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**PARAMETRIC STUDY OF
MANNED LIFE SUPPORT SYSTEMS**
Volume III Computational Procedures

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

JANUARY 1969

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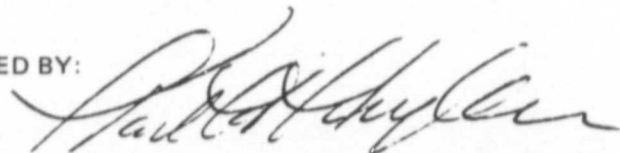
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Volume III Computational Procedures

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FOREWORD

This final report gives the results of a study which developed new parametric analytical tools and a computer program for describing and characterizing life support systems and tradeoffs of subsystems from a mission analysis standpoint. The scaling laws and characteristics developed for each of the life support system components, subsystems, or functional methods were confirmed with equipment data obtained from the latest literature and through a vendor survey. This work was performed by the Advance Biotechnology and Power Department of the McDonnell Douglas Astronautics Company - Western Division (MDAC-WD), Santa Monica, California under Contract No. NAS2-4443 for the Mission Analysis Division of NASA, Office of Advanced Research and Technology, Moffett Field, California. Work was initiated in July 1967 and continued to August 1968 under the direction of Robert S. Barker, Project Manager, McDonnell Douglas Astronautics Company and Joseph L. Anderson, Technical Monitor for the Mission Analysis Division, NASA.

The final report consists of four volumes published in the following breakdown because of physical size and utility for the users:

		<u>Report No.</u>
Volume I:	Summary	DAC-56712
Volume II:	Parametric Relations and Scaling Laws	DAC-56713
Volume III:	Computational Procedures	DAC-56714
Volume IV:	Program Manual	DAC-56715

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Section 1 SUMMARY

The three objectives of this study were to (1) develop parametric data for life support systems with a broad range of ecological closures, (2) develop the logic to implement these data computationally, and (3) develop the Fortran program to mechanize the computations. The results of the first of these study objectives are reported in Volume II. The results of the second and third objectives are summarized herein. Details concerning the second and third objectives are found in Volume IV.

The intent of Volume III is to present the scope of the second and third objectives in enough detail to facilitate evaluations of the sophistication of the mathematical models used for life support subsystems and of the capabilities and limitations of the developed computer program. The computer program is described in terms of the input data loadsheets, the computational logic, the output data formats, and special program features. Sample problem specifications and plotted and tabulated computer output data are also presented here. Sensitivity evaluations and other observations derived from the output data are included with the discussion of the sample problem results.

Through use of computational logic diagrams presented herein, in conjunction with parametric data and subsystem and component details presented in Volume II, hand calculations can be performed.

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Section 2 INTRODUCTION

Life support systems for space vehicles are categorized in terms of ecological closure. Closure extends from "open" systems such as those used in Gemini and Apollo, to "partially closed" systems which provide recovery processes for water and/or oxygen, and ultimately to "closed" systems which provide food by processing biological wastes. Ecological closure is important because of the life support system weight and volume reductions which can be achieved through increasing the level of closure. However, increasing closure entails increasing the amount and sophistication of life support system equipment which collects the biological waste products; carbon dioxide, perspired and respired water, urine, and feces; and which processes these wastes in recovering water and O_2 and in producing food. The weights and volumes of required expendable materials (water, O_2 , and food) are reduced as the closure is increased. Because the requirements for these materials stem initially from crew size and mission resupply period (or mission duration when there is no resupply), the potential savings from increasing the closure are most worthwhile for higher magnitude products (man-days) of these two quantities.

In terms of overall vehicle considerations, there are other potential uses for biological waste products besides life support system recovery processes. Two potential uses, which have been given attention recently, are providing mass for thrust for vehicle guidance and control and providing shielding and radiation protection for crewmen.

Hand calculation determinations of complete life support system weight and volume; requirements for power, heating, and cooling; and net accumulations of waste products are quite time consuming. Beyond the requirements for the basic life support system, safety and maintainability considerations should be evaluated. This extensive computational task of describing and characterizing

life support systems has been mechanized in the H738 Parametric Manned Life Support Systems Fortran Program which is run on the IBM 7094 computer. The program provides a computational tool that is capable of sizing a variety of complete life support systems, determines systems and vehicle interface requirements, and determines net accumulated waste products. Life support systems can thus be parameterized with respect to such mission variables as crew size, mission duration, flight path, vehicle configuration, resupply period, flight date, and ecological closure. Life support systems can also be parameterized with respect to life support system variations for tradeoff evaluations. These considerations include specifying alternate types of equipment to accomplish particular functions and specifying variations in equipment operating characteristics such as process efficiency and temperature of supplied liquid coolant.

The program determines equipment requirements for atmosphere and thermal control and for supporting and accommodating crewmen as well as requirements for expendables and accumulated waste products. Emergency equipment and materials and replacement spares are also computed. The requirements imposed upon the vehicle by the crewmen and the particular life support system are determined. These include items such as electrical power, cooling and heating requirements, and meteoroid and radiation shielding.

This volume (Volume III) contains a description of the H738 program, delineating the capabilities and limitations of the program, and sample computer solutions for several life support systems. Sensitivities of the computed life support system characteristics to various independent variables are discussed. Volume II describes the developed parametric relations and scaling laws which are used in the computer program in sizing life support system equipment and associated expendables, and determining required electrical power, cooling and heating. The parametric relations and scaling laws may be easily modified through new input data from that now used with the computer program in obtaining the sample problem solutions presented.

Volume II details the procedures used in the computer program for obtaining heat and mass balances and other analytical quantities required in determining life support system characteristics.

Volume IV is the Program Manual and contains the detailed information necessary in using the computer program, in running the program on the IBM 7094 computer, and in understanding the details of the programmed logic including the structure of the program subroutines. Volume IV is available in a limited number of copies.

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Section 3 COMPUTER PROGRAM DESCRIPTION

The H738 Parametric Manned Life Support Systems Fortran Program sizes life support systems for manned spacecraft within broad ranges of ecological closure, crew size, space missions, resupply period, and vehicle size. A simplified flow diagram of the complete computer program is shown in Figure 3-1. Complete life support systems are considered to be comprised of the eight subsystems shown within the dashed line. Computational logic for each of these subsystems has been programmed as individual program subroutines. The flow of program logic through these subroutines as indicated on Figure 3-1 eliminates the necessity of iterating between subroutines, regardless of the complexity of the life support system to be analyzed. The individual functional responsibilities assigned to these subsystems are delineated in Table 3-1. These subsystem responsibilities are sufficiently broad to include the various types of equipment required in life support systems with ecological closure varying from "open" to "closed". Considerable variation in the types of equipment which can be selected for accomplishing individual life support subsystem functions is provided. The program determines life support subsystem equipment weight and volume; and required electrical power, cooling, and heating to satisfy the design conditions. Weight and volume of expendable materials (which are considered to be resupplied for earth orbital missions with a specified resupply period) and accumulated materials are based on average daily operating conditions. Expendable materials include primarily food, O₂, diluent gas, and water. Accumulated materials are determined for the total length of the mission and are not considered to be removed during resupply operations.

In specifying a particular life support system to be characterized by the H378 program, optional functional methods for such functions as collecting wastes or accomplishing recovery processes are selected from a provided list of alternate functional methods. There is no restriction on the combinations of selected functional methods as long as the resulting total system is

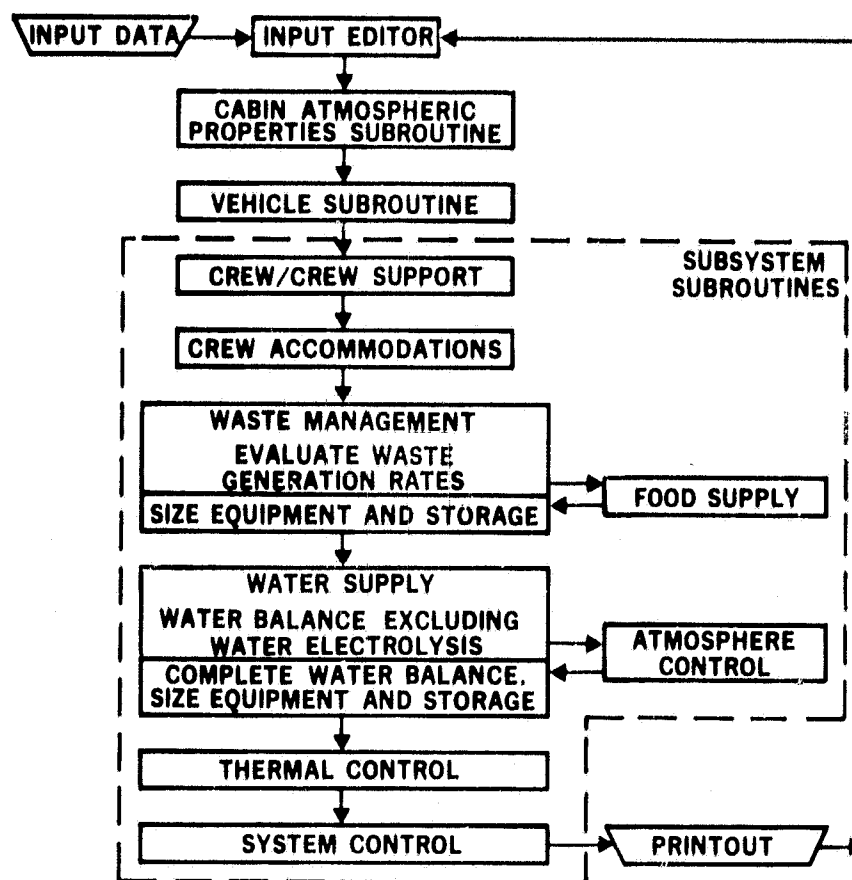


Figure 3-1. Parametric Life Support System Computer Program Logic Diagram

operable and feasible. During the development of this study it was found that most life support systems of interest fall into one of three categories: "open", "partially closed", or "closed". It became expeditious, therefore, to assemble complete sets of input data for a representative system in each of these categories. These assembled data are provided as decks of data cards and are also provided on magnetic tape to facilitate computer operations. These three systems are referred to as "baseline" systems and may serve as a starting point in specifying a particular life support system. As will become more clear in the following sections, input data changes in selected functional methods, component operating conditions, and equipment parametric data are readily achieved. These changes can be made on a temporary basis when several different combinations of individual changes are required. A particular combination of changes of appreciable interest can be imposed permanently on a particular existing baseline system; and a new "baseline" system is thereby established.

Table 3-1

SUBSYSTEM RESPONSIBILITIES AND INTERACTIONS

Subsystem	Functional Responsibilities
Atmosphere Control	Control cabin pressure. Supply stored O ₂ and diluent. Provide airlock pumpdown. Recover O ₂ from collected CO ₂ and/or water vapor.
Thermal Control	Provide cabin atmosphere circulation and control of its temperature and humidity. Provide fluid heating and cooling circuitry with rejection of heat to heat sinks. Provide cabin wall insulation.
Water Supply	Provide water storage tanks, sterilization requirements and the water distribution system. Recover water from urine, respired and perspired water, wash water, and fecal material.
Waste Management	Collection, disposal, and storage for reclamation or accumulation of CO ₂ , urine, fecal material, and refuse. Removal of trace contaminants.
Food Supply	Provide stored food, processing of food from wastes, and food preparation requirements.
Crew/Crew Support	Provide space suits and clothing, EVA support equipment, first aid and medical supplies, fire extinguishers, personal items, and biomedical data equipment.
Crew Accommodations	Provide living, work and recreational facilities, gravity conditioners, lights, and biomedical instrumentation.
System Controls	Provide automatic and manual devices, functional controls, and process monitoring equipment for the complete life support system.

3.1 INPUT DATA

There are three basic types of information which can be obtained from characterizing life support systems with the H738 program:

1. Mission analysis data such as total life support system weight, volume, and required power.

2. Life support system tradeoff data such as weights of equipment and associated expendables for a particular functional method for collecting waste material or accomplishing a recovery process.
3. Engineering design data such as gas flow at a particular equipment location or required liquid coolant flow for a particular component.

The input data for the computer program are described in this section and the particular input data most pertinent to each of the three types of desired data and information listed above are clarified. The input data are specified on loadsheets designed especially for the H738 Program. From these loadsheets data cards are punched and are subsequently loaded with the program decks in running the program.

3.1.1 Mission Analysis Data

Basic mission parameters such as crew size, flight date, and vehicle flight path are specified on the loadsheet designated as H738 MISSION ANALYSIS DATA LEVEL 1, see Figure 3-2. These mission analysis data are referred to as MAD LEVEL 1 data in the discussions which follow. The MAD LEVEL 1 data are the minimum data required in running a computer case.

Sets of data for three complete life support systems with ecological closures described as "open", "partially closed", and "closed" have been prepared. These sets of data are referred to as "baselines" and may be used as starting places in formulating particular problems to be solved. Generally, the particular baseline is selected with ecological closure closest to that desired in the life support system to be studied. As indicated on Figure 3-2, the MAD LEVEL 1 data shown call for the "partially closed" system through the input word, "PART". This word is located in columns 9 to 12 on data card, MADLEV12.

MAD LEVEL 2 data (H738 MISSION ANALYSIS DATA LEVEL 2 loadsheets) specify some basic characteristics for the particular case such as cabin atmospheric properties: gas constituents, pressure level, temperature, and humidity; resupply and emergency periods; occupied cabin volumes; and crew distributions in cabins, activity levels, and percentile. The crewmen must be assigned to cabins with corresponding activity levels for purposes of designing equipment in the cabins ("EQUIPMENT DESIGN" on MADLEV23 card) and must also be assigned to cabins with corresponding activity levels

REFPUNCH NOTES:

1. Punch as written
2. Punch on all cards

73 76

73.8

cc	CASE NO	CASE TITLE	72	77	...
1	8 9 12 13				
		NADLEVLL			
		200 PARTIALLY CLOSED SYSTEM SAMPLE PROBLEM			

[illegible]

Engineer Note: This sheet must be completed for each case.

Figure 3-2. Sample Mission Analysis Input Data Loadsheet

LEVEL 2

1. Punch as written
2. Punch on all cards

NO. OF CHAINS		CART WEIGHT(S)									
		(m3)									
		V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
1	8 9 12 13		22 23	32 33	42 43	53 54	62 63	72	77	80	...
A.D.L.V.2.12		1 2	93.5	190.5							

[illegible]

Figure 3-2 (continued). Sample Mission Analysis Input Data Loadsheet

H738 MISSION ANALYSIS DATA
LEVEL 2

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2. Punch on all cards

VEHICLE DATA									
CC	CABIN DIAMETER (in)	SHELL THICKNESS (in)	INNER	OUTER	CONSIDER VEHICLE ENDS	73	77	80	
1	8 9	3233	23	42	YES*	73	77	80	
	6.60	0.0101		000.5	YES*	73	77	80	
					YES*	73	77	80	
					NO**	73	77	80	

METEOROID DATA									
SHIELD	PROBABILITY OF NO PUNCTURE	13	16	21	30	73	77	80	
1	6	YES*	YES*	9.9		73	77	80	
	6	YES*	YES*	9.9		73	77	80	
		YES*	YES*			73	77	80	
		NO**	NO**			73	77	80	

Figure 3-2 (concluded). Sample Mission Analysis Input Data Loadsheet

for purposes of determining the expendables requirements and accumulated materials ("EXPENDABLE DESIGN" on MADLEV23 card). Thus, the equipment design designations permit the equipment in each cabin to be sized large enough to accommodate the total crew or any designated part of the total crew. These designations apply to the Atmosphere Control, Thermal Control, and Waste Management subsystems and include O₂ recovery units, cabin heat exchangers, circulation fans, and atmosphere purification loops providing humidity control, trace contaminants removal, and CO₂ removal equipment.

The redundancy which may be achieved for these three subsystems in multi-cabin cases by specifying, for example, that the equipment in each cabin accommodate 100% of the crew is indicated in the determinations of the weight and volume of spare parts required. The activity level specified for equipment design purposes is often set at a value corresponding to metabolic rates somewhat higher than average for peak activity levels are generally of short duration and the combined characteristics of the equipment and the cabin can accommodate short transients with negligible effect.

The expendable design crew distribution in each cabin is the daily average distribution. Since expendables are sized for elapsed time periods, such as resupply periods or mission durations, they are determined on the basis of average consumption rates. The corresponding crew fractions per cabin should add up to 100% and the activity levels should be daily average values (MADLEV23).

Spare parts can be determined, as an option, for the Atmosphere Control, Thermal Control, Waste Management, and Water Supply subsystems.

3.1.2 Life Support System--Tradeoff Data

The loadsheets for these data are designated as H738 LIFE SUPPORT SYSTEM-TRADEOFF DATA. There is a set of loadsheets for each subsystem, except the System Control and Crew Accommodations subsystems. On these loadsheets data specify additional quantities for the crew concerning radiation protection their diet, and so forth; but basically the data are to specify the selected functional methods used in accomplishing individual subsystem responsibilities and detail equipment characteristics such as process efficiency and temperatures of liquid coolant. These loadsheets and data are referred to as

LSS-TRADEOFF DATA in the following discussions. Figures 3-3 through 3-8 are the LSS-TRADEOFF DATA loadsheets. These are for the sample "partially closed" system considered in Section 4.

3.1.3 Table Data

Loadsheets for these data are designated as H738 TABLE DATA/SCALING LAWS and H738 TABLE DATA/PARAMETRIC RELATIONS. It is by means of these scaling laws and parametric relations data that the appropriate equipment characteristics are related to their design variables.

Selected functional equipment are specified for computer program solutions through LSS-TRADEOFF DATA consisting of alphanumeric designations indicating which functional methods have been selected, and parametric data (TABLE DATA) supplying the relations which determine for these selected equipment the weight, volume, required electrical power, heating, and cooling as functions of their independent variables such as processed material flow rates and crew size. These TABLE DATA are in two forms:

1. Scaling Laws--Scaling law data are coefficients for use in algebraic equations which relate the equipment characteristics to independent variables. These coefficients are entered on the loadsheet similar to Figure 3-9. Eight different types of scaling laws are available in the computer program. These are listed in Table 3-2. A_1 , A_2 , A_3 , and so forth are constant coefficients, while ϕ_1 , ϕ_2 , and so forth are the independent variables. In implementing a desired scaling law for an equipment characteristic the most appropriate form of those listed in Table 3-2 is selected. The input data consist of the table number, the scaling law form number from Table 3-2, the number of coefficients, and the values for the coefficients A_1 , A_2 , and so forth.
2. Parametric Relations--Parametric relations are used to describe graphical data as pairs of dependent and independent variable data points. Single curves (two dimensional) or families of curves (three dimensional) can be specified, relating equipment characteristics to independent variables. These graphical data or parametric relations are entered in loadsheets designated as TABLE DATA/PARAMETRIC RELATIONS; see Figure 3-10. PARAMETRIC RELATIONS data consist of the table number, number(s) of data points for the independent variables or arguments used in representing the curve or curves, the subscript number or argument flag for the independent variables or arguments, the scale type, and the values for the independent and dependent variables. With reference to the above, setting the argument flag equal to 1 specifies that ϕ_1 is the argument. Each coordinate scale is either linear, logarithmic, or probabilistic.

HT38 LIFE SUPPORT SYSTEM - TRADE OFF DATA
CREW AND CREW SUPPORT SUBSYSTEM

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ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
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ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY										INTERPLANETARY ONLY										1. Punch as written		2. Punch on all cards	
ORBITAL ONLY</																							

WASTE MANAGEMENT SUBSYSTEM

1. Punch as written
2. Punch on all cards

METHOD OF URINE COLLECTION		METHOD OF URINE DISPOSITION (for Air Entreatment Urinal)		URINE STORAGE TANKS	
8 9	30	33	64	67	70 73 76 77 80
U.S.S.S. 0.2	ALP*ENTRAIMENT*URINAL	ACCUM*FØR*URINE*RECØV*ØR*STØRAGE	ØVERBØARD*DUMP*TRANSFER*LINE***	ØVERBØARD*STØRAGE	YES*
	PERSØNAL*URINE*BA G***	ØVERBØARD*VENT*URINAL*	ACCUM*FØR*URINE*RECØV*ØR*STØRAGE	ØVERBØARD*STØRAGE	NØ**
	AIR*ENTRAIMENT*URINAL				

METHOD OF FECES COLLECTION		8 9		36		72 73		76 77		80	
1.	EMULSION	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3
PORTABLE IEBRIS VACUUM CLEANER 41 44 45											
YES * YES * N Ø * *											
MANUAL * BAGGING * AND * STORAGE * AIR * ENTRAINMENT * VACUUM * DRYING * WATER * WASH * AIR * ENTRAINMENT *											

	CATALYTIC BURNER	ACTIVATED CHARCOAL				
1						
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Figure 3-4. Sample Waste Management Input Data Loadsheet

H738 LIFE SUPPORT SYSTEM - TRADEOFF DATA
FOOD PROCESSING SUBSYSTEM

- KEYPUNCH NOTES:
1. Punch as Written
2. Punch on all Cards

FOOD PROCESSING FLAG	FSS PRINTOUT FLAG	METHOD OF FOOD PROCESSING	PERCENT OF FOOD PROCESSED %	
8 9 12	17 20	25	38 43 52	73 76 H 7 3 8
E.S.S.I.S.S.Q.I	YES*	GLYCEROL***** HYDROGENOONAS		
YES*	YES*			
NO**	NO**			

COLD COOLANT TEMPERATURES		HEATING FLUID TEMPERATURES	
INLET	TEMPERATURE RISE	INLET	TEMPERATURE DROP
13 16	21 30	35 38	43 52
8			
E.S.S.I.S.S.Q.I			
1 L Ø W		1 L Ø W	
2 MED		2 MED	
3 HIGH		3 HIGH	

Figure 3-5. Sample Food Supply Input Data Loadsheet

HT38 LIFE SUPPORT SYSTEM - TRADE OFF DATA
WATER SUPPLY SUBSYSTEM

KEYPUNCH NOTES:
1. Punch as written
2. Punch on all cards

WATER STORAGE TANKS										STERILIZATION	
cc	H ₂ O	RECOVERY	YES	PROTOUT	YES	RELIABILITY	34	73	76		
1	89	FLAG	12	YES	20	999	34	87	38		
1	89	FLAG	12	YES	20	999	34	87	38		
1	89	FLAG	12	YES	20	999	34	87	38		
1	89	FLAG	12	YES	20	999	34	87	38		

WATER STORAGE TANKS										STERILIZATION	
NO. OF	TANK SHAPE	NO. OF	TANK DIA.	TANK L/D	TANK PRESSURE	56	59	72	80		
1	89	20	23	32	33	2.0	59	72	80		
1	89	20	23	32	33	2.0	59	72	80		
1	89	20	23	32	33	2.0	59	72	80		
1	89	20	23	32	33	2.0	59	72	80		

METHOD OF WATER RECOVERY					RECOVERY EFFICIENCY %		
1	8 9	18 19	35	41	50	77	80
1	W.S.S.L.S.S.L.L	U.R.I.N.E*****	C.L.O.S.E.D*A.I.R.*E.V.A.P.*		75.0		
	W.S.S.L.S.S.L.L	C.O.N.D.E.N.S.A.T.E	C.L.O.S.E.D*A.I.R.*E.V.A.P.*		75.0		
	W.S.S.L.S.S.L.L	F.E.C.E.S*****					
	W.S.S.L.S.S.L.L	W.A.S.H.*W.A.T.E.R	C.L.O.S.E.D*A.I.R.*E.V.A.P.*		75.0		
			V.A.P.O.R.*C.O.M.P.R.E.S.S.I.O.N				
			V.A.P.O.R.*P.Y.R.O.L.Y.S.I.S**				
			C.L.O.S.E.D*A.I.R.*E.V.A.P.*				
			E.L.E.C.T.R.O.D.I.A.L.Y.S.I.S**				
			M.U.L.T.I.F.I.L.T.R.A.T.I.O.N**				

