Biologistics for a Manned Space Station Based on the Metabolic Approach

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Specification of biologistics for future space stations will require accurate and standardized sets of environmental specifications, nutritional data, and metabolic calculations, which must take into account the effects of prolonged weightlessness (or hypogravity in the case of a rotating space station). It is proposed that the catabolic effects of weightlessness on the musculoskeletal system, and indirectly on the cardiovascular system, should be related to the daily work output of the body. By controlled diets and exercises, astronauts could be "titrated" to their normal earth (or other prescribed) metabolic rates. (This hypothesis is, of course, subject to verification in space.) A coincident, desirable result of this metabolic approach is that biologistics for all types of spacecraft and space stations can be calculated (or, better, experimentally determined) in standard units per man-day without regard to the metabolic effects of variable gravity. A table of biological specifications is developed and then applied, with associated engineering constraints and tradeoffs on requirements for power supply, heat rejection, and integration of the power system with the life-support system, to describe optimum life-support requirements for 30- to 100-day missions.

Introduction

SPACE biologistics, as interpreted in this paper, includes two major areas of study: 1) environmental specifications and metabolic requirements based on biomedical considerations, and 2) engineering studies and tradeoffs leading to life-support systems design.

The metabolic approach proposed herein is based on the concept of maintaining normal terrestrial energy outputs, because unless the metabolic rates are more or less fixed by a quantitative method, all logistic calculations are essentially meaningless, particularly when various combinations of variable gravities are to be used. This is the only way to assure biological integrity while avoiding marked overdesigns and/or underdesigns of various life-support systems as a result of variable biological requirements.

"Chronic weightlessness syndrome" is anticipated to consist primarily of musculoskeletal atrophy and cardiovascular degeneration, which can be predicted from clinical observations of bed-rest patients in whole-body casts, as well as all other subjective symptoms, physical signs, and laboratory findings not yet verifiable until more prolonged space flights become a reality.[1] According to Best and Taylor,[2] "(basal) cardiac output is proportional to basal metabolism and, like the latter, can be predicted for a normal person, with a small error, from the surface area." It seems reasonable that prevention of musculoskeletal atrophy (directly) and cardiovascular degeneration (indirectly) can be achieved by scheduled exercises which will produce adequate peripheral work and cardiac output, and that an exercise program can be best monitored by the metabolic approach, which is a quantitative method.

The concept of energy costs of activities in health and disease is not new and has been reviewed by Gordon[3] who stated in his summary: "Inasmuch as O_2 uptake per minute is an approximately good index of cardiorespiratory stress and this metabolic measurement is relatively simple and accurate enough for clinical use, calibration of activities is possible in terms of energy expended." This view is apparently shared by some heart associations.[4] The present authors believe that good physical condition in space is partly and indirectly indicated by a normal basal metabolic rate (BMR) and adequate activity metabolic rate (AMR), which are among the most feasible and expedient methods of biomonitoring. Weightlessness experience and long-term validation are urgently needed. This paper suggests what should be done in the future, increasingly prolonged space flights which might precede the firm design of a space station.

Metabolic Considerations

Basal metabolic energy requirements for the space-station astronauts are based on the sex, age, and anthropometry of the average Project Mercury astronaut, who represents the type of flying personnel available for selection and training as space crew. This is a 55-percentile man by weight and 60-percentile man by height, with a body surface area of not more than 1.95 m^2 and a BMR not higher than 40 kcal/m^2/hr. However, using a number of astronauts, a range of 30–90 percentile is acceptable. If a potential astronaut were fed a calculated diet (e.g., 2800 kcal daily for the average astronaut), and if he could be made to work and exercise to the extent that his AMR over any 24-hr period were at least 2500 kcal and as close to 2800 kcal as possible ($1.35 < \text{AMR/BMR} < 1.5$), he should suffer minimal skeletal-muscle atrophy in a zero-gravity or hypogravity state, since he would be exercising as much as an active man on earth.[5]

