SPACE COLONIZATION PROGRESS

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TWO-LAUNCH MANNED MARS MISSION

Destination: Mars! A mission architecture that places humans on the Red Planet by the end of this decade has been developed by two engineers employed by Martin Marietta Astronautics of Denver, Colorado. David Baker and Robert Zubrin have combined existing shuttle technology with technical innovation to produce a two-launch Mars direct mission (immediate insertion in a transfer orbit after launch) without the need for on-orbit assembly or lengthy travel times. Their scenario is described in the November 1990 *Journal of the British Interplanetary Society* (JBIS).

The Mars direct mission would be made possible by three innovations. The first would be development of a heavy lift vehicle based on existing shuttle technology. This Shuttle Derived Vehicle (SDV) would use the same main and solid rocket engines as the Space Shuttle and could be ready for flight in five years. The second innovation would be to transport hydrogen in cryogenic storage and combine it with carbon available in the Martian atmosphere to produce methane for fuel on Mars and for the return trip.

The third innovation would be to utilize the same habitat used on the outbound journey to house the crew on Mars, then return them to Earth in a minimal vehicle that had been landed and fueled in advance. With the approach described above, very little new technology would need to be developed and the same strategy could be applied to lunar missions.

The odyssey would begin with insertion of 40 tons of equipment into a minimum energy transfer orbit to Mars in December of 1996. The SDV would be a variant called Shuttle-Z optimized for Earth escape. The first stage would consist of a cluster of four Space Shuttle Main Engines in a pod attached to the lower end of the main fuel tank. The usual two Solid Rocket Boosters would be strapped to the sides. The orbiter would be replaced with an in-line heavy upper stage similar in function to the second stage of the Saturn-V moon rocket.

The payload would be composed of the following cargo: an unfueled two-stage Earth Return Vehicle (ERV) with methane/oxygen engines, six tons of liquid hydrogen stored in the lower stage tanks of the ERV, an aerobrake and Mars landing module (H_2/O_2 engines), an unpressurized methane/oxygen powered electric rover, a 100 kilowatt nuclear reactor stored in the back of the rover, and an automated compressor and propellant processing unit.

Upon reaching Mars, the aerobrake would decelerate the craft into a 250 kilometer orbit and a landing site would be selected. The payload would then be aerobraked and descend with the aid of a parachute. Terminal descent would be assisted by the H_2/O_2 landing module engines.

After touchdown, the rover would transport the nuclear reactor several hundred meters away while trailing a power cable. The reactor would be deposited into a natural depression or one created by explosive charge, and started up to provide 100 kilowatts of power.

With a source of electricity now available, the compressors would be fired up to collect carbon dioxide which makes up 95% of the Martian atmosphere. A nickel/graphite catalyst would be utilized to react this CO_2 with the six tons of hydrogen to create 38 tons of methane and water. The water would then be electrolytically split to obtain oxygen and more hydrogen for production of methane. This gas manufacturing plant would require ten months of operation to produce 107 tons of methane/oxygen propellant, of which 96 tons are required for the return trip. The remaining 11 tons would be used by the rovers. The CO_2 and water would be stored in the now empty landing modules tanks. The ERV tanks would be filled with the methane/oxygen propellant.

After confirmation that the ERV is fueled by ground controllers, two more SDVs would be launched in January of 1999. One payload would be identical to the first SDV launched in 1996. This vehicle is actually an option for the next mission and would contain another ERV and propellant processing facility. The second payload, called a Transfer and Surface Habitat (TSH), would also be 40 tons and would carry a crew of four in a 55 square meter upper habitation deck with a lower deck stocked with provisions, scientific gear, and a pressurized two-place rover. The TSH would be the same diameter as the space shuttle's main fuel tank and could be built using the same tooling.

