SPACE COLONIZATION PROGRESS

Research And Technology For Space Utilization

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ALUMINUM MINE IN ORBIT

The Space Shuttle External Tank (ET) with just a little more "kick" of rocket thrust could be inserted in low Earth orbit and salvaged for building materials. The Space Studies Institute (SSI) asked the Air Force Institute of Technology's Aeronautics and Astronautics Department to investigate the possibility of recovering the vast amount of aluminum in ETs that are currently jettisoned and fall into the ocean. The question was: could the material be salvaged at a cost that would be competitive with the launching an equivalent amount of material from the Earth's surface? The results of this study were reported in SSI's March/April *Update*.

Three scenarios for salvaging the liquid hydrogen (LH_2) tank portion of ETs on orbit were examined. In each case the key technologies and hardware required were investigated. These encompassed cutting techniques, power sources, maintenance hardware, Extra-Vehicular Activity (EVA), and special tooling. The three methods were automated reduction, manned reduction, and rendezvous with Space Station Freedom.

In the automated reduction scheme, no astronauts would be utilized. A centerline track would be installed down the length of the LH_2 tank before launch. A trolley would ride the length of this track carrying an extending robot arm that would cut out sections of the tank and carry them to a storage area. Power from a solar array would be provided by a power truck riding the track ahead of the trolley. Automated reduction would start at the aft end of the tank and proceed as follows:

A cutting tool at the end of the robot arm cuts out a composite strip made up of aluminum plate, structural I-beam, and spray on foam insulation (SOFI). The strip is then transported to an interim workstation where the SOFI is removed and the I-beam and plate are separated from each other and stored in separate containers. This process is repeated until an entire barrel section of the LH_2 tank has been cut into pieces. Some portions of each barrel section are retained to maintain structural integrity. In this manner, the tank is reduced to a "birdcage" structure in about 41 hours. Over 13,000 lbs of usable aluminum have been salvaged.

The manned reduction strategy deletes the centerline track and robot, but would require an EVA crew of three to manually perform the operations of cutting, moving the composite strips, loading the SOFI workstation, and storing the reduced material. The astronauts would have designated jobs of cutter, loader, and stacker. Two cutting tools would be used instead of one with two barrel sections reduced simultaneously. Manned reduction would proceed as follows:

The person designated as cutter begins reduction of the two forward barrel sections. The astronaut sits on a seat locked on a ring frame of the tank. Power is routed into the rear of the seat and distributed to the two cutting tools on either side of the ring frame. The astronaut moves the cutters radially and hands the cut pieces to the stacker. A brake on the seat is released by the astronaut and the seat is moved manually into position at the next location.

The stacker hands off the pieces to the loader positioned at the input to the SOFI workstation. The loader feeds the pieces into the workstation. The stacker, positioned at the output of the SOFI workstation, then stacks the reduced material in appropriate containers. The stacker has the highest workload since he/she will have to handle parts twice during the operation. This may necessitate trading tasks off with the loader from time to time.

Once the two forward sections have been reduced, the workseat and cutting tools are moved to the aft barrel sections. The cutter is now close enough to the input of the SOFI station so that pieces can be handed off directly to the loader. The stacker does not need to handle parts twice during reduction of the aft sections. Reduction time for the second scheme is 23 hours, however the mission time is increased because rest is required between EVAs. There would be three 7-8 hour EVAs with 16 hour rest periods between each activity.

The third scenario would utilize either of the first schemes but in addition, would sell power to Space Station Freedom. Once the salvage had been completed in a lower orbit, the structure would be boosted to a rendezvous with the Space Station where its solar arrays could supplement existing power systems.

The conclusions of the study found that the LH_2 tank could be salvaged cost effectively. Over 52,000 lbs of useable aluminum in the form of I-beams and plates could be salvaged a year. This is equivalent to a yearly dedicated launch of the shuttle carrying equivalent materials. The automated scenario was competitive with the manned reduction option. Coming in at a close second was the rendezvous option utilizing automated salvage. This option did not come in first because the increased revenues from sale of power are offset by the high risks and operations cost of rendezvous with the Space Station. It was clear from the study that the concept of salvaging ET materials was viable and effectively increases the shuttle launch rate with no impact on schedule.

MARS IN 135 DAYS WITH WAVERIDER

What is the fastest, cheapest way to get to Mars? This question was posed to 38 senior level students in a 1990 aeronautical engineering class at the University of Maryland. The project was sponsored by the University Space Research Association and NASA to design a mission utilizing a hypersonic craft called a waverider. The results of this study were reported in a paper by Charles A. Lind and Mark J. Lewis in *The Journal Of Practical Applications In Space* for Winter 1991.

