but maintain bone mass in spite of their low gravity environment. Perhaps hypervitaminosis D plays a role in their homeostasis. (Another theory may be that whales create an "artificial gravity" loading in their neutrally bouyant world by breaching. If true, the frequency and intensity of their breach patterns may be useful in establishing an analog for the duty cycle of impact devices or rotational frequency in artificial gravity in spacecraft.)

Two other methods we looked at to decrease bone demineralization are electromagnetic stimulation and implants. Electromagnetic stimulation devices have been shown to help fracture sites. Nanoimplants that release bone morphogenetic hormone have been shown to slow the rate of osteoporosis in highly susceptible bone demineralization areas such as the heel. Both electromagnetic stimulation and nonoimplants can specifically be targeted to a problem area such as the lower extremities. They also have the benefit of being lightweight and portable, always a concern in the design of spacecraft.

The primary focus of our research was exercise countermeasures. Sian Geraghty brainstormed four different systems that provide stress to the skeletal system through impact or other means. The virtual suit resists the astronaut's movements while he or she is moving through a virtual reality display working every muscle group in the body. Bouncercise and Space Balls provide an element of fun to the exercise routine, always a concern on a thousand day mission where exercise and other routines can become tedious and unmotivating.

Another type of impact/fun exercise we looked at is partner exercise. These strengthen muscle groups as well as group dynamics without increasing the mass of the spacecraft from unnecessary exercise machines attempting to do the same function. as the astronauts use their partners as a source of resistance.

Jason Kintner's designs looked at modifying existing exercise machines using virtual realtiy to again, break the monotony of the exercise routine. One aspect of his design that is of particular interest is the shoulder bar over the stair climber device. The shoulder bars can be adjusted to provide a downward force on the astronaut so that the impact of walking may be similar to that of walking on Mars or Earth. The body loading can also be made comparable to what an astronaut may experience when wearing a Mars EVA suit. Using such a device, an astronaut's skeletal system can be preconditioned to the environment that it will face leading up to the EVA.

Lanny Rudner designed an impact machine for exercises that help maintain the muscles of the stomach, back and arms. While it looks big, imposing and too heavy to fit in a spacecraft, the concept is adaptable to a lightweight, space-saving design (next semester's work). The main points of interest in this machine are the shoulder bars and bungee harness attached to the floor. The bungee cords are attached to a belt fitted around the crewman's waist. When the astronaut jumps, it provides resistance to the jumping action, thereby working the leg muscles. The belt also keeps the crewperson rooted to the floor so that the second part of the jumping exercise can be carried out. When the astronaut rebounds the floor, the impact on the heels stress the skeletal system,especially the lower bones. The shoulder bars can also be used as a source of pressure for upper body impact exercises.

RECOMMENDATIONS

Next semester, we hope to refine our impact machine designs and continue looking at drugs and whales as topics for study. Another project we intend to study further will be the simulation of the G profile of a Mars mission, in which we brainstorm countermeasures that provide partial 1/3 gravity on earth. This simulation is especially important because the physiological information accumulated for a mission to Mars is thus far purely hypothetical. Of paramount concern is that there has been no bottoming out of bone demineralization rate in zero g to date. The extent to which bones will decalcify in hypogravity is merely an extrapolation of inadequate data.

We look forward to doing more in next year's class. However the extent to which we can actually make a contribution depends upon access to data. As we all know, gigo (garbage in/garbage out) generates woefully unimpressive work. Although we now have a useful tool in the form or our IDE website, it can only help us if we can tap into the right kind of database, such as the Life Science Archive and others. We hope that we'll be able to that with the assistance of NASA and LPI.

COUNTERMEASURES TO PROBLEMS UPON

1. Predeparture Screening of Crew*
2. Departure
3. Flight to Mars (6–8 mos.)
4. Martian Landing
5. Life on Mars (18 mos.)
6. Departure to Earth
7. Return Flight (6–8 mos.)
8. Landing on Earth
9. Post Landing Quarantine and Reconditioning

*Inclusive of the Colia 1 Genotype

COMPLEMENT WITH

Pre- and Postflight Data on Bone Status with

1. Single Energy Absorptiometry*
2. Dual Energy XR Absorptiometry**
3. Quantitative Computed Tomography***
4. Ultrasonography****

*Very precise for forearm and heel

**Very precise for total body assessment with very low dose of radiation

***Good assessment of trabecular bones

****Somewhat less precise but could be used in flight

"The Study"

In 2–3 astronauts with identical controls, measure the pre- and postflight (60–120) of the following variables:

1. Vitamin D Intake
2. UV Exposure
3. Blood Levels of:

   Ca^{++}; Inorganic P; Albumin; Vitamin D Binding Protein; Osteocalcin; Hydroxylysine; Procollagen ICP; and 25 Hydroxy Vitamin D

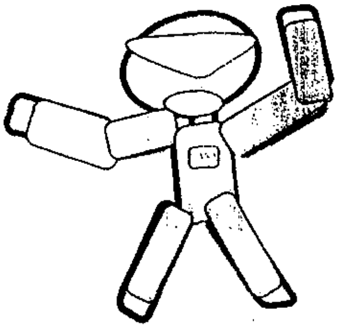
4. Urine Concentration of:

   Ca^{++}; Hydroxyproline; Creatine and Deoxypyridoline

FUTURE GOALS

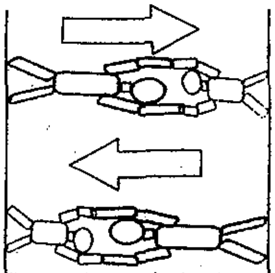
- Simulation of Mars trip
- Test of countermeasures
- Determine intensity and frequency of impact exercises
- Whale study
- Vitamin D tests