Artificial gravity would be maintained on the voyage by using the upper stage fuel tank as a counter balance at the end of a 1.5 kilometer long tether. Attached to the payload before launch, the tether would be deployed after insertion in a transfer orbit by maneuvering the upper stage to the required distance and firing the thrusters perpendicular to the tether to achieve a velocity of 400 meters/second. This would create Mars equivalent gravity in the TSH.

After reaching Mars, the TSH would release the tether and aerobrake into orbit. The ERV on the surface would be equipped with a radio beacon to guide the astronauts in the final descent. If for some reason the habitat would be unable to land near the pre-established base, the second return vehicle launched in 1999 could be targeted to land where required. Otherwise, this second ERV would be landed a few kilometers from the first.

Once on the surface the TSH would become a base camp science station habitat. The two available rovers, one pressurized, employ twin 25 kilowatt turbogenerators powering electric motors on all four wheels. They carry 600 kilograms of fuel/oxidizer which would open a range of 1000 kilometers radius for exploration and provide power on tap for energy intensive scientific investigations.

In 2001 the return trip would start with ignition of the methane/oxygen engines in the two stage ERV. The crew cab would be spartan compared to the surface habitat. Weightless and resembling a stay in the Soviet Mir, the journey would take eight months to complete the fall inward to the Earth's orbit. A final aerobrake in the Earth's upper atmosphere would bring the craft to a rendezvous with Space Station Freedom or a waiting Space Shuttle.

Back at Mars, the next mission would have arrived: a manned habitat ready to land near the already fueled return vehicle from the 1999 mission, and a third ERV ready to open a new site within the range of the rovers. Thus, every 26 months two SDVs would launch a habitat and return vehicle combination eventually accumulating five TSHs on the surface of Mars in ten years. These habitats could be gathered together to create a permanent Martian settlement.

The vehicles described above could also be used for missions to the moon except that the habitat would be launched in advance with the crew riding out and back in the ERV. Since the moon has no atmosphere, an aerobrake is not necessary but production of propellant is not possible either so the methane and oxygen for the ERV engines would have to be included in the payload. This extra fuel would actually make the lunar payload heavier than the Mars mission mass.

By combining existing and near term technology a two-launch manned mission to Mars will be possible by the end of this decade. It can be achieved through minimizing mass by manufacturing methane on Mars and developing heavy lift launch vehicles using existing shuttle hardware and facilities. The proposed vehicles could also be used for lunar exploration. The missions can be staggered in sets of two every couple of years eventually planting the seeds of a permanent Martian colony.

THE FIRST COLONY ON MARS

The design of a 21st Century colony on Mars has been developed by three employees of the Obayshi Corporation in Tokyo. Yoji Ishikawa, Takaya Ohkita, and Yoji Amemiya report on their research in the November *1990 JBIS*. The colony would be established in the year 2037 with the objectives of research on the search for life on Mars and the origin of the solar system as well as technology assessment for further colonization of Mars. The outpost would also be a way-station and refueling base for trips to the outer solar system.

The settlement would house 150 colonists including engineers, scientists, doctors, psychologists, journalists, poets, painters, and musicians. Eventually, (after 2050) people of more varied occupations would immigrate because propulsion systems will have improved to reduce travel costs and times. This would make tourism and asteroid mining viable commercial industries in which Mars would be a strategic axis.

The location of the colony would be the Kasei Vallis region where a source of water is believed to exist. This area is easily accessible from an equatorial orbit and is close to scientifically interesting sites.

A 10 megawatt Solar Power Satellite (SPS) would beam power to a receiving antenna located near the habitat site. Placed in a 17,000 kilometer high orbit, the SPS would be constructed from materials mined from the Martian moon Deimos. The SPS would be needed because solar energy collection on the surface would be hampered by dust storms. Microwave transmissions from the SPS would not be affected by dust.