Figure 3-6. Sample Water Supply Input Data Loadsheet

H738 LIFE SUPPORT SYSTEM - TRADE OFF DATA
WATER SUPPLY SUBSYSTEM

KEYPUNCH NOTES:
1. Punch as written
2. Punch on all cards

		COLD				HEATING					
		COOLANT TEMPERATURES				FLUID TEMPERATURES					
		23	27	34	43	47	50	54	63	73	76
		INLET	INLET	OUTLET (°K)	OUTLET (°K)	INLET	INLET	OUTLET (°K)	OUTLET (°K)		
cc	1	23	27	34	43	47	50	54	63	73	76
1	8 9	23	27	34	43	47	50	54	63	73	76
1	1	23	27	34	43	47	50	54	63	73	76
1	2	23	27	34	43	47	50	54	63	73	76
1	3	23	27	34	43	47	50	54	63	73	76
1	4	23	27	34	43	47	50	54	63	73	76
1	5	23	27	34	43	47	50	54	63	73	76
1	6	23	27	34	43	47	50	54	63	73	76
1	7	23	27	34	43	47	50	54	63	73	76
1	8	23	27	34	43	47	50	54	63	73	76
1	9	23	27	34	43	47	50	54	63	73	76
1	10	23	27	34	43	47	50	54	63	73	76
1	11	23	27	34	43	47	50	54	63	73	76
1	12	23	27	34	43	47	50	54	63	73	76
1	13	23	27	34	43	47	50	54	63	73	76
1	14	23	27	34	43	47	50	54	63	73	76
1	15	23	27	34	43	47	50	54	63	73	76
1	16	23	27	34	43	47	50	54	63	73	76
1	17	23	27	34	43	47	50	54	63	73	76
1	18	23	27	34	43	47	50	54	63	73	76
1	19	23	27	34	43	47	50	54	63	73	76
1	20	23	27	34	43	47	50	54	63	73	76
1	21	23	27	34	43	47	50	54	63	73	76
1	22	23	27	34	43	47	50	54	63	73	76
1	23	23	27	34	43	47	50	54	63	73	76
1	24	23	27	34	43	47	50	54	63	73	76
1	25	23	27	34	43	47	50	54	63	73	76
1	26	23	27	34	43	47	50	54	63	73	76
1	27	23	27	34	43	47	50	54	63	73	76
1	28	23	27	34	43	47	50	54	63	73	76
1	29	23	27	34	43	47	50	54	63	73	76
1	30	23	27	34	43	47	50	54	63	73	76
1	31	23	27	34	43	47	50	54	63	73	76
1	32	23	27	34	43	47	50	54	63	73	76
1	33	23	27	34	43	47	50	54	63	73	76
1	34	23	27	34	43	47	50	54	63	73	76
1	35	23	27	34	43	47	50	54	63	73	76
1	36	23	27	34	43	47	50	54	63	73	76
1	37	23	27	34	43	47	50	54	63	73	76
1	38	23	27	34	43	47	50	54	63	73	76
1	39	23	27	34	43	47	50	54	63	73	76
1	40	23	27	34	43	47	50	54	63	73	76
1	41	23	27	34	43	47	50	54	63	73	76
1	42	23	27	34	43	47	50	54	63	73	76
1	43	23	27	34	43	47	50	54	63	73	76
1	44	23	27	34	43	47	50	54	63	73	76
1	45	23	27	34	43	47	50	54	63	73	76
1	46	23	27	34	43	47	50	54	63	73	76
1	47	23	27	34	43	47	50	54	63	73	76
1	48	23	27	34	43	47	50	54	63	73	76
1	49	23	27	34	43	47	50	54	63	73	76
1	50	23	27	34	43	47	50	54	63	73	76
1	51	23	27	34	43	47	50	54	63	73	76
1	52	23	27	34	43	47	50	54	63	73	76
1	53	23	27	34	43	47	50	54	63	73	76
1	54	23	27	34	43	47	50	54	63	73	76
1	55	23	27	34	43	47	50	54	63	73	76
1	56	23	27	34	43	47	50	54	63	73	76
1	57	23	27	34	43	47	50	54	63	73	76
1	58	23	27	34	43	47	50	54	63	73	76
1	59	23	27	34	43	47	50	54	63	73	76
1	60	23	27	34	43	47	50	54	63	73	76
1	61	23	27	34	43	47	50	54	63	73	76
1	62	23	27	34	43	47	50	54	63	73	76
1	63	23	27	34	43	47	50	54	63	73	76
1	64	23	27	34	43	47	50	54	63	73	76
1	65	23	27	34	43	47	50	54	63	73	76
1	66	23	27	34	43	47	50	54	63	73	76
1	67	23	27	34	43	47	50	54	63	73	76
1	68	23	27	34	43	47	50	54	63	73	76
1	69	23	27	34	43	47	50	54	63	73	76
1	70	23	27	34	43	47	50	54	63	73	76
1	71	23	27	34	43	47	50	54	63	73	76
1	72	23	27	34	43	47	50	54	63	73	76
1	73	23	27	34	43	47	50	54	63	73	76
1	74	23	27	34	43	47	50	54	63	73	76
1	75	23	27	34	43	47	50	54	63	73	76
1	76	23	27	34	43	47	50	54	63	73	76
1	77	23	27	34	43	47	50	54	63	73	76
1	78	23	27	34	43	47	50	54	63	73	76
1	79	23	27	34	43	47	50	54	63	73	76
1	80	23	27	34	43	47	50	54	63	73	76
1	81	23	27	34	43	47	50	54	63	73	76
1	82	23	27	34	43	47	50	54	63	73	76
1	83	23	27	34	43	47	50	54	63	73	76
1	84	23	27	34	43	47	50	54	63	73	76
1	85	23	27	34	43	47	50	54	63	73	76
1	86	23	27	34	43	47	50	54	63	73	76
1	87	23	27	34	43	47	50	54	63	73	76
1	88	23	27	34	43	47	50	54	63	73	76
1	89	23	27	34	43	47	50	54	63	73	76
1	90	23	27	34	43	47	50	54	63	73	76
1	91	23	27	34	43	47	50	54	63	73	76
1	92	23	27	34	43	47	50	54	63	73	76
1	93	23	27	34	43	47	50	54	63	73	76
1	94	23	27	34	43	47	50	54	63	73	76
1	95	23	27	34	43	47	50	54	63	73	76
1	96	23	27	34	43	47	50	54	63	73	76
1	97	23	27	34	43	47	50	54	63	73	76
1	98	23	27	34	43	47	50	54	63	73	76
1	99	23	27	34	43	47	50	54	63	73	76
1	100	23	27	34	43	47	50	54	63	73	76

Figure 3-6 (concluded). Sample Water Supply Input Data Loadsheet

KEYPUNCH NOTES

1. Punch as written
2. Punch on all cards

73	76
HT 38	

cc		ACS		PRINT-OUT FLAG	ACS SUBSYSTEM RELIABILITY	NO. OF CABIN REPRESSURIZATIONS		73	76
1	b	9	12	17	26	31	34	77	80
ACS:SS.01		YES*		999		/		H738	
		YES*							
		nd**							

[illegible]

Figure 3-7. Sample Atmosphere Control Input Data Loadsheet

KEYPUNCH NOTES:

1. Punch as written
2. Punch on all cards

		COOLANT TEMPERATURES					
		INLET		OUTLET (°K)			
		CO ₂	H ₂ O	CO ₂	H ₂ O		
		RED.	ELECT.	REDUCTION	ELECTROLYSIS		
1	8 9	28	33	36 37	40 41	50 51	60
A.C. 2 L.S.S. 2,2		X		2MED 1 L Φ W		297.0	
				1 L Φ W 1 L Φ W		290.0	
				2MED 2 MED		77	
				3 HI H 3 HI H		80	

Figure 3-7 (continued). Sample Atmosphere Control Input Data Loadsheet

INSTRUCTIONS:

1. Punch as written
2. Punch on all cards

	(1)	(2)	(3)	(4)	(5)	(6)
CANIN LEAK RATES ($\mu\text{g/day}$)						
cc	89	1839	2829	4849	5859	68
L	A.C.S.L. 8.31	A.C.S.L. 8.45				
	73	76	77	80		
	73	76	77	80		

AIRLOCK DATA														
CABIN NO.	AIRLOCK	NO. OF USES	AIRLOCK VOLUME, m ³	PUMP EFFICIENCY %	AIRLOCK FINAL PRESSURE (kg/cm ²)									
8	9	12	17	20	25	28	33	42	43	52	53	62	77	80
1	A,C,B,L,8,8,3,2	1	NO**											
		2	YES*		30		A, Z, S		30.0		.010			
		3												
		4												
		5												
		6												
	A,C,B,L,8,8,3,2													

YES*
NO**

Figure 3-7 (concluded). Sample Atmosphere Control Input Data Loadsheet

HT-38 LIFE SUPPORT SYSTEM - TRADE OFF DATA

THERMAL CONTROL SUBSYSTEM

INPUT NOTES:
 1. Punch as written
 2. Punch on all cards

73 76
 2738

LIQUID COOLING LOOP				LIQUID HEATING LOOP			
COOLING LEVEL INLET TEMPERATURE, °K				HEATING LEVEL INLET TEMPERATURE, °K			
FIRST LEVEL (COLDEST)	SECOND LEVEL	THIRD LEVEL		FIRST LEVEL (COLDEST)	SECOND LEVEL	THIRD LEVEL	
8 9	18 19	28 29		41	50 51	60 61	
T.C.S.L.S.O.1	277.50	286.0	300.0	425.0	425.0	459.0	
1							

LIQUID COOLING LOOP				LIQUID HEATING LOOP			
COOLING LEVEL INLET TEMP. TOLERANCE, °K				HEATING LEVEL INLET TEMP. TOLERANCE, °K			
SECOND LEVEL	THIRD LEVEL			SECOND LEVEL	THIRD LEVEL		
18 19	28			50 51	60		
T.C.S.L.S.O.2							
1							

COLD PLATE HEAT LOADS

(1)				(2)				(3)			
INLET TEMP.				INLET TEMP.				INLET TEMP.			
HEAT LOAD KW				HEAT LOAD KW				HEAT LOAD KW			
14	17	21	30	34	41	50	54	57	61	70	80
2MED	2MED	2MED	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H
1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W
T.C.S.L.S.O.3	6.90	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10
1											

(4)				(5)				(6)			
INLET TEMP.				INLET TEMP.				INLET TEMP.			
HEAT LOAD KW				HEAT LOAD KW				HEAT LOAD KW			
14	17	21	30	34	41	50	54	57	61	70	80
2MED	2MED	2MED	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H	3H I H
1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W	1 L O W
T.C.S.L.S.O.4											
1											

Figure 3-8. Sample Thermal Control Input Data Loadsheet

KEYPUNCH NOTES:

1. Punch as written.
2. Punch on all cards.

73 76
B7C, B7D

TCS		TCS SUBSYSTEM		CABIN	
cc	PRINT-OUT	RELIABILITY	EMISSIVITY	OUTER SHELL	
1	8 9 12	21	30	36	45
T.C.S.L.S.S.C.5		YES*	X	X	X
YES*		999	935		
NO**					

**GAS COOLED EQUIPMENT HEAT LOADS, KW
(EXCLUSIVE OF LIFE SUPPORT SYSTEM EQUIPMENT)
CABIN**

[illegible]

WATER EVAPORATOR
FOR COOLING LOOP,
TOTAL USE, HRS

1 8 11 20 25 40 77 80

T.C.S.I.S.S. 0.7 X 1,000-0.0 X WATER*EVAPORATOR
EXTEND* RADIATOR*
WATER*EVAPORATOR

FRACTION OF CABIN WALL COVERED BY RADIATOR CABIN

(1)	(2)	(3)	(4)	(5)	(6)
11	2321	3021	4041	5051	6061
12	2321	3021	4041	5051	6061
13	2321	3021	4041	5051	6061
14	2321	3021	4041	5051	6061
15	2321	3021	4041	5051	6061
16	2321	3021	4041	5051	6061
17	2321	3021	4041	5051	6061
18	2321	3021	4041	5051	6061
19	2321	3021	4041	5051	6061
20	2321	3021	4041	5051	6061
21	2321	3021	4041	5051	6061
22	2321	3021	4041	5051	6061
23	2321	3021	4041	5051	6061
24	2321	3021	4041	5051	6061
25	2321	3021	4041	5051	6061
26	2321	3021	4041	5051	6061
27	2321	3021	4041	5051	6061
28	2321	3021	4041	5051	6061
29	2321	3021	4041	5051	6061
30	2321	3021	4041	5051	6061
31	2321	3021	4041	5051	6061
32	2321	3021	4041	5051	6061
33	2321	3021	4041	5051	6061
34	2321	3021	4041	5051	6061
35	2321	3021	4041	5051	6061
36	2321	3021	4041	5051	6061
37	2321	3021	4041	5051	6061
38	2321	3021	4041	5051	6061
39	2321	3021	4041	5051	6061
40	2321	3021	4041	5051	6061
41	2321	3021	4041	5051	6061
42	2321	3021	4041	5051	6061
43	2321	3021	4041	5051	6061
44	2321	3021	4041	5051	6061
45	2321	3021	4041	5051	6061
46	2321	3021	4041	5051	6061
47	2321	3021	4041	5051	6061
48	2321	3021	4041	5051	6061
49	2321	3021	4041	5051	6061
50	2321	3021	4041	5051	6061
51	2321	3021	4041	5051	6061
52	2321	3021	4041	5051	6061
53	2321	3021	4041	5051	6061
54	2321	3021	4041	5051	6061
55	2321	3021	4041	5051	6061
56	2321	3021	4041	5051	6061
57	2321	3021	4041	5051	6061
58	2321	3021	4041	5051	6061
59	2321	3021	4041	5051	6061
60	2321	3021	4041	5051	6061
61	2321	3021	4041	5051	6061
62	2321	3021	4041	5051	6061
63	2321	3021	4041	5051	6061
64	2321	3021	4041	5051	6061
65	2321	3021	4041	5051	6061
66	2321	3021	4041	5051	6061
67	2321	3021	4041	5051	6061
68	2321	3021	4041	5051	6061
69	2321	3021	4041	5051	6061
70	2321	3021	4041	5051	6061
71	2321	3021	4041	5051	6061
72	2321	3021	4041	5051	6061

Figure 3-8 (continued). Sample Thermal Control Input Data Loadsheet

H738 TABLE DATA SCALING LAWS

KEYPUNCH NOTES:
1. Punch as written
2. Punch on all cards

TABLE NO.		FORM NO.		COEFFICIENTS	
1	6	11	14	19	22
1	6	11	14	19	22
S.C.A.L.A.W.		6.1		2	3
73 76 E.7.3.8					
77 80					

TABLE NO.		FORM NO.		COEFFICIENTS	
1	6	11	14	19	22
1	6	11	14	19	22
T.I.T.L.E.*		K&Z REDUCER WEIGHT - BOSCH REACTOR			
Enter values of coefficients (A1) below, from left to right - then down, in order of ascending index (1).					
V.A.L.U.E.S		13.6		97.7	55
V.A.L.U.E.S				0.63	70
77 80					

TABLE NO.		FORM NO.		COEFFICIENTS	
1	6	11	14	19	22
1	6	11	14	19	22
S.C.A.L.A.W.		6.2		1	2
77 80					

TABLE NO.		FORM NO.		COEFFICIENTS	
1	6	11	14	19	22
1	6	11	14	19	22
T.I.T.L.E.*		K&Z REDUCER VOLUME - BOSCH REACTOR			
Enter values of coefficients (A1) below, from left to right - then down, in order of ascending index (1).					
V.A.L.U.E.S		0.264		0.51	55
V.A.L.U.E.S					70
77 80					

Figure 3-9. Sample Scaling Law Input Data Loadsheet

1. Lunch as written
2. Punch on all cards

TABLE TITLE		11	70
1	6	×	×
TIT. LE. *		OUTER SHELL DIAMETER OF SPHERICAL STORAGE VESSELS.	
		×	×
		...	...
		...	...

Enter values of 2nd independent variable below, from left to right - then down, in order of ascending value.

Enter values of dependent variable below, from left to right - then down, in the order of 2nd independent variable changing most rapidly.

[illegible]

Figure 3-10. Sample Parametric Relations Input Data Loadsheet

Table 3-2
SCALING LAWS

Form Number	
1	$A_1 * \phi_1 ** A_2$
2	$A_1 + (A_2 * \phi_1 ** A_3)$
3	$A_1 + (A_2 * \phi_1 * \phi_2)$
4	$A_1 * \phi_1 + (A_2 * \phi_2) + (A_3 * \phi_3)$
5	$A_1 + (A_2 * e ** (A_3 * \phi_1))$
6	$A_1 + (A_2 * \phi_1 ** A_3) + (A_4 * \phi_2 ** A_5) + (A_6 * \phi_1 ** A_7) (\phi_2 ** A_8)$
7	$A_1 + (A_2 * \phi_1) + (A_3 * \phi_2) + (A_4 * \phi_3) + (A_5 * \phi_4) + (A_6 * \phi_5)$
8	$A_1 + (A_2 * \phi_1 ** A_3) + (A_4 * \phi_1 ** A_5) + (A_6 * \phi_1 ** A_7) (\phi_2 ** A_8)$

A given "Table" can either be specified by SCALING LAW data or by PARAMETRIC RELATIONS data. Note that the available independent variables ϕ_1 , ϕ_2 , and so forth are automatically used in scaling laws and are specified in parametric relations. There is one restriction in the use of scaling laws and parametric relations for obtaining equipment characteristics and that is that the definitions of the independent variables ϕ_1 , ϕ_2 , and so forth cannot be changed through input data. Subroutine logic for individual subsystems determines the values for these quantities. Despite the restriction imposed by fixed definitions for the ϕ 's, significant flexibility in achieving variations in independent variables exists. For example, if ϕ_1 = crew size and ϕ_2 = mission duration and scaling law 3 is originally used to determine an equipment characteristic as a linear function of man-days,

this functionality can be changed to one involving crew size only by using scaling law 1 or 2. Also, other functionalities involving crew size and mission duration in separate terms can be achieved through using other scaling laws in the list. The use of the ϕ 's in formulating equipment characteristics as parametric relations can be similarly modified through input data.

Baseline data for each of the "open", "partially closed", and "closed" systems are loaded on tape. The baseline case data specified on the MAD LEVEL 1 card MADLEV12 is called in and used along with the remaining MAD LEVEL 1 data in running a particular case. Any desired data cards comprising baseline data can be used along with the MAD LEVEL 1 data cards, and these data cards will temporarily override the taped baseline data for individual cases.

3.2 COMPUTATIONAL LOGIC

In formulating the computational logic for the computer program, life support systems were first divided into the eight "subsystems" with the defined individual functional responsibilities as given in Table 3-1. These responsibilities are sufficient to cover all the various types of equipment which should be included in life support systems in which the ecological closure varies from "open" to "closed".

Once these subsystems were defined, it was necessary to determine a scheme for the computational logic which maximized the availability of required information at each computational step and which minimized iterative procedures required to achieve computational steps. The development of this scheme was desirable for developing such a procedure would greatly improve the efficiency of the computer program in terms of minimizing computer machine time. In determining this flow of computational logic it was found that it was particularly important to examine the computational steps required for each subsystem and between subsystems. In doing this, it was found that Waste Management, Food Supply, Water Supply, and Atmosphere Control Subsystems were highly interrelated. It was found that sequencing the logic for the Crew and Crew Support, Crew Accommodations, Thermal Control, and System Control Subsystems, in that order, was straightforward.

The Crew and Crew Support subroutine determines the basic driving conditions for the required life support system. That is, the specified total number of crewmen and their specified data for activity level, distribution in cabins (for multicabin cases), and size and percentile are used to establish required consumption rates for food, water, and oxygen and the generation rates for respired and perspired water, CO_2 , urine, and feces. The physical characteristics of the support equipment required for this subsystem, as listed in Table 3-1, were found to be basically functions of total number of crewmen and mission duration. Since these driving conditions are determined and since equipment sizing is assumed to be independent of other subsystem computations, this subsystem is evaluated early in the computational scheme. The physical characteristics of equipment in the Crew Accommodations Subsystem were similarly found to be basically functions of crew size and mission duration. Since computed data from other subsystems are not required, this subsystem can be effectively evaluated at any point in the computational scheme. The System Control Subsystem equipment is also sized on the basis of input data only, and this subsystem can be evaluated at any point in the computational scheme.

The Thermal Control Subsystem integrates the various individual cooling and heating requirements of particular elements of other subsystems. However, it was found that no feedback from the Thermal Control Subsystem need be imposed on these served subsystems. This feature permits this subsystem to be evaluated at the end of the computational scheme.

Examples of interactions between the Waste Management, Food Supply, Water Supply and Atmosphere Control Subsystems are indicated in Figure 3-11, 3-12, and 3-13 for "open", "partially closed", and "closed" systems, respectively. As may be inferred from these figures, these four subsystem interactions become more complex as the ecological closure is increased. The computational logic, which was developed, was formulated to accommodate all levels of closure. Furthermore, the logic was developed to accommodate different functional methods within a particular subsystem which it may be desired to select. Some of these functional methods modify the subsystem interactions from those indicated on Figure 3-11, 3-12, and 3-13, and the interactions shown on these figures are considered to be only typical and illustrative.

