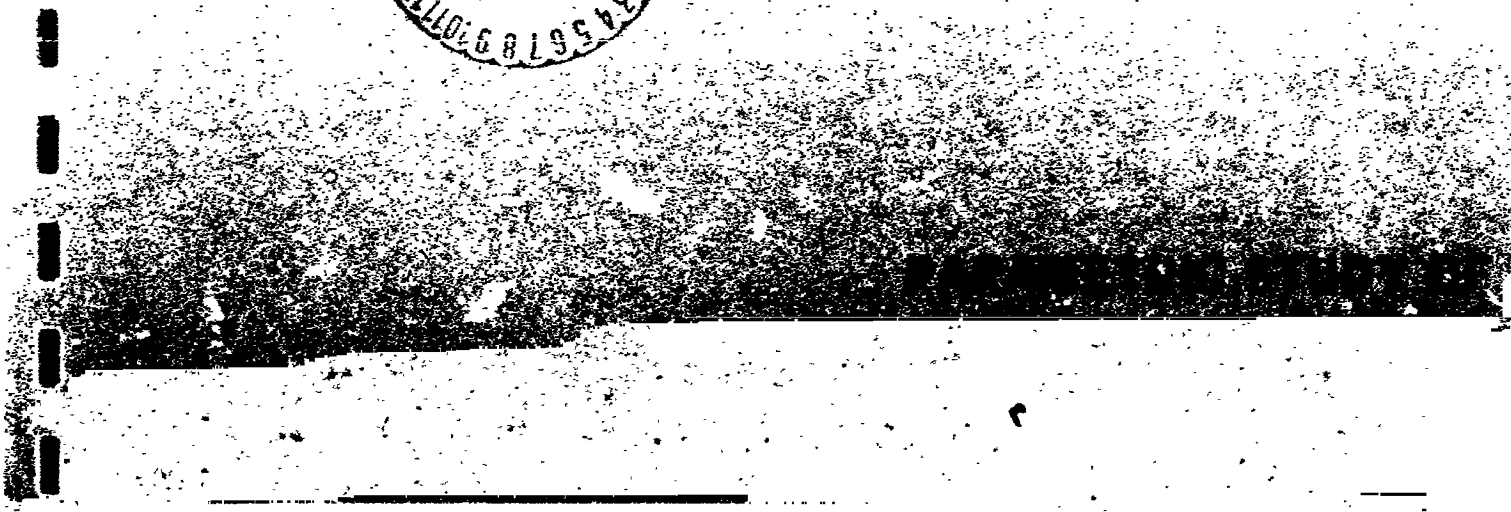

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JANUARY 1969

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PARAMETRIC STUDY OF MANNED LIFE SUPPORT SYSTEMS

JANUARY 1969

NASA CR 73282
DAC-56712

Volume I - Summary

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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, 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:

	Title	Report No.
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

ACKNOWLEDGMENT

Acknowledgment is given to the following government and industrial organizations for their assistance in the supplying of engineering life support information which proved highly beneficial and valuable for this study.

Aerospace Medical Research Laboratories, WPAFB
Air Force Flight Dynamics Laboratory, WPAFB
ARDE, Inc.
Atlantic Research Corporation
Battelle Memorial Institute
Beckman Instruments, Inc.
Beech Aircraft Corporation
Bendix, Instruments and Life Support Division
David Clark Company, Inc.
Foote Mineral Company
General Dynamics Corporation, Convair Division
General Dynamics Corporation, Electric Boat Division
Goodyear Aerospace Corporation
LTV Aerospace Corporation
MSA Research Corporation
NASA, Ames Research Center
NASA, Manned Space Center
NASA, Office of Advanced Research and Technology
Northern Research and Engineering Corporation
Ocean Systems, Inc.
The Rand Corporation
TRW Equipment Laboratories
Union Carbide Corporation, Linde Division
United Aircraft Corporation, Hamilton Standard Division
United Aircraft Corporation, Pratt and Whitney Aircraft Division

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VOLUME I: SUMMARY

VOLUME II: PARAMETRIC RELATIONS AND SCALING LAWS

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INTRODUCTION

This study was performed to provide new analytical and computational tools that permit the parametric evaluation and sizing of life support systems for Earth orbital, lunar, and planetary missions. Included were considerations of various degrees of closure, alternate methods of performing each functional process, and the types of components and subsystems employed. These relations were required to be responsive to the interrelations and interactions of other vehicle systems, the mission environment, crew size, mission duration, and the logistic supply interval. Parametric relationships and scaling laws were developed for 44 life support subsystems and/or components that permit a potential evaluation of over 675, 000 integrated system configurations. The major objectives that have been met by providing this new capability include the following:

1. The development of parameters and scaling laws representing life support functions, components, and systems, applicable to a broad range of missions, from Earth orbital to interplanetary, and a broad range of ecology closures.
2. The development of the computational logic to implement the use of the parametric data and scaling laws in a fashion that considers the whole spacecraft and permits the evaluation of both a broad range of spacecraft missions and of life support subsystem functional alternatives for each specified mission.
3. The development of a Fortran program to mechanize the computational logic such that system tradeoffs and mission sensitivity analyses can be completed expeditiously.

METHODOLOGY

Parametric relations and scaling laws were developed for the major candidate life support functional methods and associated components and systems in the context of the whole spacecraft and its mission and mission environment. The following approach was used to meet the study objectives:

1. Life support functional methods were screened using the latest available literature and vendor data.
2. Scaling laws and parametric data were developed where valid hardware data existed. Mass and thermal balances were performed in the development of scaling laws.
3. In cases where inadequate data existed, engineering designs of the components, units or subsystems were made based on prototype or laboratory model characteristics, chemical reactions, and the mass and heat transfer rates involved.
4. The interactions and interrelationships between the mission environment, the spacecraft structure and systems, and the life support subsystems were incorporated into the computational logic.
5. The logic for the analysis of life support systems, as influenced by the mission and vehicle criteria, was completed and mechanized by the development of a Fortran program.
6. Mission-oriented tradeoffs and sensitivity analysis techniques were completed to help refine the computer program and to provide guidelines for program usage.

