

# FOUNDATION REPORT:

ADVANCES IN COMMERCIAL AND GENERAL SPACE DEVELOPMENTS

## LASER AIRCRAFT PROPULSION PROPOSAL ADVANCED

Two University of Washington researchers have proposed a laser-powered aircraft concept at the recent conference on Radiation Energy Conversion at the NASA Ames Research Center, Moffett Field, California.

The proposal, advanced by Abraham Hertzberg and Kenneth Sun, suggests using a high energy continuous wave carbon dioxide laser beam from a power satellite in geosynchronous orbit to power a commercial airliner during the cruise portion of its flight. The study indicates that a laser-powered aircraft is a nearly fuelless and pollution free transportation system which is cost competitive with the fuel conservative air transport of the future.

The laser flight system requires the modification of conventional kerosene fueled aircraft. A pair of laser driven turbofans, fabricated with existing or projected technology, would receive laser light generated by an orbiting solar power satellite. The cost of the satellite, they point out, is the dominant system cost.

### Fuel Conservative Aircraft

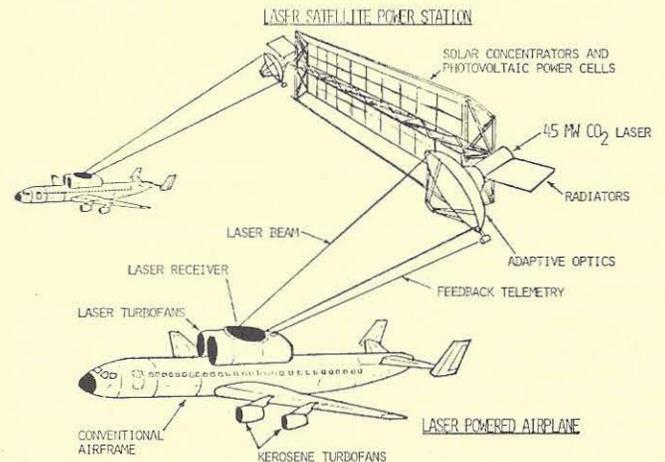
Even with advanced aerodynamic design and propulsion systems, the fuel conservative aircraft of the future will still consume large amounts of kerosene fuel. A typical transcontinental mission, for example, will require a fuel mass greater than that of the payload mass. The potentially very high cost of kerosene in the foreseeable future suggests equally high transportation costs, leading to a situation where it becomes difficult to economically justify the large initial capital expenditure for new fuel conservative aircraft in the first place.

A promising approach to this problem is the concept of a laser-powered airplane. Advances in the state-of-the-art with high power lasers, and the interest and developments with large space structure, now make the study of laser-powered aircraft possible.

Previous studies have been conducted by Hertzberg, R. Weber at the NASA Lewis Research Center, and by Ivan Bekey at Aerospace Corporation in El Segundo, California. In Bekey's study, the power for the lasers was beamed from nuclear power plants on the ground, and reflected to aircraft in flight by means of low altitude orbital mirrors. The other studies assume the use of orbital power stations to provide the electrical energy.

Hertzberg and Sun suggest the use of only presently available technology: all their systems are modifications of existing designs. The aircraft they studied was the Boeing "Terminal Area Compatible/Energy" (TAC/E) aircraft, and the laser satellite is modeled on the design developed by the Johnson Space Flight Center for supplying electrical energy to the ground. They emphasize that no optimization of design parameters has been done. Optimization would tend to make the project more feasible from both a cost and technology standpoint.

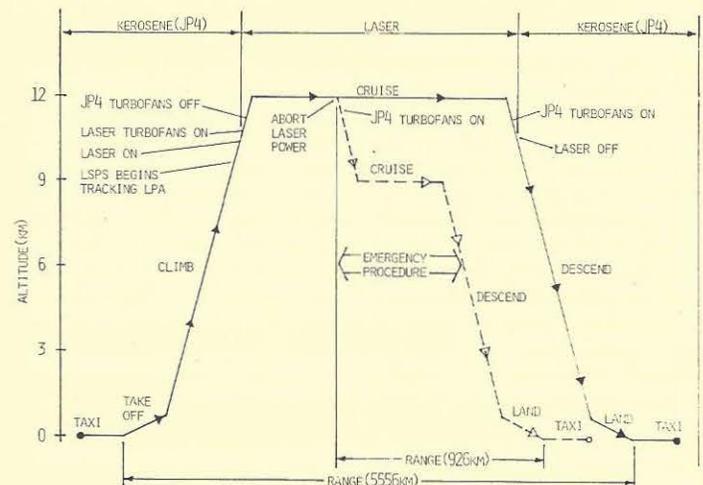
The Laser Powered Flight Transportation System proposed by two University of Washington scientists. A feedback laser system keeps the primary beam centered on the aircraft during flight. All illustrations in this article courtesy of Dr. Abraham Hertzberg, University of Washington.



