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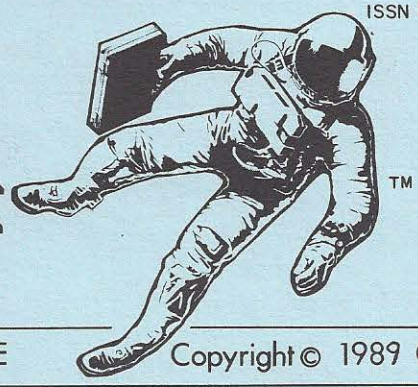

A MONTHLY NEWSLETTER ON FREE ENTERPRISE IN SPACE

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Lunar Lava Tubes May Create Ideal Lunar Habitats

The design of manned lunar facilities for long-term habitation presents a number of problems. A lunar habitat must protect its occupants against extreme temperatures (ranging from -240 to +260 degrees F.), micrometeorites, and most important, the intense and lethal radiation from solar flares and cosmic rays (the Earth's atmosphere and magnetic field protect its inhabitants from these dangers).

The best solution is to put the habitat underground, using lunar rock and soil as a shield against the elements. A few meters of lunar material is sufficient to protect sheltered structures against the hazards of the lunar surface.

There are many ingenious methods for constructing such shielded habitats, but most designs specify setting the habitat structure on the lunar surface or in a shallow trench, and then covering it in one way or another with a thick layer of lunar material. This technique presents some difficulties. The habitat structure must be reinforced to handle the load of shielding mass on top of it--not inconsequential, even under lunar gravity. Such habitats would be massive, and expensive to transport to the lunar surface (to economize on weight and required digging, these habitats would also probably be quite small). Heavy machinery, capable of operating under lunar conditions, would be required to move the large quantities of rock and dirt. This machinery would also have to be transported.

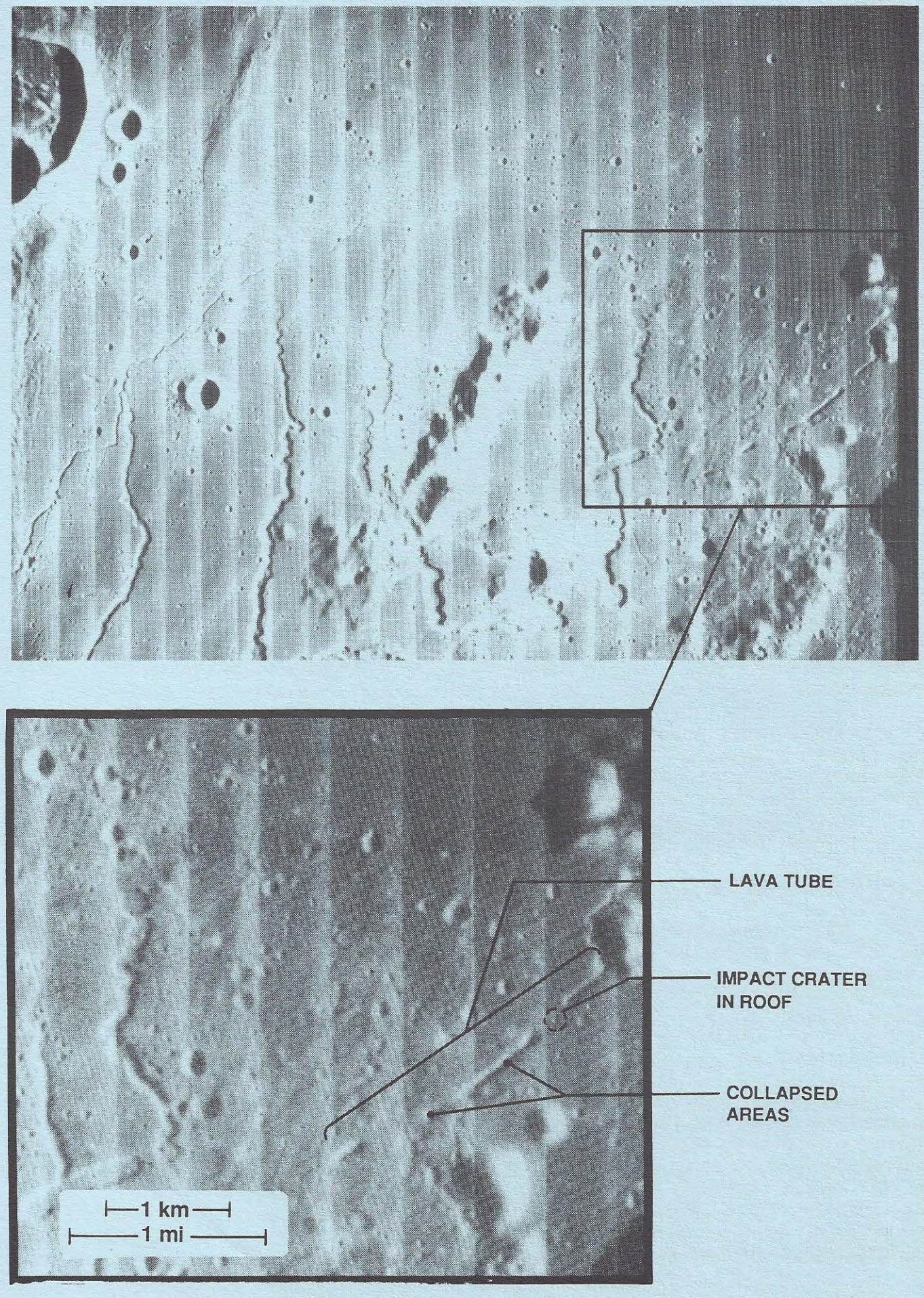
If one could locate natural caverns on the Moon, habitat design and construction would be greatly simplified. A cavern roof, which is self-supporting, would act as the shielding and insulating mass for the facilities constructed inside. Lunar habitats could be lightweight structures, without the need to support the huge mass of shielding material a surface structure would require.