MISSION AND VEHICLE CRITERIA

Mission and spacecraft criteria impose major constraints on the life support subsystems. Three typical classes of missions, in which the effects of flight duration and degree of closure of life support systems are pronounced, have been considered in this study. The first was the short-duration Apollo-type mission which may use shuttle-type spacecraft. Vehicles in this type of missions may use a nearly open cycle life support system or some degree of system regeneration. The second class of missions was characterized by lunar and Earth orbiting space vehicles which have long staytimes in orbit but may have periodic resupply intervals, such as 30-, 60-, 90-, or 120-days. The third class of missions involves long-duration space flights with no resupply, as in the case of most interplanetary missions. The latter missions require at least semi-closed if not completely closed life support systems to minimize the expendable materials carried in the spacecraft. Representative interplanetary missions have been utilized, consisting of missions into Venus and Mercury and out to Mars and Jupiter. Vehicle solar spatial locations versus the time in flight have been used to describe the missions.

Scaling laws were included in the analysis structure to permit the influence of mission-oriented requirements and their interaction with life support systems to be evaluated. These included the following:

- Space thermal environment, including solar, albedo, and planetary emitted radiations.
- Ionized radiations, including geomagnetically trapped and galactic radiations, and solar flares as a function of the solar cycle.
- Meteoroid fluxes.
- Vehicle configuration, including vehicle dimensions, wall insulation, shielding requirements, and biowell usage.
- Integration considerations with other vehicle systems including thermal loads from electronic equipment and the use of heating fluids and/or electrical power from the power system.

Parametric relations were developed to establish the weights for (1) required meteoroid shielding to be added to the vehicle structure, (2) required radiation shielding to be provided by equipment and materials within the vehicle and supplemented as necessary by additional material, and (3) any required structure to be added to the vehicle in order to provide adequate life support system space radiator surface area.

LIFE SUPPORT SCALING LAWS AND PARAMETRIC RELATIONS

The life support systems were considered to be comprised of eight subsystems: (1) Atmospheric Control--involving oxygen and diluent supply and pressure control; (2) Thermal Control--dealing with temperature and humidity control; (3) Water Supply--comprising water reclamation, storage, and distribution; (4) Waste Management--for collection and storage for treatment and/or disposal of wastes; (5) Food Supply--dealing with preparations of processed and/or stored foods; (6) Crew and Crew Support--including biomedical supplies, clothing, and personal items; (7) Crew Accommodations--dealing with living, work and recreational facilities; (8) System Controls--involving automatic and manual controls and monitoring equipment.

Mathematical models were defined for a minimum of three and, in some cases, up to eight functional methods for each of the processes involved in the above eight subsystems. Also included were considerations regarding maintainability, spare parts provisioning, and emergency mode operation. Approximately 260 parametric relations and scaling laws were developed and presented in terms of equipment weight, volume, electrical power, and heating and cooling requirements.

Parameterized life support system degrees of closure extended from open systems such as those used in Gemini and Apollo, in which no waste recovery was attempted, to partially closed systems, which provide recovery processes for water and/or oxygen; and ultimately to closed systems, which provide food and all life support needs from the processing of human wastes. Simplified schematics of open, partially closed, and closed life support systems are shown in Figures 1, 2, and 3 respectively, which illustrate