The University of Washington researchers point out that their study shows a fuel saving of 21,800 kilograms of kerosene for a 5600 km mission model using the laser for cruise propulsion. Without the laser turbofans, and with only conventional kerosene engines, 29,800 kilograms of kerosene are burnt on the same mission, versus 8,000 kilograms for the laser system.

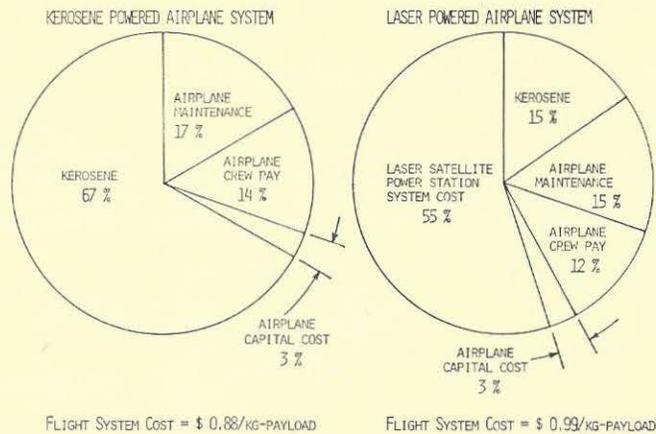
The cost effectiveness for the laser system is dependent on the cost of kerosene. Using preliminary design information, and no optimization, Hertzberg and Sun found the break-even fuel cost to be \$1.15/gallon (\$0.30/liter) for a 30 lifetime and a 5600 km mission model. If the model range was extended to 7400 km, the cost for breakeven fuel would be \$0.84/gallon (\$0.22/liter). Kerosene is now at \$0.72/gallon.

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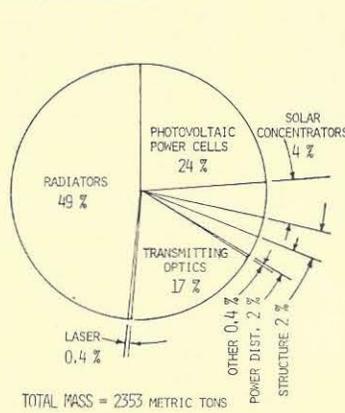


The Laser Powered Airplane Flight Profile. In the event of a laser failure, the aircraft would have sufficient kerosene reserves to fly 926 km.

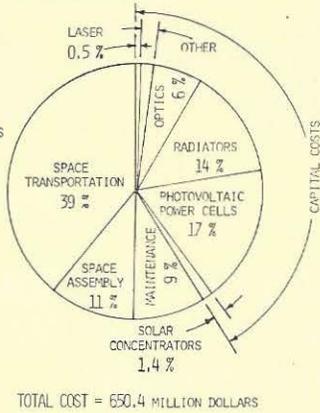
Flight Transportation System Cost Distribution (at \$0.26/liter fuel cost).



MASS DISTRIBUTION



COST DISTRIBUTION



Laser Satellite Power Station Mass and Cost Distribution.

Laser Turbofan

Key to the proposal is the laser-powered turbofan. A relatively large but conventional fan, compressor and turbine are employed, but in place of the combustion chamber, a heat exchanger is installed. This heat exchanger captures laser radiation beamed from the orbiting satellite and converts it to heat.

The laser receiver which focuses the laser energy on the heat exchanger is five meters in diameter and consumes about 20 Megawatts of laser-power to maintain the aircraft in a cruise flight regime.

Laser Safety and Environment

If the laser beam misses the aircraft, about 49% of the transmitted laser radiation could reach the ground. At the first analysis, accurate tracking of the aircraft appears necessary to prevent overexposure of people on the ground to the beam. Part of the problem may be alleviated by choosing a laser frequency which is heavily absorbed in the lower reaches of the atmosphere, but can propagate to the 1200 meter aircraft cruise altitude relatively unabsorbed.