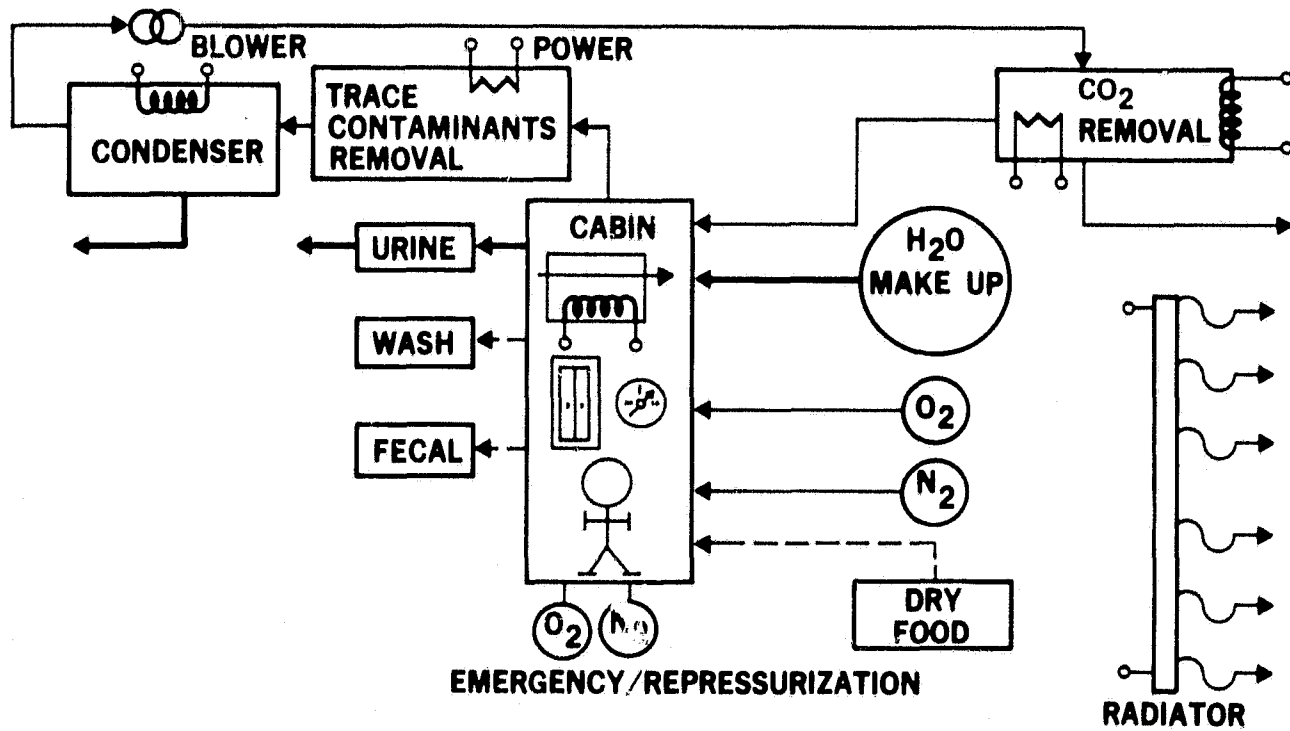


Figure 3-11. Open Life Support System

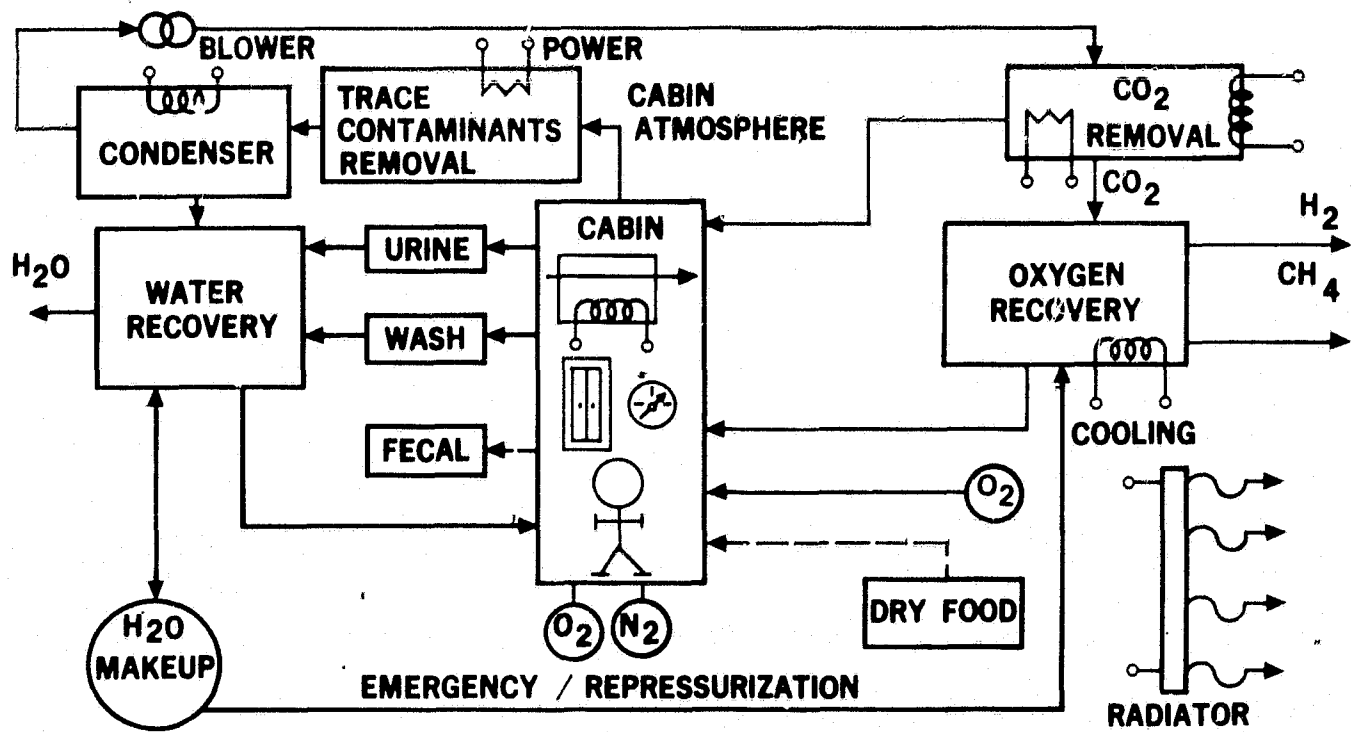


Figure 3-12. Partially Closed Life Support System

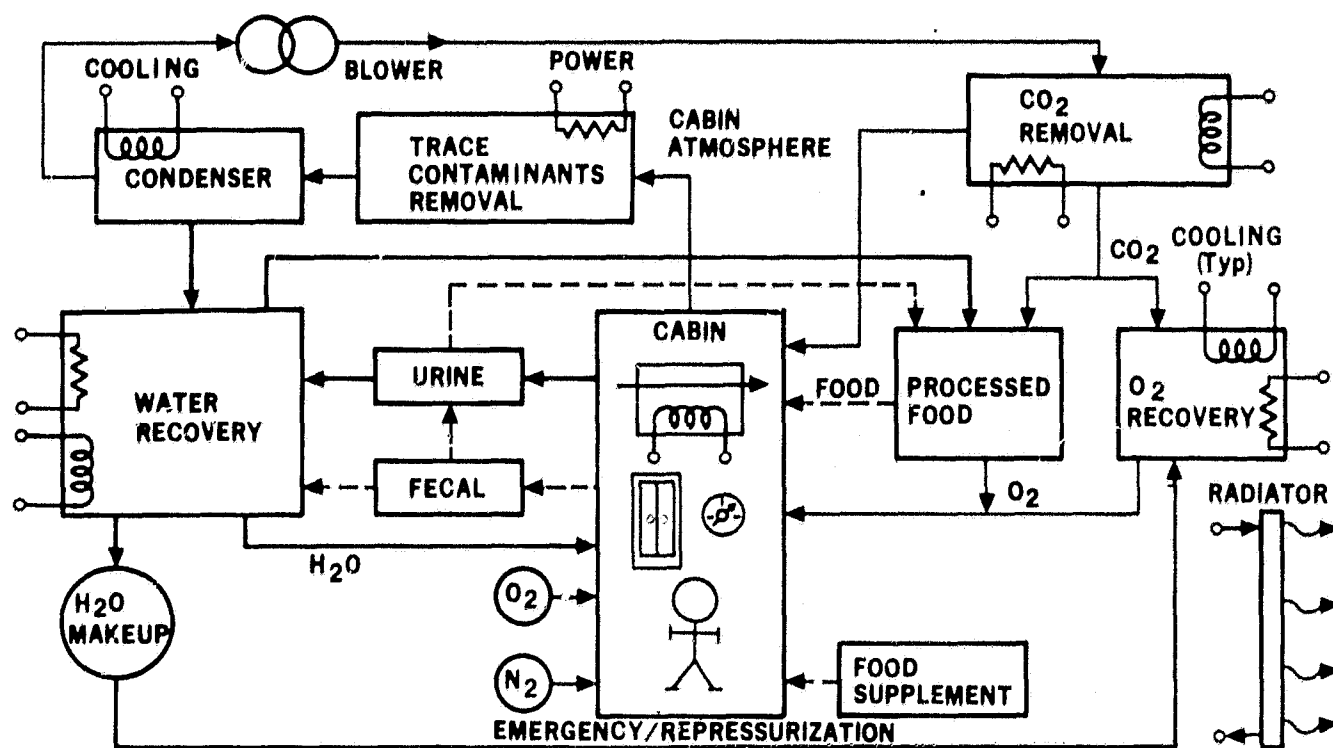


Figure 3-13. Closed Life Support System

The alternate functional methods for oxygen recovery, water recovery, carbon dioxide removal, gas storage, and food processing which are permissible within the developed computational logic are given in Table 3-3. Alternate functional methods for accomplishing functions other than those listed in this table are provided in the logic, as are many other input data provisions concerning various details of life support systems, but the alternate functional methods listed in Table 3-3 indicate the breadth of the life support system tradeoff evaluations which can be obtained with the program.

Of the four subsystems given in Table 3-3, the Waste Management Subsystem logically comes first, for the biological wastes must first be collected prior

Table 3-3
MAJOR ALTERNATE FUNCTIONAL METHODS

Subsystem	Functional Item	Provided Functional Methods
Atmosphere Control	CO ₂ reduction	1. Bosch 2. Sabatier - CH₄ vent 3. Sabatier - C₂H₂ vent 4. Sabatier - C collection 5. Molten carbonate 6. Solid electrolyte
	Water electrolysis	1. Rotating cell with H₂ diffusion 2. Double membrane with H₂SO₄ electrolyte 3. Water vapor cell 4. Membrane cell with KOH electrolyte
Water Supply	Water recovery	1. Closed-cycle air evaporation 2. Vapor compression 3. Vapor pyrolysis 4. Electrodialysis 5. Multifiltration
Waste Management	CO ₂ Collection	1. Lithium hydroxide 2. Molecular sieve/silica gel - isothermal beds 3. Molecular sieve - adiabatic beds 4. Molecular sieve/silica gel - partially isothermal beds 5. Electrodialysis 6. Solid amines 7. Carbonation cell 8. Liquid absorption
Food Supply	Food processing	1. Hydrogenomonas 2. Glycerol

to being processed for recovery purposes. Now consider the individual wastes of carbon dioxide, urine, and feces. It is assumed that carbon dioxide collected for recovery purposes is all, or partially, used for food processing and/or oxygen recovery. Food processing takes precedence with regard to collected carbon dioxide. Any unused carbon dioxide is assumed to be dumped to space. Urine and fecal material collected for recovery purposes is all or partially used in food processing or in water recovery. Food processing takes precedence also with regard to available urine and fecal material. When food processing is specified without water recovery, unused urine and fecal material are assumed to be accumulated for uses such as radiation shielding. When water recovery from urine is specified, in any combination with other processes, all available urine (after food processing) is assumed to be processed.

Due to the provision of the option for determining storage requirement for urine and fecal material which are not processed for food, it is necessary first to determine the amounts of urine and fecal material which are actually processed for food. Accordingly, the computational logic transfers out of the Waste Management subroutine to the Food Supply subroutine; determines the food processing requirements for carbon dioxide, urine, and fecal material (as well as determining the stored food supplement); and then returns to the Waste Management subroutine. This computational procedure is indicated in Figure 3-1. Accumulated urine and fecal material storage requirements, as well as the balance of the subsystem characteristics, are determined in the Waste Management subroutine; and upon completion, the computational logic then proceeds to the Water Supply subroutine.

All of the information required by the Water Supply subroutine in its computations for water storage, distribution, and recovery characteristics is available with one important exception. This exception is the amount of water required by the Atmosphere Control Subsystem for conversion to oxygen and hydrogen through electrolysis processes. If water electrolysis is included in the system, the corresponding water use rate must be available for the water tankage computations. The water tanks are determined by the expendable water which must be provided on board the vehicle at launch.

A tentative water balance, exclusive of electrolysis water requirements, is determined in the Water Supply subroutine. This balance includes all the water flows shown on Figure 3-14 with the exception of water supply rates to either the optional water vapor electrolysis unit or to the optional liquid water electrolysis unit. The tentative water balance indicates either a water deficit (expendable water is required) or that excess water is available. One of the optional oxygen recovery methods uses some or all of this excess water for electrolysis, but it does not permit the use of expendable water. For this method, makeup oxygen is provided. Other optional oxygen recovery methods permit the use of expendable water for electrolysis purposes.

[illegible]

37

completely characterized before the logic returns to the Water Supply Sub-routine with water electrolysis rates. The recomputation of the system water balance yields the true water balance, and the water supply equipment, expendables, and accumulated material are determined.

All the individual heat loads imposed either upon the liquid cooling loop or convected to cabin atmospheres are now available. The individual heating loop requirements for each unit or subsystem have been determined. The logic supplies these needs to the Thermal Control subroutine and sizes the required heat exchangers, fans, plumbing, space radiator and other thermal control equipment.

The logic for the System Controls Subsystem is very simple as can be seen from the developed parametric data in Volume II. This logic is located in the final results printout subroutine in the computer program.

Individual abbreviated logic diagrams for the other life support subsystems are presented in Figure 3-15 through 3-22. These diagrams are intended to

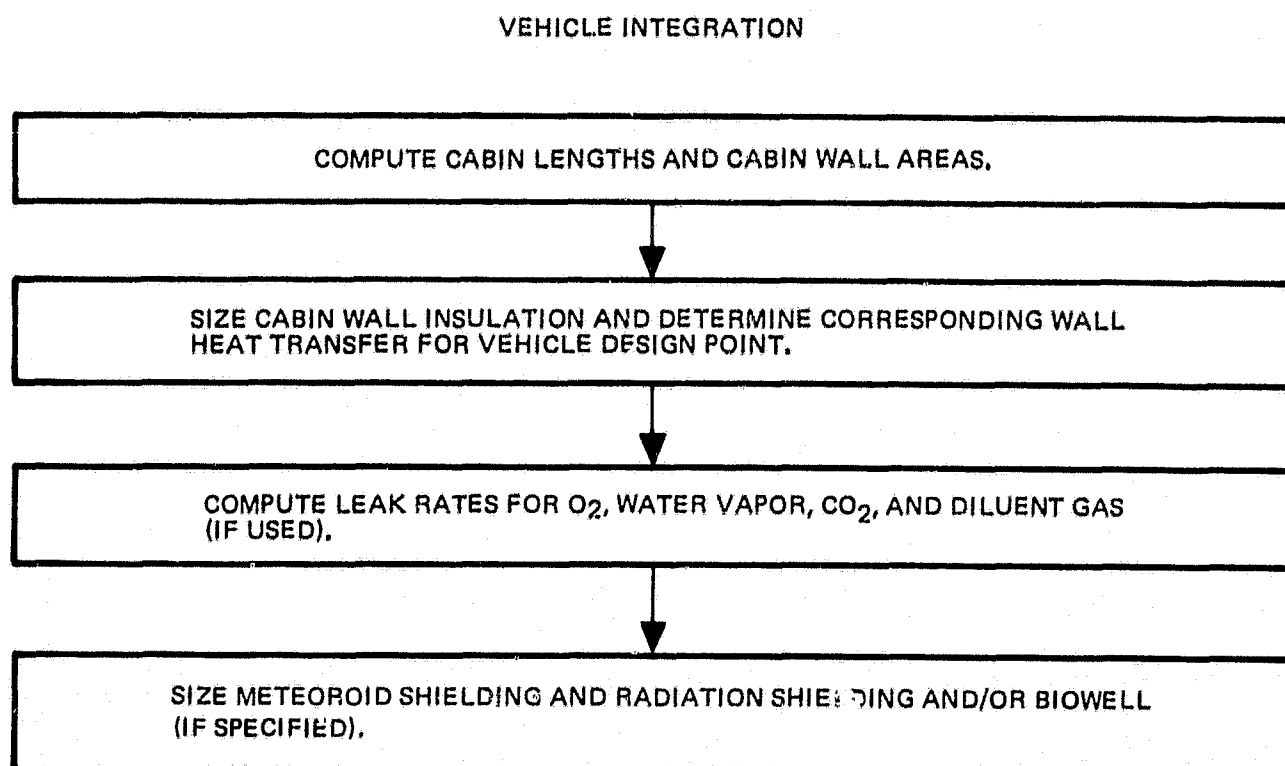


Figure 3-15. Vehicle Integration Logic Diagram

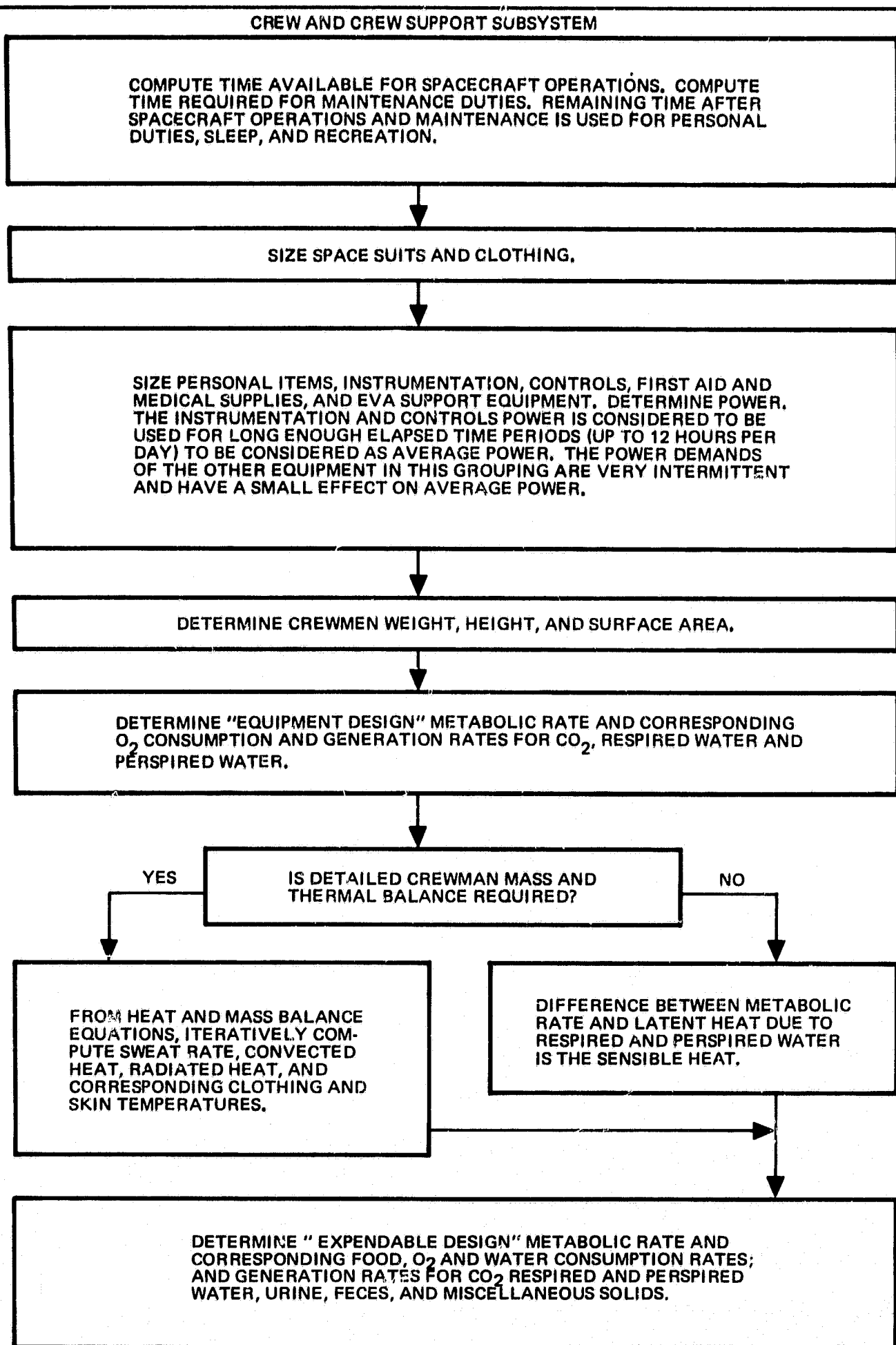


Figure 3-16. Crew and Crew Support Subsystem Logic Diagram

CREW ACCOMMODATIONS SUBSYSTEM

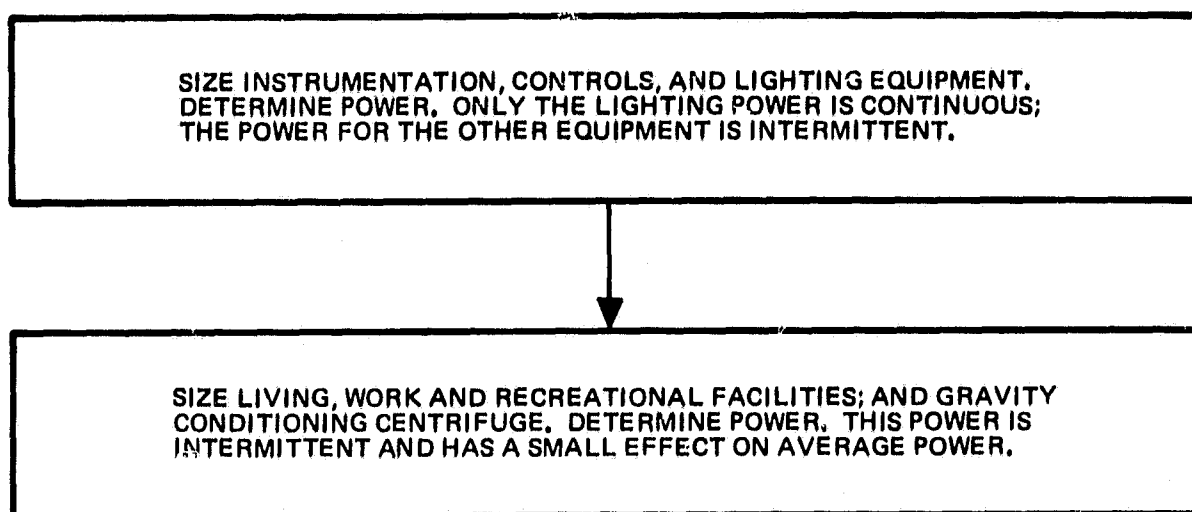


Figure 3-17. Crew Accommodations Subsystem Logic Diagram

complement the foregoing discussions concerning the program and subsystem computational logic; and they are intended to be complete enough to facilitate hand calculations of life support system characteristics when they are used in conjunction with subsystem and component logic and parametric data presented in Volume II.