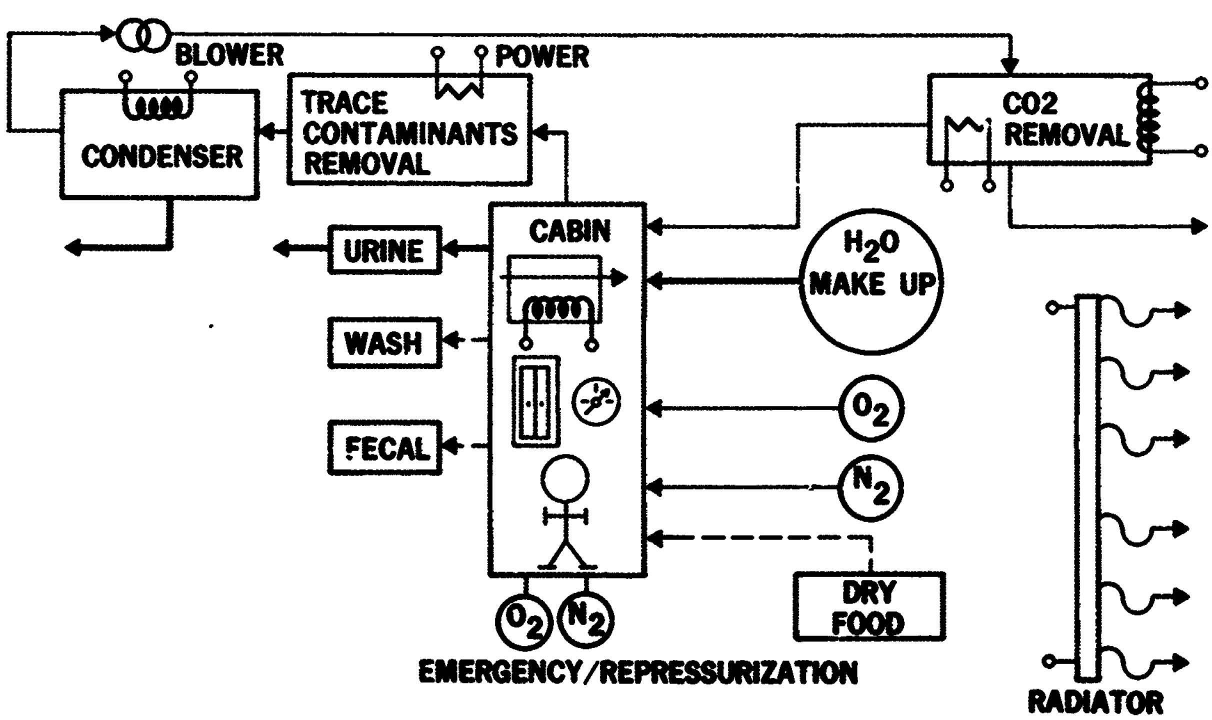

Figure 1. Open Life Support System

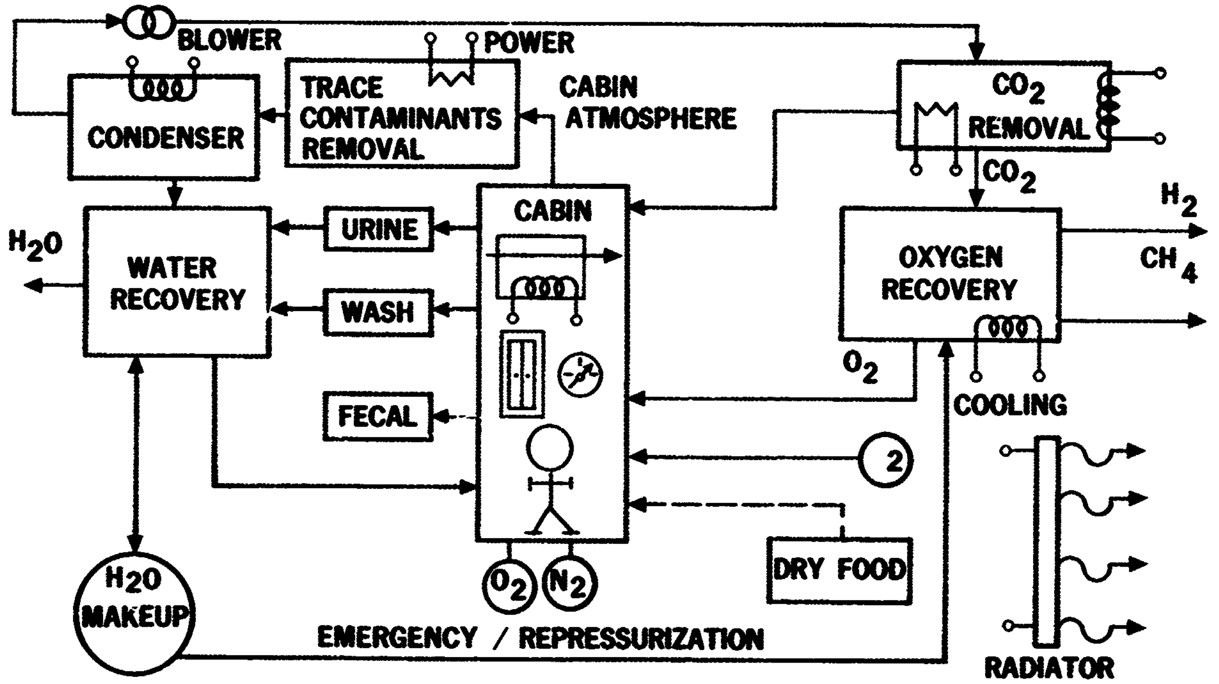

Figure 2. Partially Closed Life Support System

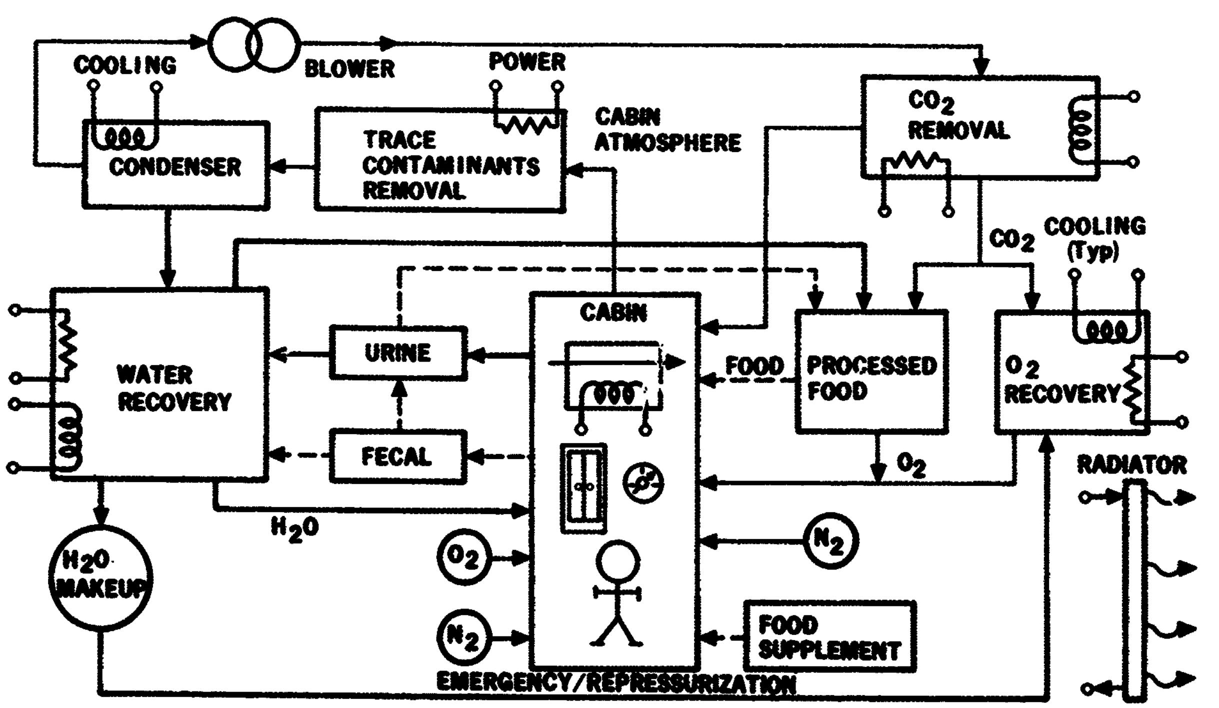

Figure 3. Closed Life Support System

the interrelations between the various subsystems. Each of the sybsystems or components shown incorporated a number of functional methods representing the most promising life support processes. Figure 4 is a simplified schematic illustrating the alternate methods for the oxygen recovery subsystem shown in Figures 2 and 3.

A summary of the status of life support system research and development obtained in the data gathering phase of the study is presented in Table 1. Thirty-six major subsystems or components, for which scaling laws were developed, are indicated in the table. However, since some of the individual processes shown, such as Bosch and vapor pyrolysis, included more than one functional method, scaling laws were actually developed for a total of 44 life support subsystems and/or components.