A refinement of this technique is also to determine the average diurnal metabolic rate of all the astronauts in a sealed space-station simulator (by means of indirect calorimetry), on earth in the presence of gravity, prior to the actual earth-orbiting mission. It will then be an easy matter to titrate the astronaut(s) by means of scheduled exercises to the desirable AMR in order to prevent the catabolic effects of the so-called "chronic weightlessness" or "subgravity syndrome" in space when the astronauts are free-floating or when synthetic gravity may be subnormal. Minor daily adjustments of the individual diets and exercises will be required for satisfactory "caloric balance," otherwise the astronauts will gain or lose "weight" (body mass or tissues) over a long period of time. The nature and extent of a pre-

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Table 1 Basic metabolic design criteria used[a]

	Wt/man-day (g)	Wt/man-day (lb)
O_2 uptake	848	1.87
CO_2 output	1053	2.32
Food weight (Ashless, dry basis)	624	1.38
Water inputs		
Water of oxidation[b]	325	0.72
For drinking: minimum[b]	2800	6.17
average	3150	6.94
maximum[b]	3500	7.72
Water outputs (waste)		
Max fecal water	150	0.33
Min urine water	1000	2.20
Sum[b]	1150	2.54
Min fecal water	100	0.22
Max urine water	1875	4.13
Sum[b]	1975	4.35
Min evap. water loss[b]	1150	2.54
Extra evap. water loss	1525	3.36
Sum[b]	2675	5.90
Maximum waste storage		
Max probable urine	1875	4.13
Max fecal water	150	0.33
Fecal solids	100	0.22
Sum	2125	4.68
Heat production	(k-cal)	(Btu)
Min insensible heat	670	2660
Max sensible heat	2130	8450
Sum	2800	11,110
Max insensible heat	1560	6190
Min sensible heat	1240	4920
Sum	2800	11,110

[a] Solid and liquid weights do balance (within 0.01 lb) taking into consideration O_2 becoming CO_2.
[b] Sum of these water input items equals sum of similar water output items.

Table 2 Design criteria used for environmental control

	Space station	Pressure suit
Temperature, °F	68	≤ 85
Pressure, psia[a]	14.7 (760)[a]	≤ 5.0 (260)
Oxygen, vol %	21	100
pO_2 normal, psia	3.1 (160)	≥ 2.9 (145)
Enrichable to, vol %	25	100
pO_2 enriched, psia	3.7 (190)	≤ 5 (260)
Carbon dioxide, vol %	0.5	1.0
pCO_2, psia	0.08 (4)	0.05 (3)
Relative humidity, %	50 ± 10 (68°F)	50 (max)
Water vapor, psia	0.18 (9) (dew point 50°F)	0.07 (4) (at inlet)

[a] Pressures in parentheses are in mm Hg.

ventive or therapeutic exercise program must be correctly prescribed and meticulously followed; these are being investigated.

It is certain that metabolic rates alone are not an adequate monitor of the correct exercise program. Certain types of high-metabolic rates, such as those accompanying fever or anxiety, are obviously useless and, indeed, detrimental. Similarly, caloric balance alone is not sufficient assurance against disuse atrophies which must be scrupulously monitored by other biochemical and biophysical techniques in addition to clinical examinations in space and on board the space station; these will also be reported on separately.

Life-support design criteria used in this paper are listed in Tables 1 and 2. A near-sea-level atmosphere is assumed here in order to eliminate some variables; the pressure is rather arbitrarily chosen as 14.7 psia, but of course a pressure of 10.1 psia (10,000-ft alt) would be sufficient for comfort. More detailed considerations used to establish the design criteria of Table 1 are discussed below. Higher metabolic excursions may result in the same AMR but will produce different water and heat balance data.

Nutritional and Water Requirements

The anticipated composition of a typical 2800-kcal, fixed-protein diet allows the following: 1 g of protein/kg of body weight daily, or about 12% of the 2800 kcal; between 1.5 and 4.0 g/kg of carbohydrate daily or about 17 to 76% of the total kcal; and corresponding fat intakes of 2.8 to 0.5 g/kg, or 71 to 12% (Fig. 1). The O_2 consumption and CO_2 production change with diet composition (Fig. 1). All calculations will tolerate a long-term respiratory quotient (RQ) of 0.85 ± 0.09.

