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Laser Propulsion: Low-cost Launch System

The current cost of launching payloads into orbit is between $3000 and $5000 per pound. Clearly, if large amounts of equipment are to be lifted into space these costs must be reduced. An innovative launch system first conceived by Arthur Kantrowitz in 1972 would use ground based lasers to vaporize solid propellant at the base of a rocket to create thrust. The Strategic Defence Initiative Organization has been studying this concept since 1987. Preliminary research has determined that launch costs as low as $250 per pound may be possible with this system.

Jordin Kare of Lawrence Livermore National Laboratory describes the scheme in the first quarter issue of this year's Space Power. The basic rocket engine, called a double-pulsed planar thruster, consists of a simple cylindrical block of solid propellant. A ground based laser fires two closely spaced pulses, the first of which evaporates a few microns of propellant forming a thin layer of gas. The second pulse heats this gas layer rapidly to 10,000 degrees Kelvin causing it to expand and produce thrust. The whole cycle lasts a few microseconds and is repeated many times a second.

There are several advantages to this system. First, no oxidizer is required to burn the fuel, resulting in a savings in weight. Second, because the thrust is uniform across the base of the fuel cylinder, no rocket nozzle is required which simplifies the design. Furthermore, the thrust is independent of the orientation of the beam implying that the rocket can fly at an angle to the beam. In fact, the thrust can be varied by adjusting the laser beam profile across the fuel surface which means the vehicle can be steered from the ground. Thus, no guidance system is needed, which further simplifies the system and reduces the weight. Finally, a payload could be launched every 15 minutes.

The system proposed would consist of a 20 megawatt average power electric discharge CO_2 laser, generating 500 kilojoules of energy in two pulses, each lasting a microsecond. The set of pulses would fire 40 times a second at a wavelength of 10 microns. The technology for large lasers of this type is well understood having been thoroughly studied in the 1970s.

The laser would be focused with a 10 meter telescope onto a 2 meter diameter vehicle. The telescope would be similar to the Keck telescope under construction by Cal Tech and the University of California. The range of the system, dictated by the fact that the vehicle must remain above the horizon and limits imposed by the size of the telescope, would be 1000 kilometers (621 miles).

The mass of the individual projectiles that could be launched with this system is about 44 pounds - rather small compared to today's rockets which routinely launch thousands of pounds into orbit. But 100 vehicles could be launched per day which would be 1.2 million pounds per year! This is more than 20 shuttle flights.

Because of the low mass, the vehicle cannot be very large or complex. This system would therefore be limited to smaller payloads, but there are numerous applications for payloads of this size. For instance, they could be used as a resupply pipeline of food, water, and equipment for Space Station Freedom, or they could launch microsatellites for communication, remote sensing, and scientific studies.

The 20 megawatt laser system proposed would cost $450 million - roughly the price of two shuttle flights. Each launch would cost about $5000 (electricity plus vehicle). The true launch cost would have to amortize the development and operations cost of the launcher over it's lifetime and so depends on how often the system is utilized. At a rate of 100 launches per day over a five year life the cost to orbit is $250 per pound. The system could be available in five years and offers an innovative alternative to the astronomical price tag on today's rockets.

NASA's Plans For A Lunar Outpost

Returning to the moon has been on the minds of NASA designers recently at the Johnson Space Center in Houston, Texas. Their current plans for a lunar base were reported in a two part article in the February and June Issues of Aerospace Engineering.

First, a way station called a transportation node (TN) will be established in low earth orbit to provide a link between Earth and lunar transportation vehicles. Separate from the Space Station, the TN will store propellant and provide for docking, propellant transfer, mating of payloads to vehicles, and vehicle deployment to the moon. There will also be pressurized habitation modules for six permanent TN personnel, three visiting Shuttle astronauts, and four visiting lunar travellers.

A typical mission vehicle would be a stack consisting of an orbital transfer vehicle (OTV), a lunar ascent/descent vehicle, a lunar payload, and an aerobrake/heat shield. Once the vehicles had been stacked in the TN, loaded with fuel, and boarded, the OTV would boost the whole package to the moon. Upon reaching lunar orbit, the lunar landing craft would separate from the OTV or the OTV can meet a landing craft which had been launched from the lunar surface. Passengers and cargo could be transferred in lunar orbit and the landing craft could be refueled.

After returning to Earth, the OTV would aerobrake by skimming the upper atmosphere. Friction would slow the craft down enough to enter an elliptical orbit, a maneuver that saves considerable fuel. The engines would then be fired to put the craft in a circular orbit to eventually rendezvous back with the TN.

