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Nutrition in Space Operations*

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Manned space operations of the future will be quite varied in nature and scope. Before we can discuss adequately the problems of nutrition in space operations, we must first classify the present and future stages of human flight. Figure 1 classifies these stages with regard to the vehicle, the environment, speed, gravitational condition, and flight dynamics.

Food logistics for each of these categories of flight will be quite different. For example, in the routine atmospheric flight of today, (Class I above) the in-flight food packs contain foods similar to those in our daily menus, and are prepared in the usual manner prior to take-off of the aircraft. This situation is likely to prevail so long as we fly in conventional aircraft which depend upon atmospheric oxygen as the oxidizer for its fuel.

In Class II—Space Equivalent Flight—food logistics are and will be quite similar. Flights in the space-equivalent region of 10 to 120 miles will be of short duration and may not require in-flight feeding. These flights include those of experimental high-altitude jet and rocket aircraft and ballistic rocket flight which will not attain orbital altitudes or velocities. One notable exception to this would be satelloid flight, defined as powered circumterrestrial flight of a vehicle in the upper space-equivalent portion of the atmosphere. Food problems here would be essentially the same as in Class III or satellite flight.

This discussion, then, is concerned only with Classes III and IV of the chart in Figure 1. In space operations in these categories food logistics will become extremely important.

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First, let us establish criteria by which we can select the types of foods and solve the food problems for each kind of space operation. These criteria may be listed as follows in the order of priority:

1. Duration of flight operation.
2. Payload.
3. Methods of preservation and storage.
4. Methods of preparation.
5. Ease of eating.
6. Palatability.
7. Disposal of remnants or waste.

FOOD IN TERMS OF DURATION OF FLIGHT AND PAYLOAD

At this time, we can distinguish only arbitrarily between short term and long term flight. The point of separation will be determined by the feasibility of a storage system for necessities such as food, water, oxygen, and carbon dioxide absorbant, as compared to a system which re-utilizes waste materials in recycling and reproducing these items. On this basis, one might suggest that short term flight would be in the order of 2 to 4 weeks in duration.

Included in this category would be earth satellite operations not exceeding this period of time, circumlunar flight and return, and lunar flight with landing and a stay of perhaps one week's duration, before returning to earth. Thus, lunar trips of these types can be classed with the short term space operations.

Long term operations would include the permanent earth satellite station, the permanent lunar station, and interplanetary operations within our own solar system. Problems associated with flight beyond our solar system are not a part of this discussion.

	I	II	III	IV
Classification Of Flight	Atmospheric Flight	Space-Equivalent Flight	Circumplanetary Space Flight	Interplanetary Space Travel
Status Of Vehicle	Airplane	Airplane Projectile	Satellite	Space Ship
Characteristics				
Environment	Atmospheric	Partial Space Equivalent (10 to 120 Miles)	Total Space Equivalent (120+ Miles) Free Space (6000+ Miles)	Free Space (600+ Miles)
Speed	Subsonic Supersonic	Supersonic Hypersonic (10+ Mach)	Orbital Velocity (17,500 MPH)	Escape Velocity (25,000 MPH)
Gravitational Condition	Normal	Subgravity Zerogravity	Zerogravity	Zerogravity
Dynamics	Aerodynamics	Aerothermodynamics Aerochemodynamics	Astrodynamics (120+ Miles) Altitude	Astrodynamics

After Strughold (11)

Figure 1. Present and future stages of human flight.

The weight of food used in all operations must be kept as low as possible.

PRESERVATION AND PREPARATION

In my opinion, for early space operations the best type of food which could be used would be the dehydrated foods which would be compressed into bite-size wafers or tablets. There are several reasons for this, and these reasons would seemingly answer all of the criteria given.

First of all, various foods could be compressed together bound by a digestible filler material. This technic would tend to diminish any strong taste which a single dehydrated food might have. Different flavorings could be added to provide pleasant and varied menus. Vitamins and minerals could be chewed and swallowed with water or other liquids. Milk could be treated in the same manner, its reconstitution occurring in the mouth and the stomach. The shape of the tablet or wafer should be tailored to fit the space designed for food storage.

It seems that such a method would make easier the preservation of foodstuffs whether this would be accomplished by chemical, electronic, or by irradiation methods.

In early space operations, to obviate the necessity of preparing food in flight would be most desirable. The various problems associated with zero-gravity might make food preparation very difficult. Let me explain.

Eating and drinking experiments have been performed during zero-gravity flights and in the F-94C at the USAF School of Aviation Medicine at Randolph Air Force Base, Texas and at the Aero Medical Field Laboratory at Holloman Air Force Base, New Mexico. These experiments have shown that it is relatively easy to drink from a plastic squeeze bottle with one small opening, whereas drinking from an open container is very inefficent, wasteful of water, and potentially dangerous. The swallowing of food is likewise not difficult if it is well masticated and sufficiently moistened.

Other experiments on the behavior of fluids and gases during zero-gravity indicate the difficulties one might encounter in trying to prepare meals in the weightless state.

It would be excellent if the first space crews were not required to concern themselves with meal preparation, but could simply put into their mouths a tablet of well-balanced food, containing all the essentials, chew, mix with water, and swallow.

