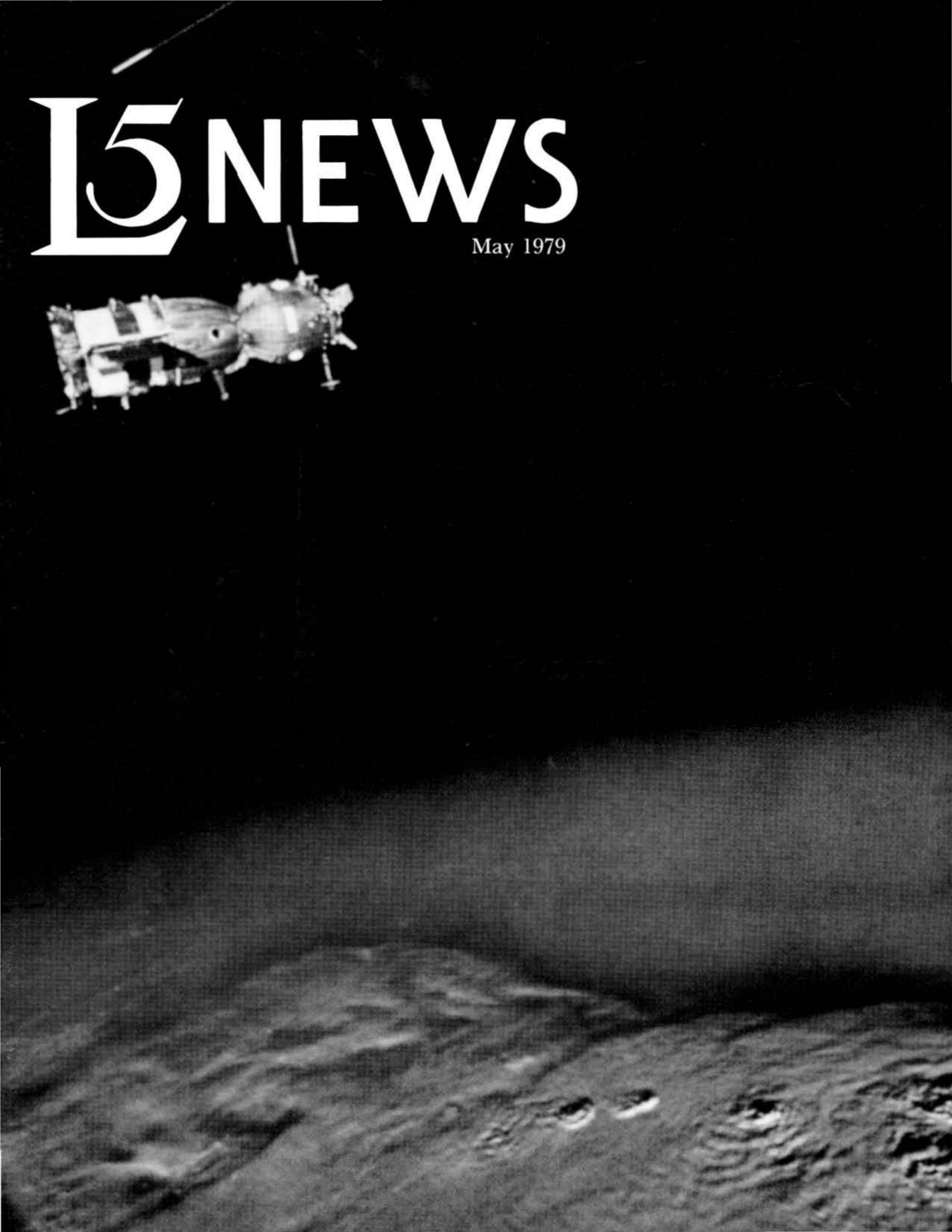

L5 NEWS
May 1979

L-5 NEWS

A PUBLICATION OF THE L-5 SOCIETY

VOL. 4 NUMBER 5 MAY 1979

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Cover: a Soyuz spacecraft (as seen from an Apollo in the Apollo/Soyuz hookup). The recent Soyuz 33 mission failed to dock with the Soviet Salyut Spact station April 10 but safely returned with crew Rukavishnikov and Ivanov 48 hours later. (Photo courtesy **NASA**.)

Publication office: the L-5 Society, 1060 E. Elm, Tucson, Arizona 85719. Published monthly. Subscription: $12.00 per year, included in dues ($20.00 per year, students $15.00 per year). Second class postage paid at Tucson, Arizona and additional offices. *Membership Services: L-5 Society, 1620 N. Park Avenue, Tucson, Arizona 85719. Telephone: 602/622-6351.*

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L-5 Society
Membership Services
1620 N. Park
Tucson, AZ 85719

THE USEFUL PIECES OF SPACE

by K. Eric Drexler

Less than ten years ago, our next big step in space seemed clear: We had reached the Moon—now on to Mars! But the likely results seemed equally clear: televised pictures of astronauts standing, at great expense, among dusty red crates. Having seen their fill of dusty craters, people simply weren't interested anymore. Aimless, the space program drifted into hibernation.

Today, people are jostling it from slumber. New ideas have revolutionized thinking about the solar system's potential, and have given the drive into space renewed vigor—with scarcely a mention of Mars. Why did we set out for the planets and what has changed?

Behind the awesome achievements of the old space program lay a political choice of goals. Behind this political choice lay not ideas for new industries or a careful quest for new knowledge, but an urge to boast guided by musty preconceived notions. Behind the notions lay history. Ancient history.

Long ago our ancestors lived where it was warm and ate what they could find. Back then, they knew that the secret of wealth was to find something valuable (and unguarded) and to keep it. When they found caves, they lived in them and defended them from others.

The night sky was a dome with a Moon and tiny lights. The Moon and some of the lights moved. This made them more interesting.

Much later, our ancestors leaned many skills. Farming, clothing, shelter, and better and better tools spread them to every corner of the globe and multiplied their number. They now knew that the secret of wealth enough for survival was to have some land and to farm as their parents farmed. The secret of wealth enough to burn was to rule great tracts of land, and to take from those who tilled it.

They called the moving lights gods, told stories, and watched them with care. Time passed.

Tools improved. A few minds escaped a few bonds of the past. Copernicus told us the Earth is a planet; Galileo showed us other planets as globes. As telescopes improved, Mars and Venus drew increasing speculation. People told stories about the planets, now not as gods but as worlds—new lands beyond the sky.

In the freer countries, people with new ideas had produced better tools and organizations, driving the Industrial Revolution. A few people had begun to suspect that the real secret of wealth was neither found things, nor merely land and labor, nor even rule and exploitation, but rather ideas, investment, production, and trade. In all countries, this remained an unpopular idea. Most countries stagnated.

Military competition between rising industrial states led to the ICBM, laying a technical foundation for development of low-orbit information services and reconnaissance systems. One of these industrial states was straining its capacities in an effort to build military strength with German technology: the Russian Empire (alias: "The Union of Soviet Socialist Republics").

The other had its share of German scientists, but was building on a base of real wealth.

During a long period of comparative

"Long ago our ancestors lived where it was warm and ate what they could find . . . the night sky was a dome with a Moon and tiny lights."

Artwork by James Babcock

Artwork by James Babcock

"Having watched record-breaking stunt machines blast around the heavens at their expense for a decade or so, people now knew 'how expensive space is.' "

freedom, U.S. citizens had built the strongest industrial economy on Earth. But by this time, the U.S. government had "found wealth" in the private sector. It took increasing control of slices of economic life, not so much by the socialist pattern of state ownership as by a pattern of taxation, regulation, and market domination. In particular, the government virtually ran the emerging aerospace industry.

Consequently, the government's whims ruled our first steps towards space: rather than begin to explore and use space with existing ICBM boosters, the government decided to develop a "civilian" booster for purely symbolic reasons. In the delay, the Soviets beat us into space, badly wounding government pride. The stage was set for the great leap forward.

To heal its wounded pride, the government decided to indulge in an economically and strategically irrational whim—to land a citizen on the biggest thing in the night sky and bring him back again. It pursued this goal in the style of state-backed bureaucracies the world over: with no concern for making profits, little concern for cutting costs, and much concern for cutting the risk of embarassing failures. (This style has been estimated to multiply costs by a factor of about three.) The safe bet for reaching the Moon in a hurry was to scale up and extend the throw-away rocket technology of the ICBM, bypassing space stations and shuttles. This took wealth enough to burn, but the government ruled great tracts of land...

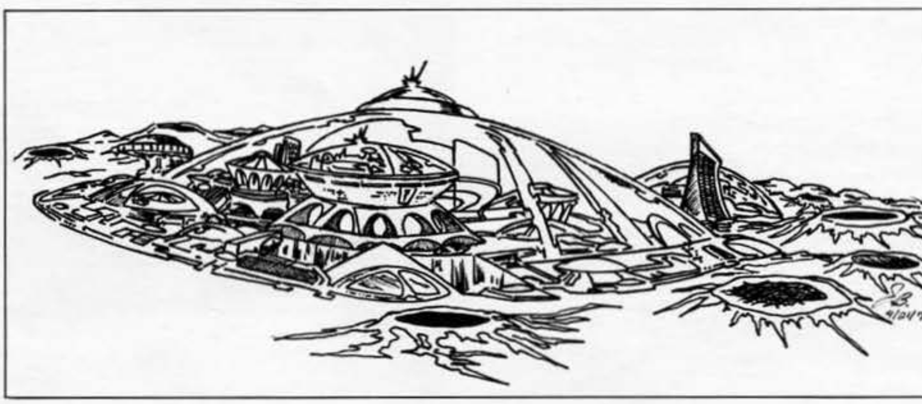
Thus America reached out, touched the Moon, satisfied the whim, and quit. Having watched record-breaking stunt machines blast around the heavens at their expense for a decade or so, people now knew "how expensive space is."

In parallel, and with a similar lack of economic motivation, the government decided to take a close look at the moving lights in the sky. In the public mind, the planets were seen as interesting because, like Earth, they had lands with sights to see, and because they too might someday serve as homes for humanity. Had Mars been more Earthlike, or alive, rather than pocked, dusty, and dead, or had Venus been wrapped in desert and jungle, rather than searing, high-pressure carbon dioxide and sulfuric acid, then the public might have kept its enthusiasm.

As it was, public interest in the planets collapsed to a tourist's curiosity about distant wastelands. Spaceflight offered an expensive ticket to nowhere.

Renewed interest in space arises from new ideas about its value. Central to this has been a turning away from searches for the "found wealth" of habitable planetary caves. For simple economic and technical reasons, emphasis has shifted to building new worlds and new wealth in space from scratch.