The preceding protein and carbohydrate allotments are adequate for normal nutrition and prevention of metabolic acidosis. However, the protein fraction is enrichable, perhaps to 2.2 g/kg (see Fig. 2), to counteract the anticipated negative nitrogen balance, at least for the first few days, under the "hypo-dynamic environment of space."[6] A negative nitrogen balance may or may not be detectable with musculoskeletal atrophy and/or cardiovascular degeneration. Should any of these occur to a significant degree as a result of incorrect and/or insufficient exercises, then it would be necessary to increase the protein intake and the extent of correct exercises to "recover the losses." This procedure is costly and not very safe. The high specific dynamic action (SDA) of protein makes its enrichment infeasible in the long run. SDA has to be accepted up to a certain extent, beyond which it becomes unnecessarily wasteful. Chronic effects of zero-*g* on gastrointestinal function are probably insignificant. However, a relatively high carbohydrate diet is recommended for the earlier and shorter missions because of its possibly better tolerance.[7]

It is assumed that completely precooked and dehydrated foods will be employed. Therefore, the water required for their reconstitution and for drinking can be considered under a single category. Wash water is additional and serves as emergency backup. Water intake is calculated to provide

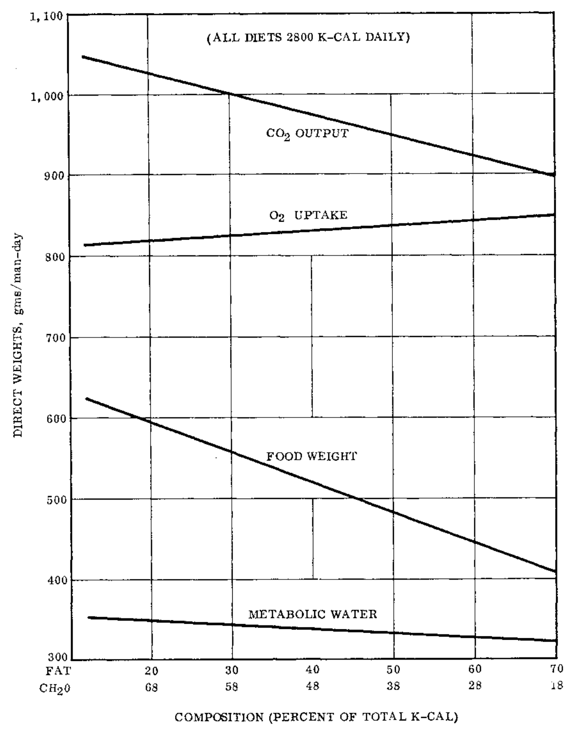

Fig. 1 Direct weight penalties due to standard (fixed) protein diets.

Table 3 Water balance (design values)

Supply	lb/man-day	Demand	lb/man-day
Respiration & perspiration	4.22	Drinking	6.94
Urine	3.17	Wash water	3.00
Wash water	3.00	Loss, urine[a] distillation[a]	0.45
In feces	0.27	Loss, feces[a]	0.27
Total	10.66		10.66

[a] The sum of losses in urine and feces equals the metabolic water of oxidation, 0.72 lb/man-day.

adequate heat dissipation and urine output. An average value of 6.94 lb/man-day, or 1.125 cm^3/kcal, is shown in Table 3, based on a minimum requirement[2] of 1 cm^3/kcal and a maximum allowance of 1.25 cm^3/kcal. The latter corresponds to a minimum daily urine output of 1000 cm^3 at the extreme temperature and metabolic excursions to be discussed below.