Virtual Exercise

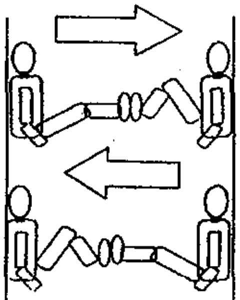


This design combines a full body resistence suit with virtual reality. The virtual reality asks the astronaut to play an endless variety of programs from sport based games like virtual basketball and virtual soccer to obstacle courses and combat games. All of the games require the astronaut to use a wide range of movements to successfully play the game. As he plays he is wearing a resistence suit that meets his every gesture with a force. In playing the game, the astronaut works against the resistence of the suit to provide a fun and interesting workout

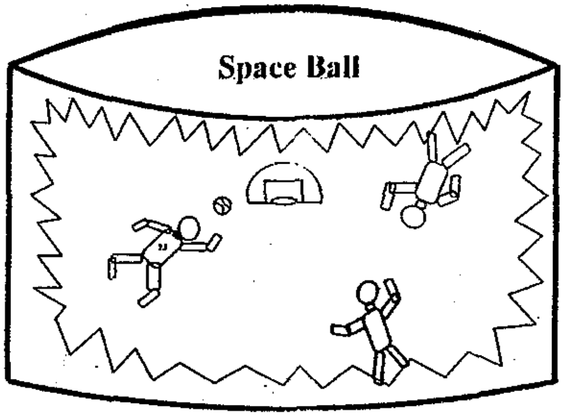
Partner Exercises



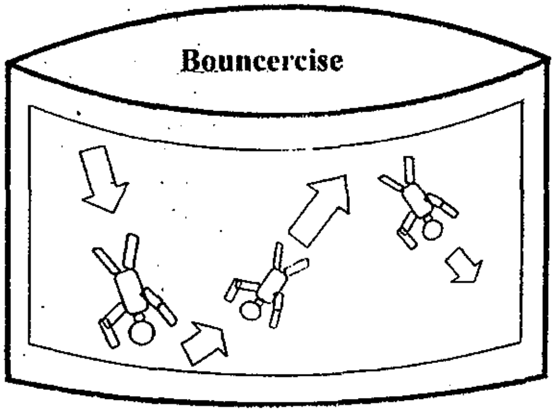
Partner exercises are another alternative to traditional exercise machines. The astronauts use each other's strength as resistence. In this exercise the astronauts brace themselves against a wall and alternate pushing on each other. This builds muscles and provides pressure on the skeleton.



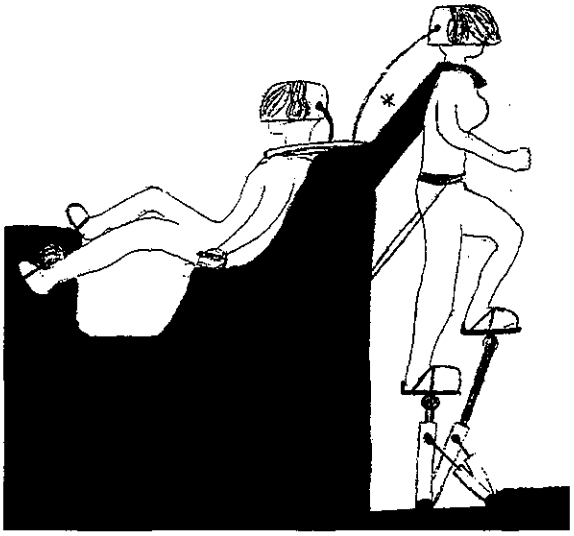
This is a partner exercise that targets the leg muscles.



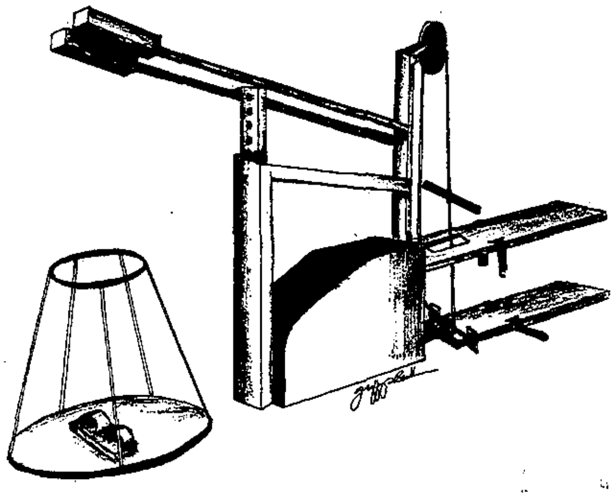
In addition to bouncing, the astronauts can make a game of their exercise. Possibilities include basketball, football and dodge ball. This would promote team unity and better social relationships.



Exercise can be done in space without complicated exercise machines. The astronaut's own force can propel him into walls, and the impact force is an effective exercise for strengthening both arm and leg muscles



Modifying existing exercise machines using virtual reality.



Impact machine for exercises that help maintain the muscles of the stomach, back, and arms.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEMS

The Environmental Control and Life Support Systems presentation was divided into two parts. The first was a summary of our observations and recommendations concerning the closing of the life support system loops, and the second, a proposal for an experiment to test the duration of liquid water on the surface of Mars. In this paper I will be describing both and then supplying other information concerning the Life Support Group's recommendations.

One of the problems with sending a six man/woman crew on a 1000 day mission to Mars is that it takes eleven pounds of food, air and water to support each person per day. This translates to a total need of 150,000 pounds of consumables, an unrealistically high weight penalty. To overcome this obstacle, the three types of life support systems: open loop, chemical/physical and closed ecological, should be integrated. By so doing, the 150,000 pound penalty could be greatly reduced.

