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MANNED MARS MISSION ENVIRONMENTAL CONTROL & LIFE SUPPORT SUBSYSTEM PRELIMINARY REPORT

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ABSTRACT

The purpose of this paper is not to present a specific design but to discuss the general philosophy regarding potential ECLSS requirements, concepts, issues and technology needs. The focus is on a manned Mars mission occurring in the late 1990's. Discussions on the Trans-Mars Vehicle, the MEM, and a Martian base facility are covered. The paper lists the functions, performance requirements, and design loads of a typical ECLSS, and briefly discusses issues and technology. It identifies several ECLSS concepts and options, and provides comparative weights and volumes for these. It contrasts several aspects of the Space Station ECLSS with Mars element ECLSSs.

INTRODUCTION

A proposed manned Mars mission to be flown around the turn of the century presents some unique requirements for the Environmental Control & Life Support Subsystem (ECLSS). The mission will require not only extremely long life verified equipment, but also several types of systems. The vehicle transporting the men to Mars will most likely utilize a different type ECLSS design from that required by the Mars Excursion Module (MEM) and that to be utilized by facilities on the Mars surface.

The mission to Mars from low-Earth-orbit (LEO) may take up to one year each way. Additionally, stay times on Mars may be from several days to months. The overall mission times from LEO to Mars and return could be on the order of three years. Since resupply will not be possible and weight/volume will be at a premium, redundancy, spares, and expendables will have to be minimized. Therefore, the equipment will have to be highly reliable for operating times in excess of three years. These types of requirements will dictate additional design/development efforts on the Space Station (S/S) ECLSS hardware in order to make it applicable to the Mars mission. The MEM will probably be used primarily for short durations and the ECLSS systems could range anywhere from open to closed loop. A permanent Mars base facility would most likely have ECLSS equipment different from that being utilized by the S/S due to the gravity environment (1/3 that on Earth) and the availability of consumables (oxygen, nitrogen, and water) in the Martian atmosphere. Additionally, the possibility of growing food in greenhouses on the Martian surface would have an effect on the total system architecture. The ECLSS design for a manned Mars mission will also be very dependent on factors other than those mentioned above. Factors such as crew size, propellants utilized, type of power system, vehicle architecture, extra-vehicular activity (EVA) requirements, safe haven philosophy, and artificial gravity requirements will also heavily influence the ECLSS design.

REQUIREMENTS

The primary system functions performed by the ECLSS are habitat temperature and humidity control, atmospheric pressure and composition control, water processing and management, waste management, and EVA support. The primary functions and major equipment associated with each is shown in Table 1.

The mission success, health, and safety of the crew will require as a minimum a fail operational/fail safe design criteria for the ECLSS hardware. The data presented in Table 2 provides a summary of currently utilized design criteria for the ECLSS equipment. The degraded level signifies a "fail operational" condition. The average design loads imposed by the crew are specified in Table 3. These loads will size the ECLSS hardware for all mission phases.

CONCEPTS

The ECLSS concepts for the Trans-Mars Vehicle will be strongly influenced by the designs chosen for the S/S. As mentioned earlier, additional requirements to that imposed by the S/S will be imposed on the equipment. The primary difference will be that of equipment lifetime, redundancy, and reliability. The potential options possible for consumables regeneration and carbon dioxide / carbon monoxide control are shown in Figure 1. The issue of resupply, which is an acceptable design approach for S/S but not for the Trans-Mars Vehicle, will drive the design to systems that are further closed than that required by S/S.

