The Care and Feeding of Spacemen

by James A. Lockhart
Research fellow in biology

Travel in the vast distances of outer space will require journeys lasting for many years. Even exploration of our distant planets will probably involve a matter of years (reminiscent of the early explorations of our globe). A low-energy, long-burning ion propulsion system may be one of the most efficient and effective for space travel, at least in certain cases. Such a system might take perhaps 90 days to acquire sufficient momentum to escape from the earth's gravitational field after being placed in orbit by conventional propulsion. Certainly, long travel times will require providing food and oxygen in prodigious quantities. Manned satellite platforms and manned stations on the moon and nearby planets also will require large amounts of food and oxygen.

For flights of short duration it will be most economical, of course, to carry along prepared food, but when it is necessary to remain out of contact with the earth for long periods of time it will undoubtedly be essential to grow it on the vehicle.

On a space vehicle or on a lunar or planetary station we must be prepared to establish what amounts to a balanced terrarium. This consists of a system (shown at the right) in which no matter is gained or lost. Only energy, in the form of radiant (light) energy from the sun, is added, and only heat is given off. The animal portion of the system will, of course, consist of man. The plant, or synthetic, portion of the system would appear to be best satisfied by the use of algae.

The principle thing an adult must get from his diet is energy. The energy is gained through the oxidation of carbohydrates in food with molecular oxygen from the air, yielding carbon dioxide which is then expelled back into the atmosphere. The protein intake is balanced by the output of degraded nitrogen products and this is true of the various other dietary requirements, including vitamins and minerals as well.

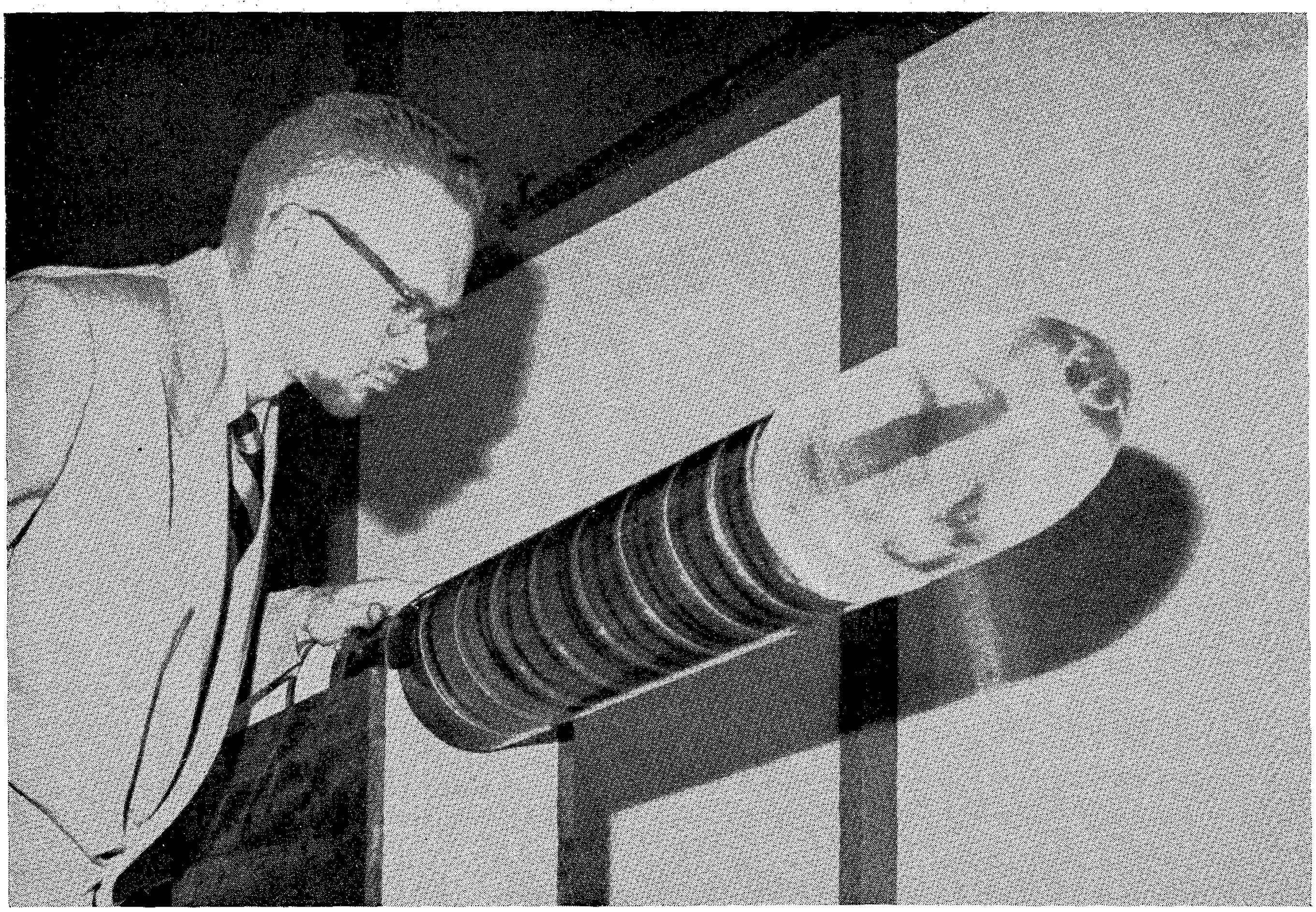
Plants, in turn, patiently utilize solar radiant energy to again reduce the carbon dioxide produced by man. In addition to carbon dioxide, the plants require only a cozy, comfortable place to work and an occasional boost by mineral nutrients.