The mission utilizes a maneuver called an "aero-gravity assist" at the planet Venus to minimize travel time. Gravity assists have been used to save fuel in the past with numerous spacecraft (Pioneers 10 and 11, Voyagers 1 and 2, Galileo, etc.) which get a free boost by swinging around a planet and "steeling" some of its velocity. An aero-gravity assist (AGA) is a variation on this tactic where the spacecraft passes through the atmosphere of the planet.

The advantage of this strategy is that the possible flight directions are increased which aids in planning a mission with the shortest travel time. With a gravity assist, because the defection angles are limited, the planets must be aligned just right to achieve the desired flight path. This means that the launch windows are short and far apart. With the AGA, however, this is not a problem. Thus, longer launch windows are possible.

The disadvantage of the AGA is that velocity is lost to drag in the assisting planet's atmosphere. This loss needs to be minimized to achieve the highest possible velocity when leaving the planet. Enter waverider. This high lift-to-drag supersonic vehicle is so named because its wedge shape is designed so that the shock wave generated when exceeding the speed of sound remains attached to it's leading edge. This increases lift and actually appears as if the craft is surfing on its own shock wave. The configuration allows the craft to hurl through a planet's atmosphere without significant losses in velocity.

The following mission scenario was conceived during the study: Before departure of the waverider, an unmanned landing/launch vehicle module (LLVM) carrying a lander/habitat, supply stage, and departure/return propulsion module is launched to Mars on a 258 day transfer orbit.

The waverider spacecraft, designed to accommodate a crew of 10 for the departure and return trips, is launched on an optimum elliptical orbit to Venus. An AGA through the Venusian atmosphere gives a deflection of 82° and a velocity change of 16 kilometers/second to put the craft on a new elliptical orbit to Mars. The craft then performs an aerobrake maneuver in the Martian atmosphere to decelerate and rendezvous with the LLVM waiting in a parking orbit.

The waverider docks with the return propulsion module and eight members of the crew descend to the surface in the lander/habitat. After a three month mission on Mars the crew returns to the waverider to be propelled back home on another transfer orbit. A final aerobrake in Earth's atmosphere safely returns the waverider to low Earth orbit.

Propulsion for the first leg of the waverider's journey would be provided by a reusable nuclear booster that would detach in the vicinity of Venus and return to Earth for reuse. To reduce costs, a propulsion module of the same design is used for the LLVM. Because of extreme heating in the atmospheres of Venus, Mars, and Earth, active cooling beneath the waverider's outer surfaces with liquid hydrogen would be necessary. The coolant would be circulated through metal heat pipes, channeled to the rear of the craft, and expanded through a nozzle to provide additional thrust to overcome some of the drag during the AGA.

The waverider profile was calculated to optimize volume, achieve the shortest travel time, and minimize drag. Using an existing computer program, the final configuration was computed resulting in an arrowhead-like craft 80 meters in length, 10 meters high, and 28 meters wide. It would achieve a speed of Mach 76 at an altitude of 80 kilometers in the Venusian atmosphere with a lift-to-drag ratio of 7. Travel time to Mars would be 135 days - half the travel time of the supply ship. With a three month stay on Mars, the total mission time would be 362 days.

The study concluded that a hypersonic waverider offers considerable advantages over conventional Mars mission designs. Travel times can be minimized. Costs can be reduced by standardizing the waverider and LLVM propulsion systems and making them reusable. Launching the LLVM separately allows the size of the more complex waverider to be reduced. The project will be feasible in that nuclear rockets will be proven in the early 21st century. With the technology of the waverider and the nuclear rocket, the solar system can be opened for colonization more efficiently.

ACCELERATED TERRAFORMING OF VENUS

Venus is the last place anyone would want to visit, let alone colonize. With a surface temperature of over 850°F, an atmospheric pressure 95 times greater than Earth's, essentially no oxygen or water, and clouds of sulfuric acid, it is not a very hospitable place. The searing heat is caused by a run-away greenhouse effect and close proximity to the sun. The length of a Venusian day is 127 Earth-days.

What if Venus's climate could be altered, however, to be more Earth-like? The process of "terraforming" our sister planet has been postulated before. Early proposals suggested seeding the atmosphere with algae which would convert carbon dioxide to oxygen through photosynthesis. It now appears that this method may be overly optimistic and that a more involved technique is needed. In any event, the process would take on the order of *thousands* of years.

A new method has been proposed by Paul Birch in the April 1991 Issue of *The Journal Of The British Interplanetary Society*, that would take less than 200 years. Furthermore, revenues generated from the project will reach breakeven within 15 years of its inception.