The problem becomes identifying and locating such lunar caverns. There would be, of course, no caverns formed by the action of water, the most common mechanism for cave formation on the Earth. However, there is evidence that there are lunar caverns formed by ancient volcanic action: lava tubes.

Lava tubes are drained conduits of underground lava rivers. They are found on Earth in volcanic areas, such as those in the Hawaiian islands. There are a number of mechanisms for their formation, but generally a tube is formed when the surface of a flowing lava river cools and crusts over, leaving the river still flowing inside. When the lava drains out, a tube remains. Typically, an Earth lava tube will be a few meters in diameter and about 1 to 2 kilometers in length.

Lava tubes have been shown to exist on the Moon in areas where lunar volcanic action once took place. Due partially to the lighter lunar gravity, along with other factors, lunar tubes are considerably larger than their counterparts on Earth, with diameters in the hundreds of meters and lengths in the tens of kilometers. Since they are beneath the lunar surface, their exact number cannot be easily determined from photographs of the lunar surface. Those tubes that have been positively identified from photographs are ones whose roofs have either partially or entirely collapsed, leaving depressions in the lunar surface along the length of the tube.

The photo at the top of page 2 shows a field of lunar rilles, formed by the ancient flow of lava on the lunar surface. Lava tubes are normally found in the same areas as rilles since, of course, they are basically just rilles that have been crusted over. The enlarged detail of the rille field shows such a lava tube collapsed along intermittent



Lunar Orbiter 5, Frame M-191

parts of its length. Despite the areas of collapse, the uncollapsed roof sections still stretch for hundreds of meters. That the intact roof sections of this tube are quite thick and strong is evidenced by the impact craters--some up to 20 meters deep--which appear smack in the middle of the roof span. These craters show that meteors far larger than most of those which currently strike the Moon on a regular basis were insufficient to destroy the solid basalt tube roof.

These tubes might be ideal for lunar habitations. Obviously, lava tubes being considered for shelter use would have to be closely examined in person by lunar geologists (or "selenologists") to be certain that the roof is structurally stable and is not prone to rockfalls or the like. Some clearing of rubble from the tube floor might also be necessary.

It may be possible to seal such tubes off, and pressurize them. This could create living environments with potential habitable volumes of tens of millions of cubic meters. However, there are still many unresolved questions about the structure of lunar lava tubes, such as the possible presence of penetrative cracks in the roof, or the roughness of the interior surface, which could make the airtight sealing of such a tube difficult or impossible. Therefore, most lunar facility designers considering lava tube shelters adopt a more conservative approach and assume that the habitats will consist of pressurized structures built inside the non-pressurized lava tube.