There appears to be little doubt that the plant chosen will be one or more species of unicellular algae. While algae are not, by their nature, any more efficient than land plants, they do possess properties which make them readily adaptable to uses such as this. The algae grow in a liquid system where automatic fertilization and harvesting would be easy. They consume a minimum of space and may be readily handled even in a zero gravity field.

This balanced system would consist of a series of clear plastic greenhouses surrounding the vehicle, through which the algae are pumped while carrying on their photosynthesis. Inside the greenhouse cham-

A BALANCED BIOLOGICAL SYSTEM

Man:	Carbohydrate + oxygen	Carbon dioxide + metabolic energy
Plants:	Carbon dioxide + radiant energy	Carbohydrate + oxygen
Net Balanced System	Radiant energy	metabolic energy



James A. Lockhart, research fellow in biology, and a model of his space ship for gracious living. The dark bands which surround the vehicle are plastic greenhouses where algae are grown to provide food and oxygen.

bers will be small tubes, permeable to oxygen and carbon dioxide (but impermeable to water) to provide a supply of raw materials to the algae in the form of carbon dioxide and to draw off the waste gas (oxygen). Monitors would periodically test the cultures for an adequate supply of the essential nutrients and inject any found lacking. When an algae culture approaches an optimum concentration it would be pumped to a continuous-flow centrifuge where it would be collected and processed to an edible form.

Algae have an additional advantage. They can be made to produce a preponderance of carbohydrates, protein, or fats, depending on the cultural conditions. The nutritional components, then, may be modified at will to satisfy the requirements and desires of the crew. Furthermore, the whole plant is edible. It would be unnecessary to discard large amounts of inedible roots and stems as we do with most higher plants.

The critical question then becomes how much surface area would be required per person in such a steady-state system. The necessary information is already available to calculate the approximate area required. About 3,000 calories are required for an average man per day, including a necessity for at least 2 ounces of protein. Just 2.2 pounds of algae contain the equivalent of this daily requirement, with a large excess of protein.

We can, at present, grow algae on a small scale with a productivity of about 3 ounces per square yard per day and it is quite reasonable to assume that such yields will be possible on the scale needed for space vehicles. At a rate of 3 ounces per square yard per day, it would require 12 square yards of illuminated surface per person. It is also quite possible that the productivity of the algae may be increased by about a factor of two or even more in the future. This would be very important since radiant energy decreases markedly (as the square of the distance) as we move farther from the sun. The ratio of greenhouses to men will define how much farther from the sun we can venture with any given photosynthetic efficiency.

It will probably be necessary to design different types of vehicles to explore and travel in different regions of the planetary system. For travel to Mars and other planets nearer the sun a relatively smaller area of greenhouses will be required, while the problems of radiation and over-heating will be severe. When traveling further away from the sun the greenhouses will have to be large, perhaps unfolding after they escape from the earth's atmosphere to intercept more of the relatively low-intensity radiation. Greater provision will presumably have to be made for heating and less for cooling the vehicle. The techniques of agriculture will also have to be modified, to make maximum use of all the radiation which can be intercepted. If highly efficient energy-generating systems (nuclear-powered) are available it might be feasible to provide artificial illumination for photosynthesis instead of relying on the sun, and thus extend the potential range of the vehicles indefinitely into space, beyond our solar system.

