SPACE COLONIZATION PROGRESS

Research And Technology For Space Utilization

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Editor's Note: The four articles in this issue are summaries of papers presented last year at the tenth Princeton/AIAA/SSI Conference on Space Manufacturing. The Proceedings of the Conference are available from the American Institute of Aeronautics and Astronautics, The Aerospace Center, 370 L'Enfant Promenade, SW, Washington, DC 20024-2518

AUTOMATED LUNAR PROCESSING PLANT

All across the barren lunar landscape hundreds of six legged micro-robots fan out from their central base. Equipped with "wings" of solar panels and pincers for picking up rocks, the 10 kg insect-like automatons return to a main plant with their cargo: oxygen rich lunar soil ready for processing. The rocks and soil are ground to a fine powder. Next the material is injected into the heart of the facility: a high energy plasma stream.

Dissociated and ionized into its constituent elements, the soil's atoms are then accelerated to a uniform energy where they are separated, cooled, and collected. Out the other end of the facility comes pure oxygen, aluminum, and other useful materials which are ready for use in the lunar colony or in space.

Such a facility is currently beyond our technology but the basic principals are the same as in fusion research. Eventually the high cost of importing oxygen and other materials from Earth as well as the risks of man-tended processing plants will soon make development of this automated plant worth pursuing in the long run. In addition, the system has potential for remote extraction of any material allowing humanity to "live off the land" anywhere in the solar system. The concept could even be used to break down and recycle terrestrial industrial wastes.

A suggested path for the evolution of this automated multipurpose materials extraction facility (AMMEF) was conceived by Howard Kleinberg of SPAR Aerospace Limited, Ontario, Canada. Development would parallel the evolution of computer circuitry in that the earliest versions were as big as a house and required enormous amounts of power. Each subsequent generation becomes more power efficient and reliable while shrinking in size. Commercial applications are envisioned to finance each stage. The development program is expected to proceed as follows:

1. A proof-of-concept prototype AMMEF is built on Earth. The unit is a single large processing chamber hundreds of feet across requiring its own power station. Too large to be launched into space, the unit is ground testable only. Nevertheless, limited applications include breakdown of dangerous chemicals like PCBs or biological weapons. Successful experiments signal the go-ahead for development of a more practical plasma-separator.

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2. A room-sized, higher efficiency processing chamber is built. Lower weight and power requirements permit testing in space. This unit is designed with improvements in the chemical separation process and paves the way for more effective generations of the device. The machine is used on Earth for limited breakdown of hazardous wastes although in larger quantities then in the first generation device. The AMMEF sees its first experimental applications on the moon.

Concurrent with the AMMEF development program, advances in robotics and artificial intelligence have enabled the creation of small, inexpensive, reliable robots. Based on an MIT design called "Genghis", these six legged automatons are delivered in mass quantities to gather soil on the moon and retrieve it to the AMMEF. They are designed with the flexibility to carry liquid and gaseous elements as well, enabling material handling in any planetary environment.

3. Television-tube sized devices are developed next. These AMMEFs utilize room-temperature superconducting magnets and are clustered in arrays to increase production. Power supplies are small and reliable enabling wide-spread service in space. Perfect for materials extraction on the Moon and Mars, the AMMEF becomes a valuable tool in colonizing those worlds. On Earth, recycling of scrap materials and disposal of toxic substances become large-scale operations.

4. Solid state devices a few inches on a side emerge from the next iteration of improvements. More efficient room-temperature superconducting magnets are incorporated into this model as are improvements in the cooling systems. Applications include industrial usage by the lunar and Martian colonies as well as compact systems operating in remote locations such the asteroid belt. Terrestrial applications include large scale recycling of industry waste and environmental clean-up of water.

5. Advancements in material handling, plasma-physics, thermal control, and processing speed enable development of microchip devices. The rate of technology advancement levels off as limits imposed by physical laws are approached. The devices are cheap, reliable, and arrayed by the thousands in compact chemical extraction systems utilized throughout the solar system. On Earth, the systems reduce industrial pollution output to zero. The unit becomes a standard sewage and garbage recycler for homes on Earth and in space.