As mentioned earlier, lunar habitats shielded inside a lava tube would be relatively lightweight, their primary job being maintaining one atmosphere (14.7 psi) of pressure against the outer vacuum. The temperature inside a lava tube under the lunar surface is thought to be relatively constant, at about -20 to -4 degrees F. A habitat would need only mild insulation, if any (the normal problem with a habitat surrounded by vacuum is getting rid of heat, not guarding against cold). It may even be possible, with the proper selection of materials, to use inflatable structures supported entirely by the atmospheric pressure inside.

Besides habitats, other hardware used on the Moon would benefit from the lightweight designs that the shielding roof makes possible. Any lunar facility will include a variety of machinery and equipment located in the vicinity, but outside the pressurized, habitable areas. Storage tanks, piping, materials processing equipment and the like could be left open and uncovered, easily accessible for inspection or repair. Space suits for use inside the lava tube could also be of lightweight design, enhancing comfort and increasing the efficiency of the wearer.

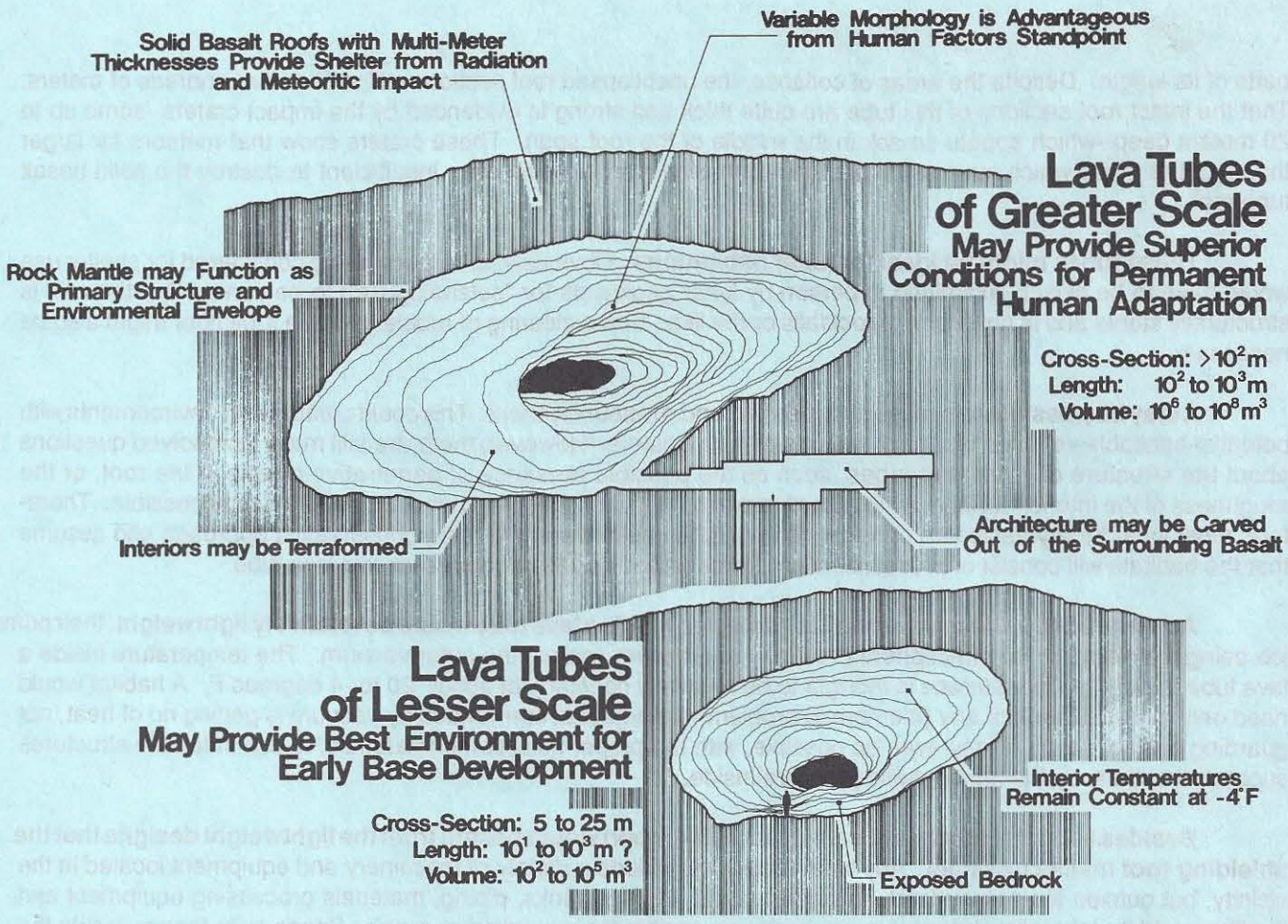
There will, of course, always be lunar equipment which must be located on the surface--solar power collectors, antennas, and scientific instruments for example. Still, even a solar power plant might be simplified if the collectors are located on the surface, but reflect or transmit the energy to power generating and conditioning equipment located in the shelter of a nearby tube.