Birch begins by outlining what physical changes are required to terraform Venus. First, the average surface temperature must be cooled to 63°F. Second, the atmospheric pressure needs to be reduced from 95 bars (most of which is carbon dioxide) to one bar composed of 25% breathable oxygen. Third, reduce the length of the day to 24 hours and finally, furnish enough water to create oceans and watertables. Sounds straight forward enough.

At the beginning of the project, around the year 2030, it is assumed that large scale space manufacturing will be common place as well as the infrastructure to support such a grandiose undertaking. The five stage cooling and pressure reduction process will take between 90 and 200 years to cool the planet to the desired temperature depending on how transparent the atmosphere is to the escaping heat. As we will see, other activities will be initiated during the cooling process. The scenario is envisioned to proceed as follows:

Stage 1 begins with the placement of several small space colonies in Venusian Orbit. Cooling is initiated by a large mirror constructed in space from lunar or asteroidal material and placed in a stable orbit between Venus and the Sun. With a diameter twice that of Venus the mirror will cause the temperature to drop as heat radiates to space.

During stage 1 which will last approximately 60 years, colonization of Venus commences - not on the surface but in the atmosphere. At the 1 bar pressure level, large floating cities are fabricated upon foundations of hollow foamed rock. The internal colony atmosphere of oxygen and nitrogen would be buoyant in the external CO_2. Birch calculates that colonies 200 km across would be stable in the high winds of Venus's atmosphere.

Stage 2 begins when the temperature in the atmosphere has dropped to about 90°F. Carbon dioxide then begins to condense out of the atmosphere as rain for 20 years until the pressure has dropped to 76 bars. More floating colonies are constructed and sold. As the pressure drops the colonies descend (eventually touching down at the end of stage 5) to 15 km.

Eventually, water will need to be imported. Some water can be obtained when the acids are neutralized in the atmosphere but this only provides about 1 mm of water planet wide. Birch suggests getting the rest from the outer solar system where ice moons are plentiful. Accordingly, a space colony is dispatched during this period to Saturn where its inhabitants will set about sending the ice moon Enceladus sunward. This could be accomplished by several methods. One technique suggested by Birch would be to create a steam rocket - a large solar concentrator will focus the sun's rays to vaporize water ice and super heat the steam creating a high velocity jet.

A jet velocity of 3.7 km/second sustained for 30 years can be achieved delivering 90% of Enceladus to Venus.

The critical pressure of 76 bars initiates Stage 3 in which the temperature falls for 90 years to 70°F and the precipitation of carbon dioxide continues until the pressure has been reduced to 7 bars (5 bars of CO_2).

At this time the temperature has fallen to -70°F and the triple point* has been reached. The liquid CO_2, now collected in lowland seas, begins to freeze and the floating colonies have descended to 8 km.

This initiates Stage 4 in which the temperature remains constant for about 20 years until the seas have completely frozen over. To slow evaporation of dry ice, the CO_2 oceans will be blanketed by insulating covers composed of transparent silica. Manufactured and lowered from the floating colonies, 12,000 of these disk shaped covers will be fabricated over a period of 15 years to completely overlay the oceans. Limited tent colonies are established on land.

Stage 5 sees a final drop in temperature for 9 years in which CO_2 now precipitates as dry ice snow until the temperature reaches -110°F. Export of excess CO_2 at a profit to space habitats in the inner solar system begins and continues for 50 years. Meanwhile, the ice moon arrives and provides an average of 120 meters of water over the frozen CO_2. Various strains of algae are released in the atmosphere and water oceans. Grain and other crops are planted on land. Through photosynthesis they begin to convert the remaining CO_2 to oxygen.

A 24 hour day is provided by retaining the sunshade and placing a space mirror in a 24 hour polar orbit. The mirror is constructed to supply the same amount of sunlight that the Earth receives. The temperature rises to 63°F.

The state of the atmosphere after cooling is 2 bars nitrogen, .8 bar CO_2, .5 millibar carbon monoxide, and traces of various inert gases. The CO is removed while the remaining CO_2 is converted to oxygen to attain a breathable atmosphere.

The year is 2250. The climate has begun to stabilize. A variety of organisms are imported to seed the oceans and land. The floating colonies descend and are converted to floating islands. Tent colonies on land are opened to the new world.

CULTURAL RAMIFICATIONS OF SPACE COLONIZATION

What will it be like to live permanently in space? What sort of customs, traditions, and behaviors, will humans adopt in the peculiar extraterrestrial environments likely to be encountered. Up until now most space researchers have focused on the technical, political, and financial problems of space colonization without regard to human behavior. Near the end of this decade and beyond, increasing numbers of humans will spend greater lengths of time isolated in space habitats. They will be a mixture of nationalities and encounter a variety of physical conditions that will force the adoption of new lifestyles. Because the well being of space colonists is of utmost importance, space scientists must start thinking about the cultural aspects of colonization.