There are three methods of life support currently used: open loop, chemical/physical and CELLS (greenhouse or closed ecological life support systems). Open loop means all consumables are brought along and used with no recycling, scrubbing or transformation. Chemical/physical are recycling processes used to create consumables such as air and water from human output (i.e., urine reclamation from vapor compression/distillation or Sabatier/Bosch reactions). CELSS (closed ecological life support) are plant-based greenhouse systems that transform sweat, CO_2, urine and metabolic heat into usable consumables, requiring only power after initial setup.

Given the learning curve constaints of one semester, our group decided to focus on the benefits and detriments of each type of system. We charted system pros and cons with an eye towards using them in a mathematical model developed in subsequent semesters. Such a model would have the goal of optimizing economy, weight and power in an integrated system. Our longer term goal will be to utilize this model to develop an evoluationary plan for an integrated life support system on the martian surface from the first three years of human missions.

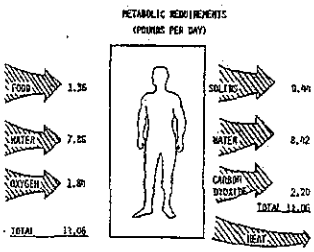
While the specifics of these tasks were beyond our technical abilities given the one semester timeframe, we did create a solution methodology that we felt could generate particulars in subsequent semesters. It is based on utilizing the IDE website discussed earlier to acccelerate information exchange and design ideas.

One conclusion our group arrived at early on was our cause would be greatly helped if we could find and use liquid water on the surface rather than bring it or manufacture it. This led to the second part of our presentation, an experiment to test for the presence and duration of liquid water on the surface of Mars. The idea stems from pressure and temperature graphs that show pressures well above the triple point pressure on the surface and temperatures above the freezing point. If these areas coincide for any length of time, thermodynamics dictate that water must exist in a liquid state. This is important for two primary reasons. First, if liquid water exists on the surface, it reduces the mass, cost, power usage and complexity of the life support system. Second and more profoundly, it greatly increases the probability of finding life (past, present, and hopefully referring). If life indeed does exist, it also creates the need for more emphasis to be placed on contamination, both forward and backward, in mission planning. It was for these reasons that we deemed an experiment to search for liquid water to be of value. As the viewgraph shows, such an experiment would use thermogenics to form ice on the surface on a mirror, then use optics and microwave radiation bombardment (for assessing molecular bond strength) to verify the presence of a liquid/ice boundary rather than the ice/vapor boundary thought to exclusively exist by sublimation alone. The advantage of such an experiment is that it could be ground tested first in a Mars environment simulation chamber such as the one at NASA/Ames. And if it shows promise, it could be implemented on a Sojourner-type rover as part of the Pathfinder series at a reasonably low cost. Our research has shown that the technologies to do this already exist, and it is possible to do it with off the shelf hardware.

Many contacts and ideas were generated concerning future work of the Life Support Group. These are summarized in the final viewgraph of action items. In addition, joint projects with the University of Washington, and other universities and companies, were discussed at the conference. Many expressed an interest in being connected ito our IDE site. We were also fortunate in being able to visit the Johnson Space Center and see what NASA is doing with life support technologies, especially in the Bioplex facility. Hopefully our research will be able to contribute in some way to the future planning of this facility and its long-term testing of human subjects in Mars mission simulations.

Problem Statement:

- A completely open loop system for a crew of six would require the transportation of 150,000 lbs of food water and oxygen, generating an unrealistic cost for the mission

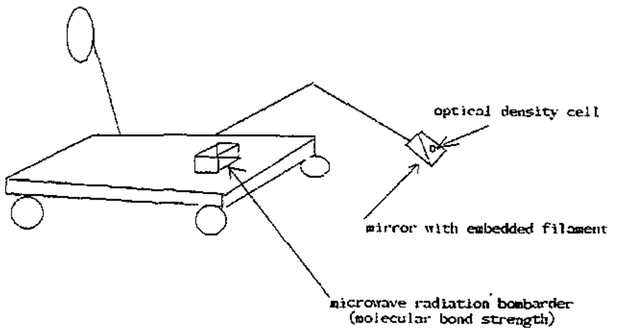


- **Methodology**
  - close Life Support Systems loops
- **Solution**
  - develop and integrate new technologies
    - design software to find best combination of open loop, physical/chemical, biological systems
    - develop communication between biological research institutions
  - continue bio-plex, South Pole , etc. experiments
  - create models showing relationships between ECLSS loops

System Pros and Cons

	Benefits	Disadvantages
Open Loop	• No research needed • Food, water, oxygen guaranteed / safe	• High Cost (Volume/Mass) • Time limited on Mars • Less information gained
Physical/Chemical	• Cost is cut down in long run • Available resources used • Extended stay possible	• More power needed • Start up time extended • Research time may cause initial delay
Greenhouse (closed loop)	• Long term costs will be the least • Possibility of colonization • Self sustaining • Less power 1. Oxygen /Air organically filtered 2. Use of sun as power • Larger work area • Wastes recycled • Extended stay allows for more research	• Start up of system 1. More than one mission is needed 2. Set up time 3. Start up cost 4. Maintenance 5. Resources required for greenhouse • Lack of research • ECLSS extremely fragile

water/ice experiment



Action Items

- Locate research topics
  - scaling problems
  - greenhouse technologies
  - recycling technologies
  - solar technology
- Update IDE with ECLSS data
  - expand web page library
  - continue to network connections
  - organize information sources
- Water/Ice Experiment
  - refine experimental design
  - develop Earth based simulation
  - Pathfinder implementation

HABITAT SCIENCE LAB

Money is obviously the primary consideration when designing any aspect of a manned mission to Mars. If one has only twenty billion dollars to spend, the habitat will look something like an oversized tin can, such as proposed by Zubrin, with only a tiny wedge in which to perform science (figure 1). If on the other hand one has half a trillion dollars, you can have a spacious facility with more than enough room to perform any science desired (figure 2). Not being privy to the budget of the future, our dilemma at UC Berkeley was how to tackle a design without first knowing the dollars available. Using our IDE website and resources available, our HABITAT group decided to attack the problem by emphasizing the science. That is, determine the scientific goals of the mission, the resources necessary to tackle them, then work from there.