A company called Integrated SpaceSystems Corp. (ISS), of Collegeville, Penn., is researching the potential of lava tubes on the Moon as habitable environments or as shelters for intermediate structures. Integrated SpaceSystems, formed in 1987, is currently engaged in lunar base architecture and construction technology research, but is involved in all aspects of space development with particular emphasis on habitation architecture and technology development.

The ISS illustration on page 4 shows lunar lava tubes of greater and lesser scale, and describes in brief the essential conditions which favor adaptation of lava tubes for lunar habitats.

ISS has been participating with Lockheed Engineering and Sciences Company in Houston, Texas, and NASA's Advanced Programs Office on a "Large Habitable Volume Study" which will evaluate lunar base environments as large as one million cubic meters (about 35.3 million cubic feet). The company has also been active in bringing together experts in the various disciplines of research affecting the design of lunar bases and space habitats. Beyond its interest in lunar-basing studies, company president Andrew Daga expects ISS to become much more deeply involved in other aspects of "astroarchitecture." In particular, ISS will be looking to apply its expertise to the education/entertainment area, where several projects, each to be based on some aspect of space exploration and habitation, are currently being planned in the United States and Japan.

For more information contact Andrew Daga, Integrated SpaceSystems Corp., 122 Larchwood Court, Collegeville, PA 19426-2904. Tel. (215) 489-7282.



Aside from ISS, the other major source for this article was a paper titled "Lava Tubes: Potential Shelters For Habitats" by Friedrich Hörz of the Experimental Planetology Branch at the NASA Johnson Space Center. The paper was presented at the Lunar Bases and Space Activities of the 21st Century symposium hosted by the National Academy of Sciences in Washington DC on October 29-31, 1984. This paper and others were collected in a book, Lunar Bases and Space Activities of the 21st Century, published by the Lunar and Planetary Institute, 3303 NASA Road One, Houston, TX 77058-4399.

Payload Selected For Pegasus Maiden Flight

The first launch of the Orbital Sciences Corp. (OSC) Pegasus expendable winged booster, scheduled for July, will carry both military and scientific test payloads. The original payload for this flight, a series of small communications satellites from the Defense Advanced Research Projects Agency (DARPA), was bumped to a later Pegasus mission because of the high risk of the vehicle's first flight. The Pegasus, launched from beneath the wing of a B-52 bomber over the Pacific Ocean, will carry its payloads into a 400-mile polar orbit (for more on Pegasus, see the May, 1988 *C.S.R.*).

The military payload will be a Glomar satellite, which is also a DARPA payload. The satellite is part of an experiment to develop a network of small satellites for relaying military data between points on Earth. One job for such satellites would be the collection of data from anti-submarine warfare sensors scattered on pack ice in the Arctic.

The scientific payload is a NASA-sponsored gas-release experiment called "Pegsat." The experiment consists of two canisters of barium gas. This gas will be released into space from the orbiting booster some time after the Glomar satellite has been ejected into its orbit. The behavior of the gas, tracked both optically and by radar, will be used to provide data on the Earth's magnetic field. Originally, the NASA payload was scheduled to fly on a Scout expendable booster, at a cost of about $10 million. By flying on the first Pegasus mission, NASA will be able to launch the same payload for less than $2 million.