3.3 OUTPUT DATA

Tabular output data on three levels of detail are produced by the program. Examples of these data are shown in Figures 3-23 through 3-34. These levels are described as follows:

1. Engineering data--This output consists of detailed information such that components like tubing, ducting, heat exchangers, and fans can be sized. This printout is optional. See Figures 3-23 through 3-27 for examples.
2. Subsystem printout--This output consists of qualitative subsystem data comprised of verbal equipment qualifications and statements of particular problem areas; and quantitative data consisting of physical characteristics of individual subsystem equipment,

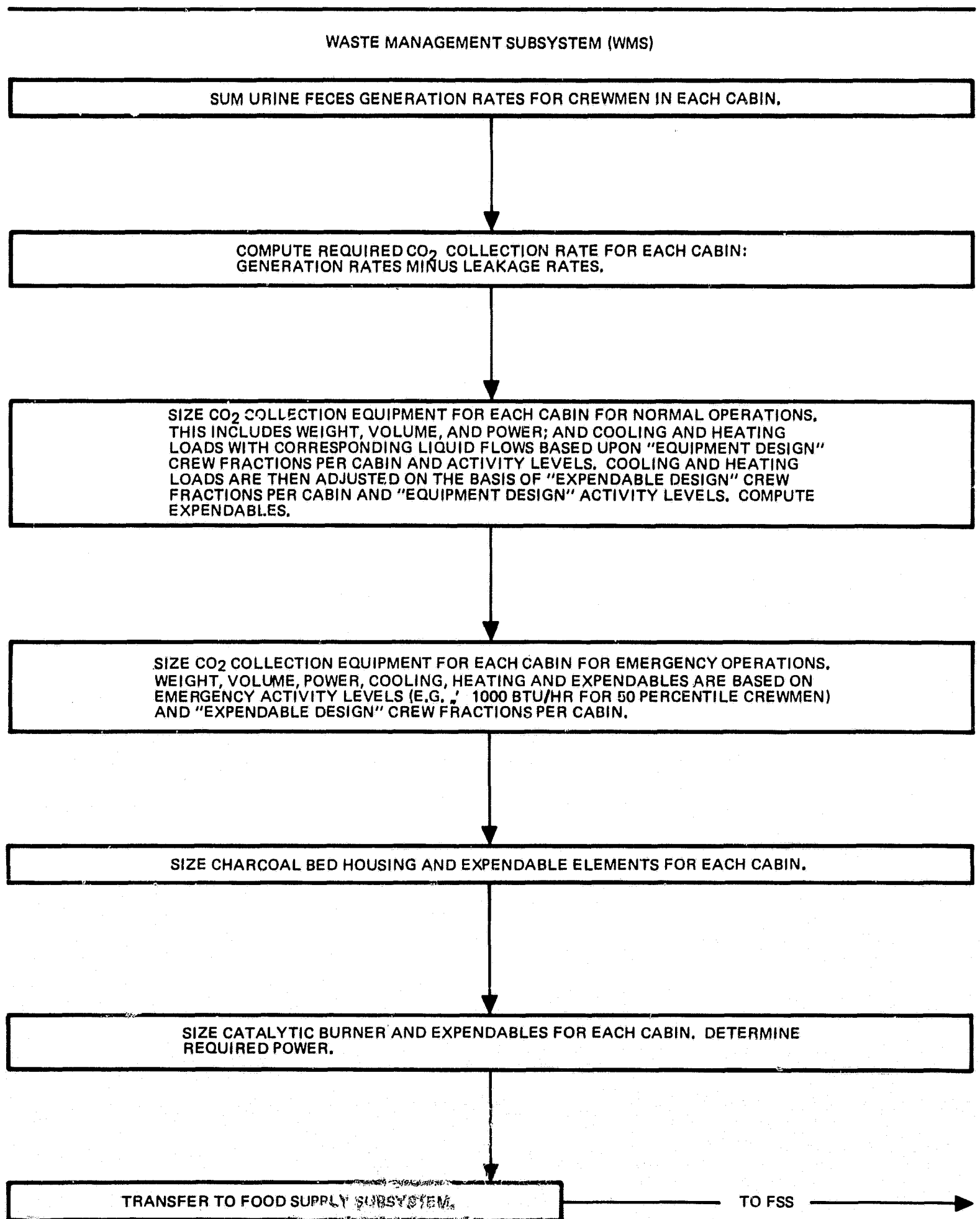


Figure 3-10. Waste Management Subsystem Logic Diagram

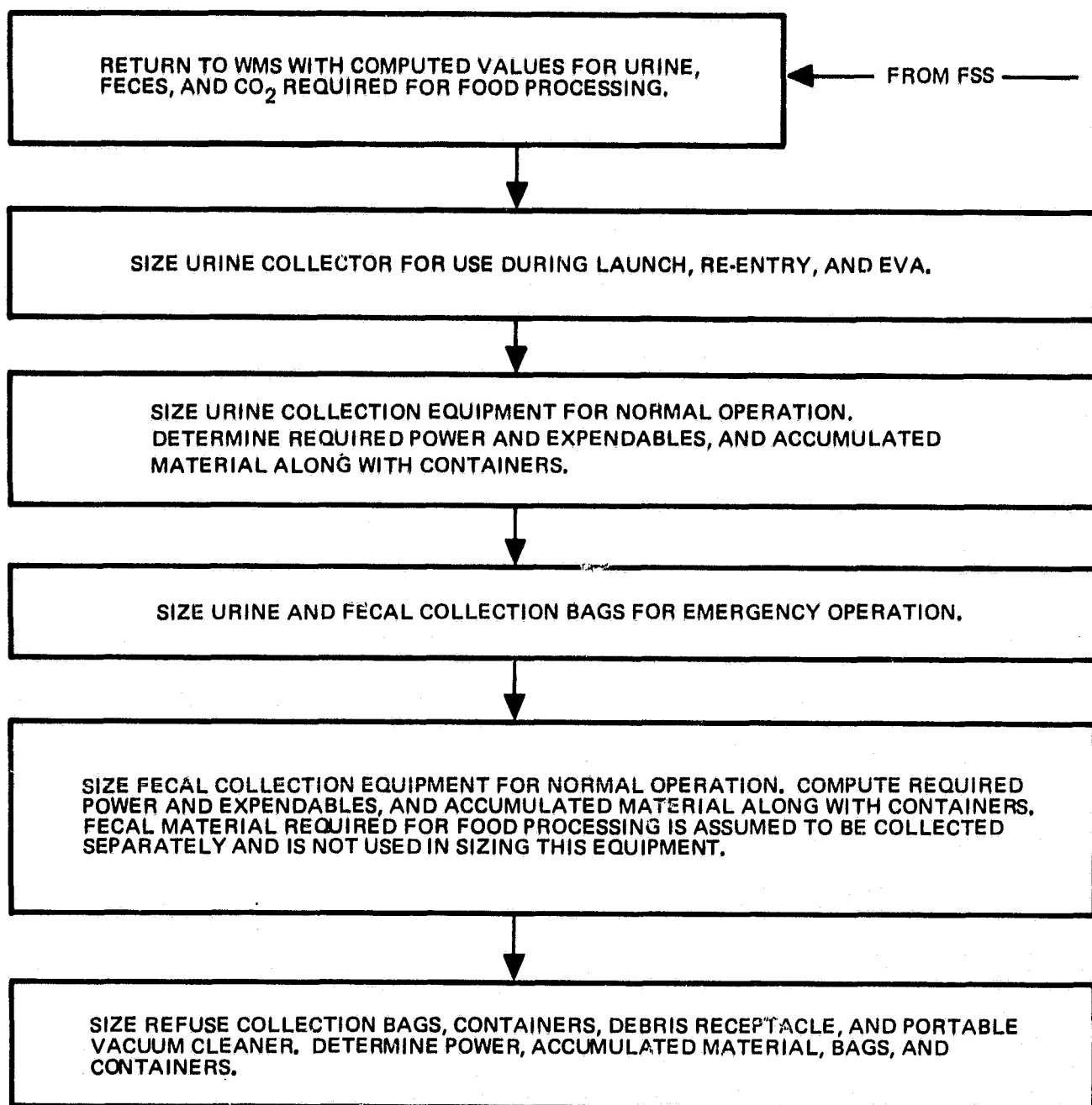


Figure 3-18 (concluded). Waste Management Subsystem Logic Diagram

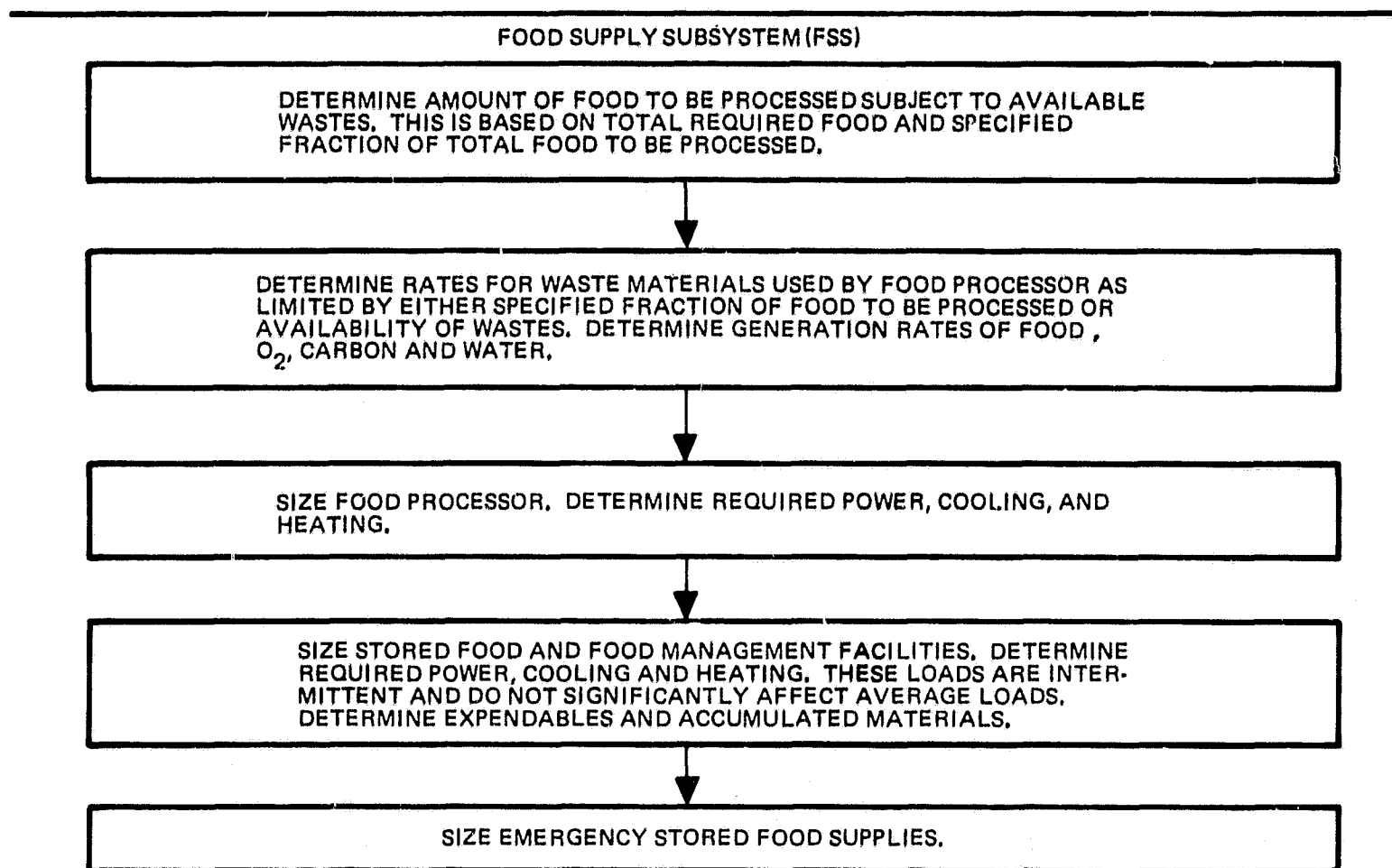


Figure 3-19. Food Supply Subsystem Logic Diagram

expendables, spare parts, accumulated material, and emergency equipment and materials. Summed subsystem equipment, spares, and emergency equipment; and summed subsystem expendables are also printed. See Figures 3-28 through 3-33 for examples.

3. Life support system printout--This output consists of total life support system equipment weight, volume, and power; and weight and volume of expendables. Total accumulated material weight and volume, and the meteoroid shield, radiation shield, and biowell characteristics are also printed. Figure 3-34 is an example.

3.4 SPECIAL PROGRAM FEATURES

In addition to sizing various elements of life support systems for use during normal operations, the program sizes emergency life support system equipment for use during an emergency period of specified duration, and determines spare parts which would be required for replacement following random failures of life support system equipment. Required electrical power, cooling, and heating are determined. Adequate meteoroid and radiation shielding for crew safety are optionally computed.

WATER SUPPLY SUBSYSTEM (WSS)

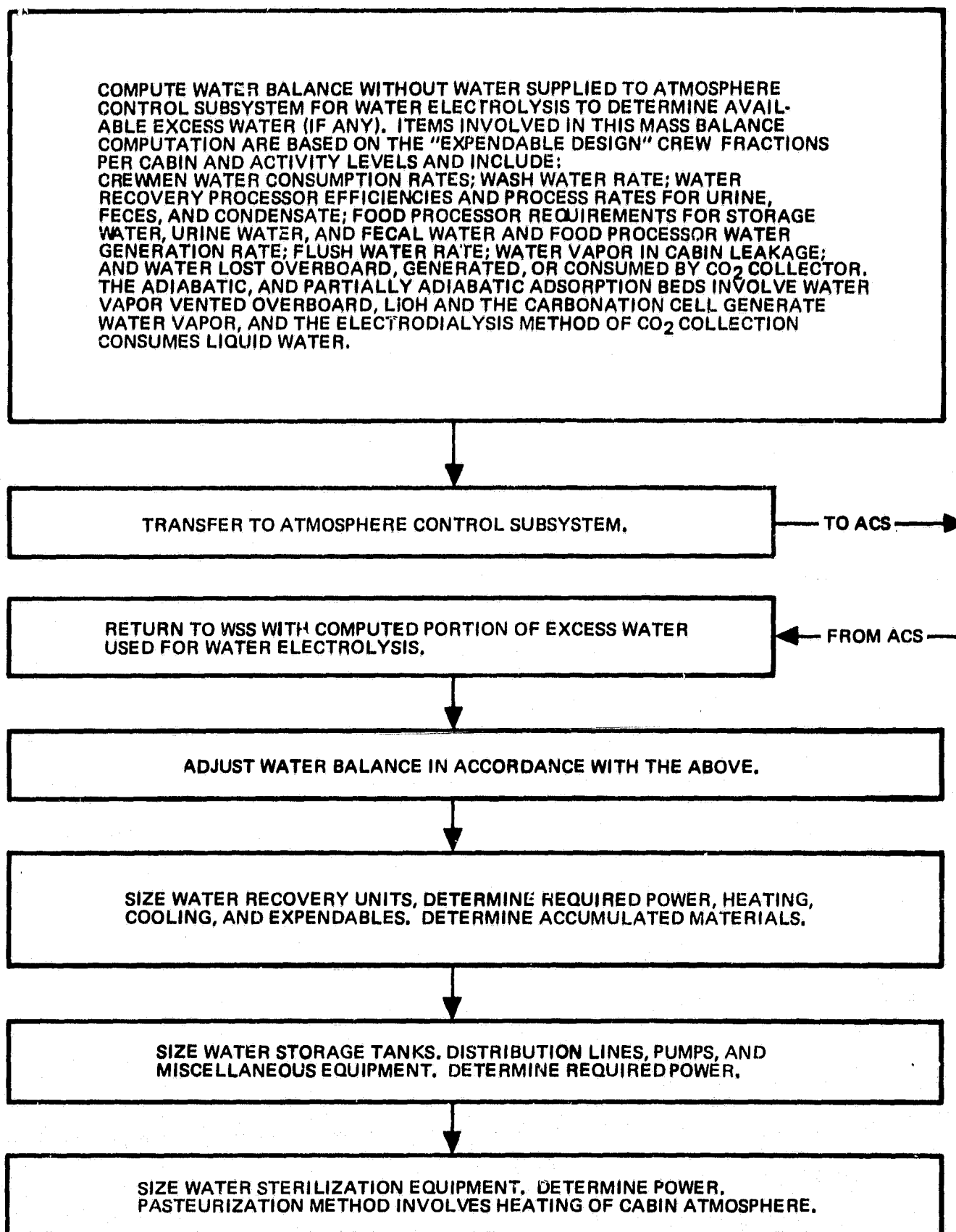


Figure 3-20. Water Supply Subsystem Logic Diagram

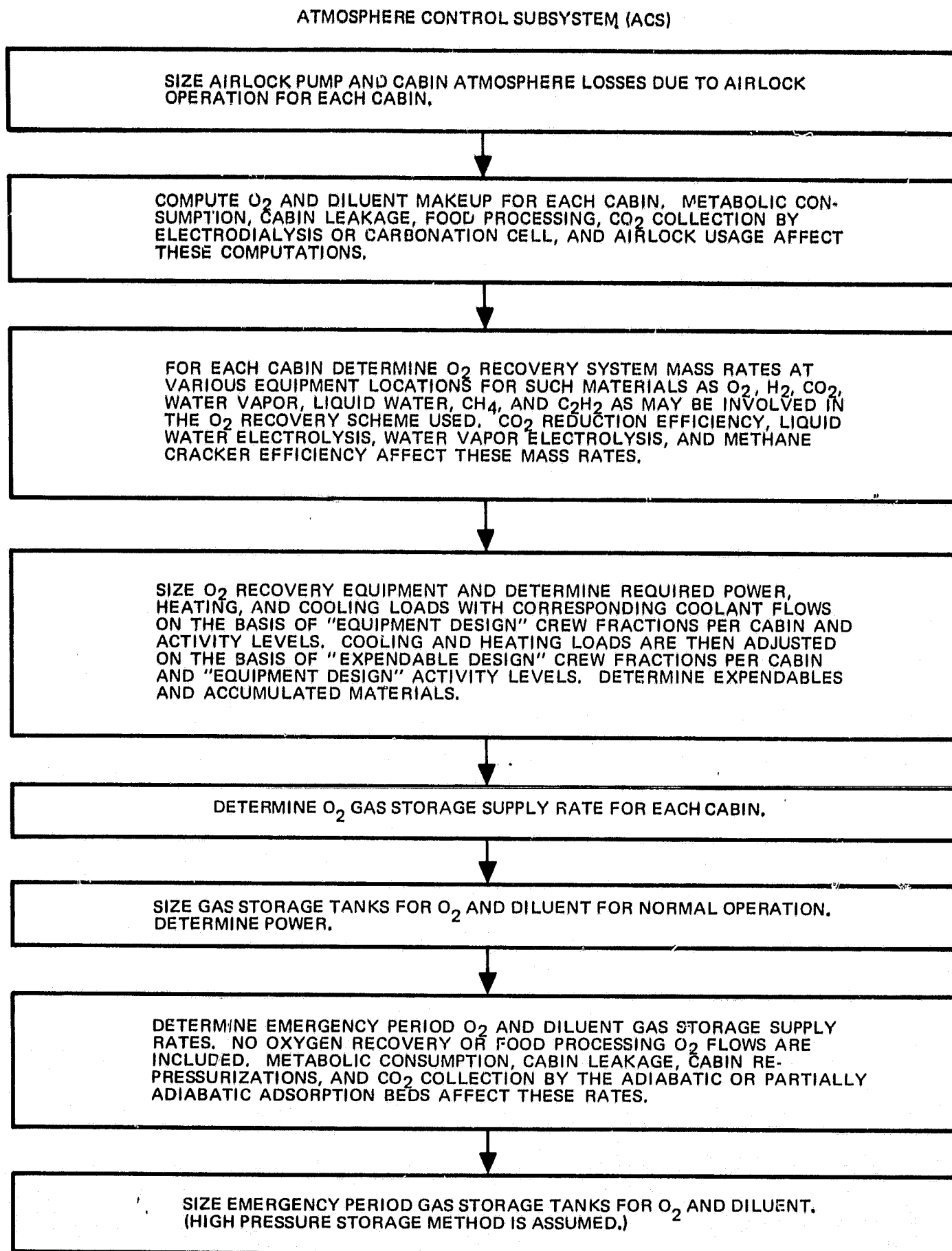


Figure 3-21. Atmosphere Control Subsystem Logic Diagram

THEMAL CONTROL SUBSYSTEM (TCS)

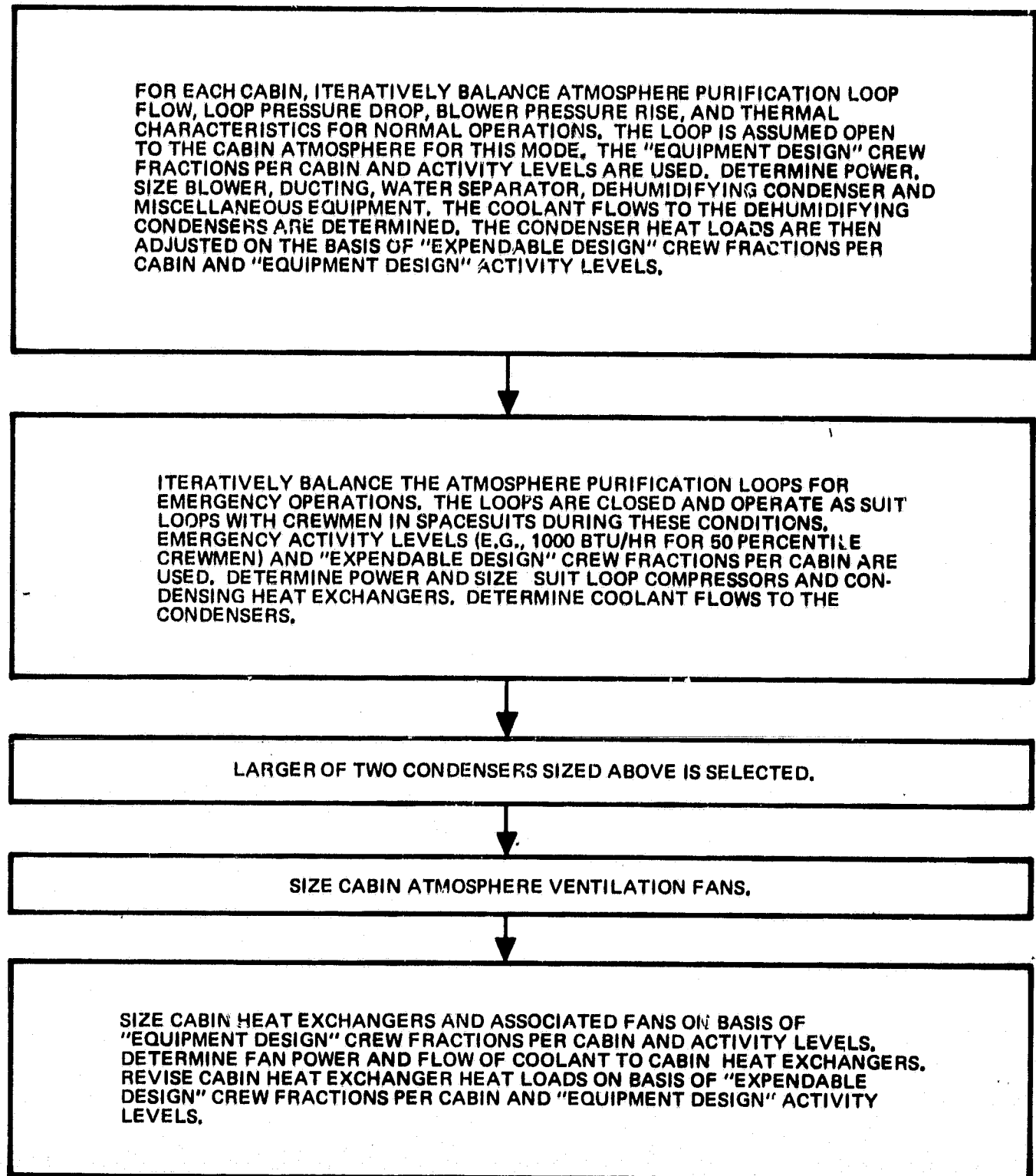


Figure 3-22. Thermal Control Subsystem Logic Diagram

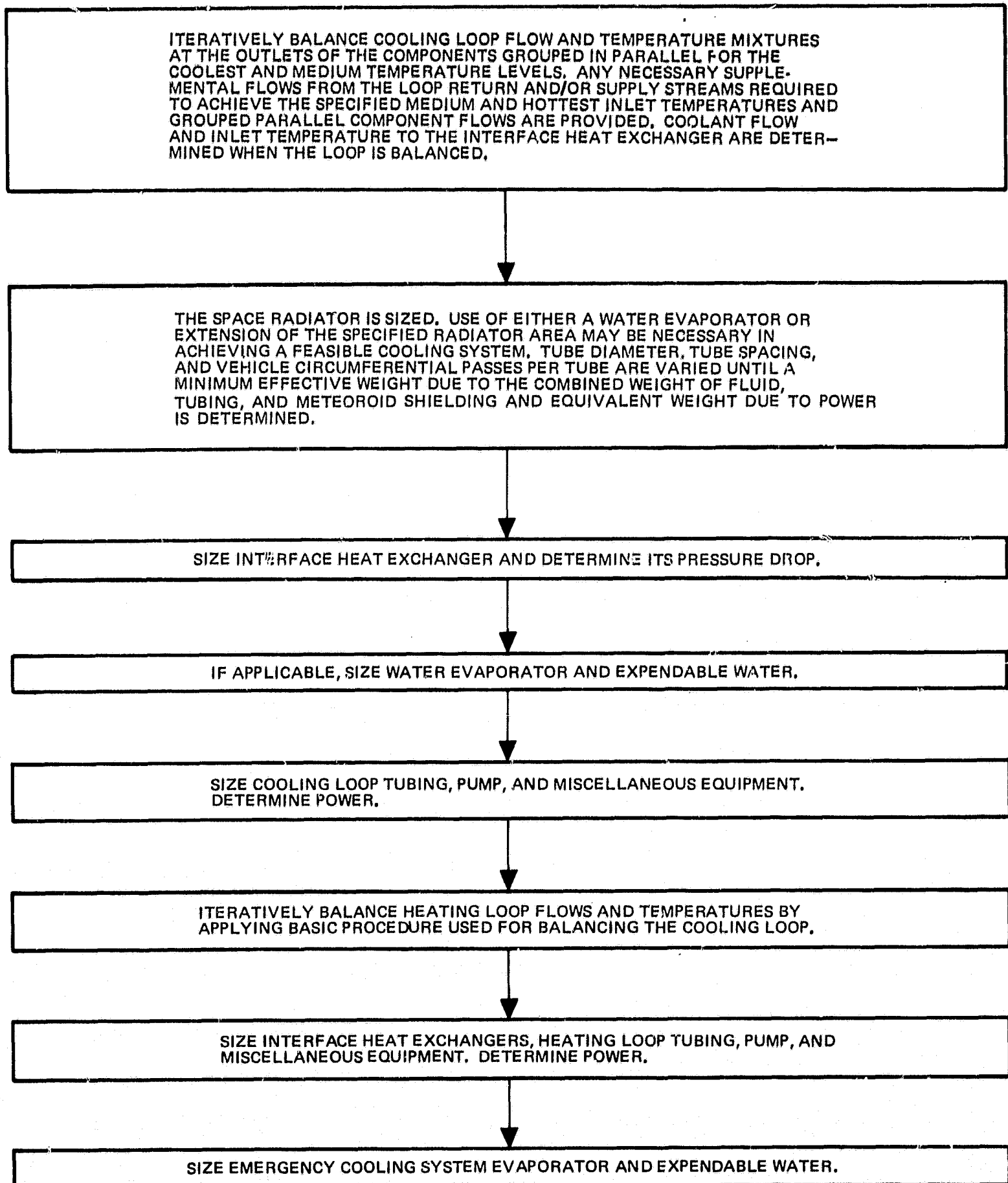


Figure 3-22 (Concluded). Thermal Control Subsystem Logic Diagram

CREW AND CREW SUPPORT SUBSYSTEM ENGINEERING DATA

CREWMEN DATA

CABIN NUMBER	NUMBER OF CREWMEN	CREWMEN WEIGHT (KGRAMS)	CREWMEN HEIGHT (METERS)	CREWMEN SURFACE AREA (METERS**2)	ACTIVITY LEVEL (NOMINAL) (FRACTION)
-----------------	----------------------	-------------------------------	-------------------------------	---	--