Culture is a uniquely human capacity for coping with surroundings and to facilitate daily living. It is a lifestyle passed on from generation to generation composed of behavioral values and norms that descendants learn and adopt often without knowledge of their origin or basis.

Physical and social environments drive changes in culture. Adaption to extraterrestrial environments will influence the development of space cultures. The absence of gravity and atmosphere, the abundance of energy and light, the presence of radiation and magnetic fields, the absence natural hazards such as earthquakes, floods, storms, and pollution, all will contribute to societal changes in space communities.

Adaption to harsh or unusual environments sparks innovation and coping

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* The triple point is that temperature and pressure for a particular element at which it can exist in solid, liquid, and gaseous form.

mechanisms that drive cultural change. Social scientists and psychologists will have to team with space scientists to plan for this transformation. In *The Journal of Practical Applications in Space* for Winter 1991, Philip R. Harris discusses some of these cultural implications of space exploration predicted by behavioral scientists. Harris, himself a psychologist, predicts that ten major human factors will influence space culture. These factors are shown in Table 1. We will briefly examine each subject in the context of a lunar colony and then draw some conclusions on what cultures can be expected to emerge during colonization of the high frontier.

1. Sense of Self & Space
2. Language & Communication
3. Dress & Appearance
4. Food & Feeding Habits
5. Time Keeping & Time Sense
6. Relationships & Families
7. Values & Norms
8. Beliefs, Customs, & Traditions
9. Mental Processes & Learning
10. Work Habits

Table 1. Factors Influencing Space Culture

Sense Of Self And Space

Humans are used to maintaining a sense of space between themselves and others. They establish a self-identity and comfort level based on physical surroundings. The first space colonies will impose physical restrictions and stress upon occupants because of confined living quarters. Lunar habitats will begin to define individual psyches. With such expansive exteriors and confined interiors, people may become more interdependent. Some method of resolving conflict within a closed environment will have to be developed. Harris's research "supports development of an open, friendly, informal, and supportive community in space, such as earthly expatriates often maintain when far away from their mother country, so as to lessen the culture shock and strengthen a new sense of self aloft."

Communication And Language

Language can be expected to change in space colonies. New vocabularies may emerge as words such as "up" and "down" or "day" and "night" take on new meanings. If a multinational mix of people populate the first outposts, there may be several languages in use or a standard dialect may be adopted. Changes in terminology is already in process to meet the needs of space culture. Terms such as "astrolaw" and "EVA" are a few examples. Eventually, human life and discourse in space will be influenced by space art, literature, architecture, music, and technology.

Dress And Appearance

Culture is represented by modes of dress and outward appearance. We have already seen that the well adorned shuttle astronaut wears cobalt blue soft cotton flight suits decorated with mission patches. Space clothing will be designed for comfort and protection. Lunar colonists may choose to wear their hair short if they are to be constantly in and out of spacesuits.

Food And Feeding Habits

Mealtime habits in space are likely to differ in many ways from those on Earth. At first, dehydrated food will be the norm. In Lunar colonies, water may be a precious beverage if ice is not discovered in craters at the poles. The very expense of importing food will likely accelerate the development of closed system farming on the moon. Preparation and presentation will undoubtedly evolve toward high quality and energy content nourishment made as attractive as is possible. Of course, the mess hall will be a catalyst for socializing as is the case in the space program today.

Time And Time Consciousness

The patterns of time passages in space are different from those on Earth. These variances are likely to change cultural norms of work, leisure, and sleep cycles. Humans operate on a 24 hour biological rhythm, which we already know can be disrupted by variations such as jet lag. What will the 14 day lunar night due to this cycle?

The time element in planning work schedules will be important. Soviets have reduced crew fatigue by a rigid schedule that matches peak cosmonaut energy with the duty cycle and allows for plenty of exercise and ample leisure time to avoid exhaustion. Enjoying the wonders of space will be a popular leisure time activity. Creativity in the arts may be enhanced as result of the space experience. New art forms will emerge such as zero-gravity glass sculpture.

Relationships And Families

Relationships between the first space pioneers will initially be based on professional disciplines such as interaction between scientists or engineers. Because the first space colonies will be composed of knowledgeable workers, complete equality regardless of sex or nationality can be expected. As bases are established on the Moon and Mars of a more permanent nature, it is inevitable that sexual relations will occur and children will be born in space. Both parents are likely to be working professionals so a support system may be required such as group nurturing and care resulting in a shift away from traditional family roles.