The authors point out that the airplane will cause no damage to the environment due to the lack of a fuel. Thus the usual combustion products of nitrous oxides and carbon dioxide are absent. Additionally, the laser frequency is such that there will be no significant interaction with the ozone layer.

Cost of Implementation

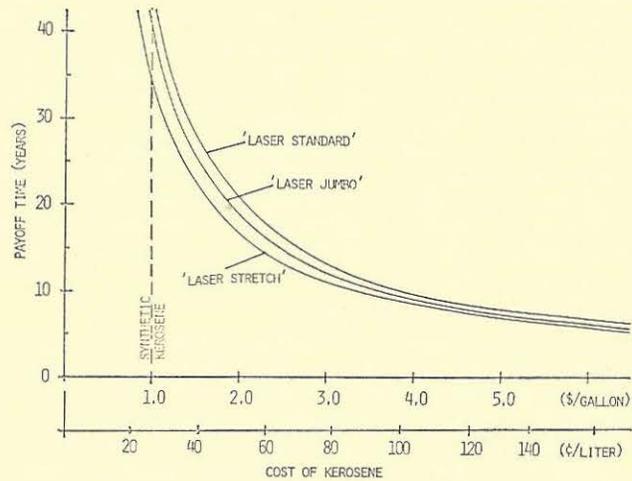
Costs for the project were based on NASA cost models for solar power stations deployed to geosynchronous orbit, and on standard industry procedures. Using these figures, which will naturally give an inflated view of the space based side of the project expenses, the authors determined that a slightly optimized aircraft, which they call the Laser Stretch version, gives the most reasonable payoff in dollars and years. They calculate that 35 years is a practical payoff time when kerosene cost is \$1.00/gallon. Additionally, they show that the best payback is achieved when the aircraft is configured for maximum payload.

The project will payback the amount of energy necessary to establish the stations in orbit in about 3 years.

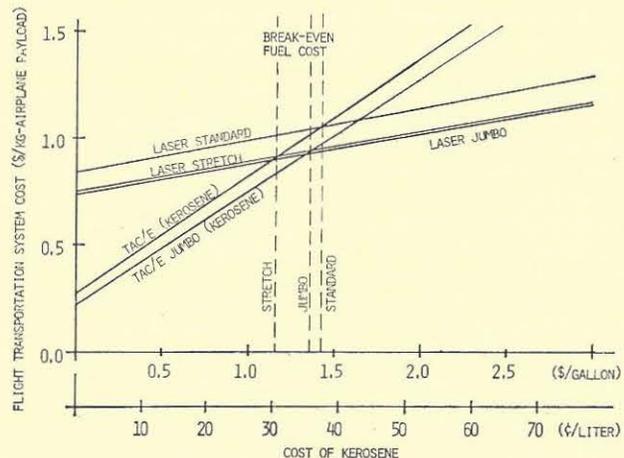
Conclusions

Hertzberg and Sun offer the following conclusions to their study:

- A laser-powered turbofan aircraft of unlimited range is feasible with existing technology.



Laser Powered Airplane Flight System Payoff Time.



Flight Transportation System Cost and Breakeven Fuel Cost.

- A Laser Satellite Power Station can be constructed in space using the Carbon Dioxide laser at reasonable cost with existing technology.

- While the required laser pointing and tracking accuracies are technically feasible, the requirements push the state-of-the-art.

- Within the accuracies of the analysis the cost of the laser airplane is economically competitive with an advanced kerosene airplane system.

- The dominant cost of the laser-powered flight transportation system is the laser Satellite Power Station cost.

- The laser flight system has an energy payback of less than three years.

- The laser-powered airplane has minimal environmental impact.

The authors conclude by suggesting that a more detailed study of a laser flight transportation system be undertaken, with special emphasis on the optimization of the overall system.

## **SATELLITE MIRROR SYSTEM PROPOSED FOR TERRESTRIAL POWER AUGMENTATION**

A system of orbiting reflectors, dubbed SOLARES, has been suggested as a possible means of providing terrestrial power using a space system of minimum mass and complexity. The key economic impact of such a system is that it can provide continuous sunlight concentrated on solar power farms located on the earth's surface, rather than in space. With this scheme, only light-weight, simple mirrors need be orbited, reducing the need for large masses to be lifted into orbit at great expense. The system seems to be compatible with a step-by-step incremental implementation, yet can be continually expanded to provide all of the power needs of the world in a few decades.