The Mars settlement would be continuously evolving. Initially built off of a safe haven drilled into the side of a hill, it would be laid out and expanding north to south along four linear lines. The primary life line would contain residential habitats and experimental biospheres call terraria. On either side of the life line structure would be pipelines carrying water extracted from permafrost in the northern hill's perimeter. These conduits would also be the service lines for atmospheric gases in the colony. On both sides of the pipelines would be a row of greenhouses in which a variety of crops would be grown. Finally, a line of research facilities would flank the greenhouses.

There would be two types of terraria connected to the residential habitat, each contained in a 80 x 160 meter inflatable structure. The Type 1 terrarium would be designed to study how to transform the Martian atmosphere into one hospitable to life. Unshielded from cosmic rays and transparent to sunlight, the Type 1 dome would be inflated with the ambient Martian atmosphere initially rich in carbon dioxide. Trees, plants, and algae would convert the CO_2 into oxygen in a few years.

Once the air became breathable, soil would be piled over the exterior for shielding and the Type 1 would be converted to a park-like amenity complete with ponds, animals, and insects. This Type 2 terrarium would provide a shirt sleeve environment for recreation and a source of animal protein such as goats, poultry, and fish (beef would not be served initially due to high transportation costs and space limitations).

A variety of crops would be grown in hundreds of low pressure inflatable greenhouses adjacent to the living facilities. Mars receives 43% less sunlight and the temperature varies from -145° to 8°F. Nevertheless, the length of the day is similar to Earth's and the indigenous soil is believed to be conducive to plant cultivation with supplemental heating.

A space of over 15,000 square meters would be required to grow enough food to support 150 colonists. The crops would include wheat, rice, potatoes, strawberries, lettuce, tomatoes, beans, and onions. Tended primarily by robots, the pressure inside the greenhouse would be 100 millibars (1/10 Earth's atmospheric pressure at sea level) enabling humans to enter with just an oxygen mask for routine maintenance or emergencies.

The activities of the colonists will initially be scientific studies including the geology, meteorology, and quest for life on Mars. Of primary concern will be long term research on planetary ecosynthesis - a field concerned with changing the chemistry of a planet's atmosphere into one habitable for humans. Eventually, a mining trade economy is envisioned among Mars, Earth, and the mineral rich Asteroid Belt.

The design concept proposed above for a permanent Martian colony could be completed before the middle of the next century. Experience gained from development and construction of this self-sufficient outpost will be an important first step in opening the outer solar system for utilization.

NONTERRESTRIAL MATERIALS FOR SPACE POWER PROJECTS

In the late 1970s NASA and the Department of Energy (DOE) funded a feasibility study on the Solar Power Satellite (SPS), an ingenious concept for cleanly generating large amounts of electricity*. The study produced a baseline design and indicated that construction of an SPS was possible but that many launches of some 500 tons each to low Earth orbit would be required. The shuttle's payload is about 25 tons to low Earth orbit. Because of the great expense of both developing a heavy lift launch vehicle and the great number of launches that would be required, in addition to the political climate of the time, no further research was funded.

As part of the NASA/DOE research, a study by General Dynamics looked at the possibility of using building materials obtained from the moon instead of launching them off of the Earth. Although this option received little

* Conceived by Peter E. Glaser, Ph.D. in the late 1960s, the SPS is a platform of solar cells and microwave transmitters in geostationary orbit that would convert sunlight to microwave energy and beam it to a receiving station on Earth where it would be converted to usable electricity (SCP; Nov./Dec. 1990)

attention at the time, probably because it was an alternative to the original baseline design, it has become the cornerstone of research commissioned by the Space Studies Institute (SSI). The Vice President of the Institute, Greg E. Maryniak, discusses this and several other sources of nonterrestrial building materials in last year's first quarter issue of *Space Power*.