TABLE 1. EC/LSS SYSTEM FUNCTIONS

ECLSS FUNCTION	MAJOR EQUIPMENT
• ATMOSPHERE PRESSURE & COMPOSITION CONTROL – TOTAL & PARTIAL PRESSURE CONTROL & MONITORING – FIRE DETECTION & SUPPRESSION	PRESSURE REGULATION PORTABLE OXYGEN SYSTEM SMOKE/FIRE DETECTORS FIRE SUPPRESSION SYSTEM
• MODULE TEMPERATURE & HUMIDITY CONTROL	DEHUMIDIFICATION VENTILATION FANS AIR COOLING HEAT EXCHANGERS
• ATMOSPHERE REVITALIZATION – CO_2 CONTROL/REMOVAL/REDUCTION – O_2 & N_2 MAKEUP – TRACE GAS MONITORING & CONTROL	CARBON DIOXIDE REMOVAL AND COLLECTION CARBON DIOXIDE REDUCTION CONTAMINATION CONTROL ODOR CONTROL ATMOSPHERE MONITORING OXYGEN GENERATION EMERGENCY OXYGEN AND NITROGEN STORAGE
• WATER MANAGEMENT – WASTE WATER COLLECTION/PROCESSING – WATER QUALITY MONITORING – STORATE & DISTRIBUTION OF RECOVERED WATER	EVAPORATION PURIFICATION WATER QUALITY MONITORING WATER STORAGE
• WASTE MANAGEMENT – COLLECT/PROCESS URINE – COLLECT/STORE FECAL MATTER	WASTE COLLECTION AND STORAGE EMERGENCY WASTE COLLECTION HOT/COLD WATER SUPPLY
• EVA SUPPORT – PROVIDE EXPENDABLES/SUPPORT TO EMU & MMU – PROVIDE LIFE SUPPORT SERVICES TO AIRLOCK/HYPERBARIC FACILITY	SUITS AND BACKPACKS RECHARGE STATIONS AIR LOCK SUPPORT

TABLE 2. EC/LSS PERFORMANCE REQUIREMENTS

PARAMETER	UNITS	OPERATIONAL	DEGRADED (1)
CO_2 PARTIAL PRESS	MMHG	3.0 MAX	7.6 MAX
TEMPERATURE	DEG F	65–75	60–85
DEW POINT (2)	DEG F	40–60	35–70
POTABLE WATER	LB/MAN–DAY	6.8–8.1	6.8 (3)
HYGIENE WATER	LB/MAN–DAY	12 (3)	6 (3)
WASH WATER	LB/MAN–DAY	28 (3)	14 (3)
VENTILATION	FT/MIN	15–40	10–100
O_2 PARTIAL PRESSURE (4)	PSIA	2.7–3.2	2.4–3.8
TOTAL PRESSURE (5)	PSIA	10.2 OR 14.7	10.2 OR 14.7
DILUTE GAS	––––	N_2	N_2
TRACE CONTAMINANTS (8)	MG/M^3	TBD	TBD
MICRO–ORGANISMS	CFU/M^3 (6)	500 (7)	750 (7)

NOTES:

(1) DEGRADED LEVELS MEET "FAIL OPERATIONAL" CRITERIA.
(2) RELATIVE HUMIDITY SHALL BE WITHIN THE RANGE OF 25–75 PERCENT.
(3) MINIMUM.
(4) IN NO CASE SHALL THE O_2 PARTIAL PRESSURE BE BELOW 2.3 PSIA, OR THE O_2 CONCENTRATION EXCEED 25.9 PERCENT OF THE TOTAL PRESSURE AT 14.7 PSIA OR 30 PERCENT OF THE TOTAL PRESSURE AT 10.2.
(5) ALL SYSTEMS SHALL BE COMPATIBLE WITH BOTH 10.2 AND 14.7 PSIA TOTAL PRESSURE.
(6) CFU – COLONY FORMING UNITS.
(7) THESE VALUES REFLECT A LIMITED BASE. NO WIDELY SANCTIONED STANDARDS ARE AVAILABLE.
(8) BASED ON NHB 8060.1B, (J8400003).