The idea was discussed by Kenneth W. Billman, and William P. Gilbreath, NASA researchers—and Stuart W.

*Continued on page 16.*

## **THIRD CONFERENCE ON RADIATION ENERGY CONVERSION**

The Third NASA Conference on Radiation Energy Conversion was held January 26-28 at the NASA Ames Research Center, Moffett Field, California. More than one hundred scientists and engineers attended the meeting, which was chaired by Kenneth W. Billman, a NASA researcher.

A wide variety of papers dealing with lasers, solar power, and radiation chemistry topics were discussed, including some novel applications of these technologies. (See for example the two conference reports in this issue of the REPORT.)

One novel concept presented at the conference was an alternative method for the conversion of solar energy into electrical power. The method consists of placing in earth orbit a very large magnetic bottle in which a solar-energy-

absorbing plasma is confined. Energy is continuously extracted from the plasma and is beamed to earth via laser or microwave beams. The principle advantage to this system, authors Craig T. Walters and George Wolken, Jr. (Battelle Columbus Laboratories) point out, is the low susceptibility of the plasma solar collector to degradation in the space environment. Additionally, there is a high ratio of collection area to overall system mass.

One of the most important papers from a commercial standpoint was presented by Jaan Jurisson of Honeywell. Titled "A Multicolor Solar Cell Power System for Space", it discusses recent Honeywell work in solar cell improvement. Present cells are from 5 to 15% efficient in converting light to electrical power. By using a concentrating multicolor solar cell which is responsive to the ultraviolet and infrared wavelengths of the sun's output, about 30% efficiency could be achieved. Such a development could significantly affect the economics of solar power stations in orbit.

A proceedings of all presented papers will be published by the American Institute for Aeronautics and Astronautics in the next few months.

## **SUNSAT COUNCIL AIM TO LOBBY**

A new organization, known as the Sunsat Council, has been formed to promote the concept of Satellite Solar Power Stations. Arranged by Dr. Peter Glaser (originator of the SSPS concept), and supported by major aerospace corporations, construction firms and research organizations, the object of the Council is to inform the Congress, industry, and the public of the benefits that can be derived from large scale implementation of space solar power and to encourage demonstration of its commercial validity.

At a recent February 7 meeting, the Council decided to charter itself as a non-profit corporation and to begin the process of nominating directors and settling membership questions. Additionally, there was discussion of House Bill HR-10601, which has been introduced by Rep. Olin Teague (D-Texas) who is Chairman of the Science and Technology Committee of the U.S. House of Representatives. HR-10601 directs the Department of Energy to build, operate and eval-

uate a demonstration Solar Power Station. According to the bill's language, DOE will build and operate the satellite, while NASA will provide the transportation system which would deliver components to earth orbit. Hearings should begin before the 8th of March, and a companion bill is planned for introduction in the Senate. The consensus of the Council is that the bill will pass unless the Department of Energy actively fights the measure.

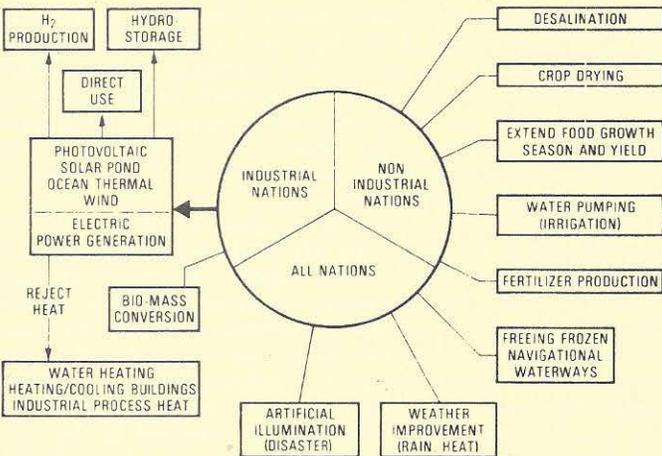
The Council believes that the greatest problems with the development of the SSPS idea will not be technical ones, but rather will revolve around the political issues of environmental questions of microwave safety as perceived by the public, and over the question of centralized vs. decentralized power production. However, as the representative of Southern California Edison pointed out, independent research has shown that solar power from space is the only alternative that could fill the electricity shortfall expected by the utilities after the year 2020. The representative from Boeing outlined cost figures which appeared to show a cost of \$1,700 per installed kilowatt for SSPS, as compared with the \$1,400 per kilowatt now needed to build nuclear power reactors.