Each experiment on Mars will require equipment, facilities, and manpower, which translates to a dollar value. If the budget is too restrictive, it inhibits not just equipment, but scientific goals. This is the key point. The point of view of our analysis focused on SCIENCE GOALS, not equipment lists. Not enough money means downwardly revised goals.

Our long term objective is to create a math model of a closed loop, iterative design process to solve this problem. While this is unrealistic in the short term of a nine-week semester, it is a reasonable goal in the long term of several semesters.

The vehicle we will use to create our closed loop model will be the IDE or Interactive Design Environment created by our IDE group. The format of our Mars by 2012 class provided us with many excellent sources of information related to our problem through the IDE website. Furthermore, by means of our guest lecture series, we had the opportunity to make contact with Dr. Chris McKay, Dr. Carol Stoker, Mark Cohen and other experts in the field. They have given us the tools to help us determine what we want to look for on Mars, where we need to look, and what equipment we need to include. We have also had access to NASA and NASA-AMES web sites to obtain background habitat designs.

Being students at UC Berkeley enabled us to visit biology, chemistry, and geology laboratories to get a better idea of the weight and volume of the equipment we were considering. Furthermore, through our IDE website, we were privy to many previous studies on Habitats and equipment list. To mention a few, these included the 90 Day Study report of 1990, the LPI/NASA Mars Design Reference Mission and Bob Zubrin's Mars Direct papers. From these sources we were able to ascertain the scientific goals of a mission to Mars. These goals can be divided into two general categories: Laboratory functions dedicated to the presence and long term survival of the human species, and laboratory functions dedicated to the understanding of Mars and its place in the universe, including the search for life. These functions will now be detailed below.

PRESENCE AND LONG TERM SURVIVAL OF THE HUMAN SPECIES

A primary need of the HAB laboratory will be to address crew health needs. This means exercise facilities for preventive countermeasures and equipment for monitoring crew health, especially in response to prolonged isolation, low (hypo) gravity, and radiation. Equipment for monitoring and preventing cardiovascular deconditioning, bone demineralization and immune system suppression will be essential.

The lab should also have facilities for testing of a biological, closed loop, life support system (i.e., a greenhouse). Such a system will eventually be integrated with a turnkey physical/chemical system but its performance must be evaluated beforehand by means of dedicated lab facilities. Determination of crop output from native resources will be critical to the long term goal of human settlement and self sufficiency. As such is it essential that the laboratory place a high priority on monitoring this output.

UNDERSTANDING MARS' PLACE IN THE SOLAR SYSTEM

First and foremost, the Habitat laboratory must have equipment for performing the search for extant and extinct life on Mars. This is one of, if not the most important scientific goals of the mission. Two other goals of the laboratory should be to support scientific studies of the geology, geography and climate of Mars and to provide a testbed for the development of in-situ resource utilization and manufacture.

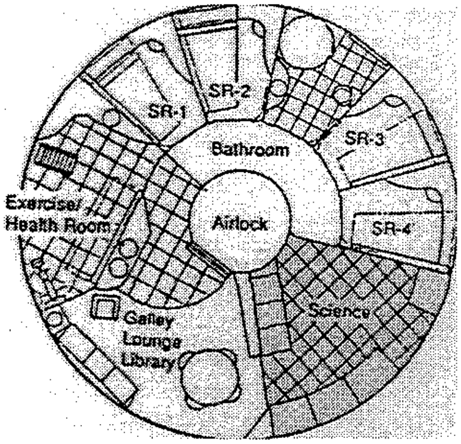
Starting with the scientific goals described above, we researched the experiments needed to achieve them. From these experiments, we then compiled lists of the equipment and facilities needed to implement them and from them, a rough idea of manpower requirements. With these pieces of the pie in place, we were finally in a position to begin prioritizing the scientific goals and experiments. This will be the work of the next phase of the project, since the compilation described above took most of this semester.

LABORATORY EQUIPMENT LIST

The laboratory equipment list is essentially a wish list of the things we would like to see included to perform all the work described above. It is only a partial list since we are still in the process or reviewing data from other sources of information. The task of next semester's team will be to complete this list and begin closing the loop of our design process. The model that does this must take account of constraints such as cost, weight, space and volume. Our goal in this model will be to use the minimum amount of equipment and man-hours to accomplish the maximum number of scientific objectives.