1	0.2000E 01	0.1469E 03	0.1760E 01	0.3786E 01	0.1500E 01
---	------------	------------	------------	------------	------------

FOOD, OXYGEN, AND WASTE PER DAY

CARBOHYDRATES (KGRAMS)	PROTEINS (KGRAMS)	FATS (KGRAMS)	OXYGEN USE RATE (METERS**3)	CO2 GENERA- TION RATE (METERS**3)	INDIGESTIBLE BULK (KGRAMS)
0.6821E 00	0.1469E 00	0.2046E 00	0.1123E 01	0.9727E 00	0.1934E 00

WATER BALANCE PER DAY

TOTAL WATER INTAKE RATE (KGRAMS)	TOTAL META- BOLIC WATER PRODUCTION (KGRAMS)	TOTAL WATER OUTPUT (KGRAMS)	TOTAL URINE PRODUCTION (KGRAMS)	WATER LOST DUE TO RESPIRATION (KGRAMS)	WATER LOST DUE TO PERSPIRATION (KGRAMS)
0.5673E 01	0.6529E 00	0.6326E 01	0.3392E 01	0.1355E 01	0.1355E 01

HEAT BALANCE (FOR EQUIPMENT SIZING)

TOTAL META- BOLIC RATE (KWATT-HR) DAY	SENSIBLE HEAT LOST BY RESPIRA- TION (KWATTS)	LATENT HEAT LOST BY RESPIRA- TION (KWATTS)	LATENT HEAT LOST BY PERSPIR- ATION (KWATTS)	SENSIBLE HEAT LOST BY RADIA- TION AND CONVECTION (KWATTS)
0.1249E 02	0.0000E-38	0.8616E-01	0.8616E-01	0.3480E 00

CREW AND CREW SUPPORT SUBSYSTEM ENGINEERING DATA

CREW SUPPORT DATA

FIRST AID AND MEDICAL SUPPLIES

PERSONAL ITEMS

WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)	WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)
0.1286E 03	0.2797E 01	0.1260E 00	0.4716E 02	0.1215E 01	0.8000E-02

SPACE SUITS AND CLOTHING

EVA SUPPORT

WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)	WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)
0.5903E 03	0.3949E 01		0.5993E 03	0.2211E 01	0.3672E 00

Figure 3-23. Sample Engineering Printout for the Crew and Crew Support Subsystem

WASTE MANAGEMENT SUBSYSTEM ENGINEERING DATA

CARBON DIOXIDE COLLECTION

CABIN	NUMBER OF CREWMEN	MAXIMUM CO2 REMOVAL RATE (KGRAMS/HR)	EMERGENCY CO2 REMOVAL RATE (KGRAMS/HR)
1	0.2000E 01	0.1618E 00	0.3641E 00

WEIGHT OF COLLECTOR (KGRAMS)	VOLUME OF COLLECTOR (M**3)	ZEOLITE, FOUR BED ISOTHERMAL POWER OF COLLECTOR (KWATTS)	HEAT LOST TO COOLING FLUID (KWATTS)	COOLING FLUID FLOW RATE (KG/HR)	HEAT GAINED FROM HEATING FLUID (KWATTS)
0.5466E 02	0.2844E 00	0.1192E 00	0.5254E 00	0.3506E 03	0.6846E 00

(EXPENDABLES)				
WEIGHT OF WATER LOST (KG/HR)	VOLUME OF WATER LOST (M**3/HR)	WEIGHT OF OXYGEN GENERATED (KG/HR)	WEIGHT OF HYDROGEN GENERATED (KG/HR)	ATMOSPHERIC GAS LOST (KG/HR)
0.0000E-38	0.0000E-38			0.0000E-38

LITHIUM HYDROXIDE BED (EMERGENCY OPERATION)				
WEIGHT OF CANISTERS AND ACCES. (KGRAMS)	VOLUME OF CANISTERS AND ACCES. (METERS**3)	WEIGHT OF LITHIUM HYDROXIDE (KGRAMS)	VOLUME OF LITHIUM HYDROXIDE (METERS**3)	WEIGHT OF WATER GENERATED (KGRAMS/HR)
0.8147E 01	0.1054E 00	0.5462E 02	0.1442E 00	0.1489E 00

TRACE CONTAMINANTS REMOVAL

CABIN NO.= 1

CHARCOAL BED*****

EQUIPMENT WEIGHT (KGRAMS)	EQUIPMENT VOLUME (M**3)	EXPENDABLE WEIGHT (KGRAMS)	EXPENDABLE VOLUME (M**3)
0.1424E 02	0.7560E-02	0.8424E 01	0.2099E-01

CATALYTIC BURNER*****

EQUIPMENT WEIGHT (KGRAMS)	EQUIPMENT VOLUME (M**3)	POWER (KWATTS)	EXPENDABLE WEIGHT (KGRAMS)	EXPENDABLE VOLUME (M**3)
0.6375E 01	0.2782E-01	0.8352E-01	0.0000E-38	0.0000E-38

Figure 3-24. Sample Engineering Printout for the Waste Management Subsystem

WASTE MANAGEMENT SUBSYSTEM ENGINEERING DATA

URINE COLLECTION FOR ALL CABINS

TOTAL MICTURATIONS (PER/DAY)	TOTAL URINE (SOLIDS+WATER) (KG/DAY)	TOTAL URINE WATER (KG/DAY)	TOTAL URINE SOLIDS (KG/DAY)
0.1332E 02	0.7085E 01	0.6784E 01	0.3009E 00

PRESSURE SUIT COLLECT- TION DEVICE FOR LAUNCH, RE-ENTRY, OR EVA (NOT INCLUDING URINE)		AIR ENTRAINMENT URINE COLLECTION WITH CONNEC- TION TO WATER RECOVERY OR STORAGE TANKS (COLLECTION AND TRANSFER UNIT)		
WEIGHT (KGRAMS)	VOLUME (M**3)	WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)
0.8200E 00	0.1440E-02	0.9588E 01	0.1570E-01	0.3236E-04

REFUSE COLLECTION

COLLECTION BAGS AND STORAGE CONTAINERS (NOT INCLUDING REFUSE)		STORAGE CONTAINERS WITH REFUSE COLLEC- TION BAGS		DEBRIS RECEPTACLE (USED WITH AIR ENTRAIN- MENT FECAL COLLECTOR)	
WEIGHT (KGRAMS)	VOLUME (M**3)	WEIGHT (KGRAMS)	VOLUME (M**3)	WEIGHT (KGRAMS)	VOLUME (M**3)
0.1440E 02	0.9072E-01	0.4497E 03	0.7560E-01	0.3320E 01	0.9790E-02

FECES COLLECTION

TOTAL DEFECATIONS (PER DAY)	TOTAL FECES (BULK, WATER, AND SOLIDS) (KGRAMS/DAY)	TOTAL FECAL BULK AND SOLIDS (KGRAMS/DAY)	TOTAL FECAL WATER (KGRAMS/DAY)	NUMBER OF TOILETS
0.4000E 01	0.1013E 01	0.5673E 00	0.4457E 00	0.1000E 01

AIR ENTRAINMENT WITH VACUUM DRYING (COLLECTION AND DRYING EQUIPMENT)			(STORAGE CONTAINERS PLUS FECES)	
WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)	WEIGHT (KGRAMS)	VOLUME (M**3)
0.2994E 02	0.7620E-01	0.2025E-04	0.3134E 03	0.3748E 00

EMERGENCY URINE COLLECTION DEVICE		PORTABLE VACUUM CLEANER		
(NOT INCLUDING URINE)		WEIGHT (KGRAMS)	VOLUME (M**3)	POWER (KWATTS)
WEIGHT (KGRAMS)	VOLUME (M**3)	0.4320E 01	0.1054E-01	0.1800E-01
0.1183E 01	0.1533E-02			

Figure 3-24 (concluded). Sample Engineering Printout for the Waste Management Subsystem

ATMOSPHERE CONTROL SUBSYSTEM ENGINEERING DATA

THE AIRLOCK IS USED 30 TIMES
 FINAL PRESSURE OF 0.0100 KG PER SQUARE CM.
 THE AIRLOCK PUMP HAS AN EFFICIENCY OF 30.00 PER CENT

THE AIRLOCK OPERATIONS REQUIRE -
 0.248682E 01 KGS OF OXYGEN
 0.217597E 01 KGS OF DILUENT
 0.103417E-02 KILOWATTS OF ELECTRICAL POWER
 0.703792E 01 KGS OF PUMP WEIGHT

CO 2 REDUCTION IS USED
 THE EFFICIENCY OF THE, UNIT IS 1.0000

THE EQUIPMENT WEIGHTS, VOLUMES AND POWER REQUIREMENTS

	FIXED WEIGHT KILOGRAMS	FIXED VOLUME CUBIC METERS	POWER KILOWATTS
CO2 REDUCER			
CABIN NO. 1	42.5179	0.1043	0.2214
CABIN NO. 2	42.5179	0.1043	0.2214
LIQUID ELECTROLYSIS			
CABIN NO. 1	22.3104	0.0695	0.6039
CABIN NO. 2	22.3486	0.0696	0.6060

THE FOLLOWING ACS RATES WERE DETERMINED KGS PER HOUR

CABIN NUMBER	HYDROGEN VENT	CO 2 VENT	VAPOR ELECT H2O
1	0.24029131E-02	0.00000000E-38	0.00000000E-38
2	0.24379189E-02	0.00000000E-38	0.00000000E-38
	LIQUID ELEC H2O	CARBON (SOLID)	CO 2 REDUCED
1	0.87703697E-01	0.22025826E-01	0.80761364E-01
2	0.88018751E-01	0.22025826E-01	0.80761364E-01

THE EQUIPMENT HEAT LOADS(KW) ARE

CABIN NO.	CO 2 RED LIQUID	CO 2 RED ATMOS	LIQ ELECT LIQUID	LIQ ELECT ATMOS
1	0.202	0.286	0.235	0.026
2	0.202	0.286	0.236	0.026

Figure 3-25. Sample Engineering Printout for the Atmosphere Control Subsystem

ATMOSPHERIC CONSTITUENT STORAGE

THE NORMAL NITROGEN IS STORED IN HIGH*PRESSURE*** SPHERICAL***** TANK(S)

THE 3 TANK(S) EACH HAVE A -

DIAMETER OF 0.422 METERS
L/D RATIO OF 1.000
WEIGHT OF 50.265 KILOGRAMS
VOLUME OF 0.039 CUBIC METERS

TOTAL WEIGHT AND VOLUME IS 150.795 KILOGRAMS AND 0.118 CUBIC METERS

THE TOTAL POWER IS 0.0000 KILOWATTS

THE EMERGENCY OXYGEN IS STORED IN HIGH*PRESSURE*** SPHERICAL***** TANK(S)

THE 2 TANK(S) EACH HAVE A -

DIAMETER OF 0.579 METERS
L/D RATIO OF 1.000
WEIGHT OF 173.801 KILOGRAMS
VOLUME OF 0.102 CUBIC METERS

TOTAL WEIGHT AND VOLUME IS 347.603 KILOGRAMS AND 0.204 CUBIC METERS

THE TOTAL POWER IS 0.0000 KILOWATTS

THE EMERGENCY NITROGEN IS STORED IN HIGH*PRESSURE*** SPHERICAL***** TANK(S)

THE 2 TANK(S) EACH HAVE A -

DIAMETER OF 0.618 METERS
L/D RATIO OF 1.000
WEIGHT OF 157.550 KILOGRAMS
VOLUME OF 0.123 CUBIC METERS

TOTAL WEIGHT AND VOLUME IS 315.100 KILOGRAMS AND 0.247 CUBIC METERS

THE TOTAL POWER IS 0.0000 KILOWATTS

Figure 3-25 (concluded). Sample Engineering Printout for the Atmosphere Control Subsystem

*** FOOD SUPPLY SUBSYSTEM ***
ENGINEERING DATA

MASS BALANCE RESULTS (KG/DAY)

WASTE MATERIALS	CARBON DIOXIDE	FECAL MATTER	URINE SOLIDS
WASTE AVAILABLE	3.87655	1.01206	0.30085
WASTE PROCESSED	0.00000	0.00000	0.00000
PROCESSOR PRODUCTS	FOOD	OXYGEN	CARBON
	0.00000	0.00000	0.00000

FOOD SUBSYSTEM CHARACTERISTICS

<u>FOOD PROCESSOR</u>	WEIGHT KG	VOLUME CU METERS	POWER KW
	0.00000	0.00000	0.00000
<u>FOOD MANAGEMENT FACILITIES</u>	WEIGHT KG	VOLUME CU METERS	POWER KW
	6.52000	1.68555	0.00800
<u>FOOD AND EXPEND</u>	263.40279	1.51515	

***** WATER SUPPLY SUBSYSTEM *****

WATER RECOVERY

WATER SOURCE	METHOD OF WATER RECOVERY	RECOVERY EFFICIENCY
URIN*****	CLOSED*AIR*EVAP**	0.9500000
CONDENSATE	CLOSED*AIR*EVAP**	0.9500000
Q000Q000Q0	Q000Q000Q000Q000Q	0.0000000
WASH*WATER	CLOSED*AIR*EVAP**	0.9500000

RECOVERY UNITS

WATER SOURCE	FIXED WT (KG)	EXPEND WT (KG)	FIXED VOL (CU M)
URINE	11.5414	10.6854	0.1322
CONDENSATE	10.3832	1.9958	0.1163
FECAL WATER	0.0000	0.0000	0.0000
WASH WATER	15.2979	4.4325	0.1825

RECOVERY COOLING LOOP LOAD	0.749 KW
RECOVERY HEATING LOOP LOAD	0.700 KW

127.1843 KGS OF STORED WATER SUPPLIED FOR EACH RESUPPLY

WATER STORAGE TANKS

TYPE - SPHERICAL NO OF TANKS	TOTAL VOL (CU M)	VOL. PER TANK (CU M)	TOTAL WT (KG)	WT PER TANK (KG)
3	0.1839	0.0613	9.9849	3.3283

Figure 3-26. Sample Engineering Printout for the Food Supply and Water Subsystems

THERMAL CONTROL SUBSYSTEM SUBROUTINE

ATMOSPHERIC PURIFICATION LOOP CABIN NO 1

VOL DUCTS (CU M) 0.0440	WT DUCTS (KG) 5.4347	VOL COND (CU M) 0.000E	WT COND (KG) 0.8878	VOL BLOWER (CU M) 0.0028
VOL COMPR (CU M) 0.0021	WT COMPR (KG) 0.8298	COMPR POWER (KG) 0.0975	BLOWER POWER (KG) 0.0646	SEPARATOR VOL (CU M) 0.0034
CABIN NUMBER	CABIN H.X. WT. (KG)	H.X. FAN WT. (KG)	H.X. FAN POWER (KW)	
1	0.7907E 01	0.7142E 00	0.1268E 00	
2	0.1741E 02	0.1370E 01	0.4407E 00	
CABIN NUMBER	H.X. DESIGN LOAD (KW)	H.X. NORMAL LOAD (KW)	VENT. FAN WT. (KG)	
1	0.1059E 01	0.8143E 00	0.1108E 02	
2	0.2670E 01	0.2424E 01	0.2257E 02	

LIQUID COOLING LOOP

COLD LEV. FLOW (KG/HR) 0.8875E 03	MED. LEV. FROM HX (KG/HR) 0.2124E 03	MED. LEV. FROM PMP (KG/HR) 0.2409E 03
WARM LEV. FROM PMP (KG/HR) 0.0000E-38	WARM LEV. FLOW (KG/HR) 0.1126E 03	WARM LEV. BYPASS (KG/HR) 0.1228E 04
WARM LEV. HT LOAD (KW) 0.1310E 01	COLD LEV. TEMP IN (DEG K) 0.2775E 03	MED. LEV. TEMP IN (DEG K) 0.2814E 03
MED. LEV. PR DROP (KG/SQ-CM) 0.9966E 00	WARM LEV. PR DROP (KG/SQ-CM) 0.9897E-01	PIPING PR DROP (KG/SQ-CM) 0.4977E-01
PIPING WEIGHT (KG) 0.4470E 02	H.X. HT LOAD (KW) 0.1468E 02	H.X. H2O FLOW (KG/HR) 0.1100E 04
PUMP POWER (KW) 0.2667E 00	SYSTEM WEIGHT (KG) 0.1288E 03	SYSTEM VOLUME (CU M) 0.1516E 00
BOILER HT LOAD (KW) 0.3090E 01	BOILER WEIGHT (KG) 0.7602E 01	BOILER VOLUME (CU M) 0.8653E-02

Figure 3-27. Sample Engineering Printout for the Thermal Control Subsystem

RADIATOR FOR THERMAL CONTROL SUBSYSTEM

TUBE DIAMETER (METERS) 0.0195	TUBE SPACING (METERS) 0.9154	EFFECTIVE WEIGHT (KG) 213.5422	FIXED WEIGHT (KG) 161.3623
TUBE WEIGHT (KG) 82.0516	FLUID WEIGHT (KG) 78.0217	ARMOR WEIGHT (KG) 0.0000	POWER WEIGHT (KG) 70.3920
REYNOLDS NO. 56153.1748	FLOW (KG/HR) 5116.3032	PRESSURE DROP (KG/CM2) 0.4350	PUMP POWER (KW) 0.1154
PASS/TUBE 1.	NO OF TUBES 4.53	ARMOR THICKNESS (METERS) 0.0000	ADDED STRUCTURE (KG) -0.0000
INLET TEMP (DEG K) 284.9992	OUTLET TEMP (DEG K) 277.5000	SINK TEMP (DEG K) 239.0000	CONVECT TEMP DROP (DEG K) 0.6841
AREA (SQ M) 86.0606	EXTRA AREA (SQ M) 0.0000	HEAT REJECTED (KW) 11.5872	RAD EFFECTIVENESS 0.8766

LIQUID HEATING LOOP

HIGH LEV. FLOW (KG/HR) 0.8217E	MED. LEV. FROM HX (KG/HR) 0.0000E-38	MED. LEV. FROM PMP (KG/HR) 0.0000E-38
LOW LEVEL FROM PMP (KG/HR) 0.0000E-38	LOW LEVEL FLOW (KG/HR) 0.2415E 02	LOW LEVEL BYPASS (KG/HR) 0.5801E 02
LOW LEVEL HT LOAD (KW) 0.7004E 00	HIGH LEV. TEMP IN (DEG K) 0.4500E 03	MED. LEV. TEMP IN (DEG K) 0.4357E 03
MED. LEV. PR DROP (KG/SQ-CM) 0.5000E-01	LOW LEVEL PR DROP (KG/SQ-CM) 0.2000E-01	PIPING PR DROP (KG/SQ-CM) 0.2738E-01
PIPING WEIGHT (KG) 0.3268E 01	H.X. HT LOAD (KW) 0.2472E 01	H.X. H2O FLOW (KG/HR) 0.8217E 02
PUMP POWER (KW) 0.9493E-02	SYSTEM WEIGHT (KG) 0.1296E 02	SYSTEM VOLUME (CU M) 0.5622E-02

Figure 3-27 (concluded). Sample Engineering Printout for the Thermal Control Subsystem

***** CREW AND CREW SUPPORT SUBSYSTEM ***			
		***** EQUIPMENT ****	
		WEIGHT KG	VOLUME CU M
FIRST AID / MEDICAL	LIVING AREA	0.129E 03	0.280E 01
PERSONAL ITEMS	LIVING AREA	0.472E 02	0.121E 01
INSTRUMENTS AND CONTROLS	LIVING AREA	0.349E 03	0.296E 00
SPACE SUITS AND CLOTHING	LIVING AREA	0.590E 03	0.395E 01
EVA SUPPORT	LIVING AREA	0.599E 03	0.221E 01

***** CREW ACCOMMODATIONS SUBSYSTEM ***			
		***** EQUIPMENT ***	
		WEIGHT KG	VOLUME CU M
INSTRUMENTS AND CONTROLS	LIVING AREA	0.195E 03	0.114E 00
LIVING, WORK, AND RECREATION	LIVING AREA	0.242E 03	0.955E 01
GRAVITY CONDITIONING	LIVING AREA	0.544E 03	0.410E 02

Figure 3-28. Sample Subsystem Printout for the Crew and Crew Support and Crew Accommodations Subsystems

***** WASTE MANAGEMENT SUBSYSTEM ****			
***** EQUIPMENT ***			
		WEIGHT KG	VOLUME CU M
NORMAL CO ₂ REMOVAL	CABIN NO. 1	0.628E 02	0.390E 00
	CABIN NO. 2	0.628E 02	0.390E 00
EMERGENCY CO ₂ REMOVAL	CABIN NO. 1	0.815E 01	0.144E 00
	CABIN NO. 2	0.815E 01	0.144E 00
EMERGENCY MISCELLANEOUS	SUBSYSTEM	0.349E 01	0.353E-02
TRACE CONTAMINANTS	CABIN NO. 1	0.206E 02	0.354E-01
	CABIN NO. 2	0.206E 02	0.354E-01
URINE COLLECTION	VEHICLE	0.104E 02	0.171E-01
FECAL AND DEBRIS COLLECTION	VEHICLE	0.376E 02	0.965E-01
SPARES	SUBSYSTEM	0.138E 03	0.246E 00
ACCUMULATED MATERIAL	URINE	0.231E 02	0.182E-01
	FECAL - DEBRIS	0.763E 03	0.450E 00