Allowable Temperature Excursions

It is assumed that at low ambient temperatures and nearly basal metabolic rates, about 24% of the total heat production of the human body is dissipated by means of insensible water loss from the skin and lungs.[2] However, there is a rapid increase in the evaporative or latent heat portion of total heat loss by the body for thermal regulation when AMR/BMR > 1.5 for several hours, even for a mild activity program at 68°F, at one atmosphere, and under one-*g* operations. The rate of change of evaporative or latent heat loss as a function of varying AMR and ambient temperature excursions is shown in Fig. 3, based on experimental data obtained from Ref. 8. In the calculations of this paper, minimum fluid allowance, maximum urine output, and minimum evaporative water or heat loss are compatible with the astronauts' performing mild activities in a nearly 1-*g* space station. On the other hand, maximum fluid allowance, minimum urine output, and maximum evaporative water or heat loss will tolerate an ambient temperature of 80° − 85°F for up to 12 hr (with or without heavy exercises as prescribed below for a hypo-*g* space station, since all of the heat loss is assumed to be evaporative for AMR/BMR > 3). These combinations are shown in Table 2.

Planned Metabolic Excursions

The metabolic approach for the prevention of the chronic weightlessness syndrome is believed to be theoretically sound but lacks experimental verification, which must be done in space.

The assumption that an average diurnal AMR/BMR of 1.5 can be obtained by averaging 8 hr of activities, each at levels

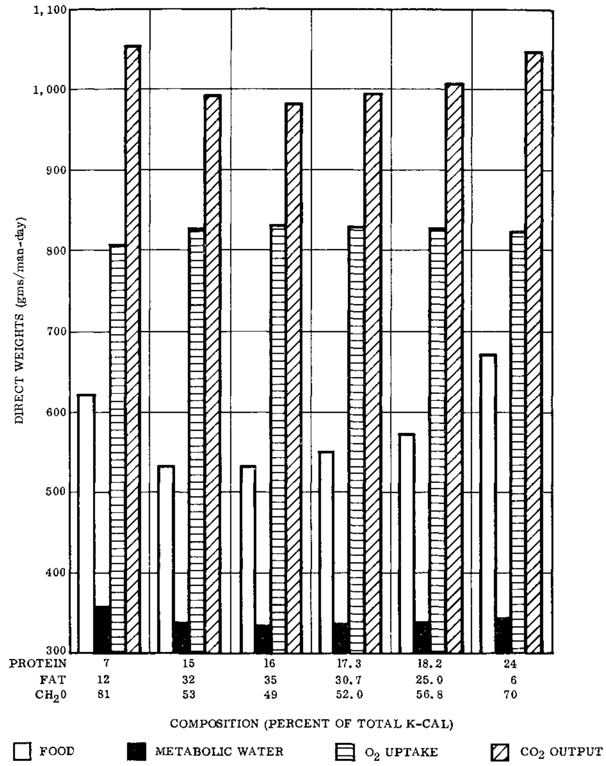

Fig. 2 Direct weight penalties due to low-protein vs enriched-protein diets.

of 1, 1.5, and 2, may not be feasible for nearly zero-*g* operations. However, calculations show that a higher AMR resulting from an exercise program of shorter duration is not incompatible with our basic biologistic design, particularly referring to the heat and water balance data. Three hypothetical exercise programs are presented in Table 4. Two hours of exercise daily at AMR/BMR = 7 are recommended and will bring the average diurnal AMR up to 1.5. One or two hours of exercise at levels of 9 or 5, respectively, may be sufficient, but will bring the average only up to about 1.35.

Evaporative or latent heat percentages for AMR/BMR ≤ 3 are taken from Fig. 3. For lack of experimental data, and in order to be on the safe side, all heat loss is assumed to be compensated by the evaporation of body moisture when AMR/BMR > 3. It is seen that the highest water-intake requirement is well within the basic design tolerances.