TABLE 3. EC/LSS AVERAGE DESIGN LOADS

– METABOLIC O_2	1.84 LB/MAN DAY
– LEAKAGE AIR	5.00 LB/DAY TOTAL
– EVA O_2	1.22 LB/8 HR EVA
– EVA CO_2	1.48 LB/8 HR EVA
– METABOLIC CO_2	2.20 LB/MAN DAY
– DRINK H_2O	4.09 LB/MAN DAY
– FOOD PREPARATION H_2O	1.58 LB/MAN DAY
– METABOLIC H_2O PRODUCTION	0.76 LB/MAN DAY
– CLOTHS WASH H_2O	27.50 LB/MAN DAY
– HAND WASH H_2O	4.00 LB/MAN DAY
– SHOWER H_2O	8.00 LB/MAN DAY
– EVA H_2O	9.68 LB/8 HR EVA
– PERSPIRATION AND RESPIRATION H_2O	4.02 LB/MAN DAY
– URINAL FLUSH H_2O	1.09 LB/MAN DAY
– URINE H_2O	3.31 LB/MAN DAY
– FOOD SOLIDS	1.60 LB/MAN DAY
– FOOD H_2O	1.00 LB/MAN DAY
– FOOD PACKAGING	1.00 LB/MAN DAY
– URINE SOLIDS	0.13 LB/MAN DAY
– FECAL SOLIDS	0.07 LB/MAN DAY
– SWEAT SOLIDS	0.04 LB/MAN DAY
– EVA WASTEWATER	2.00 LB/8 HR EVA
– CHARCOAL REQUIRED	0.13 LB/MAN DAY
– METABOLIC SENSIBLE HEAT	7000 BTU/MAN DAY
– HYGIENE LATENT H_2O	0.96 LB/MAN DAY
– FOOD PREPARATION LATENT H_2O	0.06 LB/MAN DAY
– LAUNDRY LATENT H_2O	0.13 LB/MAN DAY
– WASH H_2O SOLIDS	0.44%
– SHOWER/HAND WASH H_2O SOLIDS	0.12%
– AIR LOCK GAS LOSS	1.33 LBS/USE
– TRASH	1.80 LB/MAN DAY
– TRASH VOLUME	0.10 FT^3/MAN DAY

TABLE 4. EC/LSS TECHNOLOGY REQUIREMENTS

- FECAL WASTE MANAGEMENT
- TRASH/FOOD MANAGEMENT
- SENSOR DEVELOPMENT
  - MASS GAUGING
  - TRACE GAS
  - AIR/WATER QUALITY
- WATER RECLAMATION/PROCESSING SYSTEMS
- REGENERATIVE CO_2 REMOVAL/REDUCTION SYSTEM
- MARS ATMOSPHERE PROCESSING SYSTEM FOR OXYGEN, NITROGEN & WATER

Figures 2 and 3 provide weight and volume penalties for consumables requirements as a function of system closure.

The MEM ECLSS could consist of either an open or closed loop system, depending on the design approach that will be implemented. If the MEM will be used as either a working volume or safe haven during trans-Mars travel, the MEM ECLSS would probably be a closed system similar to the Trans-Mars Vehicle system. Additionally, if contamination of the Mars atmosphere by overboard venting is not permitted, a closed system will be required. If, however, it is decided that the MEM is to be used only for short durations (less than approximately ten days), the ECLSS could be envisioned as an open system. An open system has the advantage of design simplicity and low cost. Figure 4 shows the weight trend of open versus closed systems.

The Mars base facility is envisioned to be a self-contained ecological system utilizing the Martian atmosphere as a source of consumables. The primary consumables available from the atmosphere are oxygen, nitrogen and water. Oxygen is obtainable through the reduction of carbon dioxide which constitutes approximately 95% of the Martian atmosphere. Nitrogen, 2.5% of the atmosphere, can be directly extracted from the atmosphere. Water is found in very small quantities in the atmosphere (approximately 0.03%). However, additional sources are potentially available in the Martian permafrost and polar caps. The supply of food is envisioned to be brought from Earth in the early stages of a Mars base facility. Future development could lead to a greenhouse-type facility that would permit growth of the food supply. The greenhouse could also be a potential source of oxygen for the habitat.

ISSUES

The major issues pertaining to the ECLSS are associated with the degree of closure of the subsystems and the reliable operation of the hardware for many years. Due to the length of the mission and the weight sensitivity of a Mars vehicle, the amount of consumables will have to be minimized. Also, the weight and volume allocation for spares and/or redundant systems will have to be critically evaluated to assure a viable vehicle design. The whole issue of how much redundancy one builds into the basic design versus onboard spares and repair philosophy needs addressing in future studies.