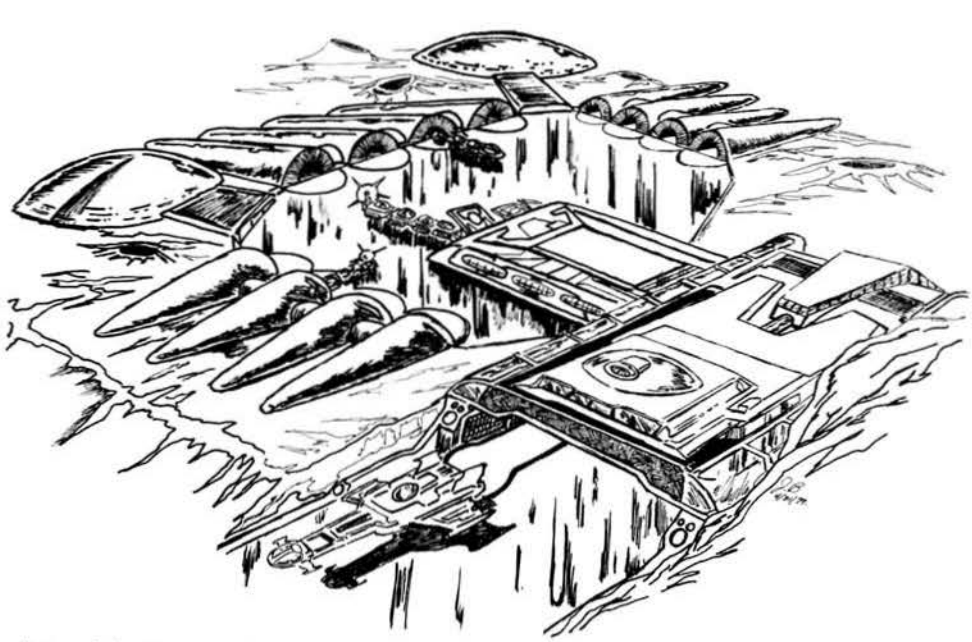
The idea of making places to live in space is far from new: science fiction and speculative projections have often featured domed cities, terraformed planets, and hollowed-out asteroids. But all these ideas propose modifying existing places to make large-scale habitations: a domed city—built on a planet; an Earthlike planet—made from a dead planet; a spinning, inside-out world—but hollowed from something, not built. Although many authors have written of building space stations from scratch (generally seen as small way-stations on the road to some **real** real estate) comparatively few before O'Neill had dared to think big.



Artwork by James Babcock

"... a domed city — built on a planet; an Earthlike planet—made from a dead planet ..."

The alternative to the old space program



Artwork by James Babcock

"Because of . . . airlessness and shallow gravity wells, the Moon . . . can easily supply materials for processing in free space."

is the New Space Program: economic development eventually leading to industrial colonies in free space, which would process lunar or asteroidal resources and support themselves by trade with Earth. In the public mind, this idea is replacing the expensive stunt with the sound investment, the dead Moon with the lush colony, and the test pilot's frontier with an endless new world to homestead. And suddenly, people are getting interested in space again.

The choice of where to go and what to do in space remains uncertain, but the outlines and opportunities are emerging. Although resources will determine where to go, the choice of which resources will depend on both their quality and accessibility. Since the terrestrial investors will expect a return, accessibility will depend on the cost of transportation from the mining site to near-Earth space.

On this assumption, the most accessible resources are those of the Moon and the Apollo-Amor asteroids. An electromagnetic catapult, called a mass driver, can make transportation from the Moon very cheap. Transportation from the Apollo-Amor asteroids (which lie well inside the main belt, crossing the orbits of Earth or Mars) can be made cheap by several means, including mass drivers used as reaction engines, and thin metal film solar sails.

By comparison, the planets seem unattractive. On most, the atmosphere prevents use of a mass driver to throw material into space, forcing reliance on some form of rocketry. Further, once off the surface, transportation of the materials to Earth costs more than it would from the Moon or a well-chosen asteroid. Finally, the planetary surface most accessible to mining, that of Mars, shows few signs of the age-old processing and re-processing of the crust that produced most terrestrial ore deposits.

For similar geological reasons, the Moon suffers from crustal blandness. In addition, the Moon has been baked to a virtually water-, nitrogen-, and carbon-free condition. Still, owing to its convenience (and, in particular, to the short travel time from Earth), the Moon may prove quite valuable. Like all rocky material, its crust contains oxygen bound in oxides of silicon and metals. These include iron, aluminum, magnesium, and titanium; together with silicon and oxygen these elements can provide most of the mass of a power satellite, an industrial plant, or a space colony.

Although the main shortcoming of [redacted] lunar materials is their lack of the biologically and industrially important elements hydrogen and carbon, the Moon is not yet completely explored. The permanently shadowed crater floors in the Moon's polar regions are intensely cold; some think they may have frozen and trapped gases escaping the lunar crust, together with water formed from solar wind hydrogen, and vapors blown from impacting comets. Instruments on a proposed lunar orbiter could detect these polar ices, but funds for the mission have been withheld: we finished with the Moon, remember?

The asteroids offer a tastier mix of resources; an industrial civilization could support itself quite comfortably on the materials in the belt. Some asteroids contain rocky material like the Moon's, others are blocks of alloy steel, and yet ohters are primitive materials left over from the solar system's formation, rich in carbon and water. Still others are mixtures of rock and steel. Asteroidal steel contains nickel and cobalt, with significant traces of copper, gold, and the platinum-group elements. Owing to its nickel content, its strength, toughness, and corrosion resistence exceeds that of most steels used on Earth today.

The water-rich, carbonaceous asteroids have never suffered melting or metamorphosis as have the rocky and metallic bodies. They contain virtually unmodified mineral grains and organic material from the earliest days of the solar system; while their overall compositions are strikingly uniform, their grain's compositions are strikingly diverse. Only research by mining and refining engineers can tell for certain, but this diversity could prove valuable. A typical bulk composition might include 10% water and 5% of an organic substance like that in oil shale.

How do we know so much about objects we've never visited? Well, things fall from the sky, people pick them up, and scientists analyze them. Other scientists observe how they reflect light and observe how asteroids reflect light. After correcting for terrestrial weathering effects, the differences between the surface of a meteorite broken open on Earth and an asteroid's surface in space, the difficulties of studying faint specks in the sky, and, of course, instrument problems, they compare spectra. And they find that meteorites match asteroids. This is fortunate, because no missions to the asteroids are now planned: Planets are more interesting, remember?

Because of their airlessness and shallow gravity wells, the Moon and asteroids can easily supply materials for processing in free space. But why process materials in free space, and not on the Moon, or an asteroid, or even a planet?

The ease of getting the materials into space and the low cost of energy there supply one motive. The energy needed to lift a kilogram of ore from the Moon is about 0.8 kilowatt-hours (from an asteroid, the energy needed is negligible). The energy needed to refine a kilogram of lunar ore, the added energy cost of hauling the dross into space will be comparatively small. And, with the need for cosmic ray shielding, even slag will have uses.

Since transportation takes little energy compared to refining (and assuming, as is often reasonable, that "energy costs" have some loose connection with true economic costs), it makes sense to take raw materials to where energy is cheap. Since fossil fuels won't burn in space, energy will come from nuclear or solar sources, depending on location and needs. In the inner solar system, for fixed, non-military installations like industrial plants, solar power appears to win hands down. While nuclear reactors are a fairly inexpensive source of heat, they do consume fuel and require considerable mass for their construction. In free space, a kilogram of inexpensive concentrating mirror can supply five to ten kilowatts of heat with no fuel costs whatsovever. The probable superiority of solar cells to any kind of heat engine merely widens the gap—where electric power is required.

On a planet, a solar electric power system suffers from grave handicaps. Winds and gravity multiply the cost of its structure, while dust and moving parts add to its maintenance costs. Expensive mechanisms must track the Sun during the day, and night renders the entire system useless half the time. If people or industry are to remain active at night, expensive energy storage systems must be built. For these reasons, nuclear power may win the cost battle for surface installations, unless-displaced by solar power beamed from space.

Even leaving energy aside, the advantages of free space for industry are substantial and unique, while the disadvantages are mild and easily overcome. The planetary environment offers industry two things: a fixed gravitational acceleration and some mixture of atmospheric gasses. Even if a process would benefit from these conditions, a cheap spinning structure like a space station can simulate an **optimal** gravity, and provide an **optimal** atmosphere. Although a planet's atmosphere can help carry away waste heat, mass-produced radiators can do the same in space (at a rate of several hundred watts per square meter at ordinary temperatures, and several thousand at elevated temperatures). Clearly, any process feasible on a planet is feasible in space.

In contrast, the unique vacuum and zero-gravity of space make many new processes feasible or more attractive. Zero gravity makes possible delicate separation processes, growth of very homogeneous semiconductors, and uniform solidification of very inhomogeneous composites (like foam steel). Some think that a number of such processes could yield products valuable enough to justify the cost of a round-trip into space on the shuttle, making them candidates for early space industries.

The absence of wind, weather, and gravity eliminates corrosion and most structures and to point them at the Sun. There, with careful shading, objects cool to cryogenic temperatures. With fixed concentrating mirrors of plastic film, heat in solar furnaces at 2,500°C becomes cheap.

Without gravity, weak forces exerted by induction coils or jets of gas can position molten globs in a furnace without physical contact, entirely sidestepping the bothersome and sometimes insoluble problem of container corrosion. With these methods adapted to no-contact plumbing, molten rock and steel can be handled by inexpensive, low-maintenance equipment in a continuous process. With no container corrosion worries, cheap, solar-powered, graphite-lined furnaces (patent pending) can make distillation of asteroidal steel practical. This will not only purify the steel, but recover copper, gold, and platinum-group metals, together with such unusual by-products as germanium and gallium. By venting steel or aluminum vapor out a nozzle and through the vacuum of space onto a form, condensed metal can be built up into plates or seamless hulls, perhaps for space colonies.

At this point the question "why build colonies in space, not on planets?" virtually answers itself: Trade, not government whim, will support colonies, and since the industries supporting trade will be in free space, colonies will be in free space.

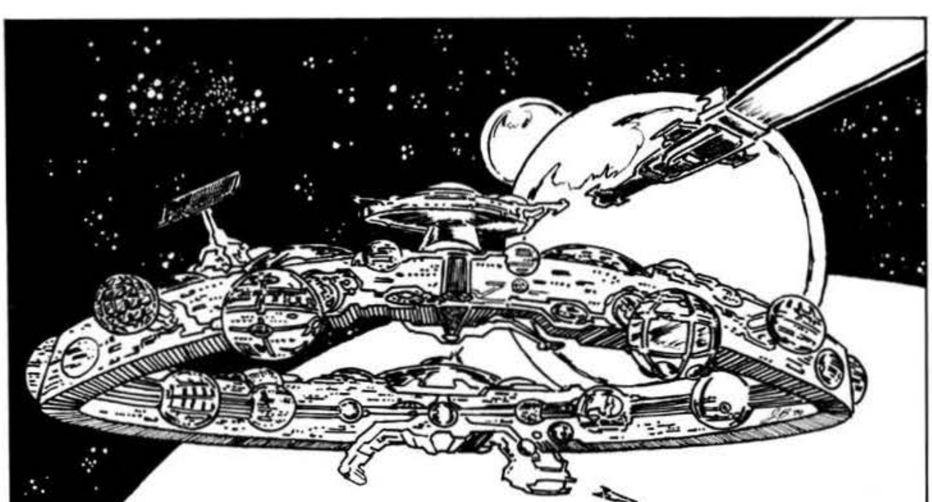
In all fairness to planetary bodies, they will draw some activity. Pre-processing of lunar rock and dust to concentrate useful materials may cut launch costs enough to be economic, and launching itself is a substantial activity requiring a Moon base. Some planets may have concentrations of rare minerals worth mining, many will draw scientific activities, and a few may eventually draw settlements and tourism.

Still, few people are apt to want to live on planets. All planets ever offered colonists, besides dubious raw materials and famous locations, was an unchosen gravity, an unchosen day length, an unbreathable atmosphere, and some stark scenery. Terraforming could perhaps produce a breathable atmosphere and improve the scenery—but for our distant decendents.