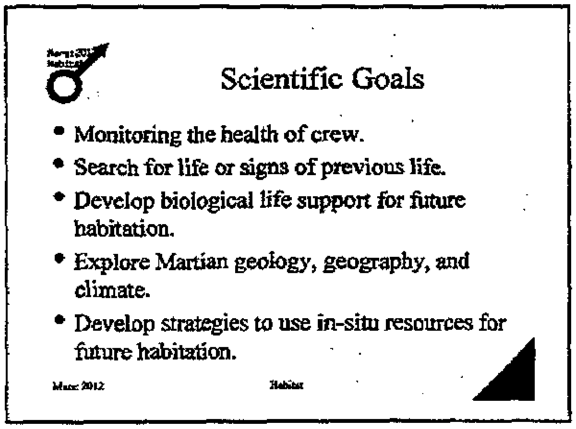
FUTURE GOALS/RECOMMENDATIONS

This semester, being the first in a new program, was a learning process. In summary, what we learned was how to focus on the definition of our problem and the development of a game plan to solve it. The IDE, though suffering through some significant growing pains at first, has reached a point enabling us to store our research, conversations, and thought processes. This will give next semester's teams a head start. It has also been our observation that the primary need of future teams will be increased contact with scientists and engineers in the field and attendance at forums such as the one held at LPI. We hope that the use of the IDE will greatly facilitate these contacts and that NASA takes the next step of making it a standard format that can be used by the government, other university teams, industry and the public.



EQUIPMENT LIST

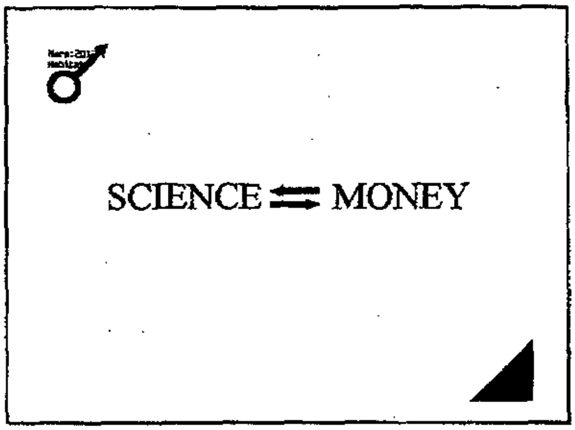
- Gas chromatograph/Mass spectrometer
- Atomic force microscope
- Ion chromatograph setup
- Gas electrophoresis setup
- Polarimeter
- Beta Counter
- Active seismometer
- Passive seismometer
- Magnetometer
- Gravimeter
- Hematocrit minicentrifuge
- Low gravity centrifuge
- Microcomputers
- Age dating equipment
- Compound microscope
- Dissecting microscope
- Dissection instruments, ie scalpel
- 10 pints O+ blood
- Surgical table
- Surgical equipment, ie scalpel
- Intravenous/vascular access products
- Anesthesiology equipment
- Cardiopulmonary control unit
- Cardiopulmonary breathing unit
- Cardiovascular/Cardiopulmonary interface panel
- Gas analyzer/Mass spectrometer
- Gas tank assembly
- Physiological monitoring system
- Blood holding kit
- Body mass measurement device
- In-flight blood collection system
- Rack mounted centrifuge
- Tracer kit
- Tissue culture incubator



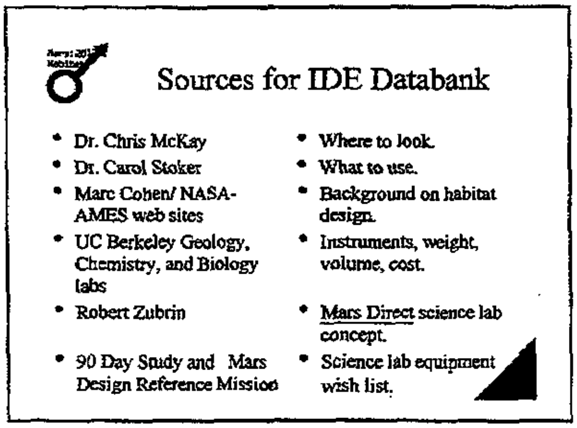
Scientific Goals

- Monitoring the health of crew.
- Search for life or signs of previous life.
- Develop biological life support for future habitation.
- Explore Martian geology, geography, and climate.
- Develop strategies to use in-situ resources for future habitation.

Mars 2012 Habitat

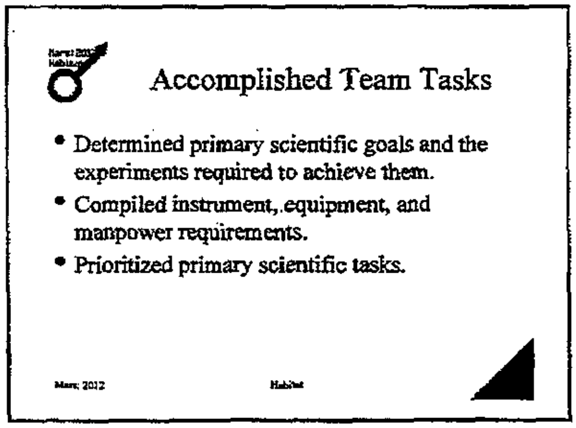


SCIENCE ⇆ MONEY



Sources for IDE Databank

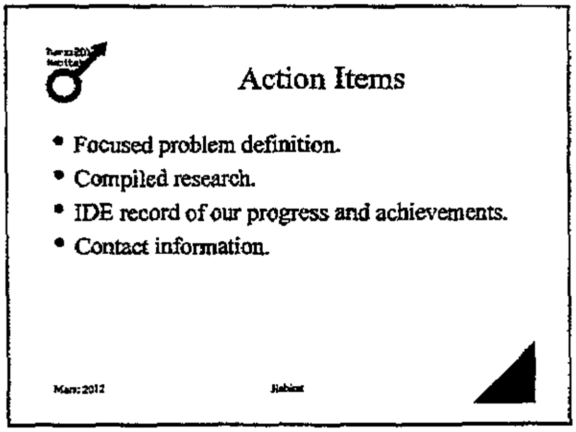
• Dr. Chris McKay	• Where to look.
• Dr. Carol Stoker	• What to use.
• Marc Cohen/ NASA-AMES web sites	• Background on habitat design.
• UC Berkeley Geology, Chemistry, and Biology labs	• Instruments, weight, volume, cost.
• Robert Zubrin	• Mars Direct science lab concept.
• 90 Day Study and Mars Design Reference Mission	• Science lab equipment wish list.