***** FOOD SUPPLY SUBSYSTEM *****			
***** EQUIPMENT ***			
		WEIGHT KG	VOLUME CU M
PROCESS AND STORAGE	VEHICLE	0.652E 01	0.169E 01
EMERGENCY	VEHICLE	0.908E 01	0.746E-01
ACCUMULATED MATERIAL	VEHICLE	0.000E-38	

Figure 3-29. Sample Subsystem Printout for the Waste Management and Food Supply Subsystems

***** ATMOSPHERE CONTROL SUBSYSTEM *****			
***** EQUIPMENT *****			
		WEIGHT KG	VOLUME CU M
OXYGEN RECOVERY	CABIN NO. 1	0.648E 02	0.174E 00
	CABIN NO. 2	0.649E 02	0.174E 00
AIRLOCK USAGE	CABIN NO. 1	0.000E-38	
	CABIN NO. 2	0.704E 01	
ATMOSPHERE CONSTITUENT STORAGE	NORMAL	0.542E 02	
	EMERGENCY	0.689E 03	0.450E 00
SPARES			
	SUBSYSTEM	0.131E 03	0.234E 00
ACCUMULATED MATERIAL			
	CARBON	0.391E 03	
***** WATER SUPPLY SUBSYSTEM *****			
***** EQUIPMENT *****			
		WEIGHT KG	VOLUME CU M
RECOVERY	VEHICLE	0.372E 02	0.431E 00
STORAGE	VEHICLE	0.944E 01	0.130E 00
STERILIZATION	VEHICLE	0.500E 00	0.000E-38
MISCELLANEOUS	VEHICLE	0.550E 01	0.310E-02
EMERGENCY	VEHICLE	0.598E 02	0.113E 00
SPARES			
	SUBSYSTEM	0.834E 02	0.149E 00
ACCUMULATED MATERIAL			
	RECOVERY WATER	0.704E 02 0.447E 03	0.353E 00 0.447E 00

Figure 3-30. Sample Subsystem Printout for the Atmosphere Control and Water Supply Subsystems

***** THERMAL CONTROL SUBSYSTEM *****

		***** EQUIPMENT ****	
		WEIGHT KG	VOLUME CU M
CABIN HEAT EX. AND FAN	CABIN NO. 1	0.862E 01	0.472E-01
	CABIN NO. 2	0.188E 02	0.104E 00
VENTILATION FAN	CABIN NO. 1	0.111E 02	0.505E-01
	CABIN NO. 2	0.226E 02	0.103E 00
ATMOSPHERE PURIFICATION LOOP	CABIN NO. 1	0.965E 01	0.106E 00
	CABIN NO. 2	0.965E 01	0.106E 00
HEATING LOOP	VEHICLE	0.130E 02	0.562E-02
NORMAL COOLING LOOP	VEHICLE	0.129E 03	0.152E 00
EMERGENCY COOLING LOOP	VEHICLE	0.264E 01	0.401E-02
LSS SPACE RADIATOR	VEHICLE	0.161E 03	
EXTERIOR THERMAL INSULATION	VEHICLE	0.700E 03	
SPARES	SUBSYSTEM	0.363E 03	0.648E 00

Figure 3-31. Sample Subsystem Printout for the Thermal Control Subsystem

TOTAL SUBSYSTEM DATA

	WEIGHT KG	VOLUME CU M	POWER KW
ATMOSPHERE CONTROL SUBSYSTEM	0.101E 04	0.103E 01	0.165E 01
THERMAL CONTROL SUBSYSTEM	0.145E 04	0.133E 01	0.150E 01
WASTE MANAGEMENT SUBSYSTEM	0.372E 03	0.150E 01	0.424E 00
CREW AND CREW SUPPORT SUBSYSTEM	0.171E 04	0.105E 02	0.919E 00
CREW ACCOMMODATIONS SUBSYSTEM	0.981E 03	0.507E 02	0.698E 00
WATER SUPPLY SUBSYSTEM	0.196E 03	0.826E 00	0.147E 00
FOOD SUPPLY SUBSYSTEM	0.156E 02	0.176E 01	0.800E-02
SYSTEM CONTROL SUBSYSTEM	0.845E 01	0.600E-01	

**** EXPENDABLES ****

	WEIGHT KG	VOLUME CU M
ATMOSPHERE CONTROL SUBSYSTEM	0.171E 03	0.509E 00
THERMAL CONTROL SUBSYSTEM	0.483E 04	0.483E 01
WASTE MANAGEMENT SUBSYSTEM	0.140E 03	0.421E 00
CREW AND CREW SUPPORT SUBSYSTEM		
CREW ACCOMMODATIONS SUBSYSTEM		
WATER SUPPLY SUBSYSTEM	0.144E 03	0.213E 00
FOOD SUPPLY SUBSYSTEM	0.263E 03	0.152E 01

Figure 3-32. Sample Total Subsystem Printout Data

O₂ RECOVERY

- O 2 RECOVERY BY MOLTEN CARBONATE
UNIT ACCEPTS CABIN AIR DIRECTLY - NO CO 2 CONCENTRATOR OR WATER ELECTROLYSIS UNITS REQUIRED - PHASE SEPARATION BETWEEN HOT MELT (780 DEGREES K) AND GASES IS A MAJOR DESIGN PROBLEM - UNIT USED IN PROGRAM, BASED ON CURRENT HARDWARE TECHNOLOGY, USES DISPOSABLE CELLS DISCARDED AFTER EXCESSIVE CARBON DEPOSIT - ADDITIONAL DEVELOPMENT NEEDED TO PROVIDE SIMPLER DESIGNS THAT MAY PRODUCE UP TO 60 PER CENT WEIGHT REDUCTION
- O 2 RECOVERY BY SOLID ELECTROLYTE
CARBON COLLECTION PROBLEM - HIGH TEMPERATURE (1400 DEGREES K) CELL MATERIAL PROBLEMS - ADDITIONAL MATERIALS RESEARCH REQUIRED - PROCESS REQUIRES NO WATER ELECTROLYSIS UNIT - 1973 FLIGHT DATE ATTAINABLE
- O 2 RECOVERY BY BOSCH
CARBON COLLECTION PROBLEM - HIGH TEMPERATURE (860 - 1250 DEGREES K) MATERIALS PROBLEM - 1972 FLIGHT DATE - GAS RECIRCULATION VOLUMETRIC RATIO OF 4.35 USED
- O 2 RECOVERY BY SABATIER
1971 FLIGHT DATE FOR UNIT WITH METHANE VENT - 1974 FLIGHT DATE FOR UNITS WITH METHANE CRACKERS - DEVELOPMENT OF METHANE CRACKERS AND HYDROGEN FILTERS SHOULD BE PURSUED

CO₂ REMOVAL

- CO 2 REMOVAL BY ELECTRODIALYSIS
1975 FLIGHT DATE - CRITICAL COMPONENT - IMPROVED CURRENT DENSITY MAY RESULT IN 40 PER CENT REDUCTION IN WEIGHT AND 50 PER CENT REDUCTION IN POWER REQUIREMENTS
- CO 2 REMOVAL BY CARBONATION CELL
1972 FLIGHT DATE POSSIBLE - UNIT USED IN H738 IS HYDROGEN-DEPOLARIZED - UNIT OPERATES H 2-RICH, CONSUMES HYDROGEN AND OXYGEN AND PRODUCES WATER
- CO 2 REMOVAL BY LIQUID ABSORPTION
SENSITIVITY ANALYSES INDICATE LIQUID ABSORPTION TO BE A HIGHLY ATTRACTIVE PROCESS FOR MANY APPLICATIONS - NO APPRECIABLE DEVELOPMENT EFFORT HAS BEEN INITIATED - ADAPTION OF UNIT TO SPACECRAFT USE REQUIRES SOLUTION OF A NUMBER OF PHASE SEPARATION PROBLEMS

Figure 3-33. Sample Qualitative Printout Data

TOTAL LIFE SUPPORT SYSTEM DATA

THE TOTAL ACCUMULATED MATERIAL WEIGHS 0.170E 04 KG AND OCCUPIES 0.127E 01 CUBIC METERS

THE METEOROID SHIELD WEIGHS 0.194E 04 KGS

THE RADIATION SHIELD WEIGHS 0.102E 05 KGS

(THE ABOVE SHIELD WEIGHT(S) ARE NOT INCLUDED IN THE TOTALS BELOW)

THE TOTAL LSS HEAT REQUIREMENT IS 2.472 KW

***** EQUIPMENT *****		**** EXPENDABLES ****	
WEIGHT KG	VOLUME CU M	WEIGHT KG	VOLUME CU M
0.575E 04	0.676E 02	0.555E 04	0.749E 01

Figure 3-34. Sample Total Life Support System Printout Data

3.4.1 Emergency Provisions and Spare Parts

Separate and independent equipment and materials are determined for the Atmosphere Control, Thermal Control, Waste Management, Water Supply, and Food Supply Subsystems to meet crew life support requirements during specified emergency periods. Weight and volume of spare parts are determined for the Atmosphere Control, Thermal Control, Waste Management and Water Supply Subsystems to achieve specified reliabilities for each of these subsystems. Spares are not determined for the remaining subsystems because of the lack of reported reliability information and mean time between failure data for the particular equipment in these subsystems. Emergency equipment is included in the Crew and Crew Support Subsystem to be used for emergencies of unspecified duration. Examples of these include fire extinguishers for use during minor fires and medical diagnostic instrumentation.

3.4.2 Power, Cooling, and Heating Requirements

In addition to sizing Life Support System equipment, expendables, and accumulated materials, the program also determines electrical power, cooling, and heating requirements. The electrical power load is imposed on the Vehicle Power System; the heating load is assumed to be provided either by waste heat from some vehicle power system, by a separate radioisotope heater, or by electrical power; and the cooling load is largely accommodated by the space radiator in the Thermal Control Subsystem. The space radiator is permitted to cover a specified portion of the available surface area of each cabin, and depending upon the magnitude of the cooling load, may require additional vehicle surface area for the space radiator or require the optional use of a water evaporator in order to achieve adequate heat rejection capability. Added vehicle structure providing required additional vehicle surface area is assumed to be obtainable at a specified weight per unit area. If the optional water evaporator is selected for supplemental heat rejection, the total time is specified for operation of the evaporator at design point thermal conditions. It is assumed that the evaporator is inoperative at all other times, and that the space radiator is sufficient to provide adequate cooling capability.

3.4.3 Meteoroid Shielding

Meteoroid shielding is provided at such a thickness to achieve a specified probability of no penetration of occupied cabin pressure shells. The beneficial contributions of thermal insulation located between the wall inner and outer structural shells in absorbing meteoroid impact are included in the computations. The thickness of the required meteoroid shielding for the cabin wall is compared with the specified input data value for the cabin outer shell. If the meteoroid shield thickness is greater than this input value, the outer shell thickness is set equal to the meteoroid shield thickness and the weight addition is determined. The space radiator tubes are assumed to be attached to the outer structural shell. A redundant set of tubes is included to improve the reliability of the radiator. Meteoroid bumpers are determined for the radiator tubes when the combined thickness of the outer shell and the radiator tube wall are not sufficient to provide adequate protection in terms of the specified radiator puncture free reliability. The radiator meteoroid bumpers are determined after the cabin wall meteoroid shielding computations are complete; so that the benefit of any required increase in outer shell thickness is considered in defining these bumpers.

3.4.4 Radiation Shielding

For earth orbital missions, the program determines the required radiation shielding thickness for protection against geomagnetically trapped radiation and a specified number of solar flare events. This shielding is determined so that all the cabin interior volume is protected; that is, the entire exterior surface area of the occupied cabins is covered. The effectiveness of Life Support System equipment and materials, as well as other vehicle equipment and materials, in providing radiation shielding can be determined through preparation of layout drawings of occupied cabins, and arranging the equipment and materials to achieve adequate shielding for crewmen during their various activities. The radiation shielding required as determined by the computer program is based on aluminum. Shielding weight ratios for other materials relative to aluminum are given in Volume II of this report. Crew tour of duty and the permissible dose in REM at the end of the tour of duty are specified. A biowell can be sized as an option for use during solar flare

events for earth orbital missions. This biowell becomes attractive when an appreciable number of solar flare events is specified.

For interplanetary missions a biowell is designed to provide adequate protection against galactic cosmic radiation as well as solar flare events. For these missions, the tour of duty is equal to the mission duration unless an interplanetary rendezvous scheme is planned. Again, Life Support System equipment and materials can be investigated for applicability as biowell shielding through the preparation of layout drawings. Weights and volumes of expendable materials are computed for the launch date (and at resupply when a resupply period is specified), and weights and volumes of accumulated materials are computed for the end of the mission. Since these quantities are normally linear with time, the amounts of expendable and accumulated materials may be easily determined at any time during the mission. Consideration of different amounts of these materials being available at different times will generally be important in investigating schemes for using these materials as shieldings.

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Section 4

SAMPLE PROBLEMS

Sample problem solutions have been obtained from the H738 program for presentation in this section. The input data loadsheets for one of these sample problems are shown in Figures 3-2 through 3-10. Implications of key input data in terms of the program's computational logic for sizing life support systems and determining interactions with other vehicle systems are discussed. Sample tabular output data for the sample input data are shown in Figures 3-28 through 3-34, and plots of output data for all sample problems are shown in Figures 4-1 through 4-12. The mission and vehicle specifications for the sample problems are listed in Table 4-1. The sensitivities of life support system equipment weight and volume, and required power, heating, and cooling to crew size, mission duration, and ecological closure are discussed. The sensitivities of total system weights and volumes, including expendables, to resupply period (or mission duration for interplanetary cases) and ecological closure are shown for a representative crew size.

The life support systems investigated for use in conjunction with these mission and vehicle criteria were "open", "partially closed", and "closed" systems. The required equipment and equipment interactions for these baseline systems are shown schematically on Figure 3-11, 3-12, and 3-13. As noted in the Input Data Section, systems of these types are treated in the computer program through the use of complete sets of "baseline" systems data specifying selected functional methods for accomplishing various life support system functions, mission and vehicle conditions, and equipment operating characteristics. Life support systems and their corresponding vehicle interactions are then parametrically determined through perturbing the baseline specifications. The functional methods and equipment operating characteristics for the three baseline systems are outlined in Table 4-2. The partially closed baseline¹ system and a one year orbital mission was used as the "basic case" for purposes of this discussion and, as such, the presented

Table 4-1
SAMPLE PROBLEM MISSION AND VEHICLE SPECIFICATIONS
(Page 1 of 2)

-
1. Mission flight path.
 - a. Earth orbit
164 nmi.
50° inclination.
 - b. Venus flyby.
 2. Time periods - 1975 Launch Dates.
 - a. Earth orbit.
Mission durations up to two years.
Resupply periods up to 180 days.
Emergency period of 5 days.
 - b. Venus flyby.
Mission duration of 1 year.
 3. Crew data.
Percentile - 50.
Activity level - 1.5.
Diet fat ratio - 0.3.
Wash water - 3 kg/man-day.
Gravity conditioning centrifuge required for tours of duty greater than 180 days.
 4. Compartment volumes.
Cabin number 1 - 93.5 m³ (3,300 ft³).
Cabin number 2 - 190.5 m³ (6,700 ft³).
Airlock on cabin number 2 - 4.25 m³ (150 ft³).
Vehicle diameter 6.6 m (22 ft).
Inner shell thickness - 1 mm.
Outer shell thickness - 0.5 mm.
-

Table 4-1 (Page 2 of 2)

-
5. External losses of cabin atmosphere.
Leakage of 0.45 kg/day (1 lb/day) for each cabin.
Airlock uses - 30.
Depressurizations - 1 per cabin.
 6. Cabin atmosphere.
Total pressure - 7 psia.
Oxygen pressure - 3 1/2 psia; balance nitrogen.
Temperature - 294°K (70.5°F)
Relative humidity - 50%.
CO₂ pressure - 4 mm Hg.
 7. Radiation protection and criteria.
Allowable dosage - 150 REM.
Tour of duty - equal to mission duration.
Solar flares - 1 each 180 days for earth orbital missions.
 - High solar flare activity and .99 probability of not exceeding
 allowable dosage for interplanetary missions.
 8. Meteoroid protection.
Probability of no cabin wall penetration - .99.
 9. Space radiator design criteria.
Thermal loads from systems other than life support:
 - a. Cold plates - 8.2 kW.
 - b. Added to cabin atmosphere heat load - 1.0 kW.Percentage of cabin wall used as space radiator - 50%.
Radiator emissivity - 0.925.
Earth orbit sink temperature - 239°K (-30°F).
-

Table 4-2

BASELINE SYSTEMS DESCRIPTIONS (page 1 of 2)

Subsystem		Function	Functional Methods, Groups of Components, and Operational Characteristics														
			Open System	Partially Closed System	Closed System												
Atmosphere Control	Atmospheric gas storage		High pressure storage method is used for normal operation and emergency atmospheric constituents. Each normal operation stored constituent is stored in three spherical tanks. Each emergency stored constituent is stored in a pair of tanks.														
	O ₂ recovery		Normal operation O ₂ and N ₂ are stored. Emergency O ₂ and N ₂ are stored.	Normal operation N ₂ is stored. Emergency O ₂ and N ₂ are stored.	Normal operation N ₂ is stored. Emergency O ₂ and N ₂ are stored.												
	CO ₂ reduction		None	CO ₂ reduction with H ₂ . Liquid water electrolysis of resulting water, supplemented, as necessary, with additional water to provide cabin O ₂ makeup.	CO ₂ not required by food processor is reduced with H ₂ . Liquid water electrolysis of resulting water, supplemented as necessary with additional water to provide entire O ₂ makeup. Food processor supplies part of O ₂ makeup.												
	Liquid water electrolysis		None	Bosch method. Coolant at Medium temperature level with 297°K outlet.													
Thermal Control	Airlock operation		None	Ion exchange membrane method. Coolant at Low temperature level with 290°K outlet.	Airlock provided on cabin 2 only. The airlock volume is 4.25 m ³ and the final pumped pressure is .01 kg/cm ² .												
	Temperature control		Cabin heat exchanger and associated fan.														
	Humidity control		Dehumidifying condenser in atmosphere purification loop.														
	Heat transport circuits		Heating and cooling circuits use water. Radiator circuit uses Freon 21. Additional structure for radiator is added if allocated cabin surface area is insufficient. Cooling circuit available temperature levels: First (Low): 277.5°K Second (Medium): 286°K Third (High): 300°K Heating circuit available temperature levels: First (Low): 425°K Second (Medium): 425°K Third (High): 450°K 6.9 kw at Medium coolant temperature level. 1.3 kw at High coolant temperature level.														
Water Supply	Non life support system cold plate heat loads																
	Water recovery		None	<table><tr><th>Source</th><th>Method</th><th>Efficiency</th></tr><tr><td>Urine</td><td rowspan="2">Closed cycle air evaporation</td><td>95%</td></tr><tr><td>Condensate</td><td>95%</td></tr><tr><td>Wash water</td><td rowspan="2">None</td><td>95%</td></tr><tr><td>Feces</td><td>-</td></tr></table>	Source	Method	Efficiency	Urine	Closed cycle air evaporation	95%	Condensate	95%	Wash water	None	95%	Feces	-
Source	Method	Efficiency															
Urine	Closed cycle air evaporation	95%															
Condensate		95%															
Wash water	None	95%															
Feces		-															
	Water storage		Water stored in three spherical tanks at 2 kg/cm ² pressure. Silver ion generation used for sterilization.														

Table 4-2 (page 2 of 2)

Table 4-II BASELINE SYSTEMS DESCRIPTIONS (concluded)			
Functional Methods, Groups of Components, and Operational Characteristics			
Subsystem	Function	Open System	Partially Closed System
Waste Management	Urine collection and disposal	Air entrainment urinal with storage of accumulated urine.	Air entrainment urinal with accumulation for food processing. Residual urine used for water recovery.
	Feces collection	Air entrainment and vacuum drying	Air entrainment and vacuum drying for any fecal material not required for food processing.
	Trace contaminants removal.	Particulate filter.	Particulate filters, catalytic burner, and activated charcoal.
	CO ₂ collection	Adiabatic two bed molecular sieve method. CO ₂ dumped overboard. Cabin CO ₂ pressure is .0052 kg/cm ² .	Four bed molecular sieve method. Accumulation for O ₂ recovery.
Crew and Crew Support	Onboard support	Coolant at Low temperature level with 280°K outlet for adsorption. Heating fluid at High temperature level with 422°K outlet for desorption. Cabin CO ₂ pressure is .0052 kg/cm ² .	
	Space suit operations	LiOH used for emergency period CO ₂ removal.	
	Operational/experimental activities	First aid and medical supplies, personal items, data management and storage, and clothing are provided. Diet fat ratio = .3. Wash water requirement = 3.0 kg/man day.	
Crew Accommodations	Gravity conditioning	Space suits and EVA support.	Two separate pressurized cabins. Instrumentation and controls provided. Living, work, and recreational facilities located in Cabin 2.
	Stored food	Centrifuge required for tours of duty of more than one year.	
Food Supply	Processed food	Dehydrated food.	
		None	Hydrogenous. 70% of diet is processed food. Coolant at Medium temperature level with 290°K outlet.
System Control	Monitoring and fault isolation	Controlling sensors, wiring, and functional controls. Displays and central control console located in Cabin 2.	

sample computer program input and output data are for this case. Emergency provisions and spare parts, vehicle interactions, qualitative output data, and projections of the state-of-the-art are presented for this case. Data for "open" and "closed" systems were similarly developed. Solutions for these baseline systems thus provided upper and lower limits in terms of ecological closure for the mission and vehicle conditions specified. Perturbations in selected functional methods for the "basic case" provided variations in levels of ecological closure within the category of partially closed systems. These modifications are shown in Table 4-3. These various levels of closure of the partially closed system are indicated in the effects on the sizing of equipment and determinations of expendables for recovery of O_2 from CO_2 by techniques which have various levels of basic recovery efficiency in combination with recovery of water by a technique which utilizes various sources of waste water.

As noted in the section, Computational Logic, complete mass balance computations are performed for the materials consumed by crewmen and the waste materials which result and must be collected and processed by the life support system.

For cabin gaseous atmosphere materials, representative cabin leakage and airlock use rates are included in the determinations of required O_2 and diluent gas. Cabin repressurizations and emergency period cabin pressurization requirements are accommodated by separate sources of O_2 and diluent.

Table 4-3
VARIATIONS IN FUNCTIONAL METHODS USED IN PARTIALLY
CLOSED SYSTEM SAMPLE PROBLEMS

Subsystem	Function	Functional Methods
Atmosphere Control	CO_2 reduction	Basic case - Bosch
		Variation - Sabatier with methane dump.
Water supply	Water recovery	Basic case - Urine, condensate, and wash water recovered by closed cycle air evaporation method.
		Variation - Condensate only recovered by closed cycle air evaporation method.