Space Expeditions Puts Space Tourism On Back Burner

Space Expeditions, Inc. of Seattle, Wash. has decided to shelve plans to be the first company to market flights into orbit for tourists. According to company president T. C. Swartz, Space Expeditions has been unable to raise the capital to proceed with the project. Swartz cites the Challenger accident and the 1987 stock market crash as negative influences on potential investors.

Swartz will be forming a new company, Private Jet Expeditions, which will offer trips to unique destinations aboard a specially-outfitted luxury Boeing 727-500. Planned itineraries include flights around the world over both poles, a trans-Sahara expedition, and trips through Tibet, China and New Guinea.

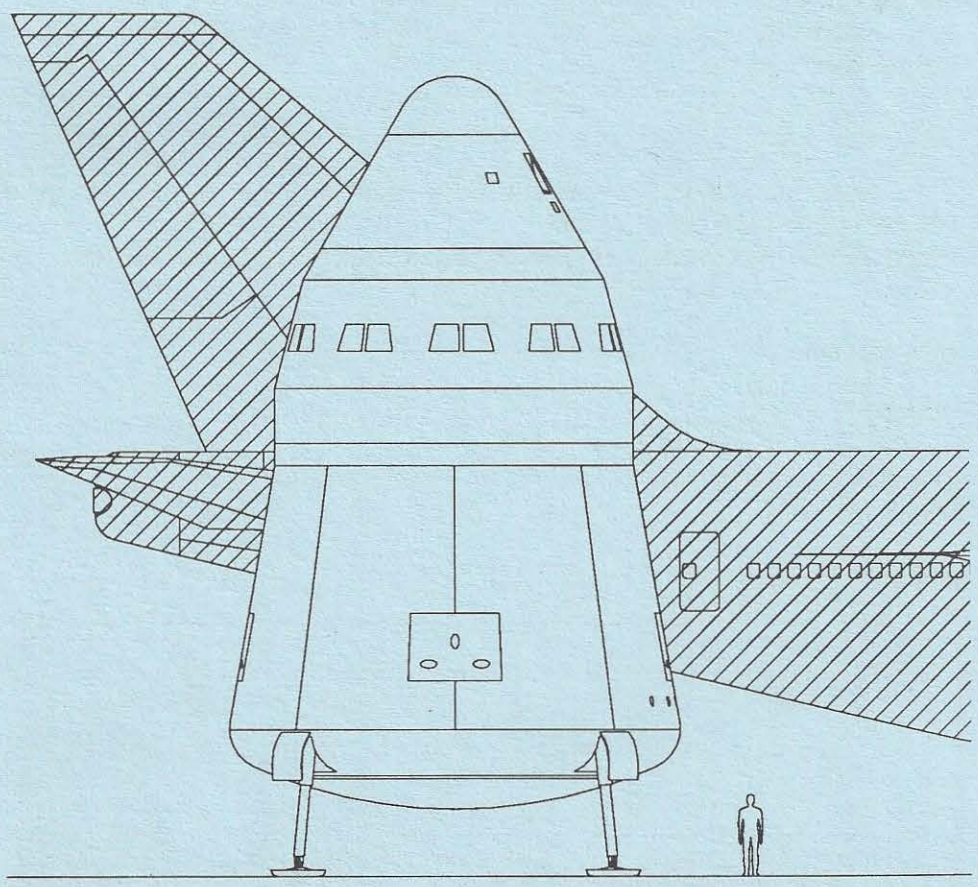
Space Expeditions has been accepting $5,000 deposits on the $50,000 price of a ticket to orbit. Letters have been sent to depositors informing them of the current status of Project Space Voyage, and offering full refunds on the deposits, which have been kept in escrow in a special bank account. Of course, depositors have the option of keeping the funds on deposit, in hopes that Project Space Voyage will be revived. Regardless of whether the deposits are withdrawn, all potential space passengers will retain their priority numbers should flights to orbit ever take place. Depositors also have the option of applying their $5,000 towards a trip with Private Jet Expeditions.

Swartz first conceived Project Space Voyage in 1983, while president of Society Expeditions, a travel company specializing in unusual trips to the Antarctic and similar places. The idea was to open space for tourism by the early 1990s. Early ideas for a tourist vehicle were based on some form of passenger module that would be carried into space in the payload bay of the U.S. Space Shuttle. This idea was abandoned--long before the *Challenger* disaster--due to lack of interest on NASA's part and high costs (about $1 million per passenger).