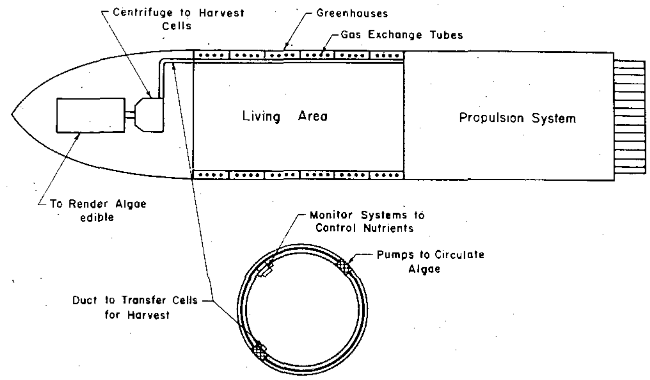
Vehicles may be designed specifically for "colonization" of the moon or one of the planets. Again, a greenhouse shell would probably surround the vehicle. In this case it would be designed so that it could be unwrapped after landing, and laid out in a sunny spot for operation. The living-quarters section could be equipped with crawler tracks for surface movement, and would return periodically to the greenhouse for food and oxygen. Whether individuals would be able to leave the pressurized cabin would depend upon the pressure equipment available. In any case, the people would be almost completely dependent on the greenhouse installation.

Algae absorb much more energy than they can utilize for photosynthesis. The rest of the energy is converted into heat, which must be dissipated to maintain a desirable temperature. The only way to get rid of this heat is to reradiate it in the form of infrared waves, just as the sun does.

Since the earth is successful in maintaining a temperature optimum for living creatures by reradiation, our vehicle should have little trouble at about this same distance from the sun. However, it must be recalled that the atmosphere of the earth prevents much of the sun's energy from reaching the surface, especially the ultraviolet and infrared. It may be expected that a desirable temperature equilibrium would be achieved somewhat further from the sun than is the earth.

For the "greenhouse," it will be necessary to use some material that is transparent to visible radiation but which absorbs or reflects almost all of the ultraviolet. Ultraviolet radiation markedly inhibits the growth and metabolism of plants. The infrared radiation, on the other hand, might be useful. It might be possible to incorporate into our system some mechanism which could control the amount of infrared penetrating the greenhouse. This would make it possible to help control the temperature without the expenditure of significant energy.

On a vehicle, the only method for dissipation of heat would be to pump some of the heat to one part of the vehicle where it would be released into space. On the surface of a planetary or lunar body the heat might be useful at "night," when the temperatures may be expected to fall drastically. Any extra heat here could probably be dissipated underground or by radiation from the dark side of the planet or moon.



How an algae farm would operate on a space ship. Such a farm could supply all of the passengers' food requirements, and also replenish vital oxygen to the air in the ship.

Algae, like other plants, have a very narrow temperature range within which they photosynthesize at a maximum rate (about 10-20°F.). We can breed varieties which have different optimum temperatures but the range generally remains narrow. Similarly, the extreme temperatures within which these plants can even remain alive is relatively narrow, although broader than the photosynthetic optimum) from about 32 to 120°F.). Our temperature control problems, then, are rather critical. The temperature controls themselves must, of course, be left in the hands of appropriate engineers. However, as a biologist, there may be some contribution which I can make even here. This is in terms of the protection of the plants from temperature stresses.

It has only recently become known that we can, in certain cases, make plants more resistant to temperature stresses simply by an appropriate chemical treatment. The common flowering plant, Cosmos, will grow at nearly maximum rate at very low temperatures if it is treated with vitamin B_1. Similarly, the wild flower, Arabidopsis, will be protected from high temperatures by treatment with the chemical called choline. Peas may be partially protected from high temperatures by treatment with the hormone gibberellic acid. This suggests that these plants are injured by chemical stresses principally through some effect of temperature on a single biochemical process. So, by learning and providing the appropriate chemical treatments, we can make our plants less demanding of critical temperature controls than they would otherwise be. Work on this problem is now being carried out here at Caltech.

When extended, manned space flights are contemplated it will be necessary for the planners and designers to take into consideration the requirements of the algae who will almost certainly be among the important passengers. And we can now be assured that the algae will be ready whenever they are called upon to promote the exploration of our corner of the universe.