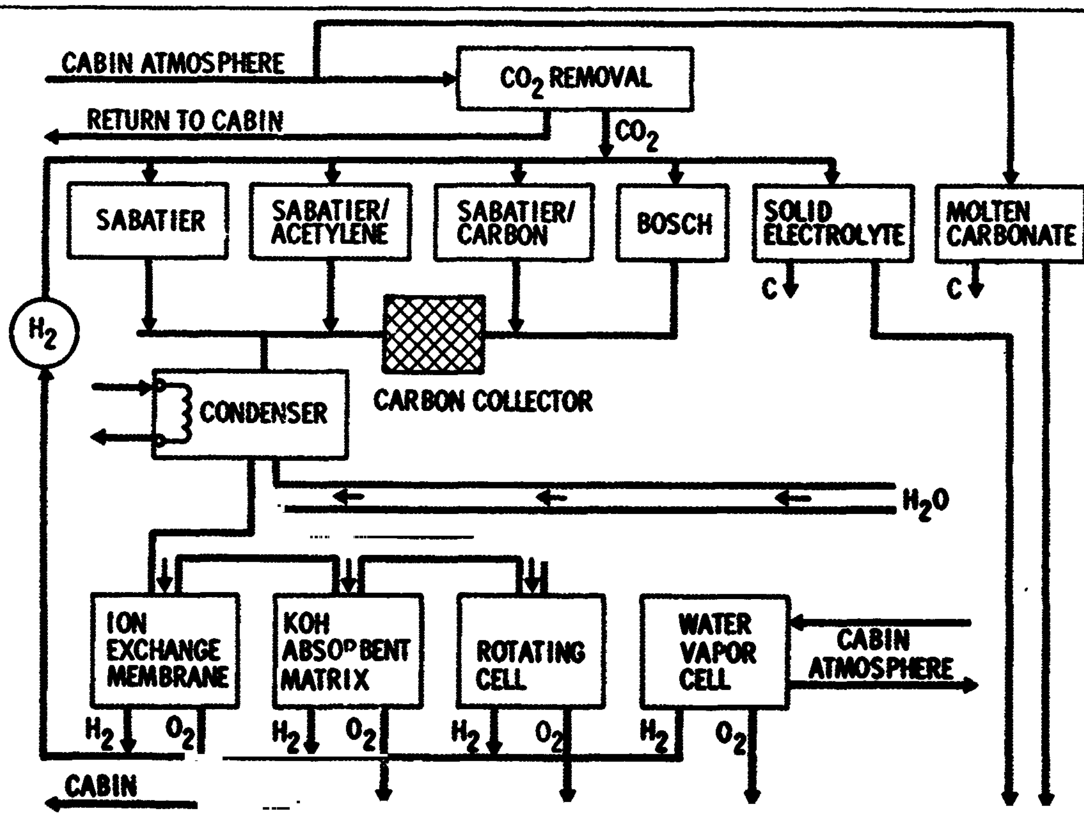

Figure 4. Alternate Oxygen Recovery Methods

Table 1
LIFE SUPPORT SUBSYSTEM STATUS

SUBSYSTEM	STATUS* 1	2	3	4	5
ATMOSPHERE SUPPLY AND CONTROL					
Subcritical Storage and Supply	▨	▨			
Supercritical Storage and Supply	▨	▨	▨	▨	▨
Gaseous Storage and Supply	▨	▨	▨	▨	▨
OXYGEN RECOVERY					
Sabatier with Methane Vent	▨	▨	▨	▨	
Sabatier with Acetylene Vent	▨				
Sabatier with All Hydrogen Recovered	▨				
Bosch	▨	▨	▨		
Solid Electrolyte	▨				
Molten Carbonate	▨				
WATER ELECTROLYSIS					
Double Membrane Electrolysis	▨	▨	▨		
Water Vapor Cell	▨	▨			
KOH Asbestos Matrix	▨	▨	▨		
Rotating Hydrogen Diffusion Cell	▨	▨			
CARBON DIOXIDE COLLECTION					
LiOH Expendable	▨	▨	▨	▨	▨
Regenerative Molecular Sieve with Vacuum Desorption	▨	▨	▨	▨	
Regenerative Molecular Seive with O_2 Recovery	▨	▨	▨	▨	
Carbonation Cell	▨	▨			
Solid Amine	▨	▨			
Electrodialysis	▨				
WATER MANAGEMENT					
Open and Closed Loop Air Evaporation System	▨	▨	▨	▨	
Vapor Pyrolysis System	▨	▨			
Vapor Compression Unit	▨	▨			
Electrodialysis	▨	▨			
Multifiltration	▨	▨	▨		
TRACE CONTAMINANT MONITORING AND CONTROL					
Toxin Burner	▨	▨	▨	▨	
Charcoal Adsorption, Particulate Filters and Chemisorbent Beds	▨	▨	▨	▨	
BIOLOGICAL MONITORING AND CONTROL					
Silver Ion Generator	▨	▨	▨		
THERMAL AND HUMIDITY CONTROL					
Space Radiators and Heat Transport Fluid	▨	▨	▨	▨	▨
Water Boiler	▨	▨	▨	▨	▨
Condenser with Liquid Gas Separation by Hydrophobic/Hydrophilic	▨	▨	▨	▨	
Vapor Electrolysis	▨				
WASTE MANAGEMENT					
Vacuum/Thermal Dehydration System	▨	▨	▨	▨	
Gas Entrainment/Centrifugation for Urine Collection and Removal	▨	▨	▨		
FOOD MANAGEMENT					
Freeze-dried Food	▨	▨	▨	▨	▨
Glycerol	▨				
Hydrogenomonas	▨				

STATUS*
1. Basic Research and Development Stage
2. A Working Prototype Subsystem
3. Prototypes Have Been Integrated and Tested in a Manned Simulator
4. Prototypes Have Been Integrated and Tested Successfully in a Manned Simulator
5. Flight Tested on Mecury, Gemini and/or Apollo

COMPUTER CODE NETWORK

The computer program has been designed to size life support systems for manned spacecraft for 2 to 20 men for broad ranges of ecological closure, space missions, resupply periods, and vehicle sizes. A simplified logic diagram of the complete computer program is shown in Figure 5, and this indicates the relationship between the subroutines for the vehicle and the various life support subsystems. The vehicle subroutine is used in the computation of such mission and vehicle criteria as particulate radiations, meteorite fluxes, thermal losses through cabin walls, wall insulation and shielding against radiations and meteorites, and vehicle shape and arrangements.