Bowen, a consulting aerospace engineer, at the Third NASA Conference on Radiation Energy Conversion in California. They show that the use of ground based solar power alternatives has been retarded due to the unfavorable economics of solar farming as compared with fossil or nuclear power plants. Among the most difficult problems faced by the ground based solar option is the low solar energy density available at most sites, variation in the density with the seasons, cloud obscuration, and the lack of 24 hour sunlight. The latter problem requires expensive storage facilities for nighttime power demands.

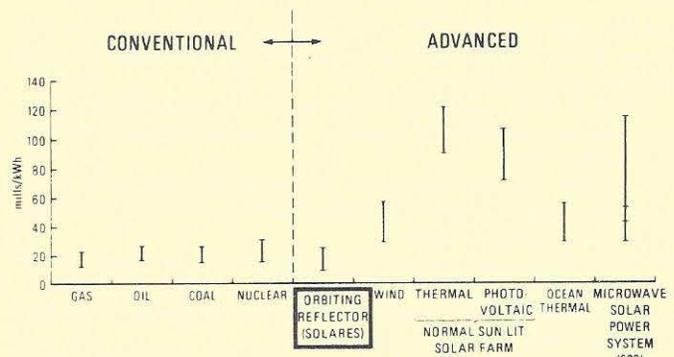
SOLARES offers a means to eliminate these problems, according to the authors. Specifically, the power density falling on ground-based solar farms could be raised from the average ¼ kilowatt per square meter to a full kilowatt. According to their calculations, this will tend to reduce the amount of land, capital costs and other area-related parameters by a factor of five for an average solar farm. The advantage of full time vs. part time sunlight has been worked into the study.

Where would the mirrors be located for maximum positive results? After dismissing geosynchronous orbit due to the excessively large round area illuminated (about the size of the state of Vermont), the authors considered a number of orbits from 1000 km altitude to about 4000 km. Choice of a particular orbit will have to be determined according to complex calculations for ground illumination spot size, amount of sunlight required and so on. While the total amount of mirror surface is very large, it is not inconsistent with the requirement to provide power for the total world needs. For example, using a 1685 km orbit inclined to the equator at 45 degrees, 21,000 square kilometers of mirror are needed. These mirrors would illuminate 35 ground stations of 200 square kilometers each, producing 40% of the total world power supply (assumed to be 800 GigaWatts Electric for 1977). While the capital cost would be 188 billion dollars, the electrical energy cost would be only 13 mills/kilowatt hour, which is less than most electrical power cost today.

Besides the production of electrical power, the SOLARES system has the advantage of being able to provide sunlight for the growing of crops and other agrarian uses, including crop drying and desalination. This means that sunlight could be used for power and process heat in the developed nations, and for food and water production in the less developed countries of the world. This multiple use feature of SOLARES, along with its incremental implementation, are the most appealing arguments in its favor. Finally, the authors state that the investment by the U.S. in this form of power system would ultimately allow our nation to regain its former position as an energy exporter, rather than continue to rely on foreign energy import.



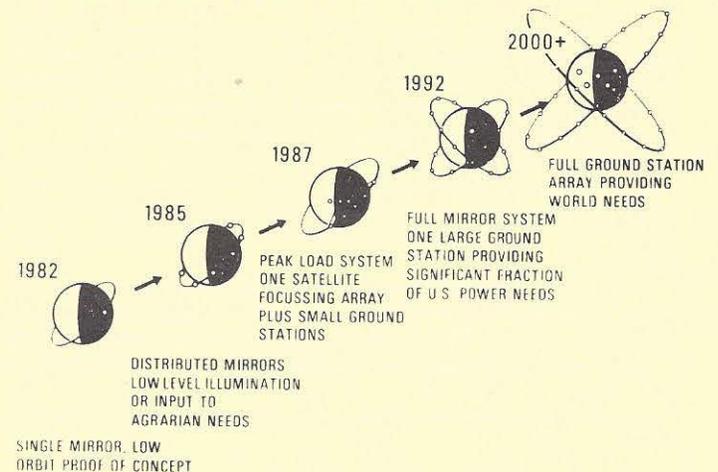
SOLARES has multiple applications besides the generation of electrical power. This, along with its incremental approach, is an appealing commercial argument.