The Lunar Outpost itself would be composed of a landing site, a solar power collector field, habitat facilities, and a lunar oxygen pilot plant. In the early stages the landing site would simply have to be a smooth area free of obstacles. Navigation beacons would be installed to guide unmanned landings. Eventually, a gravel surface would be desirable to cut down on the amount of dust kicked up by the lunar lander engines.

The solar power field would be located well away from the habitat and landing site to gain an unobstructed view of the sun and be free of dust.

The main facilities would be composed of a construction shack, an inflatable habitat, a logistics interface module (LIM), an airlock, and an environmental control and life support system. In addition, a vehicle maintenance facility (VMF) would be located adjacent to the habitat. The VMF will be essentially an inflatable Quonset hut capable of accommodating four lunar rovers.

The first structure to be placed on the moon would be the construction shack. This is a small self-contained unit complete with its own airlock. It has the primary function of supporting extravehicular activities (EVA) for science and initial construction. The construction shack would fill the gap between the first lunar landers and the permanent outpost. A number of shacks could be widely distributed across the lunar surface for expanded exploration.

Once the construction shack is activated and shielded with soil, building the main habitat would begin by driving piles into a suitable depression to form a concave foundation. The habitat would then be anchored, inflated, inspected, and shielded. A tunnel would then be excavated connecting the construction shack.

The habitat will hold a crew of twelve. It would be a 16 meter spherical envelope enclosing 2145 cubic meters, with four levels of living and working area totalling 594 square meters. A central vertical circulation shaft would allow movement between levels via a ladder.

The primary outer pneumatic shell would be composed of high strength multi-ply fabric with an internal air tight enclosure. The interior structure would be supported by a spherical rib cage composed of a central column with radial floor beams and a modular flooring system.

An appendage to the main habitat would be the LIM intended to serve as a berthing port for lunar rovers and a loading dock for crew and cargo.

The lunar base would require at least 100 kilowatts of power. Three power systems are being considered: solar photovoltaic, solar dynamic, and nuclear. The photovoltaic system consists of 2000 square meters (1/3 of a football field) of solar cells converting sunlight into electricity. The solar dynamic system would use concentrators to focus sunlight on a working fluid which would drive a generator. These two systems would need to be supplemented with fuel cells during the long lunar night. The power from a nuclear system would be continuous and plentiful, with a high power to mass ratio but would require shielding and would be a radiation hazard at the end of it's life.

Finally, several different concepts for a lunar oxygen plant would be tested to determine which design would produce oxygen most efficiently. Initially, there might be several small pilot plants operating to prove technology.

Most of the systems and concepts described above are possible with current technology. As the designs mature and markets open up for Mars mission operations, lunar observatories, and manufacturing associated with power systems like the one envisioned in the next article, the bases would expand, becoming a network of self-sufficient colonies.

Lunar Power Source. Part Two

Part One of this series discussed the Report of NASA Lunar Energy Enterprise Case Study and a concept for mining Helium-3 from the Moon. This issue will focus on the second topic of the study, the Solar Power Satellite (SPS). Part Three, the final article in this series, will describe the Lunar Power System (LPS) in the January/February Issue.

Extraterrestrial sources of energy will be the wave of the future. Passive Earth-based systems such as solar, wind, geothermal, and hydroelectric can and should be utilized but cannot provide all of the world's needs due to physical limitations. Earth-based solar power, for example, is limited to cloud free daylight hours.

Most space enthusiasts have heard of the idea for the SPS. Originally conceived by Peter E. Glaser of Arthur T. Little, Inc. in the 1960s, the system consists of an array of photovoltaic cells in geosynchronous orbit that would collect sunlight and convert it into electricity. Microwave generators would then beam the power to earth where it would be collected by ground based antennas for conversion back into electricity.

The advantage of this concept is 24 hour uninterrupted power with no damage to the environment. The power could be beamed to any location eliminating the need for lossy distribution networks.

NASA and the Department of Energy performed studies on this concept in the late 1970s and determined that it is technically feasible. These studies assumed that all the materials for the satellites would be launched from Earth. Consequently, unless launch costs can be reduced (perhaps by developing laser propulsion as described on page 1), the price of such a system would be prohibitive.

However studies commissioned by the Space Studies Institute in Princeton, New Jersey have shown that over 99% of the raw materials required for the SPS are present on the moon. This would reduce the cost by nearly 97% compared to the earlier studies because it is cheaper to launch material to geosynchronous orbit from the Moon.

The financial risks and technological challenges associated with a project of this magnitude can be reduced by a strategy called "terracing" of generic technology. The idea is to achieve incremental steps in technology development and apply them to specific space projects.