In space, colonists can choose their gravity, choose their day length, choose their atmosphere and their climate, and build...well, anything that will fit in a volume of a few hundred cubic kilometers or so. Solid city, airy tension structures, land, lakes, sunlight, and life—see any painting of an O'Neill colony for scope, then dream.....

And so the old patterns of thought have fallen. We will not "find wealth" in space, we will make it from barren rock and sunlight. The moving lights in the sky have less value than the invisibly faint asteroids, long though worthless. Land has little value in space because the best building sites are trajectories through vacuum. Exploitation and rule have no place, because space still lacks victims. Only the underlying notions of the Industrial Revolution—that wealth springs from ideas, investment, production, and trade—remain fresh. Only they can carry us into space, not to visit, but to live. L5

". . . the industries supporting space will be in free space. . ."



Artwork by James Babcock

Breakthrough!

According to recent studies, a combination of asteroid mining and high performance solar sails give us an early toehold on nonterrestrial resources. The price tag? It may be as low as $100 million.

by Carolyn Henson

Are you tired of hearing that solar power satellites are the only project big enough to justify space colonization?

Do you worry about putting all our eggs in the power satellite basket?

What we need is a really cheap route to nonterrestrial resources. So cheap we can easily justify setting up the heavily shielded (against cosmic radiation) habitats people need to permanently live in space. So cheap that we can build space farms and stop having to import our ham sandwiches from Earth. And we want those cheap resources soon.

Until recently the fastest, least expensive scenario was the "Low Profile Road" proposed by Gerard K. O'Neill (**Aeronautics & Astronautics,** March 1978, pp. 24-32). The keystones of this proposal are the use of lunar resources and the "mass driver," a linear electric motor that can either be used to fling rocks off the Moon or as a reaction engine in space with its rock-throwing action providing thrust.

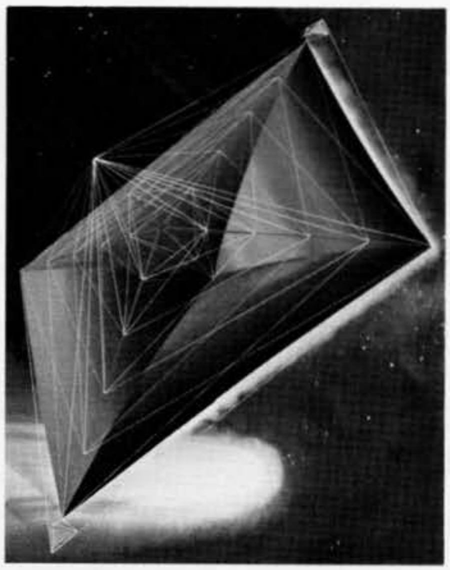
The space shuttle, for only a slight penalty in reduced payload, can leave its main fuel tank in orbit instead of letting it fall to burn up in Earth's atmosphere. O'Neill proposes grinding up these tanks for use as mass driver reaction mass.

The mass driver would carry 1,000 tons of equipment plus another 1,000 tons of fuel for a chemically propelled lunar soft lander. This equipment would be installed on the lunar surface. When completed the lunar base will include housing for 30 people, a Moon mine and a mass driver to throw rocks to L-2. A mass catcher would gather rocks there for transport via mass driver to an orbiting factory.

When these systems are all operating we will finally have a reliable supply line for nonterrestrial resources. The cost of this "low profile" scenario? One hundred shuttle flights. The development of mass drivers, lunar landers, a high orbit passenger vehicle, a mass catcher, lunar base and mine, and a space station. The estimated price tag is just under $10 billion. This part of the project would take 11 years.

That isn't unreasonable compared to the shuttle program, which will probably top $6.5 billion in research and development alone. But what do we get for this ten billion? Plenty of radiation shielding. Unprocessed rock two meters deep does just fine for stopping even the most energetic cosmic rays. We also get all the mass driver reaction mass we can use.

Unfortunately, it's a long way from lunar rock to some money-making space end product. O'Neill estimates a price tag of another $9.5 billion just to break down lunar rock into its component metals, oxygen and silicon. The next step is a dilly. Fabricating raw materials into end products is expensive, as anyone who has compared the price tag per kilogram of pig iron v.s. Mercedes Benz is aware. O'Neill estimated an investment of about $6.5 billion of research and development would set up a plant that could turn metals and silicon into power satellite parts.



Plastic film material solar soil.

This is a reasonable investment as part of a solar power satellite project. Power satellites could generate tens of billions of dollars per year of income. But no other project or group of projects on the NASA drawing boards could justify this "low profile road."

Former O'Neill research assistant K. Eric Drexler has followed another line of research. Substitute solar sails for mass drivers and asteroids for the Moon and we may get nonterrestrial resources for an investment of well under a billion dollars.

The Case for Asteroids

Many asteroids are actually closer, in terms of "delta-V," than the Moon. In space, distances are nearly meaningless. Orbiting objects follow their Keplerian choreography, changing relative positions constantly. What's really important is the change in velocity, or delta V, an object must undergo to move from one orbit to another.

A round trip from the surface of the Earth to the Moon requires a 9 km/sec delta-V. A round trip to the asteroid 1943 Anteros needs only an 8 km/sec delta-V. A "shortcut" using a double gravitational slingshot maneuver around the Moon brings the delta-V down to 2.2 km/sec. Using the same maneuver 1977 HB Bacchus has a delta-V of 3 km/sec.

Asteroids are far richer sources of materials than the Moon. The Moon lacks hydrogen (necessary to make water), nitrogen and carbon, elements essential to life. Lunar oxygen, aluminum, titanium and silicon are tied up in hard to smelt compounds such as silicates. To put it bluntly, known lunar resources are about as poor ores as ordinary Earth rocks and dirt.

However, on the basis of meteorites that have struck the Earth, and asteroidal reflection spectra, we can tell that many asteroids contain rich ores. Nickel/iron asteroids such as the nearby 77 VA Amor contain huge lumps of nearly pure nickle/iron steel. And their impurities are worth looking at twice: chromium, cobalt and platinum. Carbonaceous chondritic asteroids, such as the nearby Ra-Shalom, contain water and carbon in large quantities, and significant amounts of the biologically critical nitrogen. The water can be extracted by simple distillation.

Why Solar Sails?

According to Eric Drexler,

> "Sporadic studies of solar sailing stretch back well over twenty years. For obvious reasons, nearly all serious studies have focused on launchable, deployable sails, made of necessity from comparatively rugged plastic film materials. The recent renewal of interest in solar sailing

sprang from a Jet Propulsion Laboratory design study, which showed the feasibility of deployable sails of impressive performance.[1]

Space-manufactured thin-film materials promise sails with 20 to 80 times the performance of the best deployable sails; this would seem to justify a re-examination of solar sailing."

What are the environmental implications of solar sails?

"Most of the light reflected from high performance solar sail (HPSS) spreads in a cone some tens of degrees across, and need never be directed at Earth's night side. Still, some light will be scattered in all directions, and sails maneuvering at a few Earth radii will be visible over much of Earth's night side for part of every orbit. Scattered light might become bright enough to affect astronomical programs involving faint objects. If so, the problem may be alleviated, even for heavy sail traffic, by arranging sail schedules so as to leave the skies completely free of sails most of the time (convoying). Eventually, instruments in space will more than make up for lost observing time on the ground.

At some altitudes, orbital debris would pose a substantial hazard for sails, if they were left uncontrolled. All significant orbiting objects are tracked, however, and hence may be avoided. Further, HPSS technology can be scaled down to produce small, cheap vehicles with unlimited delta-V capability. Such vehicles, with suitable payloads, would make fine orbital garbage trucks, collecting debris economically."

Solar Sail Uses

While solar sails appear to be ideal for asteroid mining missions, they have many other potential uses. Their possibly as low as $100 billion research and development price tag could be justified by any one of the following:

*Such sails can serve as reusable interplanetary shuttles for delivery of orbiters, landers, penetration probes, etc., and can return samples from low planetary orbits to low Earth orbits.

*Their unlimited delta-V capability allows asteroid survey missions of indefinite length.

*Their high performance permits a rendezvous mission to Halley's comet with a flight time well under a year, and permits **pre-perhelion** rendezvous missions, with subsequent sample return, to objects on parabolic trajectories.

*Their high performance permits not only fast out-of-the-ecliptic missions, but establishment of permanent solar polar observatories (see Figs. 6 (a) and (b)).

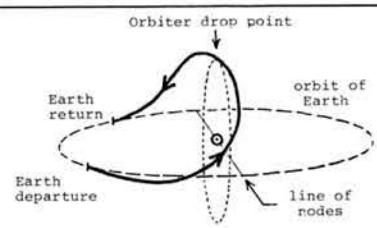


Figure 6 (a). An out-of-the ecliptic mission trajectory with sail return.

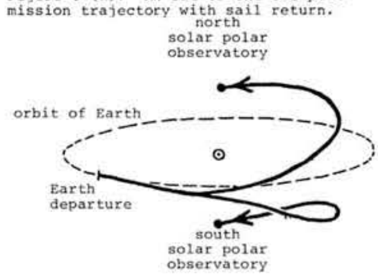


Figure 6 (b). Solar observatory mission, trajectories and operating stations. Payload about 150 kilograms per newton of sail thrust.

*With the aid of rocket stages, they can deliver large payloads into orbits around the outer planets with short mission times.

*They can perform 1.5 year flyby missions to Neptune and Pluto.

*Since they can deliver substantial payloads to solar-escape trajectories with hyperbolic excess velocities of 100 to 200 km/sec, they can greatly speed the exploration of the heliosphere and the nearby interstellar medium. Delivery of x-ray telescopes to such trajectories would permit measurement of the distances to certain suspected black holes, after a few years flight time, based on their rapidly flickering intensities and the curvature of the oncoming x-ray pulse. In a decade or so, astrometric equipment on such trajectories could measure parallax and hence distance for any visible object in our galaxy.

However, the "big time" is retrieval of nonterrestrial resources. According to Drexler,

"Historically, a great barrier to the use of non-terrestrial resources has appeared to be the high initial cost of the recovery systems. Nothing short of the solar power satellite program has appeared to justify the expense of the development, construction, and emplacement of a lunar base, mass driver, mass catcher, and other system elements necessary for the lunar scenario. The HPSS, on the other hand, provides a reliable, low-cost, deep-space transportation capability well suited to operation without crew maintenance. With it available, the threshold to nonterrestrial resource recovery may apparently be crossed with a single shuttle payload.

Figure 7 illustrates one approach to the surface mining of a small asteroid, based on a device which sweeps up loose surface matter and places it in a bag. Such a device may have many redundant sweeping heads, and seems unlikely to require human attention. A 200 ton sail-load, appropriate to a 100 newton force sail, may be swept up in under a month at a rate of one tenth kilogram per second. A few millimeters thickness of loose surface material would suffice for many loads of this size, which may be returned with trip times on the order of a year. Two accessible asteroidal bodies with much loose material are already known: the moons of Mars. It would be ironic if they proved more attractive than our own."

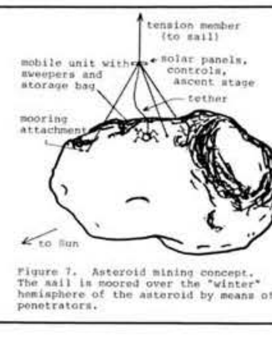


Figure 7. Asteroid mining concept. The sail is moored over the "winter" hemisphere of the asteroid by means of penetrators.