The space vehicle for this study was considered to include two separate occupied cabins. The first of these cabins is considered to serve as a laboratory area where experiments are performed by crewmen, while the second cabin serves as the crew living quarters and accommodates those functions related to this designation. Equipment used for the collection of urine, feces, and wash water and for water recovery are provided in the second cabin only. The storage tanks and containers for water and food are provided in the second cabin. Each cabin is considered to be capable of being separately pressurized. Cabin temperature and humidity control, CO₂ removal, trace contaminants removal, and O₂ recovery are provided individually in each cabin. The corresponding equipment in each cabin, however, is sized to accommodate the total crew and system redundancy with regard to these functions is thereby provided.

Cooling and heating requirements are determined for each life support system component. These individual "loads" are imposed on a generalized model for heat transport loops which permits cooling and/or heating fluid at various temperature levels to be specified for individual components. A space radiator is sized to reject to space the life support system cooling load plus any additional cooling load imposed by other vehicle systems. This load is imposed on the cooling loop either through liquid-cooled cold plates and/or through heat rejected to the cabin atmosphere which is cooled by the liquid-cooled cabin heat exchanger and thereby imposed on the cooling loop.

Figures 4-1, 4-2, and 4-3 show for crew sizes from 4 to 20 men and the "basic case" system, individual subsystem equipment weight, volume, and power for a 1-year mission. The weights shown do not include the expendable items which are supplied at 90-day intervals. The Atmosphere Control Subsystem weight and power characteristics are largely due to oxygen recovery equipment with small weight contributions for the airlock pump and for the atmospheric gas distribution system and cabin pressure controls. The tanks for expendable atmospheric gases, as well as the gases themselves, are treated as expendables and do not appear as "equipment".

The largest weight contribution for the Thermal Control Subsystem is that for the cabin wall insulation. The cooling loop circuitry provides significant weight and power contributions. The equipment which are located in the cabins and involved in temperature and humidity control for the cabin atmospheres tend to

NOTES
 1. BASIC CASE SYSTEM
 2. 1-YEAR MISSION

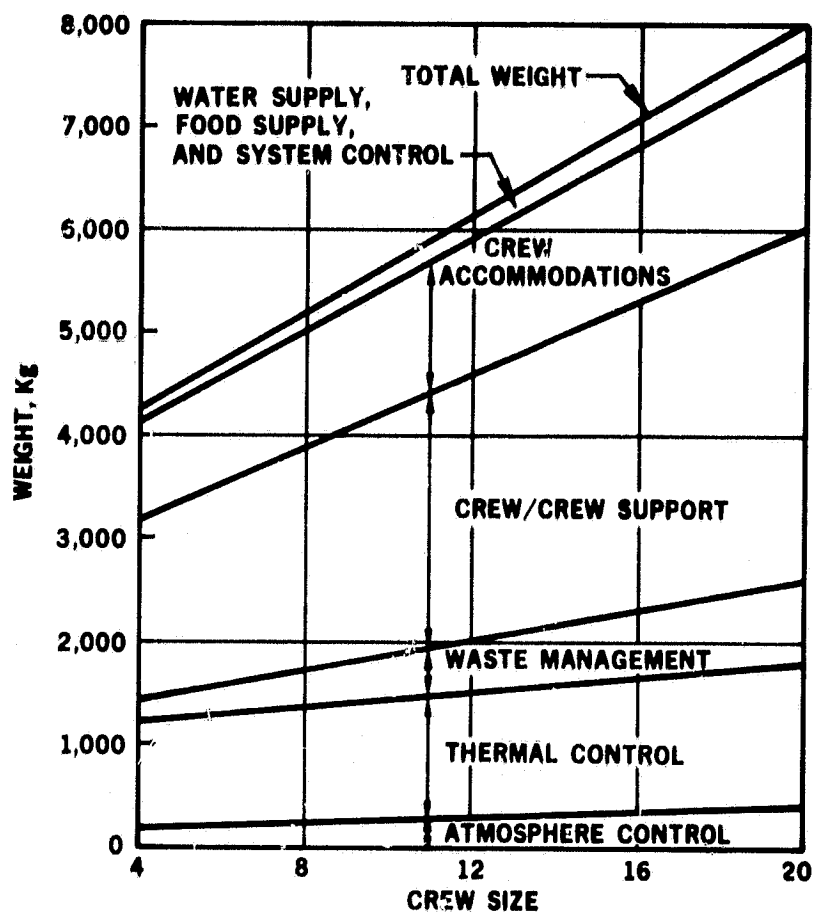


Figure 4-1. Equipment Weight

NOTES
 1. BASIC CASE SYSTEM
 2. 1-YEAR MISSION

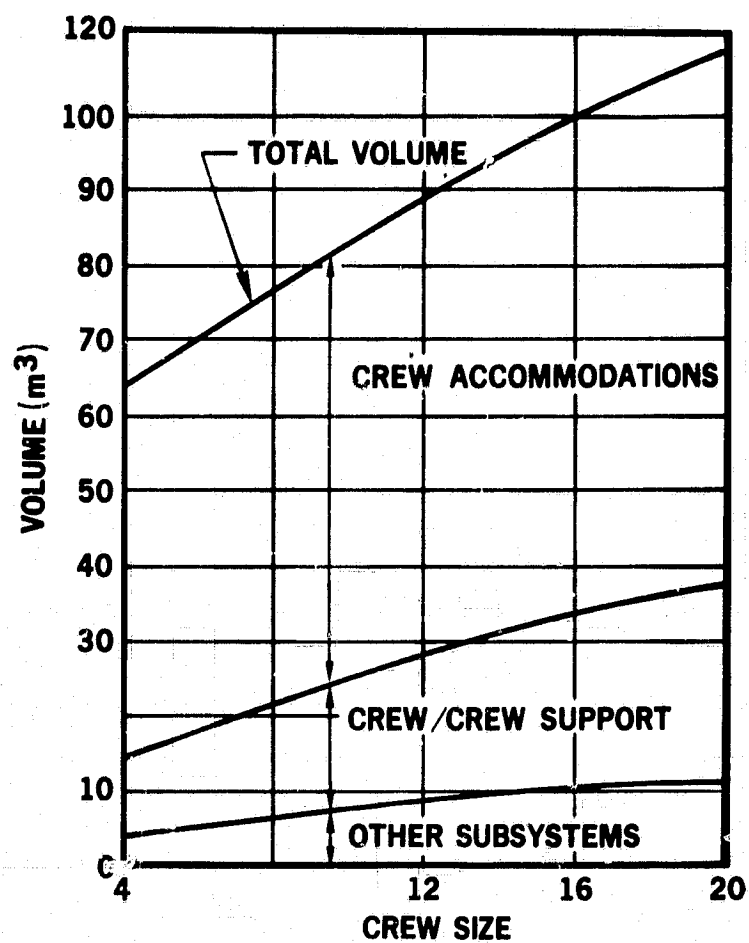


Figure 4-2. Equipment Volume Requirements

NOTES:
 1. BASIC CASE
 SYSTEM
 2. 1-YEAR MISSION

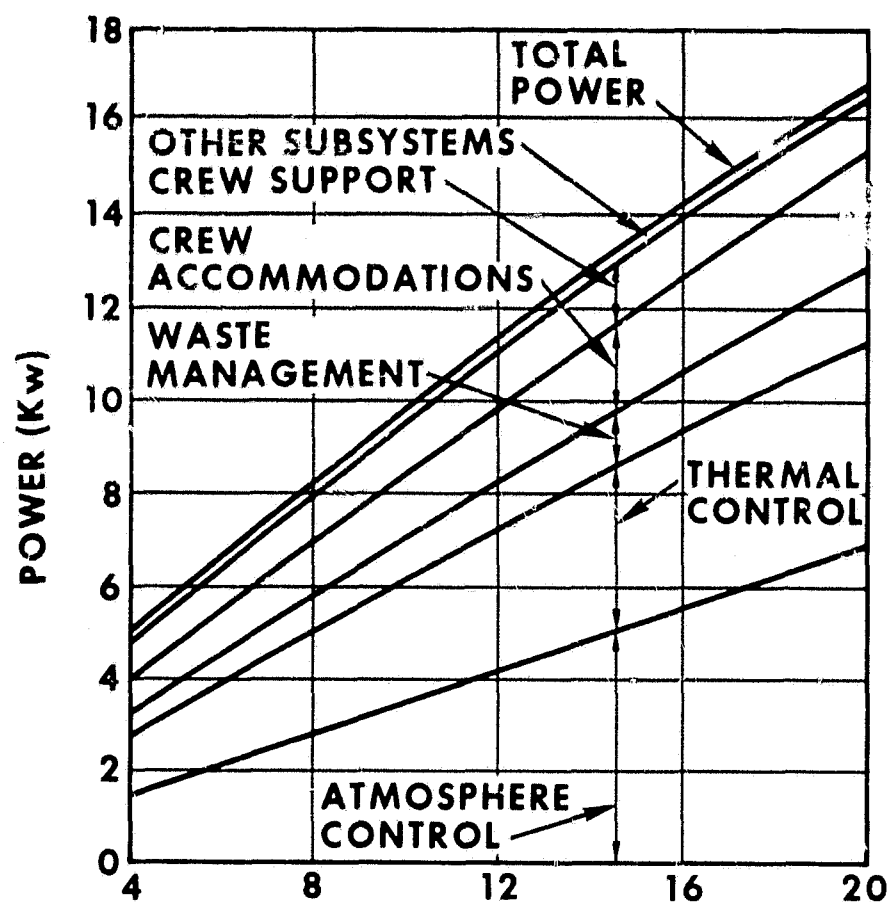


Figure 4-3. Equipment Power CREW SIZE

NOTES:
 1. PARTIALLY CLOSED SYSTEM
 2. SUBSYSTEM EQUIPMENT FOR:
 • CREW/CREW SUPPORT
 • CREW ACCOMMODATIONS
 • FOOD SUPPLY
 • SYSTEM CONTROL

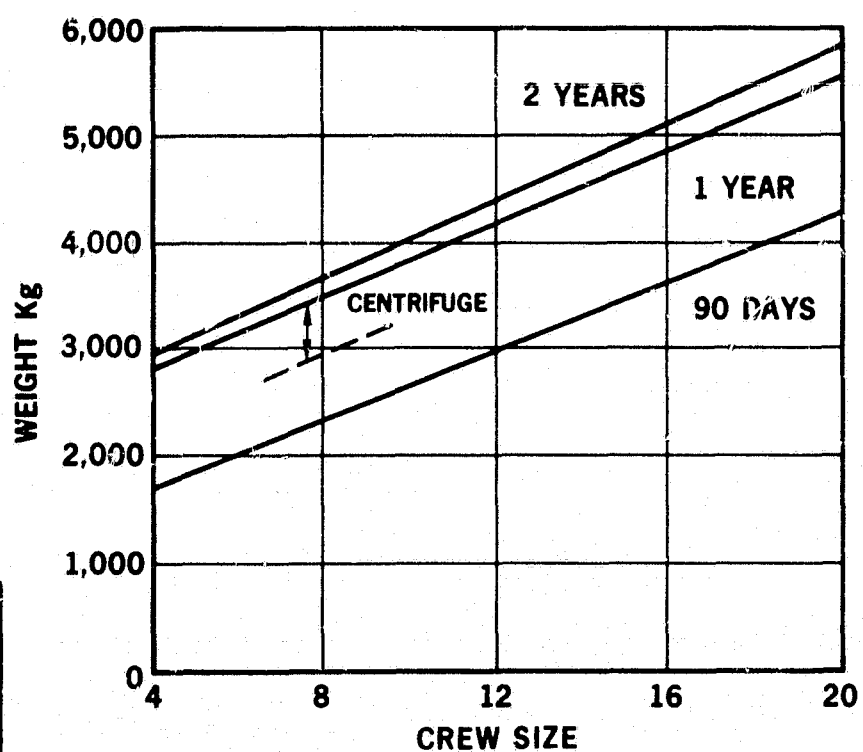


Figure 4-4. Mission - Dependent Equipment Weight

be relatively light but require significant amounts of power. Thermal control is less sensitive to crew size than are other subsystems, due to the relative magnitude of the constant non life support system heat load which is imposed on the cooling system.

Water Supply Subsystem water recovery equipment is considerably lighter and requires considerably less power than does the oxygen recovery equipment. The water tankage as well as the water distribution system is included as "equipment", rather than having the tanks included in the expendable items.

CO₂ removal equipment provides the largest contributions in terms of weight, volume and power for the Waste Management Subsystem, and the other significant contributors are the trace contaminants removal and urine and feces collection units.

The Crew/Crew Support and Crew Accommodations Subsystems provide large contributions of weight and volume. In the Crew/Crew Support Subsystem, such items as required space suits, clothing, portable life support systems, and EVA support equipment are important in this regard. Each of the items listed in Table 3-1 for the Crew Accommodations Subsystem are significant. The centrifuge which is included for gravity conditioning provides the largest single contribution in required volume. It requires a volume of 41 m³. For purposes of these sample problems it is assumed that tours of duty greater than 180 days necessitate a centrifuge. With two exceptions, power requirements for the equipment in these two subsystems are all intermittent. These two exceptions are the cabin lighting power included for the Crew Accommodations Subsystem, and the instrumentation and controls power included for the Crew/Crew Support Subsystem. For these subsystems only these power requirements are shown on Figure 4-3.

The Food Supply Subsystem and the System Control Subsystem contributions are inherently small.

In obtaining solutions for variations in the basic case considered here, it was found that equipment in some subsystems are sensitive to mission duration, but not to ecological closure. The opposite sensitivity was obtained for equipment in other subsystems. This observation is considered to be true only within the framework of partially-closed systems and should not be construed to be true

for other levels of closure. Figure 4-4, 4-5, and 4-6 show weight, required volume, and required power sensitivities to mission duration for the applicable subsystems of Crew/Crew Support, Crew Accommodations, Food Supply, and System Control.

The above mentioned centrifuge is included for the one and two year missions, but not for the 90-day mission. The centrifuge itself is assumed to be independent of crew size for crew sizes up to 20 men. As can be seen from the weight and volume data the subtotals for these subsystems are very sensitive to the inclusion of this device. Otherwise, the sensitivity to mission duration is considerably less than that due to crew size. The average power shown in Figure 4-6 is only that required for the lighting system, and for instrumentation and controls for crew support and these loads are basically a function of crew size.

Figure 4-7, 4-8, and 4-9 show sensitivities to variations in ecological closure for the Waste Management, Atmosphere Control, Water Supply, and Thermal Control subsystems. The weight variations for these four subsystems with several levels of closure considered and within the context of partially closed systems, are quite small. As the closure is increased from "Sabatier/Condensate water recovery" to "Bosch/Condensate, urine, and wash water recovery" small weight increases occur in the Atmosphere Control, Thermal Control, and Water Supply Subsystems.

Thermal Control weight must increase due to the increased heat to be rejected. A four-man open system, without water or oxygen recovery and a four-man closed system, with nearly full recovery of the wastes, are shown for comparative purposes. The volumes required for these subsystems show greater sensitivity to ecological closure; the most significant factor being the reduced volume required for storage of expendable water as the completeness of water recovery is increased. Required power also shows significant sensitivity to the level of closure. The most significant factor is the difference in power required by the Bosch and Sabatier processes for CO_2 reduction.

In Figures 4-1 through 4-9 the effects of ecological closure of the life support system equipment have been shown. Figure 4-10 shows expendable and accumulated material rates as determined for various levels of ecological closure.

- NOTES:**
1. PARTIALLY CLOSED SYSTEM
 2. SUBSYSTEM EQUIPMENT FOR:
 - CREW/CREW SUPPORT
 - CREW ACCOMMODATIONS
 - FOOD SUPPLY
 - SYSTEM CONTROL

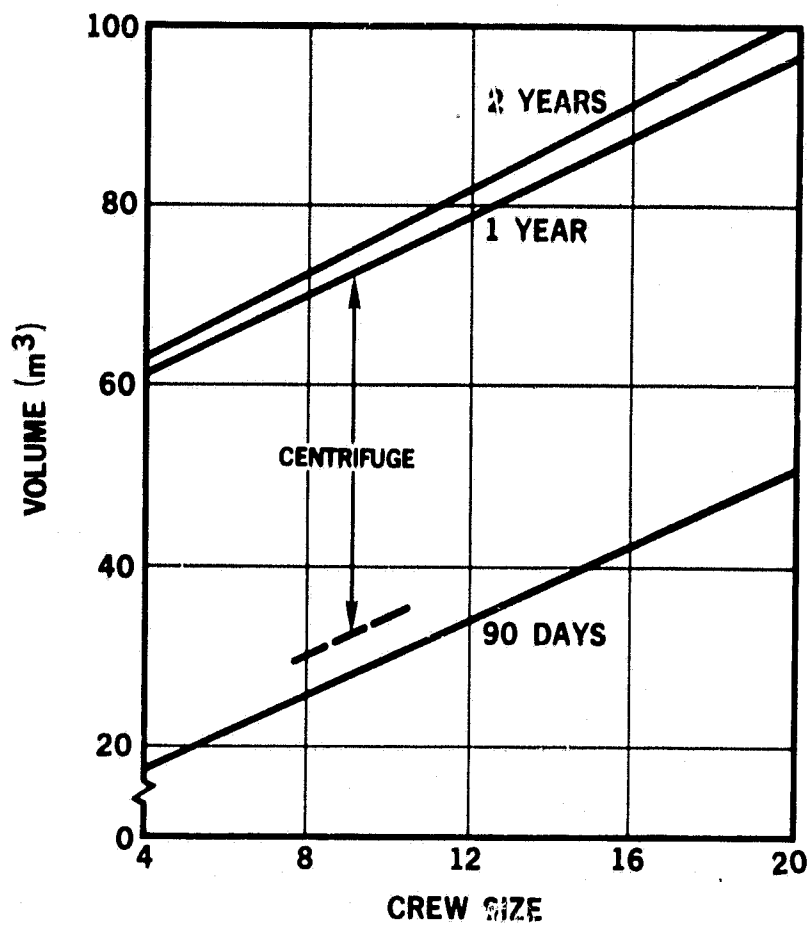


Figure 4-5. Mission - Dependent Volume Requirements

- NOTES:**
1. PARTIALLY CLOSED SYSTEM
 2. SYSTEM EQUIPMENT FOR:
 - CREW/CREW SUPPORT
 - CREW ACCOMMODATIONS
 - FOOD SUPPLY
 - SYSTEM CONTROL

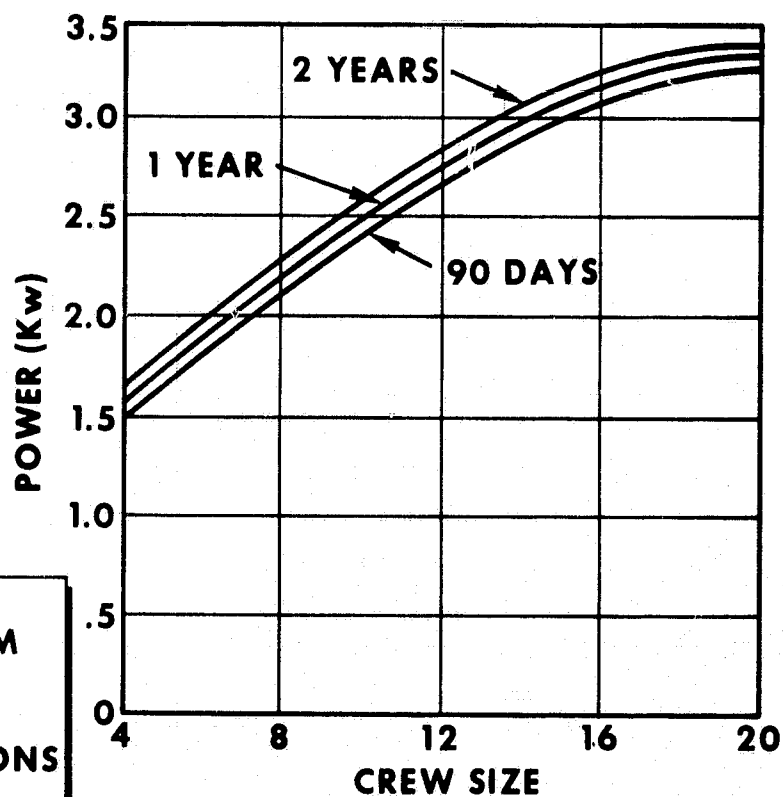


Figure 4-6. Mission-Dependent Power

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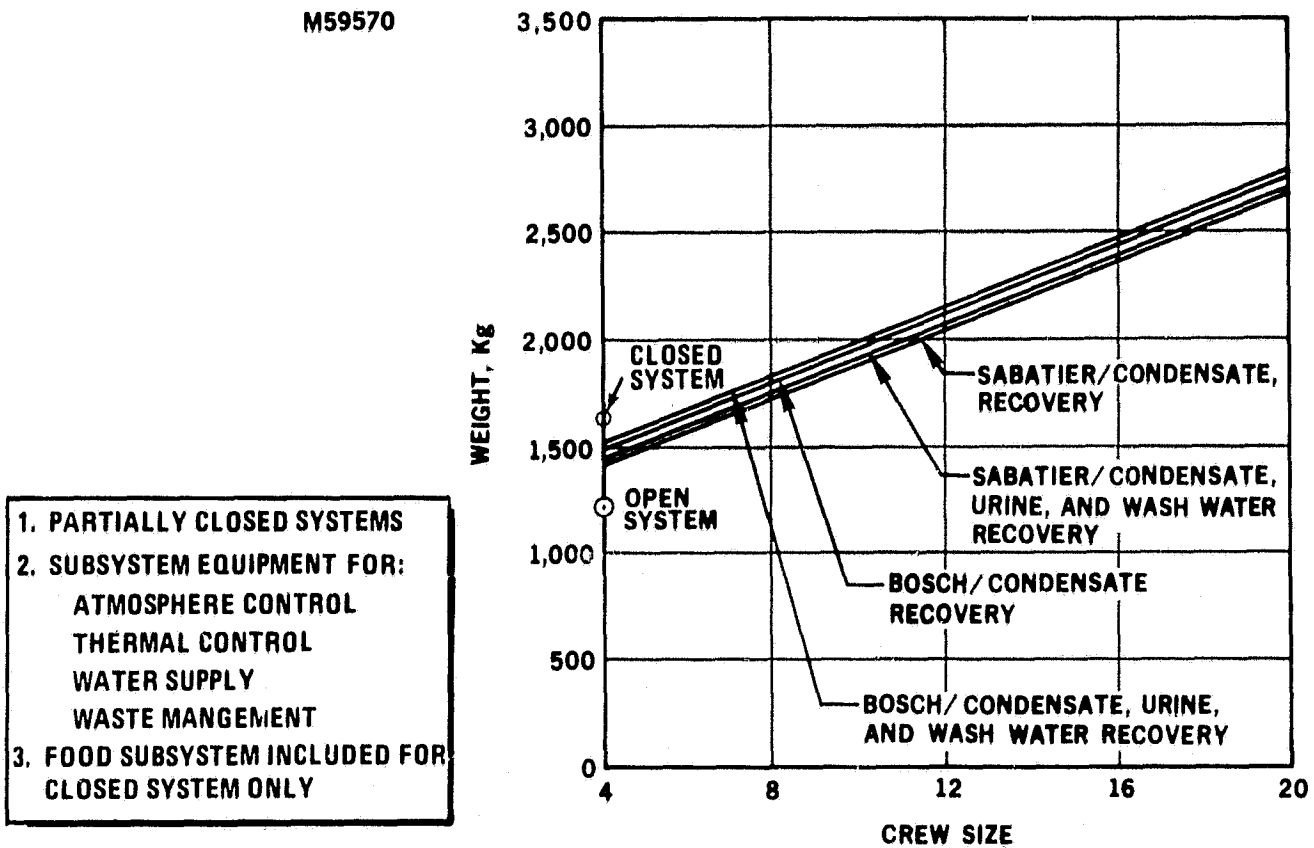