Development of the plasma-separation technology for materials extraction will provide humanity with the tools needed to "live off the land" of the final frontier. Evolution of the technology will lead to miniaturization enabling arrays of processors to be used by colonies or in remote locations to provide a ready source of raw materials. The technology will have applications on Earth in recycling of wastes and dealing with toxic materials. ★

REACTIONLESS PROPULSION WITH SPACE TETHERS

How can one get something for nothing in space? Aside from the discovery of "negative matter", that illusive material which repels normal matter instead of gravitationally attracting it (SCP; July/August 1990), there are only a few alternatives to rocket propulsion for moving around in space. One method turns out to be the ultimate free ride.

Space tethers offer a hugh discount on space transportation costs by reducing on-board fuel requirements for changing a spaceship's orbit. The savings in weight can be used to deliver larger payloads to desired destinations.

A tether is simply a long rope made from high strength material that joins two objects in orbit. That is all. If the rope is long enough, tidal forces or gradients in the gravitational fields can be exploited to raise or lower the objects to desired orbits. Some of the applications of tethers are described in a paper by Geoffrey A. Landis of Sverdrup Technology, Inc., Cleveland, Ohio.

The first example suggests a method for increasing the payload of the shuttle delivered to low earth orbit for free. Imagine a massive tether facility orbiting at an altitude of 600 miles. A 500 mile long tether is reeled out downwards. The end of the line is orbiting at an altitude of 100 miles but with the slower velocity of the higher orbit. Thus, the end of the tether is moving at about 80% of the velocity required to maintain the 100 mile orbit.

Now suppose that you would like to put a space shuttle in this lower orbit. Without the use of the tether, about 96% of the energy expended by the shuttle's engines is needed to accelerate to orbital velocity. Only four percent is needed to raise the altitude. This means that considerably less energy is needed if the only requirement is to raise the shuttle up to catch the tether. The remaining 20% of orbital velocity is provided by the space shuttle main engines.

Using the tether to boost the shuttle saves 23% of its fuel. This translates into a doubling the shuttle's payload! Of course the tether facility loses momentum in the exchange. This could be compensated for by using the tether to capture payloads from outside Earth's gravity and drop them to lower orbits. Otherwise repeated shuttle assists will deorbit the tether complex.

Another application uses a tether on board the shuttle to deploy a satellite into a higher orbit. The satellite is reeled out of the cargo bay on the end of a tether extending upward. The satellite is actually moving in a higher orbit but with the same velocity as the shuttle - exceeding orbital velocity for the altitude at the end of the tether. When the satellite is released it is flung outward to a higher orbit while the shuttle looses altitude. Since the shuttle has to come down anyway, the deployment is the last activity on the mission agenda. Less energy is needed to deorbit resulting in a further savings in fuel.

Still another application is eccentricity pumping. This is a method of changing the shape of an orbit from circular to elliptical (or visa versa). The idea is to extend and retract a tether at times that are synchronized with the orbital period. It can be used to initiate an escape orbit or transfer to a higher altitude.

No orbit is perfectly circular. There is always a high point (apogee) and a low point (perigee). Eccentricity pumping works by extending the tether at apogee and retracting it at perigee. Because the gravity gradient is stronger at perigee, more work is required to retract the tether then to extend it at apogee. This action "pumps" energy into the orbit effectively raising the high point. The process is exactly the same one used by children when extending and retracting their legs to "pump" a playground swing to greater heights.

Although this technique can not be used alone to escape the Earth's gravity, it can be used in combination with a gravity assist from the moon to achieve escape velocity.

The useful length of a tether is dependent on the strength of the material and is inversely proportional to the density. The length can be increased by tapering the profile of the tether making it widest at the attach point. Landis quoted a length of 300 km for Spectra-1000, a polyethylene synthetic fiber. Use of stronger materials such as silicon carbide or diamond will allow tethers over three times that length.