Life-Support System Selection Considerations

Proper integration of the life-support system (LSS) with other subsystems is of prime importance in arriving at the over-all design of the space station. Special emphasis must be

Table 4 Effects on water requirement and heat balance due to heavy exercise programs and high metabolic rates

Exercise program	Metabolic rate, AMR/BMR	Activity duration, hr	Rates portioned, AMR/BMR	Portion durations, hr	Total heat, kcal	Evap. heat, kcal	Evap. water, g
1A	7.0	2	7,3	2	622	622	1067
1A′	. . .	. . .	3	2	467	257	440
1B	1.0	22	1	22	1711	385	660
Av or total	1.5	24	. . .	. . .	2800	1264	2167
2A	5.0	2	5,3	2	311	311	534
2A′	. . .	. . .	3	2	467	257	440
2B	1.0	22	1	22	1711	385	660
Av or total	1.33	24	. . .	. . .	2489	953	1634
3A	9.0	1	9,3	1	467	467	800
3A′	. . .	. . .	3	1	233	128	220
3B	1.0	23	1	23	1789	402	690
Av or total	1.33	24	. . .	. . .	2489	997	1710

Table 5 Weight estimates used for life-support subsystems

Heat rejection hardware (lb/kw)	37	
Power system (lb/kw)		
Fuel cells	50 + 1.6 lb/kw-hr	
Sunflower	250	
15-kw solar unit	65	
SNAP 2 (shielded)	350–400	
SNAP 8 (shielded)	70	
Gas storage (total lb/lb gas)		
	O_2	N_2
Gas at 7500 psi	2.4	2.7
Cryogenic (positive expulsion)	1.4	1.5
Supercritical	1.6	1.8
Chlorate candles	2.8	...
Hydrogen peroxide	2.75	...
Potassium superoxide	3.15	...

placed on integrating the LSS with the auxiliary power unit (APU). The power-system characteristics will influence the LSS design due to weight penalties for: 1) power to operate the LSS, 2) heat rejection of the power system itself, and 3) integration with gas-supply, water-recovery, and food-storage subsystems. The LSS designs are based on the metabolic data listed in Table 1. The over-all weight comparisons of these subsystems have been used as a basis for optimum subsystem selection. Weight penalties associated with power generation and heat rejection (Table 5) are included in all calculations.

Environmental Control System (ECS)

Various features of the ECS are summarized in Table 2. A 14.7 psia internal atmosphere of 21% O_2 and 79% N_2 is assumed during normal operation. In case of emergency, the astronauts will don their pressure suits, which can be pressurized, supplied, and ventilated with pure oxygen through hoses connected to the ECS oxygen lines. Optional pressure-breathing is desirable.[9]

The major thermal loads are those generated by the electronic equipment and the metabolic heat of the crew members. It is found advantageous, in most cases, to radiate waste heat from the APU's by means of separate APU space radiators operating at optimum temperatures. Thus, the total heat load handled by the independent ECS space radiator is approximately equal to the electrical energy generated by the APU's plus the metabolic heat generated by the men. The crew metabolic heat of 2800 kcal/man-day or 463 Btu/man-hr is divided between sensible and latent heat in Table 6 for various levels of activities as compared to design values.

The space radiators considered in this paper are for the special case of a space station in a 200-naut m orbit, inclined 30° to the equator. It is necessary to assume here that the space station rotates in the plane of the orbit. Operations at zero-g may affect detailed designs of the radiators somewhat. The radiators are of the fin-and-tube type, with spaced, semicircular tubes, which are coated with TiO_2 to obtain a low α/ϵ ratio. The heat-transport fluid is a 40% aqueous glycol

Table 6 Metabolic heat outputs of crew at 68°F, 1 atm and 1 g

	Sensible	Latent
Estimated levels, Btu/man-hr		
At rest, AMR = BMR	239	70
Sedentary activity and scheduled exercise, AMR/BMR = 1.5	258	205
Moderate exertion and some work, AMR/BMR = 2	328	290
Design values		
Normal (av of preceding)	275	188
Emergency operation	205	258