The U.S. Department of Defense might develop an interest in extraterrestrial resources.

"Asteroid resource recovery systems open a range of non-solar power satellite scenarios for space development. Demand for a few hundred tons of asteroidal material for radiation shielding could justify mining operations. Military demand for asteroidal steel to harden orbital installations could easily exceed 10,000 tons (or 100,000 tons, for that matter). Mass transport rates of this order of magnitude would drop the total amortized program cost per kilogram returned into the \$2-20 range. Incremental costs for sail production would be low, and incremental costs for the use of existing sails would be almost negligible."

In the longer run, asteroid mines may sell their products to Earth surface customers. Drexler points out that:

"Many asteroids apparently contain a good grade of steel, with a typical cobalt content around 1% and a nickel content around 10%. Sail transportation costs from Apollo objects, at substantial traffic levels, should fall below \$50/kilogram. This may be compared with the market prices and world demands for cobalt (about \$10/kg and 20,000 tons/year) and nickel (about \$5/kg and 700,000 tons/year). If a suitably low-cost concentration or purification process can be found, and if return of materials through the atmosphere proves as inexpensive as expected,[2] these metals might be sold on Earth. World markets are several billion dollars.

A large market might also be developed for foam steel. It should be easy to produce in space, and would require little refining of the raw material. Its unique properties might bring a price of several dollars per kilogram (roughly comparable to that of some wood products).

Preliminary estimates of the cost of mass-produced solar sails, using nonterrestrial feedstocks and a shuttle-derived heavy lift launch vehicle for equipment transport, fall around 0.75¢/m², yielding transportation costs around 6¢/kg from a suitable asteroid. Since pig iron sells for over 20¢/kg, and steel bars, plates, etc. for over 40¢/kg, a nonterrestrial steel production industry is not out of the question. U.S. demand for pig iron is presently over 70 million tons per year; worldwide demand is almost 500 million tons per year. Cheap process heat, zero gravity, and accessible vacuum all make space attractive for steel processing. Steel and cheap energy as a basis for industrial development is an old story."

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High Performance Solar Sail Concept

by K. Eric Drexler

High performance solar sails (HPSS) are truss structures built from tension members which support reflective panels assembled from vapor-deposited films 15 to 100 nanometers thick (see Fig. 1). Light pressure and payload inertial reaction provide axial tension, while slow rotation provides radial tension. HPSSs are expected to have high performance, low cost, and high reliability because of their low mass, ease of fabrication, and virtually passive mode of operation.

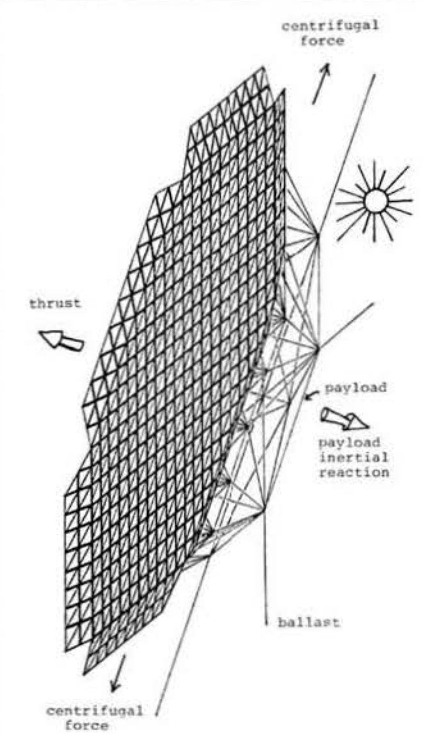

Figure 1.

The core of the HPSS production system is a device which fabricates and mounts sheets of thin-film material. Film sheets are fabricated by depositing a sublimable material and then the reflective film onto a moving belt of metal foil, and then incising the film to separate it into sheets. The sheets are then mounted by gluing springy foil tabs to their corners, and freed by subliming away the intermediate layer through perforations in the foil or the film. This approach can apparently produce thin film sheets in a continuous stream while subjecting them to negligible loads. Two alternative approaches with different risks but similar results are proposed. Preliminary estimates suggest that a 3,000 kg device (inclusive of power supply) can produce some 3×10^7 m² of film sheets per year. Another device assembles the sheets into triangular panels framed by tension members, which are accumulated for subsequent assembly to the sail structure. Together these devices make up a panel fabrication module, with a mass around 4,000 kg.

The sail's main tension structure is launched as a compact package, and then deployed from reels. Deployment takes place within the confines of a centrifugally-tensioned scaffolding structure incorporating six parallel beams. The main plane of the deployed sail structure is a hexagonal triangulated grid. A crane attached to the scaffolding conveys panels from the fabrication device to apertures in the grid, where they are hooked onto the structure. All fabrication and assembly operations may be accomplished without direct human intervention.

Air drag imposes an operational floor on solar sails between 700 to 900 km altitude. If sails are made below this altitude, they must be kept in orbit during manufacture by constant thrusting. Thrust requirements have not been estimated, but may be minimized by proper choice of sail attitude. If sails are made above this altitude (prior to the establishment of a high-orbit station), all equipment must be designed for maintenance or replacement by teleoperator, owing to the radiation environment of intermediate altitude orbits.

After panel installation and release from the scaffolding, the sail becomes operational. The sail's attitude to the Sun then determines the direction and magnitude of its thrust. Since the sail spins, changes of attitude require a precessing torque. Tilting some of the panels produces torque for spin-rate control of slow precession; shifting the payload to an off-axis position in inertial space will produce torque for faster precession. In near-Earth maneuvers, the latter method would be used, permitting the sail to precess at rates around five radians per hour. In interplanetary flight the first method can be used, and the sails may be left passive for weeks at a time.

Development and Implementation Considerations

The only system elements embodying substantially new technology are the film fabrication device and the film sheets themselves. The fabrication device has moving parts comparable in complexity to those of the beam-builders already under development for space use. Adequate control of the various substances handled will require careful design (baffles to confine vapors, bearings sealed against loose flakes of vapor-deposited materials, etc.). The device is designed to deposit and free the film sheets under conditions better than those commonly employed in the laboratory for producing unbacked films even thinner than those proposed for use in the HPSS. Several candidate film materials are fairly well characterized, and have strengths over 1,000 times what the present application demands.

The greatest uncertainties in the system—the minimum practical film thickness and the optimal film composition—have little effect on the system design. They affect the sail's acceleration and maneuverability, but the proper choice of sail rotation rate negates effects on the sail's structural design or major internal modes of vibration. They affect the design of the evaporators in the film fabrication device (and the sizing of their power supply and cooling system), but the design of the rest of the sail manufacturing system remains unaltered. Figure 2 indicates the range of uncertainty in the sail's final mass and performance. Since the worst likely case yields excellent performance, and since these uncertainties are effectively decoupled from program risk, they may be greatly reduced by a very modest experimental program of film deposition and testing.

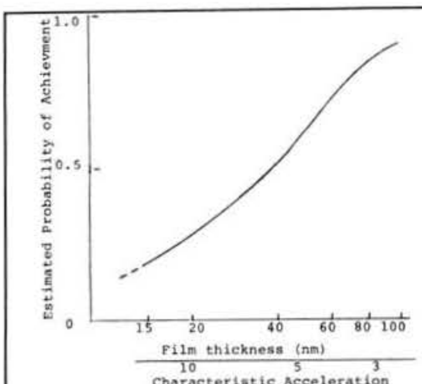

Figure 2. Estimated probability of achieving films of various thicknesses and sails of various performance levels.

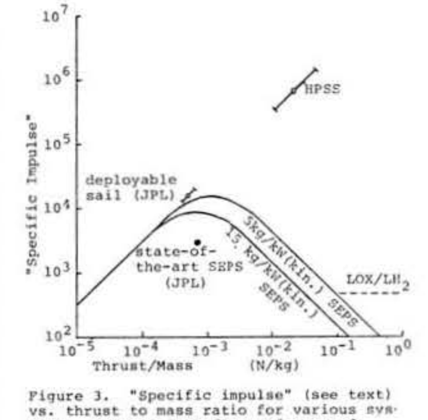

Figure 3. "Specific impulse" (see text) vs. thrust to mass ratio for various systems. Current SEPS from reference 6.

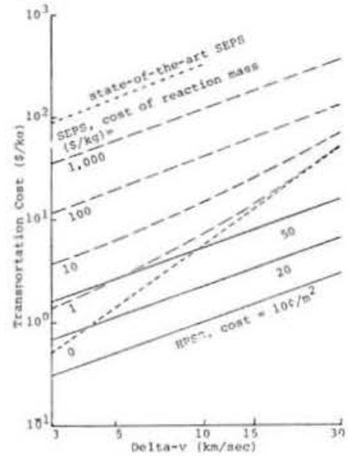

Figure 4. Comparisons of HPSS and SEPS costs. See Table 1 for assumptions.

The balance of the system presents the typical problems of the design of a reliable, maintainable mechanical system. A preliminary estimate of the masses of the system elements to be developed is five tons. Applying a typical aerospace development cost of $20,000/kg to this mass yields a crude development cost estimate of $100 million. A substantially higher development cost could clearly be tolerated, if the system proves attractive enough.

The total mass of a system able to produce sails of 1 to 100 newtons thrust (0.5 to 5 km diameter) is estimated to be around 13 tons (a smaller scaffolding with lower mass is apt to be built during development). Such a system could produce sails with thrusts totaling 200 N in a year's time, and this capacity could be expanded in 200 N/yr increments by the addition of four-ton panel fabrication modules. Sails of greater thrust could be made by clustering smaller sails or by means of the construction of a larger scaffolding. The basic system, together with raw materials for sails totaling several hundred newtons thrust can apparently fit within the mass and volume constraints of a single shuttle launch.

Performance Comparisons

To be of practical interest, the HPSS must outperform its competition in a sufficient range of applications. At present, the competition is the solar electric propulsion system (SEPS), using either ion engines or possibly mass drivers for conversion of electric to kinetic energy. The latter system is an efficient, omnivorous mass accelerator proposed for industrial-scale space propulsion.

Two performance parameters commonly compared among thrusters are specific impulse and thrust to mass ratio. Strictly speaking, the specific impulse of any sail is infinite, as it expends no mass. Still, sheet metal makes poor sails. In the spirit of amortization applied to durable goods, a performance measure related to specific impluse may be calculated by introducing a fictitious expenditure of 10% of the vehicle's mass per year, and adding this to any mass actually expended. Sail thrust characteristics are also unusual: as a sail varies its angle to the Sun, its thrust varies in both magnitude and direction. For heliocentric trajectories, the useful component of thrust is frequently that perpendicular to the radius vector from the Sun. On this basis, the useful thrust of a sail is about 38% of its maximum thrust.

Figure 3 plots the measure of "specific impulse" described above as a function of the (useful) thrust-to-mass ration for sails of varying mass per unit area, at Earth's distance from the Sun, and SEPS with varying specific powers and exhaust velocities. As may be seen, the HPSS greatly outperforms state-of-the-art, multi-mission ion-engine SEPS, in both dimensions. An idealized (or mass driver) SEPS can exceed the sail's thrust-to-mass ratio, but only at a low specific impulse, or with a very high specific power.