Comparison of Estimated Energy Cost from SOLARES with Conventional Sources and Other Advanced Systems.

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- ↑
- CONSERVE FOSSIL FUELS FOR NON-ELECTRICAL NEEDS
- USE ELECTRICITY FOR NEW USES NOW ONLY PROVIDED BY FOSSIL FUELS
- POSSIBLE WEATHER IMPROVEMENT
- LAND USAGE (INVESTMENT TO FUTURE LAND CONSERVATION?)
- PHOTOCHEMISTRY
- SENSIBLE HEAT RELEASE
- SPACE TRANSPORTATION POLLUTANTS
- LIGHT GLINT AND SCATTERING
- } DECREASE CHEMICAL POLLUTION DUE TO MINING, TRANSPORTING AND BURNING FOSSIL FUELS

Range of environmental impact of SOLARES. The authors conclude the environmental effects are more positive than negative.



SOLARES can be implemented incrementally. Here, in a technology-paced scenario, SOLARES is shown developed to its full potential of providing electrical energy and power to the whole planet.

## SPACE-RELATED FACILITIES PROPOSED BY SPACEPORT ENTERPRISES

A group of international centers for space-related activities has been proposed by Spaceport Enterprises, Inc., a California firm. The first center, Spaceport Alpha, is to be located in the U.S. Southwest. It is planned as a complex comprising a large hotel, a convention center and a space center. Most activities of the complex will be housed in the Delta Ring, a large circular building of advanced design.

Spaceport Alpha will be a simulation and prototype of

operational terrestrial spaceports and space stations of the future. Subsequent projects are being planned as elements of actual space operations. One such design is being considered as a major component of the World Space Center, proposed by the Sabre Foundation as the centerpiece of its Earthport project.

The SEI group see Alpha as a public attraction which will strongly promote the development of space industry, commerce and technology. Its activities are aimed at increasing public awareness of the potential of space and at building support for public and private space ventures.

Alpha and other centers being planned by SEI will be both public interest attractions and space forums. They will provide an interface between space science and space arts and between the public and the new generation of space professionals.

The Delta Ring structure will be one of the first terrestrial major buildings to utilize aerospace technology—in computer-aided design systems such as NASTRAN and ANSYS; in prefabrication methods; in new high-strength, low-weight materials; in highly efficient insulation; and in electrical energy supply, use and storage systems. As in many space station proposals, the main volume is contained by a clear-span space shell. Rooms will be completely prefabricated and “plugged in” within the shell. Utilities will be carried in easily accessible chases. Ecological innovations will include water recycling and cisterns, closed environment food production and a system of low-energy demand appliances. The architecture and technical systems at Alpha will incorporate concepts of space planning being developed by NASA and other space agencies.

The Convention Center is planned particularly for use by aerospace, electronics and other high technology industries, by science and education groups and by special interest groups such as computer and space enthusiasts. This facility will be ahead-of-the-art in rapid, facile handling of large numbers of guests and vehicles, in delivery and storage capabilities, in technical workshops, in communication cen-