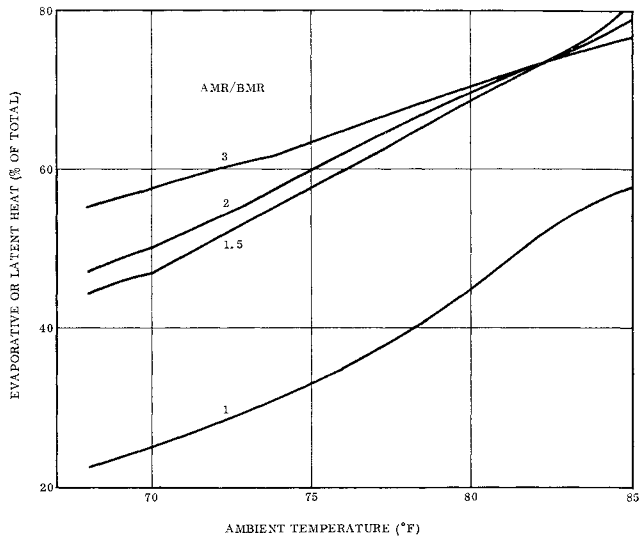

Fig. 3 Rate of change of evaporative heat loss as a function of ambient temperature and metabolic rate.

solution. A portion of the equipment heat is transferred directly to the cabin atmosphere. The cabin return air, at 120°–130°F, is passed through counterflow heat exchangers, where it is cooled by the glycol to approximately 45°F and returned to the air-distribution system. The warm glycol (~55°F) is pumped back to the space radiator. Heat loads due to the radiative heat transfer between the space station and its environment are not considered here because they depend on the particular configuration of the space station.

Supercritical storage of both oxygen and nitrogen is preferred for early space stations. This method is favored because of its smaller weight penalties and the fact that the fluid is maintained entirely as a single-phase homogeneous gas which alleviates zero-g operating problems. For advanced space stations, where a closed oxygen cycle is provided, makeup and emergency oxygen is best stored as a high-pressure gas in 7500-psi bottles. Supercritical nitrogen supply is still considered for use in advanced space stations. Table 5 gives the total weights required for the supply of metabolic oxygen and leakage nitrogen; the weights include the containers, the gases supplied, and the unavailable residues.

Several methods for the removal of CO_2 have been considered. These include LiOH, KO_2, molecular sieve, and CO_2-reduction with hydrogen. However, since KO_2 and CO_2-H_2 reduction systems include oxygen supply as well, it is

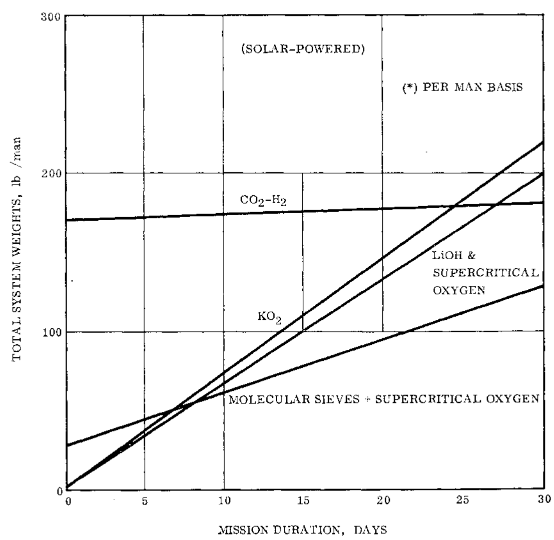

Fig. 4 Tradeoff studies of CO_2–O_2 systems (solar-powered).

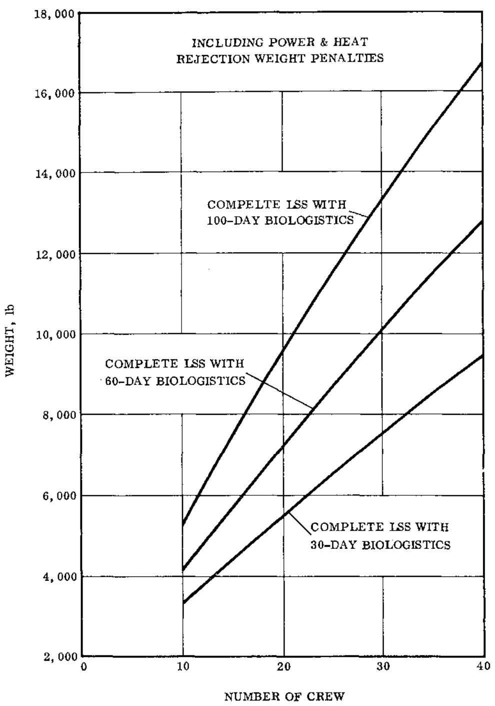

Fig. 5 Total weight penalties of complete life-support systems in advanced space stations.