Accomplished Team Tasks

- Determined primary scientific goals and the experiments required to achieve them.
- Compiled instrument, equipment, and manpower requirements.
- Prioritized primary scientific tasks.

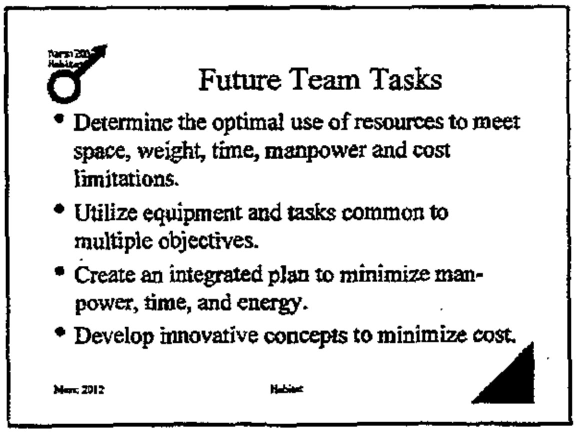
Mars 2012 Habitat



Action Items

- Focused problem definition.
- Compiled research.
- IDE record of our progress and achievements.
- Contact information.

Mars 2012 Habitat



Future Team Tasks

- Determine the optimal use of resources to meet space, weight, time, manpower and cost limitations.
- Utilize equipment and tasks common to multiple objectives.
- Create an integrated plan to minimize man-power, time, and energy.
- Develop innovative concepts to minimize cost.

Mars 2012 Habitat

MARS CREW SIZE PROJECT

Mars Crew Size Team Members: Alexia Cooper (Team Leader), Danielle Lee, Homan Yuen (Webmaster), Todd Muehlenbeck, Michelle Cameron, Rudy Provoost, Dan DaSelm, Cliff Sarkin, Molly Friend, Keith Watanabe

INTRODUCTION

The possibility of human beings standing upon Mars by the year 2012 is now greater than ever considering the increases in scientific knowledge and collective advances of various technological fields during this decade. However, it reamins a massive project such that a single country cannot supply all the knowledge, technology, resources, and funding required for completion. A mission to Mars will require the cooperative effort of universities, industries, and governments from the international community. It will be expensive, but the world possesses all the components essential for its success.

Before we can proceed, two important questions must be answered: (1) What will we do on the surface of Mars to justify the multibillion-dollar cost once we get there? (2) How many people do we send to accomplish these tasks and goals? This research proposal will address these two questions through the use of a design project in an interdisciplinary class entitled "Mars by 2012" at the University of California, Berkeley. Information about this class and our on-line discussions may be found at http://mars2012.berkeley.edu/.

BACKGROUND/RELEVANCE

The current NASA design reference for a preliminary human mission to Mars envisions a crew of six. The basis for this number has been largely a matter of conjecture. In a situation where the addition or subtraction of one person can greatly affect the costs and goals of the mission, a "guestimate" is unacceptable. Resources and funds for such a large project would certainly be under a large amount of scrutiny from members of Congress and from critics of the project itself. In light of the monetary and budgetary problems the International Space Station has had since its conception, a thorough examination of the tasks (which directly correlates with the size of the crew) is required in order to obtain the massive support needed.

One cannot make a list of the tasks that are to be completed in transit and on the surface and then assign them to an arbitrary number of people. The mission planning committee must realize that certain combinations of various tasks can minimize the size of the crew. In addition, some tasks can be completed without any or very little human interaction and can save valuable personhours on the surface. Other parameters such as remote operation, safety, and fail-safe systems must also be considered. The more one looks at it, the more obvious it becomes that the factors affecting crew size form a very complicated relationship. This relationship is subject to analysis and it is this analysis that will form the basis of this project.

OBJECTIVES

The goal of the Crew Size Team is separated into two parts. The first part of the project is to compile a list of tasks that are to be completed when the crew arrives on the surface of Mars. After this is finished, a methodology for determining crew size is constructed by analyzing and comparing the type and time required for the list of tasks generated from the first part of the project.

METHODOLOGY

During the first few weeks of the project, we (the Crew Size Team) had brainstormed the various tasks that it thought would be performed on the surface of Mars. That list will not be displayed here for it was incomplete due to the lack of a complete knowledge base at the time of study (and the limited knowledge base of undergraduates beginning such a project). Generalizing the various tasks instead, we decided it was necessary to include the disciplines of planetary geology, biology, chemistry, medicine, and engineering. However, the list is not important because the methodology should not depend on the list it is given; it should be usable given any sort of parameters and conditions.

Initially, our main goal was to summarize our methodology and decision-making process in the form of a single Crew Size Equation expressed by the following polynomial:

$$\text{Crew Size} = cl*T^{a} + c2*S^{b} + c3*A^{c} + C4*P^{d} + c5*G^{e} + c6*I^{f} + c7*E^{g} + c8*F^{h} + c9*IS^{i} + \ldots + \text{etc.}$$

where cl, c2…cN are constants, a, b, c, d are exponents, and T is tasks, S, safety constraints, A, degree of automation, P, physical limitations of the crew, G, gender constraints if any, I, international constraints, if any, E, ethnic factors, F, funding effects, IS, human factors isolation constraints and so on. Ultimately we decided not to use the above method because of the scarcity of data effecting the constants, exponents, etc.