Organizational structure of space society will depend on the composition and background of the settlers. A subculture has already been created by astronauts and cosmonauts which reflect their unique experiences and training. There may be a mixture of civilian, military, and multinational cultures which will affect the structure of government and human interactions.

Since space exploration will be on the cutting edge of technology, interactions with machines can be expected to define changes in culture. Robots will become more common place in work and leisure activities. Humans will develop new attachments to their mechanical servants as advances in artificial intelligence enable them to become more human-like.

Values And Norms

The values adopted by space cultures will evolve out of priorities and goals to ensure survival. Group goals may be highlighted over individual ones. For example, a lunar colony may adopt values of non violence, economic well being, guaranteed social and political justice, and environmental quality. These values will lead to norms in acceptable behavior which are handed down to subsequent generations.

Beliefs, Customs, and Traditions

The spiritual life and philosophy of an international blend of spacefarers may be influenced by traditional religious beliefs. Like the early American colonies, freedom of religion might be the norm which would preserve the traditions of Judeo-Christianity, Islam, Buddhism, Hindu, or some combination of these. On the other hand, new directions in human spiritual development may emerge that might raise the human race to a new state of consciousness. Space colonists might create their own beliefs influenced by the necessity of cooperation and togetherness that the space experience engenders. The view of Earth from space is already influencing human perceptions of themselves as one species united in survival on a planet with limited resources and a fragile biosphere.

Mental Processes and Learning

Human thought processes and learning behavior vary among cultures because mental development and education are focused on the needs of each particular society. In space, education will rely heavily on computers and electronic transfer of information since teachers will be in short supply. Self-instructional systems will be developed and colonists will be expected to share their expertise. Electronic networks will be established linking ground-based databanks with those in space. Eventually, universities will be established in orbit and on the Moon.

On long space voyages, learning new skills will not only prevent monotony but may also insure survival by cross training crew members and teaching them to deal with unexpected problems or system failures.

With development of a multinational space culture Harris suggests that "...a synergy may emerge between Eastern and Western cultural orientations to learning, so that an integration of logic, conceptualization, abstract thinking, and intuition may evolve."

Work Habits and Practices

The final factor influencing space culture is the vocation of space workers and their products. The initial jobs offered on the high frontier will be those concerning themselves with converting extraterrestrial materials into useful products and the maintenance and repair of those products. Space construction workers will be required to build the colonies and the facilities to support them. Automation will be prevalent as well as teloperated machinery. These initial colonists are likely to be highly educated, multiskilled professionals with backgrounds running the gamut from geology to astronomy to biology to ecological, financial, and legal disciplines. Their applications in the space arena are likely to be unique.

The novel vocations created in space will influence culture through innovative lifestyles and art forms. New cultures are likely to emerge that will change the directions of social development.

Harris concludes that the next century will see the human race in transition to a space-based culture. The elements of that culture will initially be extensions of Earth's societies into space. Eventually, new lifestyles will emerge with legal and political structures, artforms, work habits, and recreational activities appropriately evolved for the space environment. Subsequent generations born in space will be independent of earth with their own customs and beliefs.

The colonization of space will involve macromanagement of global projects which will require cooperation among nations. The utilization of space resources has the potential to unite humanity in an effort to eliminate world hunger, poverty, and inequities in energy use while at the same time improve human social and educational development. The creation of space culture will help true human potential emerge.

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Commercial Markets For Space Stations
Electromagnetic Launchers For Small Payloads
Magnetic Sail For Interplanetary Travel
The Space Economy Of The Next Century

High Frontier News Briefs

Probes Of Asteroid Resources Possible Before Century's End
(Space News, Aug. 19, 1991)

An inexpensive mission to rendezvous with an asteroid was presented at the first International Conference on Near-Earth Asteroids held June 30 to July 3 in San Juan Capistrano, California. The low thrust robotic space probe could be launched by a Delta 2 rocket by 1997 and reach its target within a year. Simple in design with a minimum of instrumentation for prospecting the asteroid, the craft would cost $150 million - a bargain compared to probes like Galileo.

Lunar Exploration With Pegasus Launcher
(Space News, August 5, 1991)

A Jet Propulsion Laboratory proposal would utilize Pegasus, an Orbital Sciences Corp. air launched rocket, to propel a 176 pound prospecting probe to the Moon. The craft would take a 5 month course that would make use of the gravity of the Earth, Moon, and Sun to reduce fuel requirements. With shrinking NASA budgets, the $8 million Pegasus launch cost looks very attractive for an early return to the moon for reconnaissance.

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