Tethers can help accelerate space development by lowering space transportation costs. Any orbit can be raised or lowered by extending tethers across a gravitational gradient and exploiting the differences in potential energy. The savings in fuel will allow larger delivered payloads. With improvements in the strengths of materials, greater lengths in these "bootstraps" will enable a wider range of possible orbits.★

DESIGN FOR AN ASTEROID MINING COLONY

A team of New York architects and engineers have designed an inhabited mining colony for refining asteroidal materials. Their concept took first prize in a competition sponsored by the National Space Society back in 1989. The Asteroid Resource Colony or ARC is described in a paper by the team leader, Claudio Veliz.

The key design considerations were safety, optimum use of asteroid materials, early economic payback, high quality habitation, and use of near-term technology. Factors for selecting the appropriate asteroid included stable temperature ranges and power requirements. A circular orbit is dictated by the former, and getting too far away from the sun impacts the latter. The Apollo asteroids fit the requirements having stable orbits similar to the Earth's.

The size of the asteroid must provide enough material for the colony and turn a profit for commercial trade. On the other hand, too large a body will exert a gravitational field that will begin to impact the function of the habitat structures. A size of 2 kilometers was judged to be about right.

Once the asteroid is located and surveyed, it must be despun to enable safe surface operations. A collection of computerized thrusters are attached at appropriate thrust points and fired in sequence to arrest the asteroid's rotation.

Next an automated module is attached to the surface. This robotic mining facility becomes the central hub of operations. A multi-function complex, the module conducts mining activities, refining of processed material, and assembly of surrounding facilities. The complex may contain versions of the AMMEF mentioned in the first article.

Mining proceeds below the surface to prevent dislodging of dust that might interfere with the functioning of equipment. Shielded temporary crew facilities are constructed first followed by a launch complex composed of payload processing facilities and electromagnetic launchers. These mass drivers are used to launch processed minerals and ores toward Earth to help pay for the colony.

The primary habitat modules are constructed next. Borrowing heavily from terrestrial bridge building and pressure vessel technology, these facilities are fabricated from asteroidal low mass concrete. A total of four of these cylindrical habitats are suspended on a complex of tethers extending seven kilometers from the central hub, each at 90 degrees from the others. The whole complex is gradually spun around the central hub up to an rpm that provides 1/6 Earth normal gravity in the habitats. Transportation between each of the habitats is made possible through elevators running up the tethers to the central mining facility.

Each habitat has its own unique interior climate and landscape. One may be tropical while another is temperate or even arid. The inhabitants enjoy scenery that is park-like with storage and service equipment interlaced beneath the surface. Sunlight is piped in with fiber optics and regulated so that day-night patterns of lighting are established, making the environment as Earth-like as possible.

Eventually the asteroid is hollowed out and can serve as a shell for a habitat in its own right. At this point either a new mining hub can be despatched or the whole colony-mining facility could detach an spin over to a fresh asteroid to start the process over again. In this manner a mining industry is established that not only provides raw materials for near-Earth space commerce but also establishes living communities and "new lands" to colonize among the Apollo asteroids. ★

MINING URANUS FOR FUSION FUEL

Mining the moon for helium-3 has been proposed (SCP; September/October 1990) as a source of fuel for fusion power plants in the next century. This element when fused with hydrogen produces less radioactivity and is more efficient in energy conversion than the usual choice of fuel, namely tritium. The problem is that helium-3 is rare on Earth. The solar wind enriches lunar soil with the element but only in concentrations of parts per billion. Thus, extensive processing equipment is required to extract the material. Might there be another source of helium-3 in the solar system that could be competitive with operations to extract it from the Moon?