For example, in low Earth orbit a small pilot SPS could be built to prove power beaming technologies over short distances and at the same time provide supplemental power for the space shuttle. Similarly, additional power will be needed in higher orbits in greater amounts for the Space Station and co-orbiting platforms. Orbital transfer vehicles which utilize beamed microwave power to operate electric thrusters would be the next step. Eventually, larger systems would be needed for a lunar base, and ultimately, the full scale system could meet the energy needs of Earth in the middle of the next century.

Advances in robotics and artificial intelligence in the next few years will make possible the construction of a "Von Neumann" machine. This is a self-replicating device capable of building and programming copies of itself. The two resulting machines would repeat the process to make four, the four would again repeat the process to make eight, and so on, resulting in exponential growth. Given a source of raw materials on the moon such machines could rapidly build the required facilities for a

SPS lunar manufacturing plant with comparatively little investment in initial machinery. This sort of technology will further reduce the financial risk of the SPS.

The SPS has been considered as economic justification for the construction of space colonies. Revenues raised from the generation of electrical power would enable the colonies to pay for themselves in just a few decades.

Next time we will conclude this series with the third option for power from the Moon. The Lunar Power System.

The Report of NASA Lunar Energy Enterprise Case Study Task Force is available from the National Technical Information Service, Springfield, Virginia 22161-2171

Antimatter Electric Starships

Antimatter. The fuel proposed for the 23rd century Starship Enterprise. Produced in minute quantities in today's particle accelerators, antimatter is the ultimate in conversion of mass into energy. Every physics student knows that particles that come in contact with antiparticles annihilate each other resulting in a shower of high energy photons and charged subatomic particles. The U.S. Air Force has actually been studying rockets utilizing this principal of nature. The main technological hurdles appear to be producing sufficiently large quantities of antimatter and designing storage and feed systems for delivering the antimatter to the reaction chamber.

Gerald D. Nordley of the USAF Astronautics Laboratory at Edwards Air Force Base, California discusses a design for an interstellar rocket using antimatter as fuel in the June issue of the Journal Of The British Interplanetary Society. The concept presented converts the kinetic and thermal energy of the charged annihilation products of the antimatter reaction into electricity which is then used to power an electric thruster.

One of the challenges to overcome is producing antimatter in sufficient quantities (about a ton) to make the system practical. Again, Von Neumann machines are suggested (see the previous article) as a means of making antimatter factories in space using the cheap energy of sunlight and the asteroids as raw material.

Once enough antimatter is produced, the next problem is storing it and moving it around. How does one move a substance whose very proximity to matter tends to obliterate it? The answer is magnetic fields. Antiprotons (the antimatter equivalent of an ionized hydrogen atom) have already been stored for minutes in electromagnetic traps at moderate densities. It is believed that as superconducting magnet technology improves they could be trapped indefinitely. The Astronautics Laboratory is investigating growing ion clusters of antihydrogen which could significantly increase the density of antimatter stored.

Antimatter could be transported out of the storage system and into the reaction chamber by opening a hole concentric to the applied magnetic fields. Electrostatic repulsion would then force the antimatter out along the field lines to the reaction chamber.

At the heart of the system are the almost magical properties of magnetohydrodynamics (MHD), that branch of plasma physics which deals with the interaction of charged fluids in motion in an applied magnetic field. This was the concept used to propel the Russian submarine in the famous movie "The Hunt for Red October". Our starship engine takes advantage of a MHD principal which says that a magnetic field imposed on a moving stream of charged particles (such as that which would be created exiting an antimatter annihilation chamber) will induce a force on the particles perpendicular to both the magnetic field and direction of the flow. This force in turn generates an electrical current in a circuit whose electrodes are properly placed in the stream. To boost efficiency, the exhaust products leaving the MHD stage would be the inputs to multiple turbo generators that would generate still more power.

All of the energy would then be applied to an ion accelerator engine which has the capability of achieving the highest exhaust velocity of all know propulsion systems. An analysis of an interstellar flight was performed by Nordley which indicated that a robotic probe using this technology could achieve a velocity of 0.07 times the speed of light and would reach Proxima Centauri (4.2 light years) within 390 years. This is a significant improvement over today's chemical rockets which would require tens of thousand of years to make the same journey.

Antimatter propulsion is moving out of the realm of science fiction and into the rocket scientist's laboratory. Improvements in the systems for the production and storage of antimatter will make it a practical fuel for the next generation of rockets.

In The Next Issue:

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Space Industry As An Alternative To SDI
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