Preliminary Cost Comparisons

For industrial applications, the unit cost of transportation is of central concern. SEPS costs will depend on the delta-V of the mission, and on the costs of the reaction mass and the kinetic energy in the exhaust (the latter amounts to the cost of vehicle amortization). HPSS costs will depend on the cost of the sail, its distance from the Sun, and the efficiency with which its thrust may be used. The following comparison will neglect other costs for both systems, and hence cannot be considered to represent total costs.

Figure 4 presents such a cost comparison. Table I summarizes the assumptions used, intended to represent an early era of space development. As may be seen, sail costs are lower than state-of-the-art SEPS costs across the board. The advanced, idealized, mission-optimized SEPS beats the more expensive sails at low enough delta-V, if a cheap enough source of reaction mass can be found. However, even the cost of mass-driver derived lunar materials has been estimated at over \$1/kg.

Figure 5 graphs comparative costs in the context of a solar power satellite program. Table 2 lists the assumptions used. Once again, SEPS appears competitive only with low reaction mass costs, and at low delta-V's.

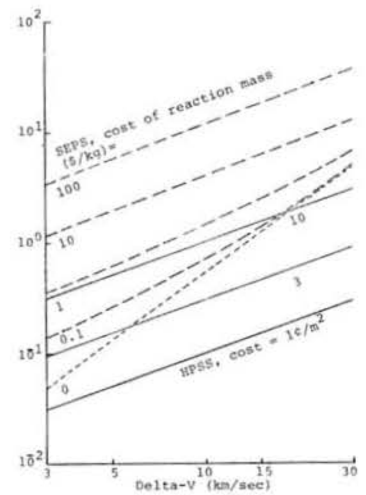

Figure 5. Comparison of HPSS and SEPS costs in the context of an SPS program. See Table 2 for assumptions.

Conclusions and Recommendations

In light of the unique capabilities, extreme versatility, low transportation costs, and modest development cost promised by HPSS, this concept seems worthy of review by aerospace groups. If this promise holds up under closer scrutiny, work should begin to improve sail and sail fabrication facility design, to improve understanding of the proper role of the HPSS in space activities, and to initiate development of the sail fabrication technology itself.

Acknowledgements: The author would like to thank the National Science Foundation for its support during the greater part of this work, and the members of the JPL solar sail design teams: without them, this work would never have been done.

More details are available in "High Performance Solar Sails and Related Reflecting Devices," Eric Drexler, AIAA paper #79-1418, May 1979. This paper was presented at the 1979 Princeton Space Manufacturing Conference.

Table 1. Cost assumption for Figure 4.

General Assumptions:

Discount rate, 10%

Cost of equipment purchase, \$600/kg.

Cost to transport to orbit, \$700/kg.

Only the cost of equipment, materials, and their transport to orbit is considered.

HPSS:

Cost of structure purchase, \$600/kg.

Cost of evaporator feedstock purchase neglected.

One panel fabrication module used at capacity in a large scaffolding.

The resulting cost is 12 to 26¢/m², depending on film thickness.

SEPS:

"State-of-the-art SEPS" curve represents a JPL multi-mission design, costed as above.

Other SEPS are assumed to have mission-optimized exhaust velocities, and to be able to supply kinetic energy to the exhaust for 25¢/kw-hr. This corresponds to a 70% efficient system with a mass of about 12 kg/kw (electric), costed as above.

Curves are plotted for various assumed reaction mass costs.

Table 2. Cost assumptions for Figure 5.

General Assumption

Cost of transport to orbit, \$100/kg.

Other assumptions as in Table 1.

HPSS:

Cost of structure purchase, \$200/kg.

Cost of evaporator feedstock neglected.

Many panel fabrication modules per scaffolding.

\$600/kg for initial module purchase, 80% learning curve applies to the cost of enough modules to provide 100,000 tons/yr transport capacity to geosyncronous orbit after 5 years production.

The resulting cost is 1.5 to 3.5¢/m², depending on film thickness.

SEPS:

Same assumptions as in Table 1, but 2.5¢/kw-hr (a commonly quoted target cost for SPS electrical energy delivered to the ground) is assumed as the cost of kinetic energy in the exhaust.

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Salyut-6 Step Towards a Permanent Space Station

by James E. Oberg

The latest Soviet piloted space launch involving a Bulgarian cosmonaut briefly attracted public attention to the Salyut-6 space station mission. Soyuz-33, launched April 10, was also the first Soviet piloted spaceship commanded by a non-pilot civilian engineer.

But the space breakthrough of 1979 had already been in progress, unheralded by the news media. For seven weeks, unnoticed by most of the world, the crew of Soyuz-32 had been working on board the Salyut-6 space station. What they have accomplished marks a major advance in space exploration, perhaps the most important single space feat since the first inhabited space stations were launched in the early 1970's.

Cosmonauts Lyakhov and Ryumin (temporarily joined by cosmonauts Rukavishnikov and Ivanov) have opened the way to the establishment of orbiting space stations of unlimited lifetime. By their repair and refurbishment of the eighteen-month old Salyut space lab, they have given proof of the USSR's serious intentions to carry out what has up until now been only a promise: "We believe that permanent inhabited orbiting space stations with interchangeable crews will be the main road into space," goes the litany repeated time and time again by Soviet politicians, cosmonauts, and space scientists. That forecast has moved measurably closer to reality with the flight of Soyuz-32.

For seven weeks, unnoticed by most of the world, the crew of the Soyuz-32 has been working on board the Salyut-6 space station . . . (they) have opened the way to the establishment of orbiting space stations of unlimited lifetime.

"Salyut" is the name of the Soviet inhabited space station program, in some ways comparable to the U.S. Skylab project of 1973-1974. The Salyut design is smaller than Skylab, with lower electrical power capacity, a lower orbit, and less sophisticated instrumentation. It generally operates with a crew of two, compared to three on Skylab (and, unlike Skylab, the Salyut has never hosted true scientist-astronauts).

But the Salyut program, unlike the one-shot Skylab, is an ongoing program. New improved Salyuts are launched about once per year, are visited in sequence by different teams of cosmonauts, and then are safely crashed into the uninhabited North Pacific at the end of their missions.

The latest Salyut, numbered "6" but actually at least the eighth in the series which began in 1971, has incorporated an operational capability for double docking of ferry ships, for crew replacement "on the fly", for automatic resupply, and for advanced space walk systems. Using such technology, backed by a remarkably confident flight planning process, cosmonauts have smashed all American space records from the Skylab program.

The key difference on Salyut-6 is in the way it has been designed to facilitate repair. It is the first space station so conceived. All future space stations will be built this way.

On Skylab and on earlier Salyuts, the ability to repair equipment and restock consumable supplies was the main limiting factor on how long the space stations could remain functional. The efforts by Skylab astronauts to replace sun shields, unfold balky solar power panels, repressurize coolant lines, and perform similar tasks, were all newsworthy and exciting. Less well known was the fact that such tasks were made more difficult by the basic design of Skylab, which did not allow for easy in-flight maintenance and replacement.

After about a year or two at most, space equipment wears out. Even if breakdowns do not occur, the performance and reliability of the equipment are seriously degraded. On Skylab today, after five years of cold storage, the newly repowered systems have been failing one by one, eliminating the chance that the space station could have remained under control even if its orbit had not been decaying so rapidly.

The Soviets on Salyut-6 have overcome this basic inherent lifetime limitation by a two-fold approach. First, practically all of the internal systems of the Salyut are modular in design, and can be replaced piecemeal with new equipment sent up in robot freighters of the "Progress" type. Second, systems which cannot be so easily renovated (such as solar panels) can be augmented by supplementary equipment on newly attached modules launched separately.

The technology of this approach, while not particularly sophisticated, is impressive for its flexibility. "Progress" robot ships, for example, can deliver more than five thousand pounds of cargo and rocket propellants, and can transfer that payload onto the Salyut — the cargo via manual handling, and the liquid propellants via pressurized lines (in-flight ship-to-ship fuel pumping has never been accomplished by the U.S.). Special modules loaded with auxiliary power packs, rocket engines, or laboratory equipment promise to give the Soviets soon a capability similar to that planned for the U.S.—European Spacelab program of the early 1980's.

Frequent flights between the space station and the Earth allow Soviet space engineers to study results of cosmonaut experiments which have been returned, plan changes to the procedures, and send new instructions back up to the crew on subsequent flights. A major new advance in this procedure was implemented in March with the installation of a television screen and video recorder unit on the Salyut. New procedures, documents, blueprints, and other visual information can now be transmitted to the spacemen for study. This supplements a teletype unit which was already in service.

The current plans for the duration of the present space station crew are not known. Soviet space medicine experts have expressed guarded satisfaction with the re-adaptation of the cosmonauts who spent 140 days in space last summer and fall. Ground tests and some vague public statements suggest that the Soviets are aiming for an ultimate duty tour in space of about 365-380 days. Their past practice of extending each long flight by about 50% over the previous flight suggests that a mission duration of 230 days for the present crew is logical. They would thus come back to Earth next October, after having been relieved by a new pair of cosmonauts who would be aiming at twelve months in orbit.

However impressive the current Salyut-6 achievements may be, they represent only the tip of the iceberg of forthcoming Soviet piloted space activities.

Such long flights exceed the orbital operating lifetimes of Soyuz transport ships. That is why periodic launches must occur for visiting crews for exchanging spaceships, returning to Earth in the nearly worn out Soyuz and leaving their fresh spaceship attached to the Salyut. Their visits are also useful for logistics and psychological reasons.

Since such flights are routine and not particularly challenging, the Soviets have allowed representatives of their satellite countries to fly on them. Such "guest cosmonaut junkets" are essentially public relations gimmicks, since the foreign visitors are not sufficiently trained to make any significant contribution to the success of the main mission. Their propaganda value, however, is immense, and they do represent one reward for the political loyalty of their countries and for a genuine program of Soviet bloc cooperation in space science.

However impressive the current Salyut-6 achievements may be, they represent only the tip of the iceberg of forthcoming Soviet piloted space activities. Over the past several years, a mysterious series of unpiloted orbital test flights has proved out several different types of advanced pilot-related space hardware. These vehicles, which may include auxiliary Salyut docking and power modules, a space tug, and an small "lifting body" reusable piloted spacecraft which can land at an airport after its flight, have yet to become operational, but this is expected to occur over the next year or two.

During that time, the Soviets will probably make it clear that they have every intention of establishing a permanent presence in orbit, with tired space crews being replaced by fresh cosmonauts. The assembly of larger space stations out of modules launched separately is another theme often discussed in the Soviet literature, and it would make good sense to do such a thing. Several different specialized Salyut stations, some for scientific research and some for military reconnaissance, will probably be set up. Salyuts could also be sent into lunar orbit within five years.

All these present accomplishments, and the obscure but highly suggestive space tests of the last few years, indicate that a major change in space operations is now occuring. Cosmonauts have established a bridgehead into space and will be expanding it, utilizing space stations for scientific, industrial, medical, and military purposes.

Our Space Shuttle and Spacelab, once operational, may go a long way towards redressing this imbalance of operational capabilities.

But the Salyut is operating today, and the Soviets, too, have big plans for piloted space flight in the future.

More Mystery Soviet Space Tests

Another mystery human-related Soviet spaceship has completed an orbital test flight, space watcher Jim Oberg reports from Houston. Kosmos-1074 was launched on January 31 and was recovered April 1 on a mission just one hour short of sixty days.