The outer planets have atmospheres that are composed of mainly hydrogen and helium left over from the formation of the solar system. Helium-3 is far more abundant there. It turns out that Uranus and Neptune have the highest percentage of helium in their atmospheres. Of these two, Uranus is the easiest from which to obtain helium because it has the lowest mass and the highest rotation velocity at the equator. Thus the escape velocity for a quantity of helium at the equator is the least for Uranus.

The two competing scenarios, obtaining helium-3 from the Moon verses Uranus, can be compared by determining which option returns the most helium-3 for a given mass of equipment launched to low Earth Orbit. This analysis was summarized in a paper by Dani Eder of Boeing Aerospace and Defense Group, Huntsville, AL.

References cited by Eder mention that about 25 tons of helium-3 could supply most of the worlds energy needs for a year. For the purposes of this study Eder assumed that 10 tons per year of helium-3 would be sufficient in an economy supplied by mixed sources of energy. Another assumption fixed the transport ship payload at 1 ton.

Eder examined two methods for collection of helium-3 at Uranus. Scoop mining and on site separation. The first concept utilizes a collection vessel placed in an orbit that grazes Uranus's atmosphere so that atmospheric gases can be scooped up and the helium separated. The power requirements for this scenario turn out to be prohibitive because the atmospheric drag must be overcome. Not even the most powerful nuclear rockets currently foreseen could accomplish the task.

The second scenario involves placing a balloon borne processing plant in the Uranus atmosphere and launching minimal payloads of helium into orbit. The balloon is made buoyant by a nuclear powered heat source (since the atmosphere is mainly hydrogen it would be hard to find a lighter gas). The plant separates the helium and liquifies hydrogen for propellant.

The payloads are carried aloft by a reusable nuclear ramjet/rocket. The ramjet concept allows the craft to take advantage of the free hydrogen fuel in the atmosphere thereby reducing on-board fuel requirements and increasing payload. Current ramjet technology allows velocities up to about Mach 6 (six times the speed of sound). On Uranus the speed of sound is about 1300 miles per hour so the ramjet operates up to 8000 miles per hour. Then the nuclear rocket kicks in, utilizing on-board propellant. Once in orbit the helium is then sent back to earth via low thrust nuclear electric rockets.

Eder estimates that to return 10 tons/year using the on site helium separation scheme, about 550 tons of equipment must be placed in Earth orbit. This includes the nuclear ramjet/rocket, balloon, on site refinery, aerobrake, and the nuclear electric rocket for bringing the cargo home. To return the same quantity from the moon, 5000 tons of processing equipment need to be boosted to Earth orbit. Nine times as much!

It can be concluded that mining Uranus for helium-3 is competitive with extracting it from lunar soil. This fact holds as long as launch costs to Earth orbit continue to be expensive. ★

News Briefs From The Frontier

Space Industry Incubator

From Space News February 10-16, 1992

The University of Maryland has established a Technology Advancement Program (TAP) aimed at helping small companies get started in the space industry. Entrepreneurial start-ups can take advantage of office facilities, computers, and state-of-the-art laboratories such as a new $1.8 million neutral buoyancy tank. The new tank will allow tests of space hardware under water to simulate assembly techniques in microgravity conditions. One of the dozen companies assisted under TAP is Global Outposts, a company attempting to utilize spent fuel tanks from the shuttle as platforms for commercial space activities.

Funded primarily by the university, the program provides new companies with low-cost office space and support of faculty and students. After three years the companies must make it on their own, but often locate locally providing jobs as well as revenue to the state.

Increase Proposed For Exploration Funding

From Space News February 10-16, 1992

The White House is asking Congress for a 20% increase in funding for lunar and Mars exploration. The proposal would include $99 million in 1993 to define robotic missions to the moon starting in 1995 leading to humans returning before the end of the 90s. Missions to Mars would also be studied under the plan.

Space News quoted NASA's associate administrator for exploration, Mike Griffin, who suggested that the programs be justified on the basis that it would stimulate the economy, enhance technological leadership, and boost U.S. competitiveness in global markets.

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