We next approached the problem from a much more conceptual standpoint by using a flowchart to help with the decision making process. In the flowchart, two main branches dealt with budgeting and skills/tasks. Within these two branches were smaller sub-branches with more detailed scenarios. From this flowchart, we derived two simpler equations in relation to the number of people needed/allowed for the mission. Those equations are displayed on the viewgraph entitled "Crew Size Equations." There are two equations because we could not combine them in a logical sense. This arose from the fact that the total funding and the tasks and workload are both dependent variables. It is at the discretion of the mission planners to decide whether or not the total funding or the amount of workload be the independent variable. There are also several other factors that affect crew size and mix that could have been included in the equation. But dealing with time constraints and our primary goal (to obtain a methodology of determining size), we did not include them. These included psychological, political, gender, and ethnic factors (discussed later in the report).

After obtaining the conceptual crew size equations, we created three situations that displayed how the various ideas came into context. We created sample work shifts for a week for a four-, six-, and eight-person crew. These three sizes were the most popular among the team. We had disliked the idea of an odd-numbered crew for reasons of team dynamics. There could be an odd person out if the crew had paired up psychologically. A two- or three-person team would be ill advised because of safety concerns when dealing with rover excursions. Numbers greater than eight are possible, but having such a large crew would result in a greater financial burden and might not be much more advantageous over an eight-person crew.

In the shift schedule, we assumed that the martian day, although 39 minutes longer, was basically the same length as an Earth day. For the six- and eight-person crew shift schedule, there are 21 shifts of eight hours each. The four-person shift schedule shown on the viewgraph has 28 shifts of six hours each. We had also created a four-person shift schedule with 21 shifts of eight hours each, but it was much less efficient in terms of workload than the 28-shift schedule. Within the weekly schedules are subschedules in which the rovers would be in use. A majority of the hours of the week are in the rover because we believed, as Chris McKay had stated in his lecture to our class, science and exploration could not be done in a stationary base.

In the four-person shift schedule, there could only be two people in a rover because there needs to be two in the base if a crisis situation arises and a rescue is required. This limitation greatly decreases the efficiency of the usage of person-hours. A maximum of only twelve hours work could be completed in a 24-hour period. The explanation for this is as follows: Referring to the first rover time block for the four person crew, one can see that the first shift consists of Member A driving and Member B sleeping. In the next shift, Member A is now working while Member B observes various conditions to make sure everything is in proper order. Members A and B switch roles in the next shift. A crewmember cannot have consecutive work shifts because it could lead to physical and mental exhaustion. Now on the fourth shift, Member A must sleep since sheathe has not had sleep in 18 hours. But since Member A is sleeping, Member B must observe. There has to be at least one person observing every shift to maintain safety (with the exception of the first and last shift of the rover mission in which the person driving is the observer). Consequently, after 24 hours, only a total of 12 hours can be spent performing actual scientific work, the lowest work-hour to total person-hour ratio of the 3 options.

In the six-person shift schedule, there can be three people in the rover because that leaves three people for an emergency situation. The duration of the rover mission is also longer here because there is an extra crewmemberto help work and observe. This creates shifts where two crewmembers can sleep or have recreation time. In this situation, there is now a total of 24 hours of work time per 24-hour period. This is an eight-hour per day increase in work time over the four-person crew. In the eight-person shift schedule, the rover mission duration is even longer. This arises from the fact that there are enough people in the base to perform work and base functions while the excursion crew has three shifts of off-duty to rest and relax.

A summary of the total number of work hours total and per person is displayed in the viewgraph entitled "Work Output by Crew Size." The six-hour shift cycle is only slightly more efficient than the eight-hour cycle for the four-person crew. But when we observed the performance of the six- and eight-person crew, we noticed a marked improvement in the number of total work hours even though the total number of work hours per person did not show a drastic increase. As greater crew sizes are examined and plotted on a graph similar to this, we expected that the curve would level off because of diminishing returns. In the viewgraph entitled "Performance by Crew Size," the findings from the example work schedules are summarized. Although the eight-hour shift for the four-person crew had a longer maximum rover travel time, the total work hours was smaller than the one for the six-hour shift. And again, the six- and eight-person crews had drastic increases in total work hours and substantial increases in maximum rover travel time.

CONCLUSION/RECOMMENDATIONS

At the conclusion of the semester-long research project, the Crew Size Team decided that a six-person crew would be the optimum choice. As stated before, the crew must contain at least four members. Odd-numbered crew sizes are not preferred because of the situation in which members will pair up as confidants, leaving one person alone. A four-person crew would not be as efficient as a six, eight, or higher number crew. Since funding is one of the major influential factors in a mission to Mars, keeping the costs down would be advantageous to its success and popularity among various governments. Adding two people to an four-person crew (with six-hour shifts) would increase the total amount of work hours by 77.8%. However, adding two more people to a six-person crew only results in a 45.8% increase in total work hours. Each additional person would increase the total budget of the mission by several tens of millions of dollars. This is an example of the Law of Diminishing Returns, thus we chose a six-person crew because it gives more for the money.

That said, there are still many other aspects and factors that were not examined as deeply as we would have liked. Given the time, we feel the original crew size equation is still a valid and logical method of approaching this very complex problem. But factors such as T (tasks), S (safety constraints), A (degree of automation), P (physical limitations), etc., need to be better defined. Within these main factors are subfactors and issues. What kind of tasks, how many skills can a single person be reasonably cross-trained to absorb, how much time should be spent on each task? How much safety should the mission be constrained to, do we want computers and robots that can perform human jobs or use computers just for data storage and calculations? Do we want athletes or normal people? Do we want a coed group, which can lead to sexual tensions, or an all-male group, which can have psychological effects? Which countries will participate and how much control will they have over the overall mission? How do we assign which ethnicities and what number to the crew size and make-up? Where is the funding coming from and how will it affect the mission? As the reader can see, there are a plethora of topics that must be researched and explored. We have only laid the groundwork for a methodology here.