The vehicle appears to be part of a test series which began with Kosmos-869 (late 1976) and Kosmos-1001 (April 1978), possibly leading to use of a larger-capacity piloted spacecraft descended from the current two-seat Soyuz. Kosmos-1074 was apparently about the same size and weight of the present Soyuz design but may have been of a different configuration, based on visual observations from Texas.

Based on a past analog to this mission, the new vehicle (possibly with a crew of 4 or 5 cosmonauts) could become operational later this year. The 60-day Kosmos-613 flight in 1973-1974 was a precursor of the Soyuz spacecraft used on the Salyut-4 missions of 1974-1975; a similar 10-12 month delay may now ensue before Kosmos-1074 becomes operational, or, with greater confidence which now characterizes the Soviet space effort, that period may be cut in half.

Alternately, Kosmos-1074 may represent a special Soyuz-based "laboratory module" which, according to Soviet space officials, is being prepared to transport special already-assembled pieces of scientific and industrial equipment into orbit, as a complementary approach to the progress freighter-tankers. Samples could be returned to Earth in an unoccupied Soyuz.

Only time will tell, Oberg concedes, but he warns that the test series, and other even more mysterious tests, presage major new Soviet space advances in the next 12-18 months.

Evolving Shuttle Designs

by Leonard David

In a time of nationwide economic constraints, the message for space planners is clear — "make do with what you've got." With the Space Shuttle as this country's main space transportation system, engineers are investigating a multitude of concepts that will literally and figuratively stretch the Shuttle's abilities far beyond its initial design. Such improvements could have tremendous impact upon the building of large structures such as satellite power systems or, conceivably, space habitats.

Advanced studies by Rockwell, Boeing, Johnson and Marshall Space Flight Centers indicate the possibility of using "kits" to modify and adapt basic Shuttle system elements to extend the Shuttle Orbiter's life-time, increase payload delivery weight and volume to orbit, and even create the first space passenger plane!

Currently, the base-line Shuttle can carry up to 65,000 lbs. within its 60 x 15 foot cargo-bay. However, space engineers are devising modificatins to the Shuttle which would enable it to boost almost 5 times as much weight! An early possibility for Shuttle upgrading would be more modest, however, involving use of additional solid rocket motors positioned on the end of the Shuttle's external tank. This technique would permit delivery of payloads up to 93,000 lbs.

One design by Marshall Space Flight Center centers on fully reusable, liquid propellant, rocket powered boosters, instead of the conventional solid strap-on engines now planned. The reusable liquid propellant boosters would increase the Shuttle's payload-into-orbit capability to 100,000 lbs.

One plan, devised by Rockwell, has demonstrated the feasibility of turning Shuttle vehicle hardware into a Heavy Lift Launch Vehicle (HLLV). This design would utilize present Shuttle external tank and solid rocket boosters, and the Orbiter's aft fuselage, modified into a fully reusable propulsion module. This concept would produce an HLLV with at least a 170,000 lb. lift capability. It's rumored that Rockwell has one Shuttle derived modification that could loft up to 300,000 lbs. into space!

Since 1975, Rockwell engineers have studied options to extend the duration of the Shuttle orbiter beyond its current 30 days of maximum spaceflight. Changes in electrical power subsystems, based on a deployable solar cell array kit, coupled with the Shuttle's fuel cell subsystems, and improved techniques for storing or recycling water, would give the Shuttle up to 180 days of life. The technology to develop these extended duration subsystems exists today, states Rockwell designers.

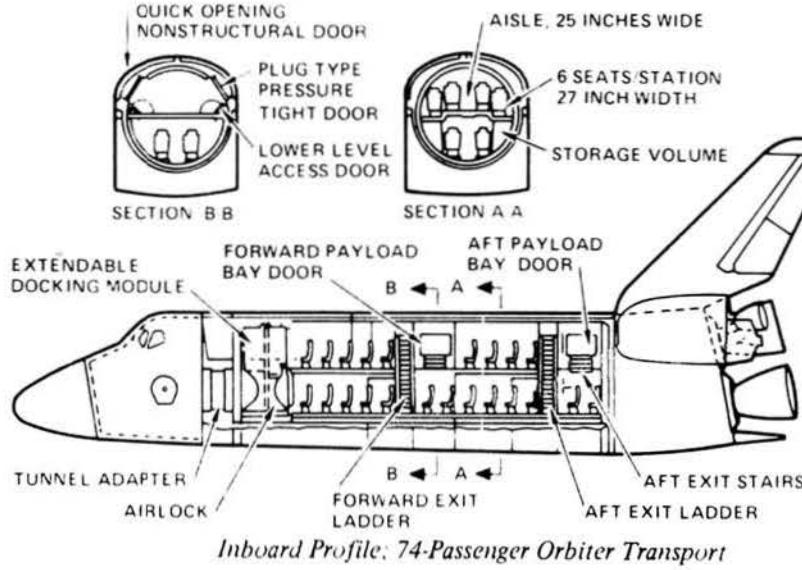
. . . engineers are investigating a multitude of concepts that will . . . stretch the Shuttle's abilities far beyond its initial design. Such improvements could have tremendous impact upon the building of large structures such as satellite power systems or . . . space habitats.

Additional studies have also been underway which allow for larger diameter and longer payloads. Currently, payloads of only 15 feet in diameter can fit inside the Shuttle's cargo hold, but conceptual studies indicate the need to handle wider payloads. Shuttle designers believe the Shuttle's external tank can be modified to house extra payloads, up to 37 feet in diameter and weighing 47,000 lbs. Once the Shuttle's main engines have cut off, a special shroud on the external tank would open, with the payload separating from the tank under its own propulsion system.

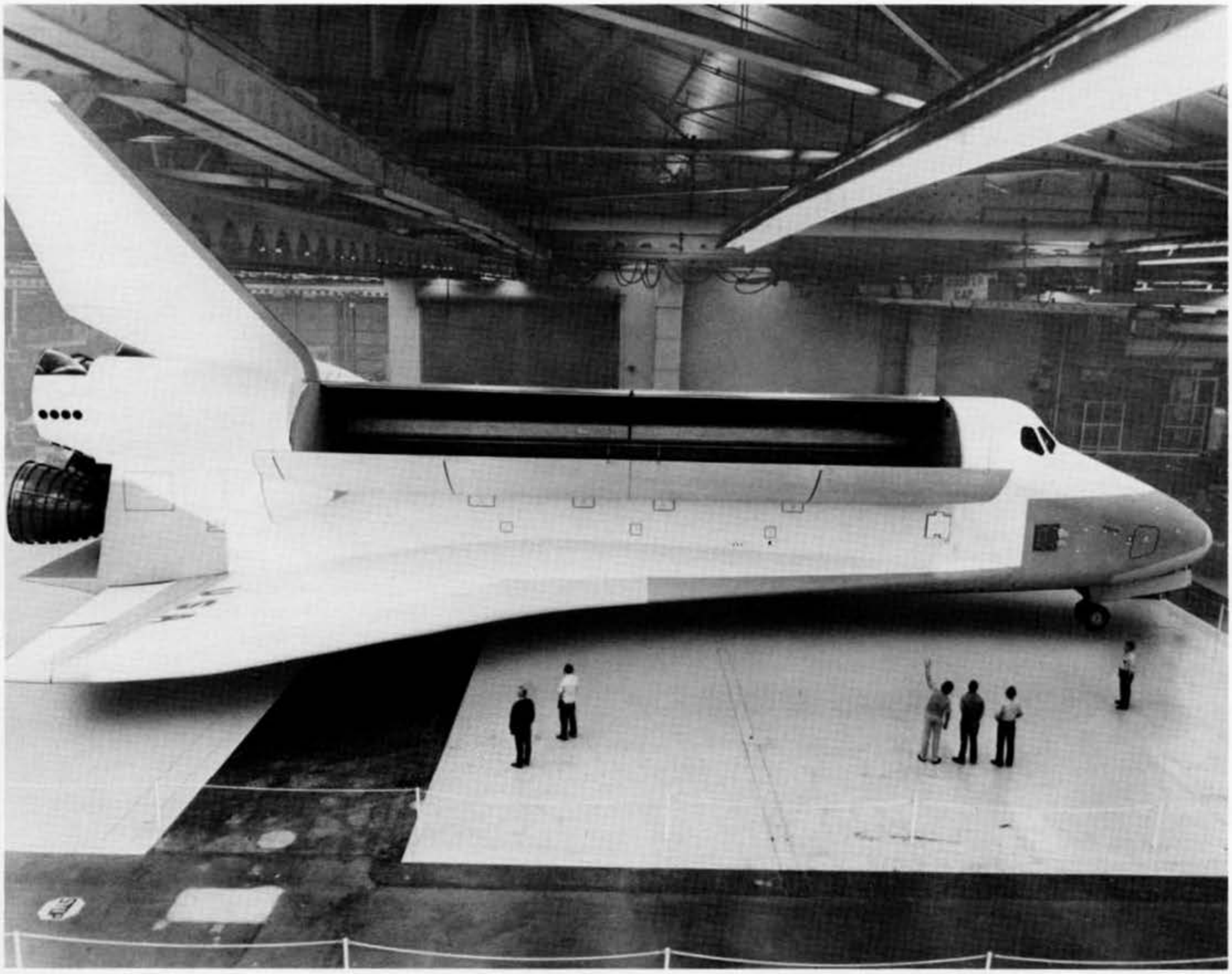
One option also available is to physically "stretch" the Shuttle orbiter by adding an extra section to its fuselage — a process similar to that already in use by commercial airline companies. This extra-long orbiter (longer by 16.5 feet) would require some modification of the wing sections and landing gear, allowing payloads up to 100,000 lbs. and 76 feet long. The modifications would result in a Shuttle with almost identical stability as its current design.

For those missions which will require delivery of payloads to geosynchronous orbits and beyond, both NASA and Rockwell studies envision the possibility of using one Shuttle to carry into space a core vehicle, capable of being piloted. Once the core stage is orbited, subsequent Shuttle flights would surround the stage with fuel tanks. Depending on the mission, up to six of these fuel tanks could be strapped to the core vehicle. It is possible future piloted flights to the Moon or planets may utilize this technique. The concept could be supported by the current Shuttle transportation system.

The most intriguing extension of the



Inboard Profile: 74-Passenger Orbiter Transport



Shuttle designers investigate new uses for the space transportation system — including a passenger-carrying system.

Shuttle is an L-5er's dream come true — a passenger-carrying orbiter. Rockwell engineers have studied a passenger transport kit which can hold up to 74 passengers for trips to and from low orbit. The passenger kit would be designed with special exit ladders and stairs for normal entry and unloading, and in case of emergencies. The kit, which would cost upward of $220 million, would include added life support equipment, seating and supplemental environmental control systems. Some modifications to the orbiter's wing would be needed, to accomodate the passenger module. It is conceivable with such future plans as building large structures in space, the need for construction crews may make this Shuttle design a practical possibility. No word yet on first class or coach seating arrangements!

As one Rockwell advanced study concludes, "The Space Shuttle System design has been shown to be economically adaptable to a wide spectrum of advanced missions, substantially more demanding in their requirements than envisioned when the Shuttle system requirements were delineated. This economical growth potential, coupled with the fundamentally new capabilities being introduced by the Shuttle for payload recovery and reuse, on-orbit construction, assembly, maintenance and repair and performance of other complex functions, is expected to result in an extended program lifetime. We can anticipate rapid evolutionary growth of operational space mission capabilities during this program lifetime."