The first men in space will have so much to think about and to do that, considering the difficulties which might attend food preparation, it would be far better if the concentrated food tablet were available to them.

You will notice that palatability is near the end of the list of criteria. It is one of the least important from the standpoint of necessity. Psychologically of course, it should be higher on the list, particularly during flights of a week or more.

DISPOSAL

The last of the criteria—disposal of remnants—would be completely eliminated by use of the food concentrate. In addition, because of the low residue of such a diet, the amount of human waste would also be diminished, thereby facilitating handling of such materials in zero-gravity.

An alternate type of food could be thick liquid or paste foods in a tube, from which the food could be squeezed directly into the mouth.

I realize that there are many difficulties associated with the concentration and preservation of various foods, but I am sure that these difficulties are also not insurmountable.

REGENERATION WITHIN A SEALED ECOLOGY

Long-term space operations have been categorized as the permanent satellite station, the lunar station, and interplanetary operations.

In all these operations, it will be necessary to utilize a recycling, regenerative system to produce within the sealed ecology all necessities for life, and to re-utilize all waste materials in doing so. The most feasible method of accomplishing these objectives at present seems to be the use of a natural photosynthetic exchange system, utilizing one or more of the common algae.

Under proper conditions, a given amount of algae can be made to produce enough oxygen to support one man, and to absorb the carbon dioxide given off by the man. Dr. Jack Myers at the University of Texas, has found that five pounds of the green alga *Chlorella pyrenoidosa* can effect the balance in gas exchange with one man. A lesser amount of a blue-green alga, *Anacystis nidulans*, might do the same.

Tamiya and Morimura, of Japan, and others, have conducted feeding experiments and chemical analyses of the alga *Chlorella*, and have found this alga is almost a complete food, offering the essential amino acids (except those containing sulfur), lipids, carbohydrates, and most of the vitamins and minerals required by humans. The chemical composition can be altered to some extent by controlling the variables affecting the growth and composition. These include light intensity, method of illumination and wave length used, composition of nutrient solution, density and thickness of suspension, turbulence, rate of aeration and carbon dioxide concentration, pH of suspension, and frequency and rate of harvesting. One unknown factor at present is the effect of zero-gravity on the growth of algae. It may be necessary to provide an artificial gravity of up to one *g* for best results. It is even possible that more than one *g* would increase the efficiency of the algae! The gravity factor must be assessed.

A simple means of separating the algal cells from the nutrient solution should be developed. To this end, it may be possible to develop a digestible and nutritious filter made of food materials required to supplement the algae. The filter could be inserted at some point into the algal exchange system to filter the cells from the suspension. This would be removed after an optimum period of time. The filter wafer which holds the algae could then be suitably processed, depending upon the method required, for human consumption. A filtration method of this type could also be the means of continuously harvesting the algae, and of maintaining the density of the algal suspension at the point of optimum growth or oxygen production, or both. Of course, a system for manufacturing the filters must be provided on board the space ship. This system must also be very compact and of low weight. The filter residue after digestion with the algae could then be processed with other waste in the closed system to provide nutrients for the algae. Thus, another step in developing a balanced closed system could be accomplished.

Gotaas and Oswald of the University of California have utilized sewage wastes to grow algae. Wastes of this kind contain all elements necessary to life in low energy form. In reality such materials are not wastes but necessities. Algae grown on sewage in Southern California yield as high as thirty tons to the acre, whereas the field crops in the area produce only 1.5 tons per acrs. These algae crops have been used successfully as livestock feeds.

Dr. Robert Gafford at the USAF School of Aviation Medicine has maintained mice and the alga *Anacystis nidulans* together in a closed system for a period of 12 days. The oxygen content of the system increased to 38% during that time. That particular alga also produced carbon monoxide but not in sufficient amounts to permanently harm the mice.

The trend of future research in this area will be

1) toward the screening of many algae for their suitability in these exchange systems;
2) investigations of the physiology of these algae;
3) the utilization of wastes of the animals in closed systems to feed the algae;
4) the harvesting of the excess algae to feed the animals in the system.

When these objectives have been accomplished, man will be incorporated into a closed system in place of or with the animals.

OUR MOTHER SPACE SHIP—THE EARTH

Perhaps all this may sound difficult or even unattractive to some of you, but stop to consider for a moment. We are even now on a giant space ship—the earth. It is moving in its own orbit as a satellite of the sun, at a velocity of 18.6 miles per second—3.5 times the velocity of an earth satellite. The earth is also a closed ecological system, sealed off from the unfriendly environment of space by its gravitational force. This force holds to the earth all the substances critical to life. These critical materials are constantly being recycled, from waste to product and back again.

In our feeble attempt to leave the protection of our mother space ship and venture into space, we must create in miniature, a world of our own which will duplicate all the essential functions which the earth performs for us. In this age of sub-miniaturization, it does not seem an impossible task to produce such a system. Our knowledge will increase and the job shall be done.

The challenge of the algae offers several new areas for research. Some of these are:

1) The screening of many different algae for suitability as food as well as for oxygen production and waste re-utilization.
2) Treatment of algae to improve their acceptability and "customer appeal."
3) Use of algae as ingredients in food concentrate tables or wafters.
4) Determination of the best combination of other ingredients to use with algae, to supplement the nutritional value of the algae.

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