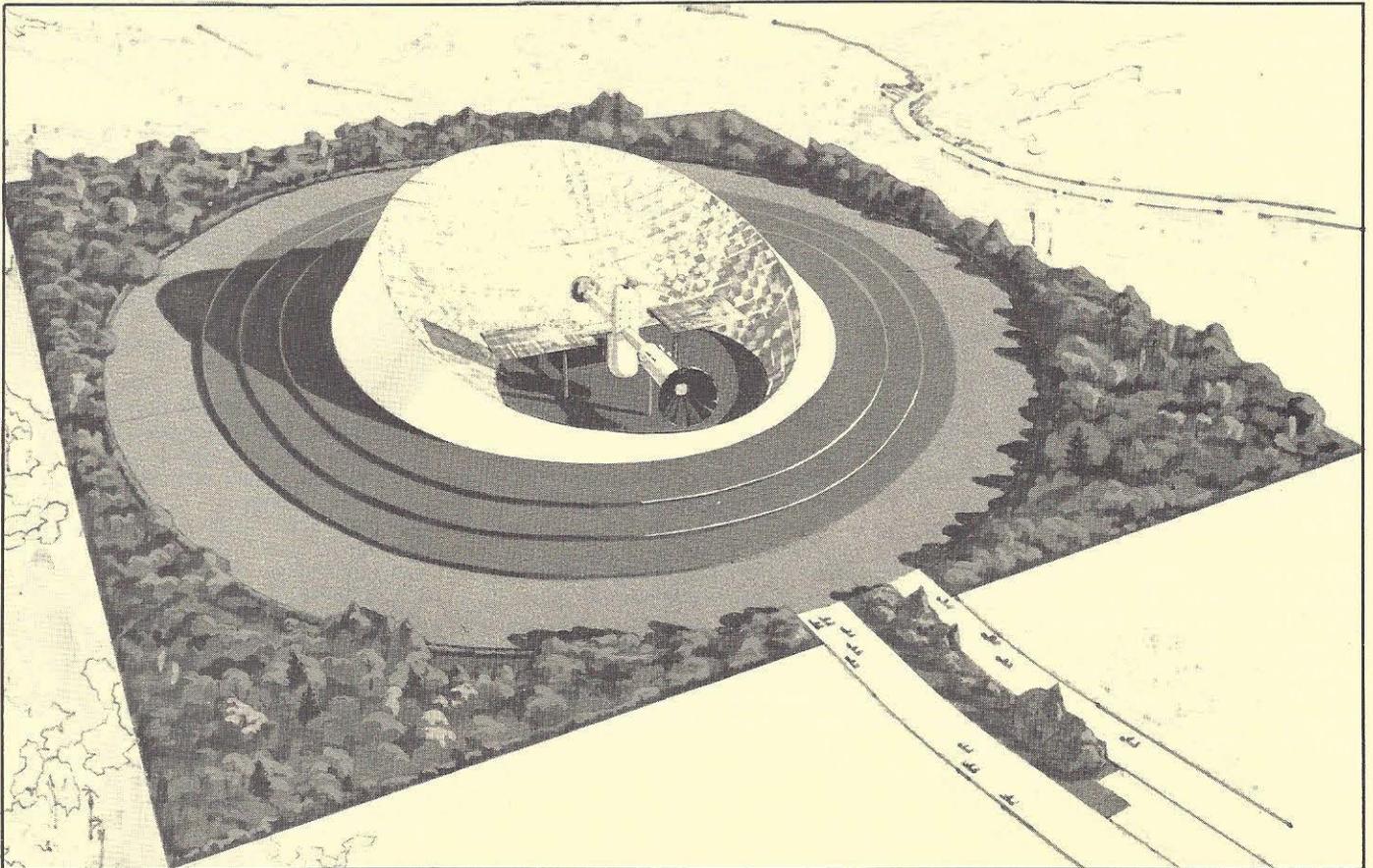
ters and in automated systems.

Spaceport Alpha's Space Center will be a public service attraction offering both educational and amusement functions. It will have three elements, a Museum of Space Science and Technology, a Museum of Space Arts and a Space Academy. The Space Science and Technology Museum will feature exhibits of past, present and future activities of NASA, ESA and other international, national and private space agencies. Proposals for space exploration, industrialization and research will be shown. The Space Arts Museum will spotlight Science Fiction classics in all media and new art forms on space themes. Initially, the Space Academy will be limited to supplementary education in space activities for students aged 8 to 18, leading toward space careers. University courses in various space professions may be instituted at a later date.

SEI plans completion of Alpha during 1980-81, with similar facilities envisaged for the U.S. eastern seaboard, western Europe and Japan in the following five years. Technical and operational expertise developed in these first Spaceport complexes would be applicable to actual future space operations. In this second stage, the SEI physical, technical and operational systems would support and facilitate international commercial, industrial and scientific space programs. The SEI systems would be developed particularly for public participation space projects.

For information contact:  
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Santa Barbara, CA, USA 93105  
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The illustration shows the Delta Ring, a structure designed by Spaceport Enterprises Inc., a California group, to house Spaceport Alpha, a proposed hotel, convention and space center complex. *Artwork by James McMenamin, Spaceport Enterprises Inc. copyright 1977.*



# news notes...

**WORLD SPACE CENTER...Santa Barbara...**The Earthport Project has completed an informational brochure on its proposed World Space Center. Earthport Project Executive Director Mark Frazier reports that the revenues generated by lease of Earthport land could fund the Center to a level of \$125 million a year. The Center would consist of an Earthport Users Fund, an International Space Agency, and an Institute for Space Research. The aim of the Center would be to promote commercial development in space and to provide a means for developing nations to participate in space activities. The brochure is available from Earthport Project, 221 West Carrillo St., Santa Barbara, CA 93101.