Each of the subsystems has been assigned its individual functional responsibilities complete enough to cover the various types of equipment and ecological closure from open to closed. Three to eight alternate types of equipment, as previously mentioned, comprise each of the individual

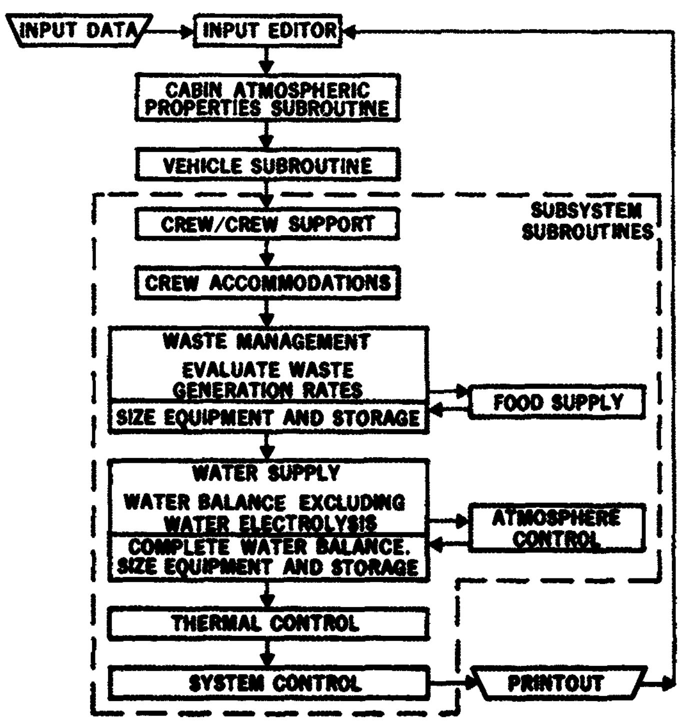

Figure 5. Simplified Computer Program Logic Diagram

subystems. The order in which the supply quantities and waste flows are involved in each subsystem was used to direct the order which the computational logic must follow in determining the quantities for the whole system. This logic was developed to permit the determination by a procedure which maximizes the availability of required information at each step, and minimizes the iterative processes required to achieve each step. Such a procedure was found through sensitivity analysis to greatly improve the efficiency of the computer program. Sensitivity analyses also showed that no iterations were required in the determination of the Crew Support, Crew Accommodations, Thermal Control and System Controls subsystem subroutines. The other four subsystems of Food Supply, Water Supply, Atmosphere Control, and Waste Management were highly interdependent but careful preparation of the subsystem logic obviated the necessity of extensive iterations between the subroutines for these subsystems. The specified number of crewmen, crew physical size and activity level, and the crew distribution in compartments were found to be the primary determinants for the entire life support system, and were thus used to establish the equipment processing rates for carbon dioxide, urine, feces, and respired and perspired water. Of the four interdependent subsystems, the Waste Management subsystem must be evaluated first, for the biological wastes must be collected prior to any recovery processing, and depending upon the rate and degree of waste recovery the precedence then changes for the order in which the quantities are determined.

COMPUTER PROGRAM INPUT DATA

The three basic types of input data employed in the program are as follows:

- Mission Analysis Data
- Life Support System Tradeoff Data
- Table Data

The input parameters included in each type of these data are given in Table 2. Data are input on load sheets especially designed for this program.