Maryniak points out that growing environmental issues over the last decade have renewed interest in the SPS as an alternative energy source. The burning of fossil fuels causes acid rain and is believed to contribute to global warming. Nuclear power is still raising safety concerns in reactor design and disposal of nuclear wastes. In addition, our dependence on oil imports helped contribute to the current war in the Middle East. Several countries have started studying the SPS as a clean alternate source of power, most notably Japan. The December 3, 1990 Issue of *Space News* reports Japan is planning a series of orbital experiments to test microwave transmission technology from space with the aim of eventually developing a power satellite. Maryniak states that Germany and the Soviet Union have also expressed interest in starting their own SPS development programs.

The General Dynamics study took the SPS baseline design and simply substituted material known to exist in lunar soil. No attempt was made to change the baseline design. In 1984, SSI sponsored a study by Space Research Associates of Seattle, Washington to optimize the SPS design for use of lunar materials. The study concluded that 99% of the mass required for an SPS could be obtained from the moon. Most of the mass of the lunar derived design would be composed of aluminum although glass-composite construction is possible with available glasses in the lunar soil.

SSI has also studied techniques for refining lunar soil into building materials. One such project, a joint effort with McDonnel Douglas Space Systems Co. and Goldsworthy Engineering has succeeded in producing a prototype "solar oven" for melting the lunar soil as part of a process to produce glass fibers. Lunar soil simulant contained in a specially designed crucible was placed at the focus of a solar collector. Preliminary results achieved a temperature of 2200ºF, the required melting temperature of the simulant.

Significant cost savings for building the SPS from lunar materials could be achieved if frozen water or other hydrogen rich volitiles could be found on the moon. This would eliminate the need to bring drinking water or hydrogen fuel to the moon. Accordingly, SSI is developing a Lunar Prospector Probe designed to search for ice in the polar regions of the moon. The Soviet Union has expressed interest in providing a launch vehicle for this mission.

Another potential resource in space is the space shuttle external tank (ET). This structure usually burns up in the atmosphere after it is jettisoned from the orbiter but, with just a little more "kick", it could be placed on orbit (ETs already possess 98% of orbital velocity) where it could be utilized for building materials. Moreover, a significant amount of residual propellant (typically about 10,000 lbs.) is left in these tanks and can also be utilized. The ET has a known composition (mostly aluminum) eliminating the need for spectroscopic analysis or reconnaissance probes to prove its existence. Finally, only relatively simple processing such as cutting and melting is required. Procedures for "mining" this resource are being developed by SSI and the Air Force Institute of Technology in Dayton, Ohio.

Earth-approaching asteroids are another resource under investigation as possible sources of building materials for the SPS. Last year SSI participated in the International Asteroid Mission Project at the 1990 Summer Session of the International Space University held in Toronto. The project focused on search and identification techniques as well as asteroid resource recovery, engineering, process design, policy and law.

A wealth of resources are available in space for construction of space power projects. Current research by SSI indicates that the approaches outlined above will reduce the cost of building the SPS as compared to the Earth-launched system. With environmental issues becoming increasingly important as well as the need to reduce dependence on oil imports, clean power from space will become a very attractive alternative in the near future.

COLONIZING SPACE: THE RATIONALE

Why colonize space? Those of us who are fascinated with outer space do not need more of a reason then just that. Fascination. Others may take some convincing. A rationale for expansion into space is presented by Michael A.G. Michaud in the December 1990 Issue of JBIS.

Michaud starts by reminding us that the spectacular successes of the world's space programs can be traced to an origin in science fiction. Dreamers of spaceflight such as Jules Verne and H.G Wells wrote stories about travelling to other worlds. Spaceflight advocacy gradually gained scientific clout with serious theoretical work in rocket propulsion started by Russian born Konstantin Tsiolkovski in the late 1800s. Advances in astronautics continued in the early 1900s with research by Hermann Oberth in Germany and Robert Goddard in the United States.