Society Expeditions then settled on a new space tourist vehicle concept: Pacific American Launch Systems' Phoenix, a single-stage-to-orbit, vertical-take-off-and-landing, reusable launch vehicle. The two companies signed an agreement in 1985 wherein Society Expeditions would charter Phoenix flights when the vehicles became available several years down the road. Pacific American and Society Expeditions released drawings of the Phoenix-E, a version of the Phoenix designed to carry twenty passengers on an 8 to 12 hour flight in low earth orbit. Price per passenger: an astonishingly low $50,000 (*C.S.R.*, Sept. 1985). Society Expeditions began collecting the aforementioned $5000 deposits from prospective passengers, to be placed in escrow. Over 200 such deposits were received.

Swartz sold Society Expeditions in 1987, retaining the rights to Project Space Voyage, and formed a new company, Space Expeditions. Marketing of the orbital flights continued. In addition to the proposed orbital flights, Space Expeditions also offered tours of various space facilities on Earth.

As time went on, Pacific American moved its focus from Phoenix over to low-cost, expendable launch vehicles (ELVs). Neither PacAm nor Space Expeditions had been able to raise the extensive outside funds required to proceed



PHOENIX–E COMPARED WITH BOEING 747

with construction of the Phoenix, so PacAm decided to concentrate instead on immediate, near-term development of the Liberty ELV to produce revenues. The Phoenix became a Pacific American ongoing research and design project, awaiting the time when development funding--most likely PacAm ELV revenues--would become available. Society Expeditions, although unable to help raise any capital for the Phoenix and lacking Pacific American's technical background, decided nevertheless to try and develop a Phoenix-like vehicle on its own. Nothing came of these attempts, and Space Expeditions finally threw in the towel, although the prospect of future flights--perhaps sometime in the first decade of the next century, according to Swartz--has not been ruled out.

Market studies show that if safe, low-cost manned space systems become available, space tourism would be a highly successful and beneficial endeavor. Almost without exception, astronauts and cosmonauts who have been in space have described the views of Earth from orbit as one of the most memorable features of their flights, and expressed a desire to go again. In addition, as a result of what they have seen, many of these same space travellers returned home with powerful and sobering alterations in their views of Earth, the human race, and the cosmos. Many of the petty squabbles that divide nations and cultures are seen as largely irrelevant after experiencing the planet Earth as a whole, self-contained system. A new awareness of the seemingly fragile, yet surprisingly durable ecology of Earth are also part of this experience. It is likely that few people could spend time in space watching the Earth below without undergoing similar positive attitude adjustments, indicating that the benefits of a large-scale space tourism industry could go far beyond the monetary.

A recent book, The Home Planet, attempts to transmit to the reader the feelings that space travellers from around the world have had while gazing at the Earth from spacecraft in low earth orbit, and on trajectories to the Moon. The book was conceived and edited by Kevin W. Kelley for the Association of Space Explorers, an independent, international, non-governmental organization of individuals, from thirteen countries, who have orbited the Earth. The book contains 150 beautiful color photographs, many never before published, combined with commentary--in several languages, translated to English--from the astronauts and cosmonauts who experienced these sights personally. A special section at the end of the book describes each photograph in detail, and lists the men and women who have orbited the Earth. The Home Planet is priced at $38.95, published by Addison-Wesley Publishing Co., Reading, Mass., and is available at bookstores and through some book clubs. I cannot recommend this book too highly. Recently, when it seemed like I would be overwhelmed by the myriad financial, engineering and strategic details and obstacles that are the major part of a new private space venture, this book helped remind me what it was all about. More than ever, the need is urgent for a space transportation system that will allow the rest of us to see Earth from space in more than just photographs.

* * *

Note to readers: the last issue, November-December, was mislabeled "Volume 12, No. 9-10." The actual number should have been "Volume 12, No. 11-12." For those of you wondering what happened to the bimonthly telephone book you have been receiving, this issue marks the first normal-sized (4 to 6 pages) *C.S.R.* in quite a while.

Until next time,

Tom Brosz
March 23, 1989

The Commercial Space Report (C.S.R.) is published monthly, and endeavors to report and analyze developments in the field of private initiatives in space transportation and exploitation.

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