The most intriguing extension of the Shuttle is an L-5er's dream come true — a passenger-carrying orbiter.

Yet to be determined, however, are specific space projects which would make these Shuttle design changes necessary. An encouraging sign is President Carter's space policy which does not preclude such Shuttle growth potential.

Leonard David is Director of Student Programs for the Forum for the Advancement of Students in Science and Technology (FASST).

NEWS BRIEFS

This summer the United Nations Committee on the Peaceful Uses of Outer Space will once again consider the Austrian draft of the proposed "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies". This draft of the treaty, if approved, may outlaw private enterprise use of the Moon or asteroids. At last year's June 26 through July 7 meeting on the treaty the U.S. delegation opposed those provisions. A new face that might show up in this year's round of negotiations is Kenneth S. Pedersen, recently named director of NASA's international affairs division.

Rockwell International was recently awarded a $1.9 billion contract to build two new space shuttle orbiters and refurbish two others. This cost-plus-award fee contract is one of the largest agreements in NASA's history.

UCLA is offering a 5 day course on "Space Shuttle - Payload Accomodations and Applications" June 18 - 22 at the University of Maryland University College. For details write to Registration Clerk, University of Maryland University College, Conferences and Institutes Division, University Blvd. at Adelphi Rd., College Park, MD 20742.

Boeing advanced planners are considering a private enterprise space shuttle operation.

The U.S. Dept. of Energy is sponsoring a conference on the impact of solar power satellites on astronomy May 23 and 24 at the Batelle Pacific Northwest Laboratory.

The Soyuz 33 craft launched April 10 failed to dock with the Salyut space station. Russian pilot Nikolay Rukavishnikov, 46, and Bulgarian copilot Georgi Ivanov, 48, reported a system failure in the maneuvering engine at approach. They made an emergency nightime landing 48 hours later, thanks to their Oms backup engine.

Ironically, the news of the aborted mission was broadcast on Soviet radio as fireworks were blasting in the sky in celebration of Cosmonaut Day, April 12. A total of 10 of the 27 Soyuz docking missions have failed. However, observers point out that this simply reflects a Soviet design philosophy that accepts high failure rates. The Soyuz 33 failure, while disappointing, is not a setback for the Soviet space program.

Funds to approve a 5th shuttle orbiter have been authorized by the U.S. Congress. The mothballed Enterprise may be outfitted for space, or, alternately, an entirely new orbiter may be built. The price tag for FY'80 will be $27 million.

The U.S Senate is expected to authorize $3 million for NASA's large space structures work. The Office of Management and Budget, Carter's penny pinching arm, has opposed the project.

Last year Rep. Richard C. Ottinger, (D-NY) was the major opponent of the unsuccessful push to appropriate $25 million for solar power satellite work. Stating, "My eyes have been opened," he has suggested that this year he may back the $25 million effort.

NASA's Marshall space center has awarded a $2.7 million solar array wing contract to Lockheed Missiles and Space Co. The solar array, measuring 105 x 13.5 feet will produce 12.5 kw. An experimental flight is scheduled for November 1980.

Announcements:

Conference for the 80s

An international futures convention, expected to be the largest ever held, will take place in Toronto, Canada, July 20-25, 1980. The event will be a combination of the Third General Assembly of the World Future Society and the fifth conference of the Canadian Association for Future Studies (CAFS). The theme of the meeting will be "Through the Eighties" with a focus on problems of world resources and common human values and goals for the near-term future.

Earlier themes of the World Future Society had a broader scope: "Dimensions of the Future" (1971) and "The Next 25 Years: Crisis and Opportunity" (1975). The current sharper focus on the decade ahead represents the general feeling that this will be a particularly crucial period of time. The 1980 conference committee stated: "As we enter the 1980s, the people of this world face more crises and problems than ever before. But the problems and dangers of the present should not blind us to the real progress that has been made or to the real opportunities which lie ahead."

Persons wishing to submit proposals for seminars, presentations or other participation in the conference should write to:

1980 Conference Committee
World Future Society
4916 St. Elmo Avenue
Washington, D.C. 20014, U.S.A.

Errata

A misquote appeared in the "Space Policy" article by Ken McCormick, **L-5 News,** March 1979. Dr. Frank Press was quoted as saying, "The era of 'one-shot spectaculars' is over, and the space program wll now proceed in an 'evolutionary' manner." Actually the only direct quotes from Press in this sentence were "one-shot spectacular" and "evolutionary;" the rest of the sentence was worded by the author.

Free Literature

NASA's Mailing List

Those persons interested in being placed on NASA's mailing list to receive the agency's News Releases can write to the following new address:

NASA
Public Information, LED-10
Washington, D.C. 20546

Lunar and Planetary Information Bulletin (formerly the Lunar Science Information Bulletin).

There are usually four issues per year, distributed free to lunar and planetary scientists, educators, students and their institutions.

Editor:
Frances B. Waranuis
Lunar and Planetary Institute
3303 NASA Road One
Houston, Texas 77058
(713) 488-5200, ext. 35

Air & Space Magazine

This magazine is published by the Smithsonian Institution's National Air and Space Museum and is issued bimonthly from September through May. Registration is free to individual educators, librarians, scientists and engineers interested in aerospace education, or affiliates of professional societies or non-profit organizations (such as L-5). Registration is permanent. State the reason that you qualify for free registration to:

National Air & Space Museum
Room 3569
The Smithsonian Institution
Washington, D.C. 20560

"Cities in the Sky"

The Robert J. Novens Planetarium of Ocean County College, New Jersey, is preseenting a program on space colonies entitled "Cities in the Sky." The show is set in the future and will "review" the first 100 years of space colonization and space manufacturing. The program will continue through June 24, and further information may be obtained by calling the planetarium at (201) 255-4144.

Your Ticket Into Space

Starlog/Future Life (S/FL) Magazines are pleased to announce that space is available aboard the first reusable vehicle into orbit—the Space Shuttle. S/FL has purchased room on the Shuttle, to be filled with a winning experiment or experiments from a nationwide "Getaway Special" contest now underway. In the current issue of **Future Life** (#10), now on sale at newstands, an informative article provides the best look yet at how to plan a project for the contest.

What pet idea, bright theory or burning question would you like to test in space? How will the zero-gravity of outer space affect biological processes? What new alloys might be created in the airless void above Earth's atmosphere?

The experiment(s) chosen will be fitted into a carefully designed container, which is attached inside the Shuttle cargo area for a round trip flight into space.

Who may enter? The opportunity is open to all individuals or groups regardless of planet of origin. Contestants can be students, professional biologists, artists, photographers, high school or college teachers, gardeners—anyone and everyone is eligible—with S/FL picking up the tab for the experiment's ride into space. The deadline is July 20, 1980.

To aid those submitting payload experiment ideas for consideration, S/FL, in cooperation with the Forum for the Advancement of Student in Science and Technology (FASST), is now offering a Space Starter Kit. The Kit includes information to acquaint contestants with the space "ground rules" for designing orbit-worthy experiments; a bibliography of selected space publications; a resource list of organizaitons and individuals who can help in designing ideas; update material on past and possible space experiments; and an overview of the Space Shuttle program and its various missions.

For the S/FL Space Starter Kit, and an entry form for the "Getaway Special" contest, send $3.00 to:

STARLOG/FUTURE LIFE
Getaway Special Starter Kit
475 Park Avenue South
New York, NY 10016

Inside the L-5 Society

New England L-5 on the Move!

The recently formed New England L-5 is starting out with a burst of activity. Their newsletter "Hubcap" reports preparations for Space Day and Space Week celebrations and the formation of a Liason Committee to establish relationships with outside groups and promote L-5 goals. Their chapter meetings have included such speakers as Dr. Arthur Kantrowitz, Dr. Philip Chapman and Mr. Christian Basler. The New England L-5 Chapter will soon be incorporated as a non-profit corporation in Massachusetts and will be electing officers. For information, contact:

Marcia Allen
29 Catherine Street
Roslindale, MA 02131

News Niagara Frontier

The Niagara Frontier L-5 Society has been accepted as an affiliate club of the Buffalo Museum of Science! We will have a public meeting the fourth Sunday of each month at the Museum. Come help us with exhibits, slide programs and our July Space Day celebration! Is there anyone out there in Albany? Ithaca? Potsdam? We'd like to share ideas, resources and moral support. Write to:

Mrs. Elissa Wynn
40 Kings Trail
Williamsville, N.Y. 14221
(716) 689-9140

L-5 in Miami

A miami chapter of L-5 is organizing! All those interested please call or write:

Miami L-5
c/o Ted Apelt
3010 NW 36 St. Ct. A135
Miami, FL 33142
(305) 633-2089

New Brunswick L-5

A new L-5 chapter has been formed in Fredericton, New Brunswick. The chapter is named Starover Fredericton and is an evolution of a newly formed science fiction and futurist club. The membership is diverse, ranging from junior high school students to professionals. For more information, contact the chapter coordinator:

Fred Brown
357 Montgomery Street
Frederickton, New Brunswick
Canada
E 3B 2X2
(506) 454-5319

Local Chapter Update

Flagstaff/NAU L-5 Society
Dr. Reed D. Riner, Faculty Advisor
Dept. of Anthropology
Box 15200
Northern Arizona University
Flagstaff, AZ 86011
Douglas Cosper, President
Jonh Benner, Vice President
Peter Hoffman, Secretary-Treasurer

Fresno L-5
36874 Cressman Rd.
Auberry, CA 93602
(209) 225-0768
Gale Smith, President
Eric Forster, Vice President
Chris Gudger, Secretary

Greater Phoenix L-5 Society
P.O. Box 635
Tempe, AZ 85281
Steven Mark Cohn, President
Katherine Blair Herman, Vice President
Katherine Blair Herman, Secretary
Steven Mark Cohn, Treasurer

L-5 Society Bay Area Chapter
814 Miramar Ave.
Berkeley, CA 94707
(415) 526-9346
Ross Millikan, President
David Brandt-Erichsen, Vice President
Jess Millikan, Secretary
Norm Albright, Treasurer

L-5 Society of Houston
P.O. Box 10161
Houston, TX 77206
(713) 491-1480/749-7555
Jimmy Rosamond, President
Dan Woodward, Vice President,
City Coordinator
Margaret Adamson, Secretary
Michael Pelizzari, Treasurer
Clifford Carley, U.H. Coordinator

L-5 Society of Texas
Box 8213, UT Station
Austin, TX 78712
Ron Nickel, President
John Strickland, Vice President
Joseph Vissers, Secretary
R. J. Howe, Treasurer
Claudia Crowley,
Communication Officer

Lehigh L-5
Box 441 Lehigh University
Bethlehem, PA 18015
(215) 691-6805
Pete Goldie, President
Barb Geekie, Vice President
Charles Peters, Secretary
George Lein, Treasurer

Niagara Frontier L-5 Society
40 Kings Trail
Williamsville, N.Y. 14221
(716) 689-9140
Elissa Wynn, Co-chairman
Michael Cooper, Co-chairman

OASIS
P.O. Box 704
Santa Monica, CA 90406
(213) 536-3209 (after 5 P.M.)
or (714) 554-0276
Terry C. Savage, President
Howard Gluckman, Vice President
Michael Thal, Treasurer
Charles Carr, Secretary

Raleigh L-5
Box 5381
Raleigh, N.C. 27650
(919) 779-2384
Tim Kattermann, Co-coordinator
Hubert Morris, Discussion/
Projects Chair

Space Futures Society
3059 Cedar St.
Philadelphia, PA 19134
(215) 739-7780 (after 7 P.M.)
Richard W. Bowers, President
Ron Smolin, Treasurer
Eric Laursen, Secretary

Upstate Space Alliance
78 Lattimore Rd.
Rochester, N.Y. 14620
B. Voris, President
Roy Craig, Vice President
DeWain Feller, Treasurer
Wendy Ng, Secretary

West European Branch L-5
45 Wedgewood Dr.
Poole, Dorset
BH14 8ES

United Kingdom
0202 730395 (phone UK)
Roger Sansom, Co-coordinator

The above chapters are officially affiliated with the L-5 Society. That is to say, they can legally make use of L-5's tax exempt status and nonprofit mail privileges. Also, a number of chapters not listed above operate under the aegis of some of these chapters and as a result also can take advantage of those privileges.