Interplanetary journeys began to be advocated by rocket societies in the U.S., Germany, Britain, and the Soviet Union where practical experiments with rockets were performed in the 1930s but there was little public or political support for exploring space. Rockets of significant scale were not launched until World War II and their use as anything but a weapon or sounding rocket was not considered until Arthur C. Clark predicted the communications satellite in the 1950s. Within a decade machines were in orbit permanently; within 30 years men had walked on the moon and a spectacular photographic reconnaissance had begun of most of the solar system.

A historical turning point was made in February of 1988 when the U.S. announced a national policy advocating expansion of the human presence beyond earth and into the solar system. Plans for colonies on the moon and Mars are being given serious consideration.

Support for interstellar travel likewise first appeared in the science fiction literature of the 1930s and 1940s. The first theoretical paper on interstellar flight appeared in the 1950s but appreciable academic recognition did not occur until the 1970s with Project Daedalus, a design for a starship conceived by the British Interplanetary Society. Much serious theoretical work is currently being done indicating a motivation to explore and expand beyond the solar system. An unmanned interstellar probe has even been endorsed by the Space Science Board of the National Academy of Sciences in its 1988 report entitled *Space Science in the Twenty-First Century*.

Nevertheless, it may be some time before human travel beyond the solar system is taken seriously by world leaders. Recall that it took many decades for advocates of interplanetary travel to convince the public to support the space ventures of the last 30 years and we are not there yet. Successes have come in stages with setbacks caused by political and cultural events.

Michaud suggests a look at a larger context. The above examples of advocacy of interplanetary and interstellar travel reflect a basic human need for exploration followed by expansion. Humans have already explored the Earth, and having completed an initial survey of the solar system, are about to expand into it. Sometime in the future, we may eventually find the solar system confining and have a desire to free ourselves from dependence on one star just as we are beginning to free ourselves from dependence on one planet.

Space colonization may not be accepted easily by the public. Support may come slowly. Many will be initially be resistant to change and fail to see the benefits. Michaud believes that a continuity of purpose and long term perspective are required if advocacy for colonization is to be successful. He suggests the following six point "Manifesto For Expansion":

1) Expansion should be adopted as the long range plan for humanity. Development of new ecological niches is natural and beneficial in nature. Space is the next natural environment in our evolution.

2) Exploration precedes expansion. Humans always benefit from improved knowledge of their surroundings. Thus, support should be given to astronomy and unmanned space probes.

3) Expansion should be planned in stages. The rate of expansion will be dependent on technological, economic, and cultural factors. We should take it one step at a time as suggested in the Report of the National Commission on Space entitled *Pioneering The Space Frontier*. The Commission recommended that transportation systems be developed first, a lunar base should come next, then the exploration of Mars, etc. Expansion should be attempted when the technical and economic base can support it.

4) The technologies for expansion should be developed. Science fiction becomes reality when technology becomes available. The telescope prompted dreams of other worlds, rocketry increased our knowledge of the outer planets, development of life support and interstellar propulsion systems will allow us to travel through the solar system and to the stars.

5) Colonizing the Galaxy is an appropriate goal for humanity. It could provide a means to unite nations as a shared enterprize over many generations.

6) Expansion will require organized and persistent advocacy. Arguments will arise against each stage of colonization. To move on to the next step will be considered by many to be too expensive or impractical. Strong support will be needed by proponents at each stage of colonization.

Humanity has benefitted significantly from the exploration of space. Satellites have brought advances in communications, navigation, observing the Earth's biosphere, and space sciences. Perhaps one of the greatest values has been views of the Earth from space which show no boundaries between nations, uniting us as one species. As we move out into our next ecological niche, utilization of the vast energy and natural resources of space will raise the standard of living of our species.

Linked to exploration is a drive for expansion and the evolutionary advantages that it brings. At each stage in the colonization of the galaxy there will be resistance to change by those who do not see these advantages. To get to the next stage will require advocates with a strong drive to explore and expand. Those individuals will need little reason to justify colonization to themselves, but they must convince a critical portion of the population that the next step is necessary.

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