**SPACE PROCESSING BIBLIOGRAPHY...Huntsville...**The Marshall Space Flight Center has available a 167 page bibliography on Space Processing Applications. Containing annotated listings of all papers dealing with the subject of space processing, the document is an invaluable aid for those planning entry into this field. Available from the Space Processing Applications Task Team, PF11, Marshall Space Flight Center, Huntsville, AL 35812.

**MATERIALS PROCESSING IN SPACE...**The Final Report of the NASA/ASEE Summer Faculty Fellowship Program conducted by the College of Engineering, University of Alabama has been released. Titled Planning for Materials Processing in Space, the report was produced under the direction of Dr. Russell E. Lueg, Professor, University of Alabama and Mr. Mathias P. Siebel, Space Sciences Laboratory, Marshall Space Flight Center. The report addresses the planning and management questions, from a NASA perspective, surrounding operations of both large and small scale space manufacturing.

**AAS GODDARD MEETING...Washington...**The Goddard Memorial Symposium will be held in Washington, D.C. March 8, 9, and 10 with the theme: Space Shuttle and SpaceLab Utilization. Among the two sessions which promise to be most interesting are "Financing Space Ventures" with Russell Hensley of Aetna Life and Casualty, and Fritz Rudolf of Dresdner Bank in Düsseldorf, plus "After the Shuttle: What's Next". The latter will be a panel discussion including Charles Sheffield of Earth Satellite Corporation, and Dr. Jerry Pournelle, author. For more information, contact the American Astronautical Society, c/o Martin Marietta Aerospace, Phone: (301) 687-3800, Extension 2201.

**SHUTTLE COLLOQUIUM...San Diego...**A one-half day colloquium for Space Shuttle payload designers will be held on April 23 at the Town and Country Hotel in San Diego. Conducted by J. Mike Smith and George Baker, NASA, it will focus on buying Shuttle launches and designing within Shuttle limitations. A colloquium on Communications Satellites will be held the same day. For further information, contact Mr. Walter Morgan of COMSAT Laboratories, Box 115, Clarksburg, MD 20734 or call him at (301) 428-4000.

**SPACELAB COURSE...Maryland...**A Space Experimenter's Workshop will be held at the University of Maryland from April 17-21. For information regarding the technical content of the workshop, contact Hap Hazard at (213) 643-1648. A brochure is available from Judith Orth, Administrative Coordinator, Univ. of Maryland, University College Conferences & Institutes Dept., University Blvd at Adelphi Road, College Park, MD 20742. Phone: (301) 454-2537.

## FAIRCHILD SELECTED FOR LANDSAT-D

NASA has selected Fairchild Space and Electronics Co. of Germantown, Md., for negotiation of a fixed-price incentive contract to integrate, test and provide two Multimission Modular Spacecraft.

The MMSs will be the basic spacecraft buses for the Landsat-D flight spacecraft (to be placed in orbit in 1981 aboard a McDonnell-Douglas Delta) and a backup. The other elements of this spacecraft are to be obtained under separate contracts. The new spacecraft is to be an advanced version of Landsats 1 and 2, now in orbit and surveying the Earth's surface to obtain data useful to agriculture, forestry, geology and other fields.

The Report is published monthly, and has a subscription price of \$20 per year (\$15 per year for students, \$25 per year for institutional and library subscriptions and \$25 per year for overseas airmail). Back issues are available at \$2 each from September, 1977. Xerographic copies may be substituted as stocks are depleted. Address all correspondence to Foundation, 85 East Geranium Avenue, St. Paul, MN 55117 or call (612) 489-4466. Editorial Direction: Gary C. Hudson; Special Assistance: Resident Fellows E. Anne Roebke and T.A. Brosz; Staff Artist: David Egge. The Foundation Report accepts VISA/BankAmericard and Master Charge. Please give us your full credit card number, expiration date, and the four digit Interbank number (Master Charge only). Your signature is also required on mail orders. Phone orders accepted at (612) 489-4466. No collect calls please.

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