Table 2

TYPICAL COMPUTER PROGRAM INPUT AND OUTPUT DATA

INPUT DATA	
Mission Analysis Data	mission, space environment, and vehicle data
Life Support System Tradeoff Data	selected functional methods and equipment characteristics
Table Data	parametric equipment data include weight, volume, power, heating, and cooling
OUTPUT DATA	
Life Support System Printout	gives total system weight, volume, expendables, electrical power, and accumulated wastes. Also, meteoroid and radiation shielding characteristics
Subsystem Printout	summarizes subsystem weights, volumes, expendables, accumulated wastes, spare parts, and emergency equipment. Also qualitative subsystem data, including availability, operating envelopes, use considerations and technology development benefits.
Engineering Printout	gives detailed equipment and component physical and performance characteristics

COMPUTER OUTPUT DATA

The data developed by the computer can be presented in three levels of detail depending upon the need and purposes of the analyst. Table 2 details these three levels. The three types of output data are as follows:

- Life Support System Printout
- Subsystem Printout
- Engineering Printout

The input mission parameters are also printed with the output data.

COMPUTER DATA CHANGE

One of the main features of the program is the ease with which design data included in the logic may be changed to reflect advances in the state-of-the-art or to include new functional methods. An example of data change may be illustrated as follows: "Table No. 61", in the computer tradeoff input data, contains scaling law data for a Bosch Reactor CO_2 Reducer. The data may be input in Table No. 61 in any one of 8 equation forms. In this example, Equation Form No. 2 is used, for this approximates most closely the characteristics of the Bosch reactor:

$$\text{Dependent Variable} = A_1 + A_2 \, \phi_1^{\,A_3}$$

where $A_1 = 13.6$, $A_2 = 97.7$, and $A_3 = 0.63$ are the three coefficients for the example, and are specified through input data. ϕ_1 is the independent variable and it indicates the mass flow of CO_2 processed by the reducer. The data represented may be readily changed by simply changing the values of the coefficients A_1, A_2, or A_3. Any of the other seven equation forms available also might have been used in lieu of Form No. 2, if the substitute scaling law differed algebraically from the original law.

LIFE SUPPORT SENSITIVITY ANALYSES AND RESULTS

SENSITIVITY ANALYSES

The types of sensitivity analyses conducted during the performance of this work included the following:

1. The effects of changing the degree of closure.
2. The effects of changing the functional groups or a functional method in a particular life support system.
3. The effects of multiple life support systems in the spacecraft cabin or in a number of cabins.
4. The effects of input parameters on computer program output data and consistency with expected results.
5. The effects of projected state-of-the-art technology.
6. The interrelationships and interdependencies of the life support system on other vehicle systems.
7. The effects of maintainability, spares, and logistic requirements.

The results of sensitivity analyses were used as a guide in the development of the computer program. The developed computer program also may be used to conduct sensitivity analyses for space missions with broad ranges of mission flight times, crew sizes, and mission objectives, and to examine, concurrently, the interactions of a large variety of supporting subsystems, and mission operations and phases. The computer program results presented below, which illustrate the application of sensitivity analysis techniques, may be used as a guide for future users of the computer program.

COMPUTER PROGRAM RESULTS

Sample cases of selected life support systems for a representative space vehicle for Earth orbital and Venus flyby missions were selected. Types of life support equipment, and their characteristics and operating conditions were specified for open, partially closed, and closed systems. Computer solutions for these sample problems were obtained and their detailed results presented in Volume III of this report. The results for the Earth orbital mission are summarized in this volume. The life support subsystems considered are similar to the partially closed life support system shown in Figure 2, with minor functional changes incorporated within several subsystems.

The subsystems of Crew and Crew Support, Crew Accommodations, Food Supply and System Controls were found to be sensitive to mission duration for the particular life-support systems considered. The effects of mission duration upon their summed total weight, volume and power are shown in Figure 6. On the other hand, the Atmosphere Control, Thermal Control, Water Supply, and Waste Management Subsystems were found to be sensitive to the degree of ecological closure. In the latter group, the differences in weight, volume and power shown in Figure 7 are reflected largely in the Thermal Control System, which must handle progressively more rejected heat with each increased degree of closure.

In Figures 6 and 7, considerations have been given only to the equipment involved in the various life support systems considered. Another consideration, which in weight and volume often overshadows that for the equipment, concerns the expendable supplies. These are the materials to be supplied