In conclusion, the mix of the crew has yet to be dealt with seriously. Crew size and composition, contrary to many mission designs, is a very important aspect. One cannot whimsically say five, or six, or even fifty without examining the consequences, limitations, and advantages. Crew size and composition are the factors in determining the actual crew and the actual crew determines mission success.

Crew Size Equations:

C_F = Crew size # determined by budget
F = Total budget
P = Price per person
S = Economies of scale (dependent upon C_F)

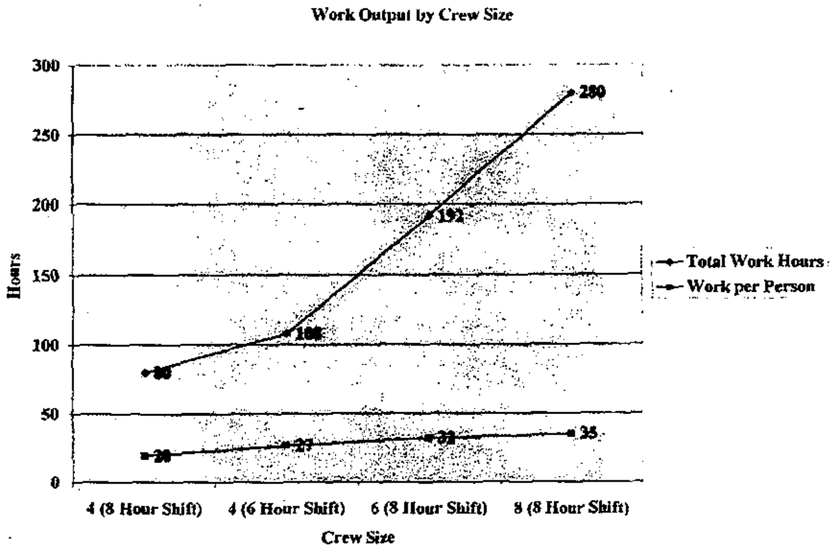
$$C_F = \frac{F}{P-S}$$

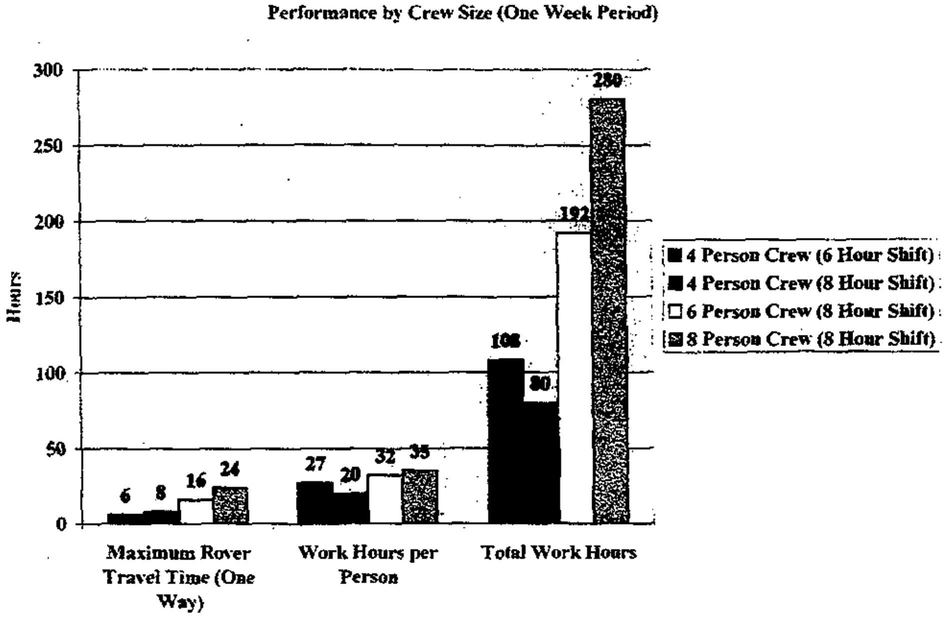
$$C_W = \frac{\sum_{i=1}^{l} B_i + \sum_{j=1}^{m} E_j + \sum_{k=1}^{n} L_k}{W}$$

C_W = Crew size # determined by workload
B_i = Number of hours for a certain base task
E_j = Number of hours for a certain field/enviroment task
L_k = Number of hours for a certain lab task
W = Total number of hours of a person can work a day

If $C_F > C_W$:
Assuming W remains a constant, adjust Bi, Ej, and Lk accordingly until $C_W = C_F$.
If $C_W > C_F$:
Assuming P and S remain a constant, attempt to increase F or adjust Bi, Ej, and Lk accordingly (or any combination of the two) until $C_W = C_F$.

There are two additional factors which set boundary ranges for crew size:
Psychological Factors and Political Factors


Work Output by Crew Size
300
250
200
150
100
50
0
Hours
280
192
108
80
35
32
27
20
Total Work Hours
Work per Person
4 (8 Hour Shift)
4 (6 Hour Shift)
6 (8 Hour Shift)
8 (8 Hour Shift)
Crew Size


Performance by Crew Size (One Week Period)
300
250
200
150
100
50
0
Hours
6
8
16
24
27
20
32
35
108
80
192
280
4 Person Crew (6 Hour Shift)
4 Person Crew (8 Hour Shift)
6 Person Crew (8 Hour Shift)
8 Person Crew (8 Hour Shift)
Maximum Rover Travel Time (One Way)
Work Hours per Person
Total Work Hours