advantageous to analyze the combined CO_2-removal and O_2-supply systems as a unit. Tradeoff curves shown in Fig. 4 give weights for combined CO_2-O_2 systems. These curves are based on the use of solar power, but curves based on nuclear power are not too different. Lithium-hydroxide and molecular-sieve systems are supplemented with supercritically stored oxygen. If the CO_2-H_2 and the molecular-sieve straight lines were extended to longer times, they would intersect at some point before 60 days. It is therefore concluded from these weight tradeoffs that the CO_2-removal system should utilize a molecular sieve for the early space stations and CO_2-H_2 reduction for the advanced space stations. A catalytic burner is used to oxidize trace contaminants such as H_2S and CO, so that their combustion products can be removed by the molecular sieve and the charcoal filter. The catalytic burner comprises an electrically heated, platinum-plated, nichrome-wire catalyst in a cylindrical container. Air from the catalytic burner is returned to the upstream side of the ECS blower.

Food, Water, and Waste Management

It is assumed that the food is 100% precooked and dehydrated. An ash-free weight of 1.38 lb/man-day is required for the space-station crews when averaged throughout the mission. Additional penalties of 5 and 10% of the weight mentioned are allowed for ash content and food packaging, respectively. Electrical heaters, utensils, and bellows are required for preparing food and heating water in the space station. Dehydrated food will be placed in bellows dispensers and hot water added to it from the heater unit. After a short time for hydration, the reconstituted food is ready for consumption. Liquids may be consumed by using the mouthpiece and valve assembly provided.

Table 7 Design values for waste quantities

	lb-man-day
Solids in feces & urine	0.22
Fecal water	0.27
Water lost in urine distillation	0.45
Food packaging & residue	0.22
Expendable filters & sanitary supplies	0.25
Expendable supplies for water recovery (if applicable)	0.17
Miscellaneous & contingency	0.05
Total	1.63

The daily water balance is shown in Table 3. This balance is based on an average of the metabolic values listed previously and is used for design purposes over the mission duration. The equipment, however, should be designed to handle peak loads for relatively short periods. It is noted that the water consumed is less than the water produced, by about 0.72 lb/man-day, which is the equivalent to the metabolic water produced by the body.

For the mission durations considered in the paper, the weight penalty for expending water without recovery far exceeds the penalty for equipment and power to recover water from liquid wastes. Waste-water sources are atmospheric condensate, urine water, and wash water. Atmospheric condensate may be reclaimed directly from the air dehumidifier and passed through activated charcoal and bacterial filters to produce potable water. For the emergency pressure-suit mode, additional water separators (centrifugal type) are used to collect the moisture from the increased volume of air circulated. The urine and wash water may be recovered in a vapor-compression type of still. These units, even though they consume slightly more power than other types, are favored due to the higher degree of purification obtained.

Facilities are required for the collection and storage or disposal of waste materials, such as fecal and urine solids, food packaging, sanitary supplies, and expendable filters (Table 7). The volume of these waste materials is about 0.16 ft^3 man-day. In early space stations, the wastes may be stored in emptied food compartments at about $-7°F$ to inhibit bacterial growth. Since the volume of the waste materials exceeds that of the food packages which require about 0.11 ft^3/man-day, the refrigerator design is based on the larger volume. Advanced space stations may use electrically heated, 1800°F incinerators, due to their simplicity and high reliability; they are, essentially, insulated pressure vessels with controlled venting to space.