The following chapters are either recently formed, in the process of forming, or, by the time you get this list, may have already become officially affiliated groups.

Bristol, CT L-5
c/o Jordan D. March II
28 Trout Brook Rd.
Bristol, CT 06010

Finland L-5
c/o Ari Harenko
Valskarinkatu 1 B 43
00260 Helsinki 26
FINLAND

High Frontier Society
321 O.E.H.
University of Pittsburg
Pittsburg, PA 15260

L-5 Society, Boston Chapter
P.O. Box 162, Prudential Center
Boston, MA 02199

Maryland Alliance for
Space Colonization
c/o Gary Barnhard
4323 East-West Highway
Bethesda, MD 20742

Milwaukee L-5
3514 S. 17th St.
Milwaukee, WI 53221

New England L-5 Society
c/o Marcia Allen
29 Catherine St.
Roslindale, MA 02131

Blaine Atkins, President
Marsha Allen, Secretary
Mike Gerardi, Treasurer

North Carolina State L-5
c/o Robert Baldwin
Rt. 4 Box 121A
Waxhaw, N.C. 28173

Northwest L-5 Society
c/o Tom Buxton
928 18th Ave. W
Kirkland, WA 98033
or
c/o Hugh M. Kelso
550 Bellvue Way SE
Bellevue, WA 98004

Nova Scotia L-5 Society
c/o Dept. of Geography
Saint Mary's University
Halifax, N.S.
B3H 3C3 CANADA

Ohio L-5
c/o Steven Stein
570 Fairhill Dr.
Akron, OH 44313

Pioneer Valley/Five College Area L-5
c/o Eric Carlson
318 Lincoln Ave.
Amherst, MA 01002

Vancouver L-5
c/o Ms. Camile H. Dionne
51 S. Hendy Ave.
North Vancouver, B.C.
V7L 4C6 CANADA

VA Tech L-5
c/o Cindy Hartman, President
4038 West A. J.
V.P.I. & S. U.
Blacksburg, VA 24061

West Germany L-5
c/o Uli Lochner, Pfaffstr 16
7500 Karlsruhe 41
WEST GERMANY

Jacksonville L-5
c/o Prof. Jay S. Huebner
College of Arts & Sciences
U. of North Florida
Box 17074

Jacksonville L-5
c/o Professor Jay S. Huebner
College of Arts & Sciences
University of North Florida
Box 17074
Jacksonville, FL 32216

Hartfort, Connecticut L-5
c/o Jordan Marché
28 Trout Brook Dr.
Bristol, CT 06010

Letters

I enjoyed William Agosto's article on mining the Moon in the December issue. The thorough review in print of the possibilities and problems of mining and using lunar and asteroidal materials is the report of a 1977 summer study entitled "Summer Workshop on Near-Earth Resources," NASA Conference Publication 2031. Some copies are still available from Dr. Michael Duke, Johnson Space Center, Houston, Texas.

A number of related studies are now in progress, and some useful new documents can be expected to appear in 1979. There is a lot of room still for the technical creativy, before we have a chance to get to work.

James R. Arnold
La Jolla, CA

Please print this letter. I just finished reading O'Neill's **The High Frontier** and I have a question that needs to be answered.

O'Neill talks endlessly about swimming pools, lakes, large numbers of people growing plants, mining (which needs plenty of water) and manufacturing (also needs a great supply of water).

But nowhere in his book does he mention where all this water is going to come from to maintain these operations.

What are the costs of making it or transporting it?

Think of how much a modern city depends on a good supply of water?

San Francisco, for example has to buy water from the State of Idaho just to survive.

Being in space and being dehydrated doesn't sound very pleasant to me.

Rick Stoner
Longmont, CO

If lunar resources are used, hydrogen must be shipped from Earth and combined with lunar oxygen. If carbonaceous chondritic asteroids are used, water (up to several percent by weight) may be extracted by distillation. — CH

I find it strange that the November 1978 **L-5 News** article, "Russia's 'Guest Cosmonaut' Program", a commentary by Jim Oberg, questions the significance and purpose of the latest series of cosmonaut launchings. The purpose of this plan, at least as outlined by the U.S.S.R.'s Novosti press agency, is to develop a permanent space station accommodating 12 to 24 people by 1980. In view of no official U.S. plans for a permanent space station, and a manned space program dependent on the NASA space shuttle with flight periods of 7 to 30 days, I am concerned about your snubbing this Soviet effort.

According to information I have, which quotes East German sources, the Russian station would be assembled from modules by unmanned Soviet Progress "space tugs" which would be used to ferry goods into space. Cosmonauts would travel to space aboard the Kosmolyot, a re-usable spacecraft now in development, although present Soyuz-type manned craft would also continue in this operation. A 1980's Soviet space station could initially involve docking two Salyut stations nose to nose with a multiple docking adapter between them. Progress, Soyuz and Kosmolyot ferries could then dock at midship or at either end.

Aside from determining the threshold beyond which it may be unsafe to go, these long duration flights could be seeking data for medical purposes on such things as human muscle tone, the cardiovascular system, and loss of calcium from bones, which, in turn, will affect design of future space stations and the ferry craft. It is also reported that in their "space home cum laboratory" the cosmonauts have performed over 50 technological experiments to obtain semiconductors in the Splav and Kristall space furnaces. Making new materials of this nature under weightless conditions might be of particular importance to the electronics industry.

In addition to these activities, there are a couple of other significant items related to the Soviet flights which your article fails to mention or take into account. First, photos, for example, taken by Salyut 6 indicate a huge underground water reservoir in a now inhospitable desert area of Kayahlitan. Don't you think that this discovery might lead to large scale development in that region? Second, I wonder if you have thought of the possibility of our needing the Soviet "guest cosmonaut stunts" to save our own Skylab space station. Our space shuttle is expected to be making orbital missions by late 1979 but I understand Skylab's orbit might deteriorate before then. The Soviets have the hardware, the trained personnel, and apparently the budget commitment to rendezvous with Skylab and move it into safe orbit, if need be, before that time.

If we can use outer space as a means for peaceful cooperation among nations, we do not need articles demeaning such efforts.

William Mattison, President
Futuristics, Inc.
Glen Ridge, New Jersey

Read my article again, I have great respect for Soviet space technology and vision; I have contempt for political manipulation of space to deceive public opinion. The "guest cosmonauts", alas, seem to come from the latter motivation.
—Jim Oberg

I agree with Mr. Albanese (**L-5 News**, Dec. '78) that the ocean floor is a potential human habitat, but I think we'll be able to exploit it fully only after we have settlements in space. The vacuum of space is a warm environment, flooded with radiant energy. The ocean floor is dark and cold. Hence a settlement in space can be a net producer of energy, while an ocean-floor settlement would need to be tied in to some energy source.

Furthermore, space is utterly transparent. Its resources are on public display and may be prospected by anyone with eyes to see. The ocean floor is a murky mystery, with visibility often limited to a few meters. Locating and exploiting its undoubted mineral treasures is likely to remain an elusive goal for generations.

I think we may someday need temporary settlements on the ocean floor, like the motor homes used to house construction workers drilling oil in inaccessible places. The motivations for permanent undersea settlements are still obscure. I think it would be a mistake to divide our efforts between the sea and space, when the payoff from space is so clear and obvious and that from the sea is so moot.

Dick Crawford
Walnut Creek, CA

I have read the article by Hans Moravec concerning "Skyhooks" and anchored satellites (**L-5 News**, August, 1978) with great interest. However, in his article Mr. Moravec states that the "mass driver" concept does not offer any means by which payloads could be safely softlanded on the Moon or any other airless body. I can not accept that statement as correct. With a mass driver on the Moon and of sufficient capacity a payload can be launched to either L1,L2, L4 or L5 — or with the aid of a small rocket thruster for trajectory corrections, incorporated in the payload, into an orbit around the Moon. Simple ballistic analysis will show that the payload can just as easily travel in the opposite direction, i.e. from an orbit or from any of these Lagrangean points down to the "muzzle" of the mass driver. Since the Moon lacks an atmosphere and any gravity aberrations along the trajectories can be carefully measured, any trajectory disturbances would be few and small. Necessary trajectory corrections to counteract these disturbances and the scatter effect they cause could easily be provided by small rocket thrusters with great accuracy a system similar to the instrument landing system of aircrafts could be used, using beacons of microwaves or laser light as reference points. Similarly the initial launch down a trajectory of this kind could be made with very high accuracy using such a beacon as reference point. The payloads would, so to speak, home in to the mass driver like a "smart bomb". The mass driver would then work as an electrical generator to brake the speed of the incoming payload. The payloads and therefore the drivers would have to be of fairly large size of course and in the case of orbiting payloads the "landing mass driver" will have to point in the opposite direction relative to the launcher.

Doktor Claes-Gustaf Nordquist
Stockholm, Sweden

Your proposal is, of course, correct. My statement that the lunar mass driver provides no way of bringing payloads in was too dogmatic. I meant that the driver, as proposed, has no provision for slowing them down.

I do feel the practical difficulties are considerably higher for an electromagnetic catcher than for a skyhook transporter. Firstly, as you point out, the current proposals for lunar mass drivers, with 50 kg payload units and 1000 gravities of acceleration, would have to be scaled up considerably, making the total size very large. Secondly, the high accelerations would restrict the nature of the payload. Finally, the rendezvous with the end is at a relative velocity of 2.5 km/sec, and the required precision is very high, so the guidance will be difficult and the consequences of a miss occasionally very serious.

An optimum size Kevlar skyhook, on the other hand, masses only 13 times as much as its payload, and generates a maximum of 1/2 gravity. The rendezvous velocities are near zero. On the negative side, a skyhook sweeps out a large orbital area, and provides plenty of opportunities for collisions. Such a collision might be disastrous for the skyhook's payload.

A few picky details: regenerative braking is difficult enough that an electromagnetic decelerator might actually consume net electrical energy. The wasted power would show up as eddy current heating in various conductive parts, and resistive heat in the magnet coils and drivers. The inertial path from the Moon to L4 or L5 is not the same as the path in the reverse direction. To move from the Moon to L5, an object must temporarily move to a higher orbit than the Moon. To go from L5 to the Moon, it must temporarily drop to a lower orbit. This means the angles of arrival and departure are different at both ends.

The transportation problems in space are so ubiquitous and so varied that I'm sure most of the methods so far proposed (and many yet to be invented) will be used sooner or later.

Sincerely,
Hans Moravec
Stanford, California