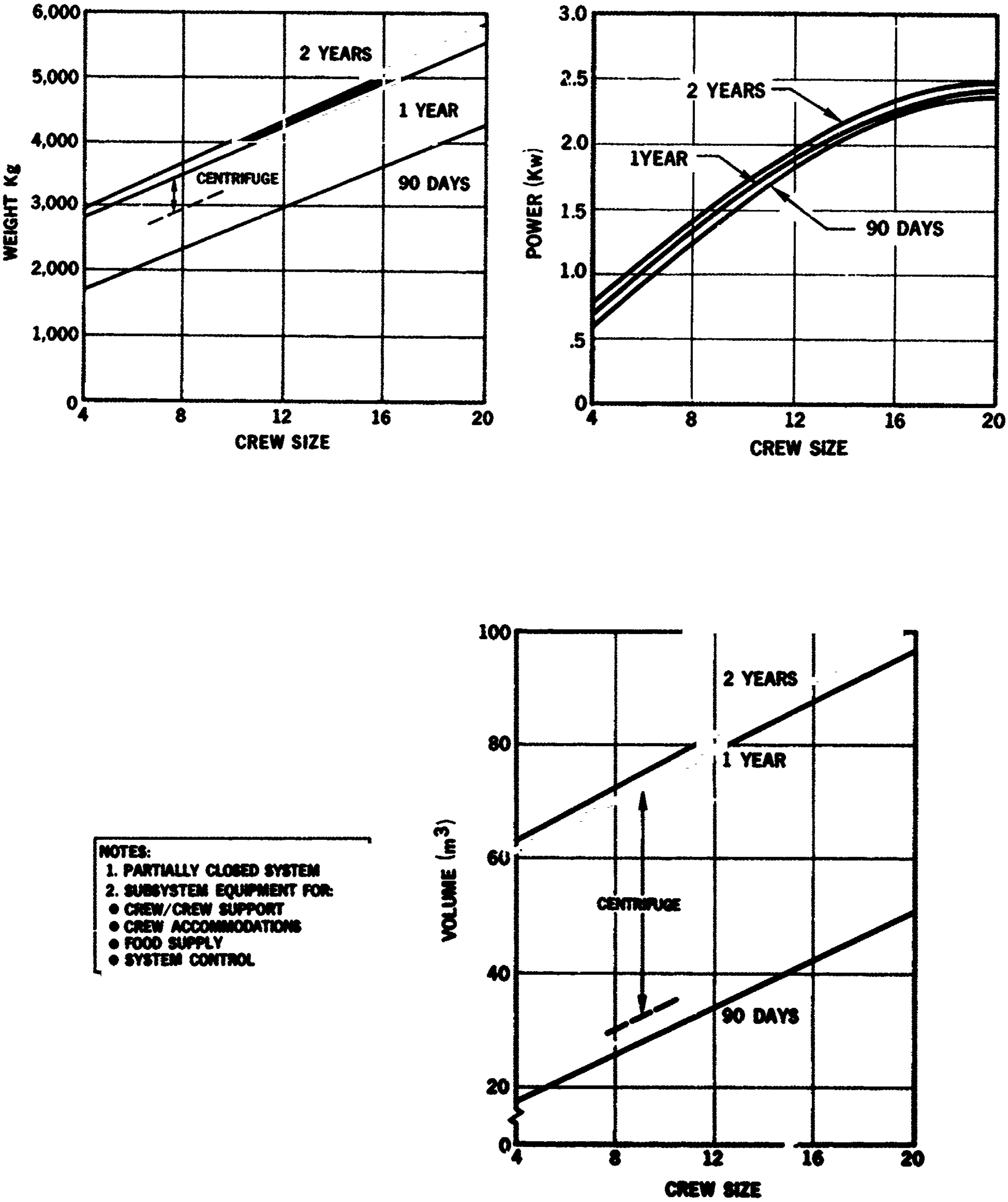

Figure 6. Mission-Dependent Equipment Characteristics

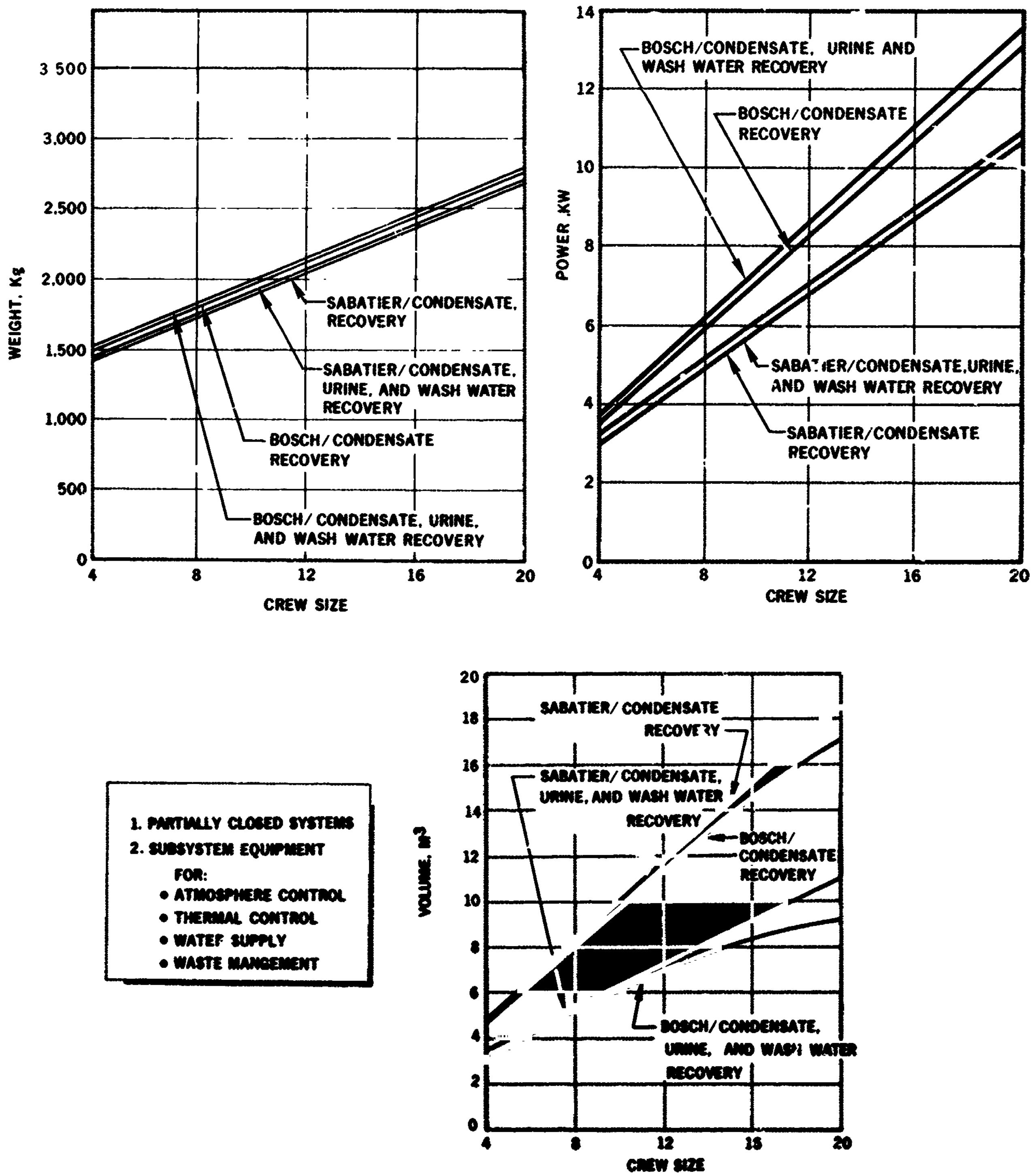

Figure 7. Closure-Dependent Equipment Characteristics

for human utilization and the human wastes which must be collected and stored or dumped to space. Figure 8 gives one man's daily expendable requirements and the accumulated wastes for several different life support systems. The closed system is not completely closed ecologically for there is some water lost in the required processes, and there is a small amount of food supplement necessary.

The computer program develops the weight of spare parts allocated to each of the subsystems to enable repairs to be made and to assure a given reliability for the total system. For the type of systems shown in Figures 6 and 7, increasing a 1-year mission reliability from 0.9 to 0.999 was found to represent a 3-1/2 times increase in spare parts weight, or a change from 5 to 17% for the spares weight allowance in terms of the total life support equipment weight.

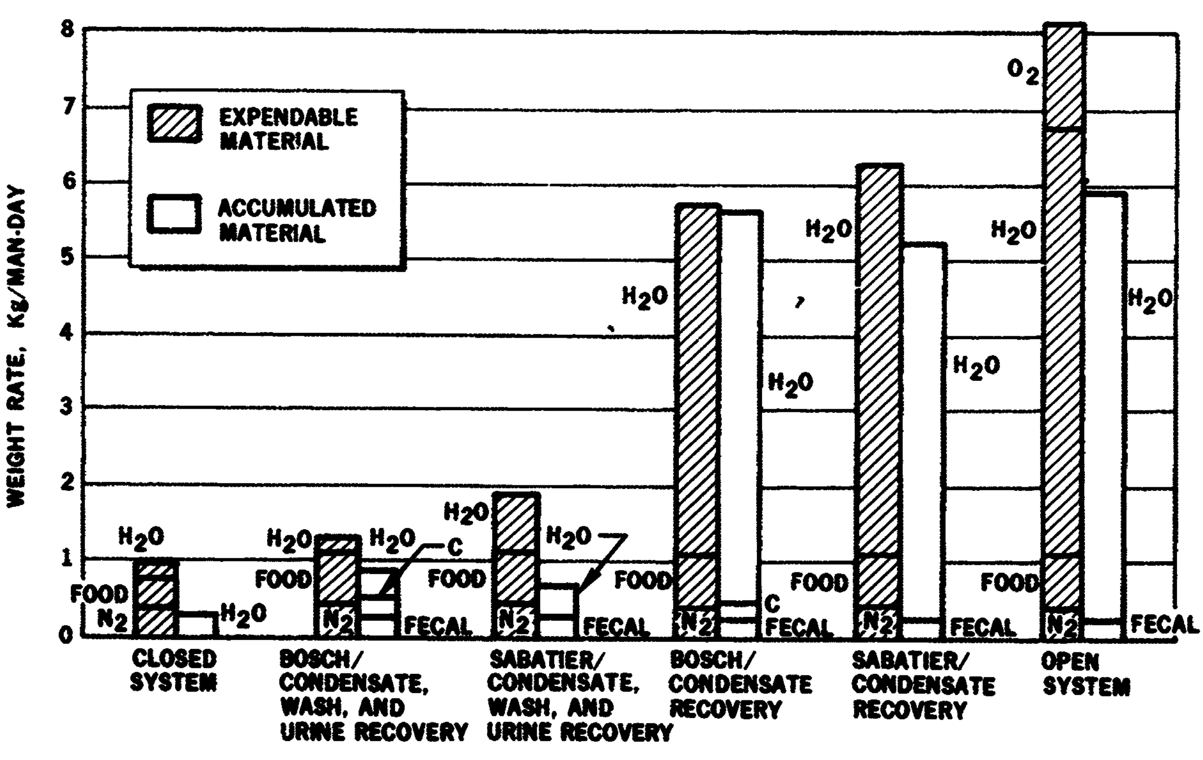

Figure 8. Expendable and Accumulated Materials Rates

CONCLUSIONS

New analytical tools and a computer program have been developed for conducting life support system tradeoffs from a mission analysis standpoint. The scaling laws and characteristics developed for each of many life support system functional methods were confirmed with equipment data obtained from the latest literature and through a vendor survey. The computer program developed can be used to describe and characterize a variety of life support systems. These systems can be identified with respect to such mission analysis variables as mission flight path, mission duration, and crew size, and they can be characterized with respect to life support system variables such as ecological closure and selected types of equipment for performing particular functions. Emergency and spares provisions are determined. Vehicle interactions such as those involving meteoroid and radiation shieldings, electrical power systems, and equipment heat sources can also be computed. The results are given in sufficient depth to provide the spacecraft designer with all the necessary data for sizing and locating the life support system within the vehicle. Provided also are data which define the interfaces of the life support subsystems with interrelated vehicle systems.