Instrumentation

A space station with the ECS specifications of Table 2 should be equipped with basic sensing and readout equipment to monitor these parameters. Thermocouples and gas-pressure thermometers may be used to measure the various critical temperatures. Humidity of the cabin air and the air leaving the dehumidifier unit should also be sensed and displayed. The cabin total pressure and the partial pressures of O_2 and CO_2 should be monitored continuously. Orifice meters with calibrated readout units may be used to determine the flow rates of O_2 and N_2.

The average metabolic rate and respiratory quotient (RQ) of the space-station crew members, as a group, can be readily calculated for any specified time interval by using the entire space station as an indirect calorimeter. Oxygen consumption is known from the average flow rate required to maintain a constant pO_2, or the average time required to produce a certain $\Delta\ pO_2$ in the absence of O_2 flow, or the average duration between fixed injections of O_2 required to maintain a suitable average pO_2. These three methods may be called the constant-flow, intermittent-flow, and quantized-flow methods, respectively. A similar $\Delta\ pCO_2$ method may be used to determine the CO_2 production. It is necessary to turn off the O_2-recovery and/or CO_2-removal systems temporarily during the measurements. It is also advisable to minimize all errors which may be introduced into the gas equation. For instance, cabin leakage rate can be used as a correction factor; it can be determined from N_2 consumption or flow rate.

Measurements of BMR, AMR, and RQ for the individual astronauts are most easily made in zero-*g* by means of a modified Douglas-bag technique,[2] which employs lightweight meteorological balloons attached to high-velocity, low-resistance mouthpieces and valve assemblies. It is assumed that a gas chromatograph will be on board the space station for the accurate analysis of trace contaminants, atmospheric composition, and respiratory gases. Preliminary experimental results are available and will be reported by the present and other authors elsewhere.

Estimated Weights for 30-, 60-, and 100-Day Missions

The design criteria and inputs given in Tables 1–3,6, and 7 for the LSS just described have been used to estimate the curves for total LSS weight vs crew size for 30-, 60-, and 100-day missions in Fig. 5. These weights include the weights of required power and heat rejection equipment. Requirements for resupply for an equal time after a given period would be reduced by the fixed weight penalty of the solar power supply.

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Approach to Space Station Logistics Optimization

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The paper presents an analytic-computational method, utilizing dynamic programming techniques, designed to minimize the cost of supplying an extraterrestrial base. The minimization is accomplished by selection and scheduling of supply vehicles. The criterion of optimality was chosen to minimize the expected cost in order to account for the probabilistic nature of the problem implied by vehicle reliabilities of less than 1. Illustrative results from a current study of small space station logistics conducted by the described method are presented.

Introduction

ONE of the distinguishing features of any mission in space is its complete dependence on supplies originating on earth; satisfactory logistics planning is, therefore, central to the eventual effective exploration and utilization of space. This is particularly true of missions requiring the delivery of comparatively large cargo tonnages, as it may be the case with some extraterrestrial bases. In view of the cost of delivering a pound of supplies to even a "nearby" base such as an orbiting space station, it is clear that in many cases the very feasibility of proposed missions may well depend on one's ability to reduce logistics costs to the minimum level possible.

It is the purpose of this paper to contribute to this end by presenting an analytic-computational method well suited to determining some of the major defining elements of a logistics operation, namely, the optimal choice and scheduling of supply vehicles. The criterion of optimality is to minimize the expected cost of the supply operation; this criterion allows ready inclusion of the cost-reliability tradeoff on supply vehicle selection. The method of analysis is based on dynamic programming techniques. See, e.g., Refs. 1–4; Refs. 1–3 represent very readable and thorough presentations of the dynamic programming techniques utilized in this paper, and Ref. 4 describes a technique that will be found most useful in attempting the numerical solution of problems of higher dimensionality than discussed herein. Its application is briefly illustrated by considering the problems of supplying a manned space station.

Statement of the Problem

The purpose of this paper is to describe and demonstrate a method for the solution of the following basic problem in supplying an extraterrestrial base as follows.

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