Figure 4-7. Closure-Dependent Equipment Weight

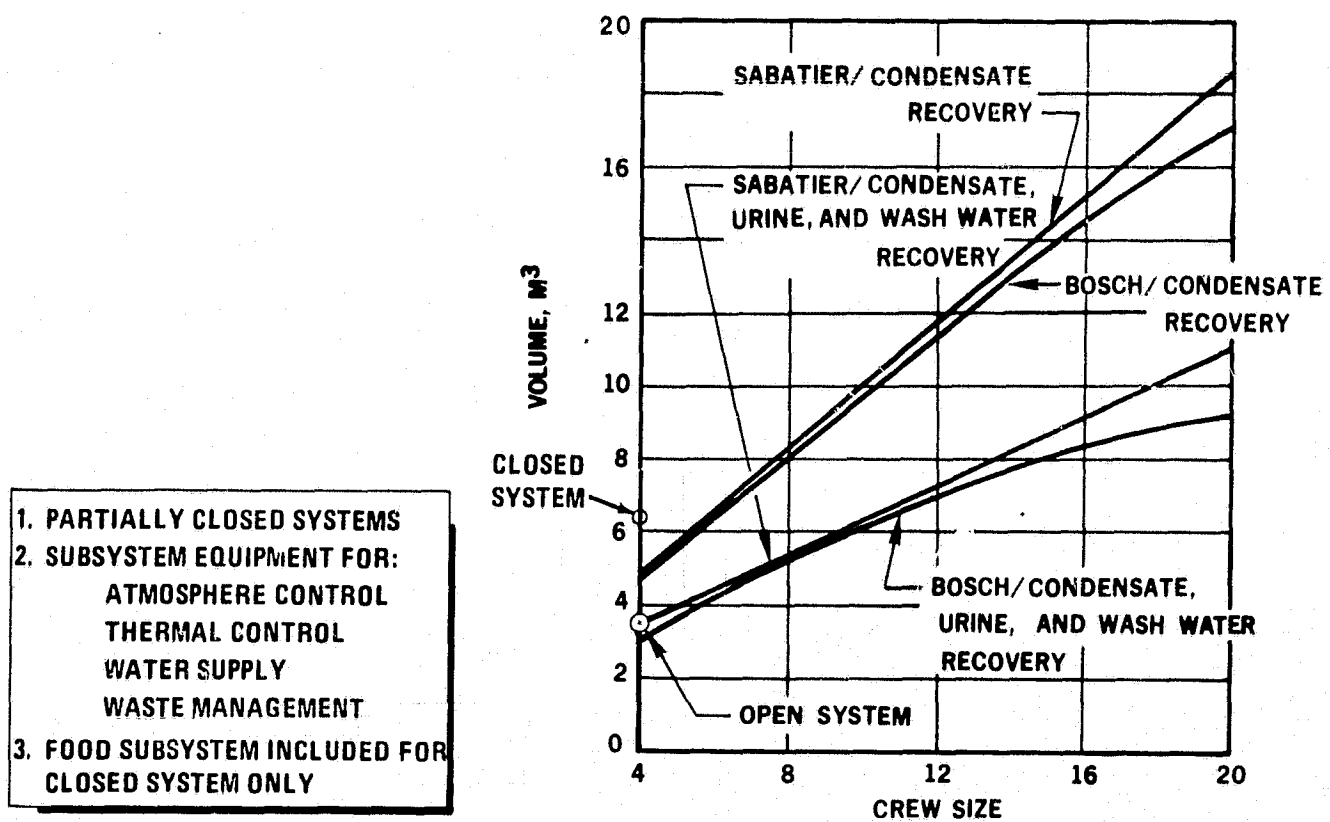


Figure 4-8. Closure-Dependent Volume Requirements

- NOTES**
1. PARTIALLY CLOSED SYSTEMS
 2. SUBSYSTEM EQUIPMENT FOR:
 - ATMOSPHERE CONTROL
 - THERMAL CONTROL
 - WATER SUPPLY
 - WASTE MANAGEMENT
 3. FOOD SUBSYSTEM INCLUDED FOR CLOSED SYSTEM ONLY

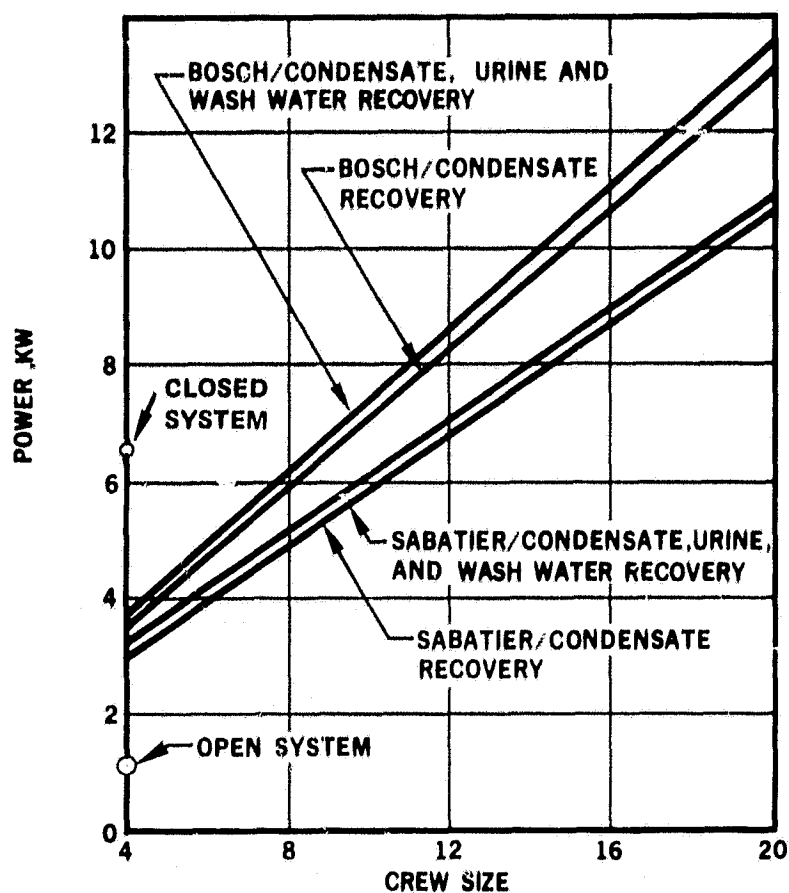


Figure 4-9. Closure - Dependent Power

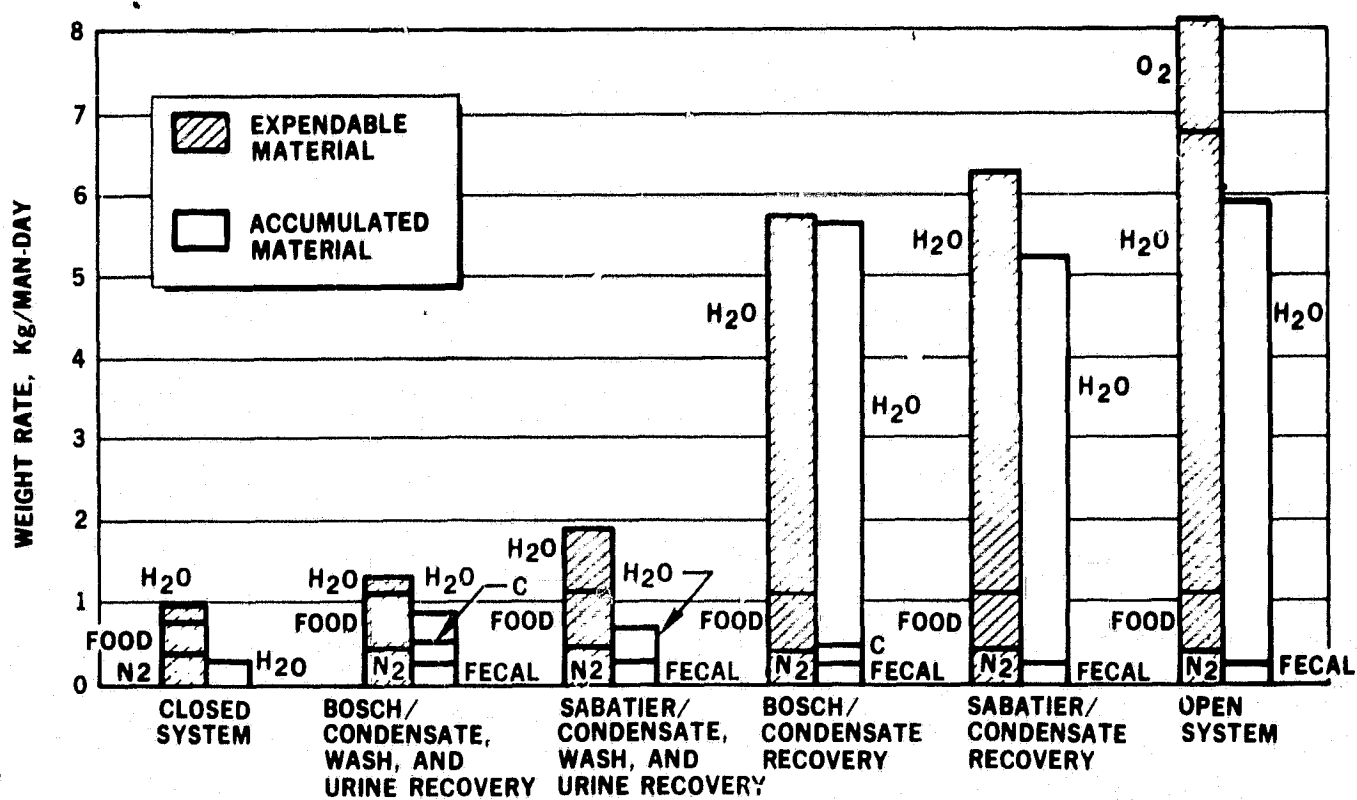


Figure 4-10. Expendable and Accumulated Material Rates

Representative material rates for the open and closed systems are included for comparative purposes. Note that the closed system is not completely closed since some expendable food is still required. The large decreases in expendable and accumulated water rates for increasing completeness of water recovery from condensate only to recovery from condensate, wash, and urine is highly influenced by the assumed wash water rate of 3.0 kg/man day. It is assumed that the unrecovered wash water is stored. Required wash water rates are presently considered to be largely a matter of opinion, but the rates shown on Figure 4-10 can be easily modified to include other assumed wash water rates.

Figures 4-11 and 4-12 show application of Figures 4-4 through 4-10 systems for two levels of closure and a crew of four men for a range of resupply periods. Figures 4-11 and 4-12 show that for these subsystems, the selected equipment has small direct effect upon weight and volume. However, large differences between the two systems show up in the expendable requirements, with the recovery of urine and wash water giving significant savings. The major contribution is the expendable wash water requirement. Reducing the wash water allowance would correspondingly reduce the resupply requirements.

Table 4-4 shows the emergency and spare parts provisions for a four-man crew, one year mission, and the "basic case" system. An emergency period of 5 days was specified and the required emergency equipment and expendable materials weight and volume indicated are for this period. These expendable type items are not tabulated with the expendables required for normal operation and are not considered to be normally logistically resupplied. These equipment and supplies satisfy the crew requirements during the emergency period for the following emergencies: loss of cabin pressure, failure of the heating circuitry and failure of the cooling circuitry. The listed miscellaneous collection devices provide for emergency urine and fecal material collection.

The redundancy provided by specifying the provision for Atmosphere Control and Waste Management equipment in each of the two cabins is reflected in reduced spare parts weight required for these subsystems. The Thermal Control and Water Supply Subsystems, on the other hand, do not include this redundancy and therefore require proportionally more spares.

NOTE
4 MAN, 1 YEAR MISSION
 ——— SABATIER/
 CONDENSATE
 RECOVERY
 ——— BOSCH/CONDENSATE,
 URINE, AND WASH
 WATER RECOVERY

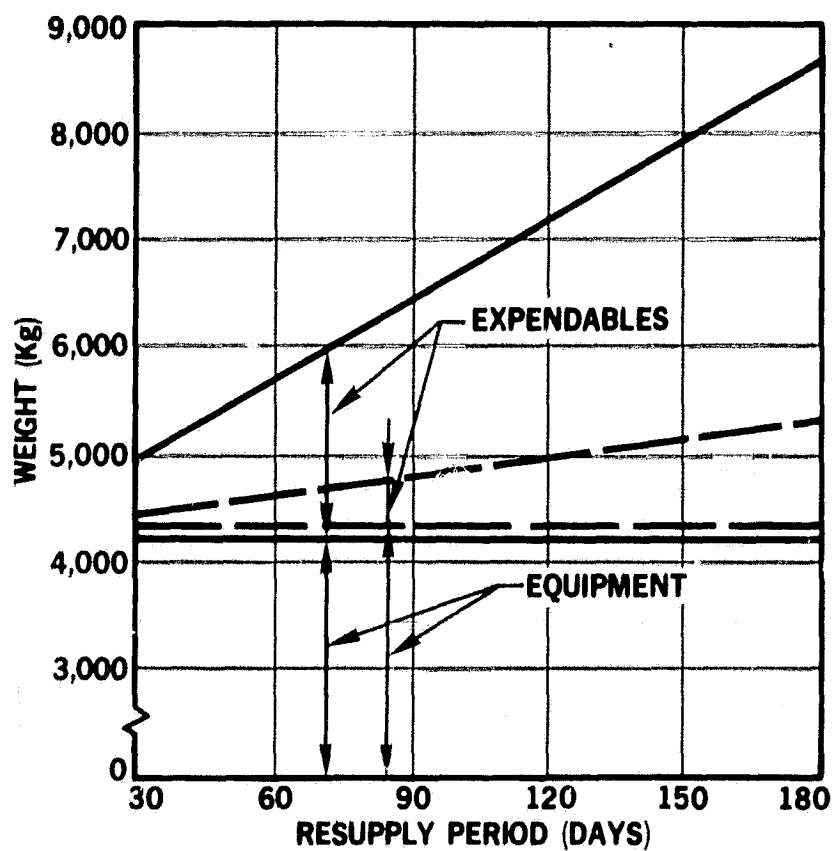


Figure 4-11. Partially Closed Systems Weight

NOTE
4 MAN, 1 YEAR MISSION
 ——— SABATIER/
 CONDENSATE
 RECOVERY
 ——— BOSCH/CONDENSATE,
 URINE, AND WASH
 WATER RECOVERY

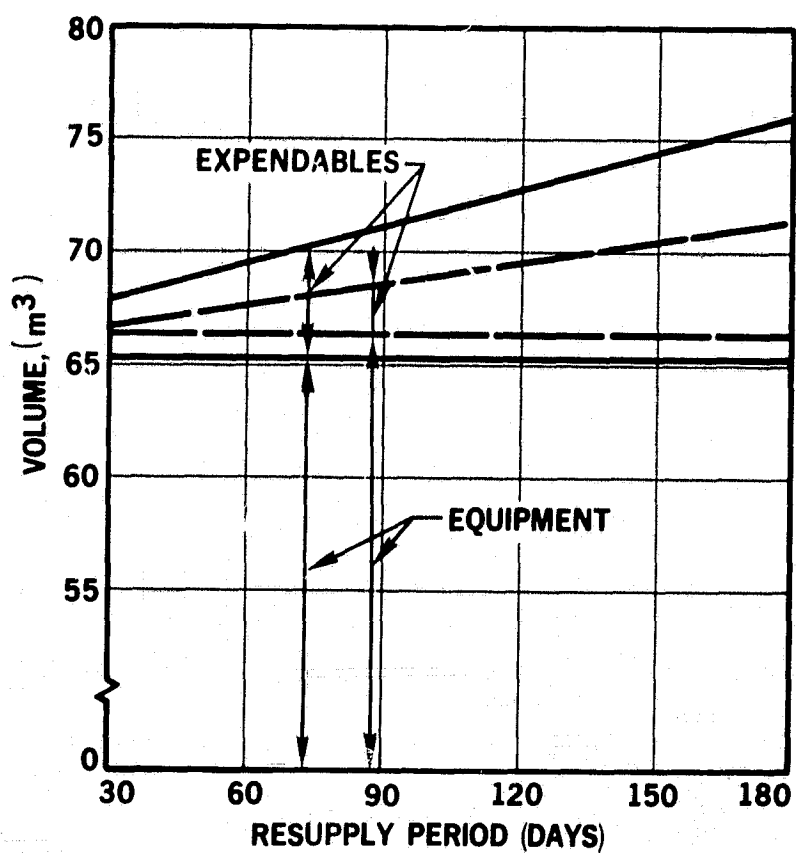


Figure 4-12. Partially Closed Systems Volume

Table 4-4
EMERGENCY AND SPARES PROVISIONS

Four man crew, 1-year mission, Basic Case System from Table 4-2

I. Emergency Provisions for 5 day Emergency Period:

<u>Subsystem</u>	<u>Items</u>	<u>Equipment Weight (kg)</u>	<u>Volume (m³)</u>	<u>Expendable Material Weight (kg)</u>	<u>Volume (m³)</u>
Atmosphere Control	High pressure O ₂ and N ₂ storage	24.		151.	0.1
Thermal Control	Water evaporator and stored H ₂ O	1.2	0.01	60.	0.06
Waste Management	LiOH for CO ₂ removal	8.1	0.07	27.	0.07
	Miscellaneous collection devices			15.	0.05
Water Supply	Stored H ₂ O			117.	0.12
Food Supply	Stored food			10.	0.07
		<u>33.3</u>	<u>0.08</u>	<u>380.</u>	<u>0.47</u>

II. Spare Provisions:

<u>Reliability</u>	<u>Subsystem</u>	<u>Spares weight (kg)</u>	<u>Spares volume (m³)</u>
0.9	Atmosphere Control	9.6	0.02
	Thermal Control	124.	0.26
	Water Supply	42.5	0.09
	Waste Management	11.5	0.02
		<u>187.6</u>	<u>0.39</u>
0.999	Atmosphere Control	115.	0.24
	Thermal Control	364.	0.76
	Water Supply	100.	0.20
	Waste Management	129.	0.27
		<u>708.</u>	<u>1.47</u>

Data for the basic case system from Table 4-2 were used to characterize life support systems for a 1-year duration, 90-day resupply, earth orbital mission and for a 350-day Venus flyby mission. The results are shown in Tables 4-5 and 4-6. Table 4-5 gives the life support system equipment and expendable characteristics for each mission. The slight increases in system equipment weight and volume for the flyby mission are due primarily to increased sizes for fecal collector canisters, water storage tankage, and food storage facilities. These increases result from the necessity for the Venus flyby mission to provide adequate fecal collectors, water and food for the entire mission. While for the earth orbital mission, fecal collectors, water, and food are resupplied each 90-days, and resupplying these items reduces the sizes of the required tankage and storage facilities. The expendable requirements for the two cases are determined from the expendable rates shown on Figure 4-10.

The vehicle interactions as shown by the weights given in Table 4-6 indicate rather small differences for the two cases. The very slight increase in meteoroid shielding for the Venus flyby case is due to the greater net asteroidal flux imposed on the vehicle for that case.

Comparing the radiation shielding requirement for the earth orbital case with the required biowell for the flyby case is difficult since the radiation environments and the computational procedures are quite different for these two cases. For the earth orbital case, the shielding thickness is determined for the combined effects of geomagnetically trapped radiation with the superposition of one

Table 4-5
LIFE SUPPORT SYSTEMS FOR EARTH ORBITAL AND
VENUS FLYBY MISSIONS

Four man, Basic Case System from Table 4-2		
Life Support System Equipment	Earth Orbital (One year duration, 90 day resupply)	Venus Flyby (350 days)
Weight	4,310 kg	4,370 kg
Volume	64.1 m ³	68.2 m ³
Power	4.16 kW	4.16 kW
<u>Expendables</u>		
Weight	685. kg	2,660. kg
Volume	2.4 m ³	9.3 m ³

Table 4-6
VEHICLE INTERACTIONS FOR EARTH ORBITAL
AND VENUS FLYBY MISSIONS
Four man crew, Basic Case System from Table 4-2

	Earth Orbital (1-year duration, 90-day resupply)	Venus Flyby (350 days)
Meteoroid Shielding	1,940 kg added to vehicle outer shell	2,010 kg added to vehicle outer shell
Radiation Shielding	10,200 kg (3,380 kg provided by vehicle wall)	11,850 kg biowell
Required Heating	1.77 kW	1.77 kW
Required Power	4.16 kW	4.16 kW

solar flare event each 180 days. The computed shielding thickness required to control radiation dosage to 150 REM at the end of the mission is applied to the outer surface area of the occupied compartments in determining the total shielding weight. The existing structural walls of these compartments, including the additional meteoroid shielding, contribute 3,380 kg toward the total required radiation shielding weight. Life support system equipment, other vehicle systems equipment, expendables, and accumulated materials can also be construed to participate in providing shielding. However, design layout drawings are considered to be necessary in fully evaluating the effectiveness of these items in contributing to the shielding. These drawings would indicate the distribution of equipment and materials in the vehicle so as to distribute the mass of the various items as uniformly as possible about the vehicle walls while not locating them so that operations and maintenance of vehicle systems are jeopardized.

For the Venus flyby mission, the biowell is sized for a maximum solar flare activity based on the data obtained from the 1951-1961 solar cycle. The shielding thickness required to control the radiation dosage to 150 REM at the end of the mission is based on statistical determinations. The vehicle structural wall is not considered to be heavy enough to effectively contribute to the shielding for this case. The biowell is considered to be a rather compact, thick walled, enclosure located within the vehicle. It is just large

enough to accommodate all of the crewman and to permit comfortable ingress of each crewman. The shield for the biowell for the Venus flyby mission is distributed over a much smaller surface area than is the shielding for the earth orbital case.

Section 5

CONCLUDING REMARKS

A computational tool has been developed which can be used to size and describe life support systems. This information can then be used in tradeoff evaluations. Life support systems can be defined with respect to mission duration, and crew size. Additionally, the life support systems can be characterized with respect to system variables such as ecological degree of closure and the selected types of equipment for performing particular functions. Emergency and spares provisions can be determined. Vehicle interactions such as required meteoroid and radiation shielding, required electrical power, and required heating can also be computed.

Sensitivities of life support system equipment weight, volume, and required power to crew size, mission duration, and degree of ecological closure have been presented for sample problems. Partially closed life support systems were emphasized in these computed results. In the assessment of computer program output data for a categorical level of ecological closure (open, partially closed, or closed) for these sample problems it was found that subsystem equipment was mainly dependent upon only two of the above variables (either crew size and mission duration or crew size and variations in selected functional methods for achieving the categorical level of closure). This reduction from three to two independent variables significantly facilitated deriving sensitivity evaluations from the output data. The computer program results indicated, for a partially closed level of closure, that the subsystem equipment most sensitive to crew size were those for Crew/Crew Support, Crew Accommodations, Waste Management, and Atmosphere Control. For partially closed systems, the major mission duration dependent subsystem equipment are assigned to the Crew/Crew Support, Crew Accommodations, Food Supply and System Control subsystems. The closure dependent subsystem equipment are assigned to the Atmosphere Control, Thermal Control, Water Supply, and Waste Management subsystems.

It has been shown that parameterized equipment characteristics and required expendable materials can be easily combined for variations in such variables as crew size, mission duration, and resupply period to obtain complete life support system characteristics.

In addition to crew size, mission duration, and level of closure some other variables which life support system equipment are known to be sensitive to include: limited available cabin volume, limited available vehicle surface area for space radiators, number of cabins, crewmen activity levels, availability of waste heat, cabin atmosphere leakage, required maintainability and spares provisioning, crew percentile, crew diet, and required wash water. The sensitivity of life support system equipment to these variables can also be evaluated with the developed computer program.