FIGURE 1. EC/LSS SYSTEM OPTIONS

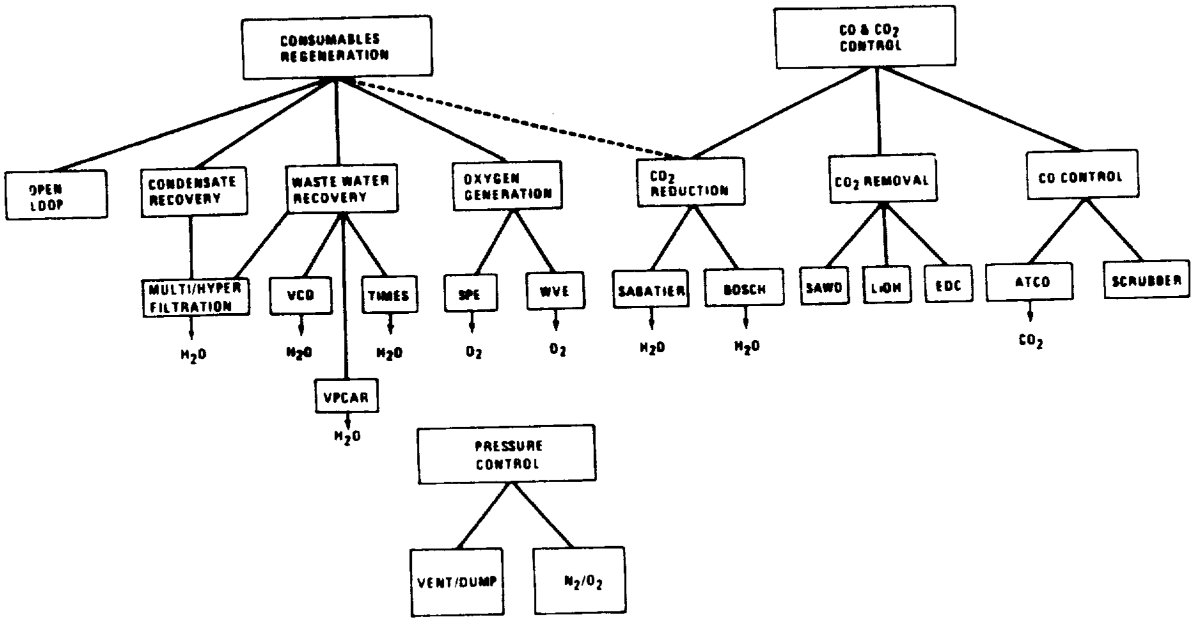


FIGURE 2. WEIGHT VS. EC/LSS SYSTEM CLOSURE OPTION

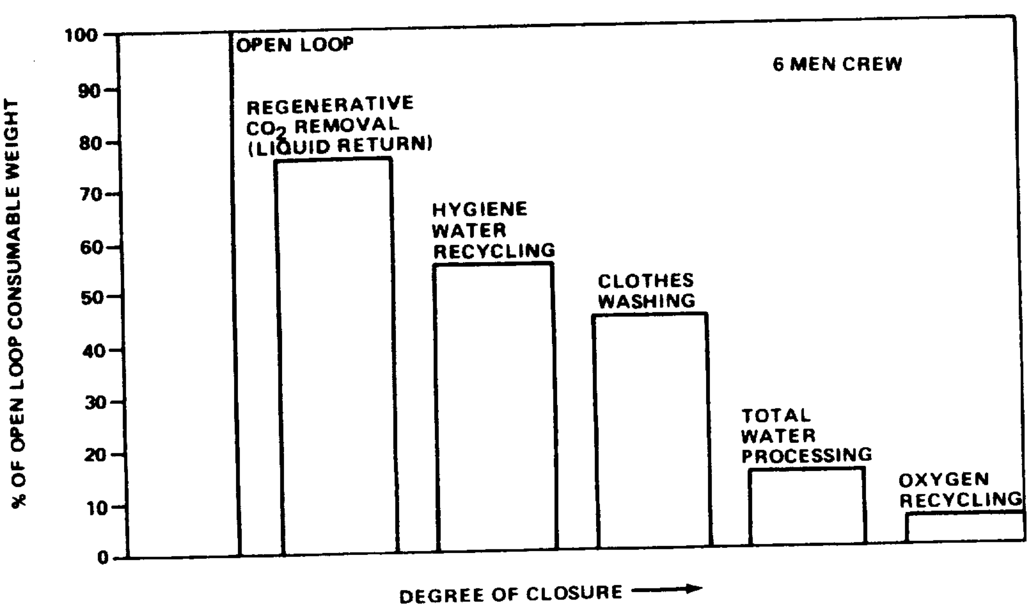


FIGURE 3. VOLUME VS. EC/LSS SYSTEM CLOSURE OPTION

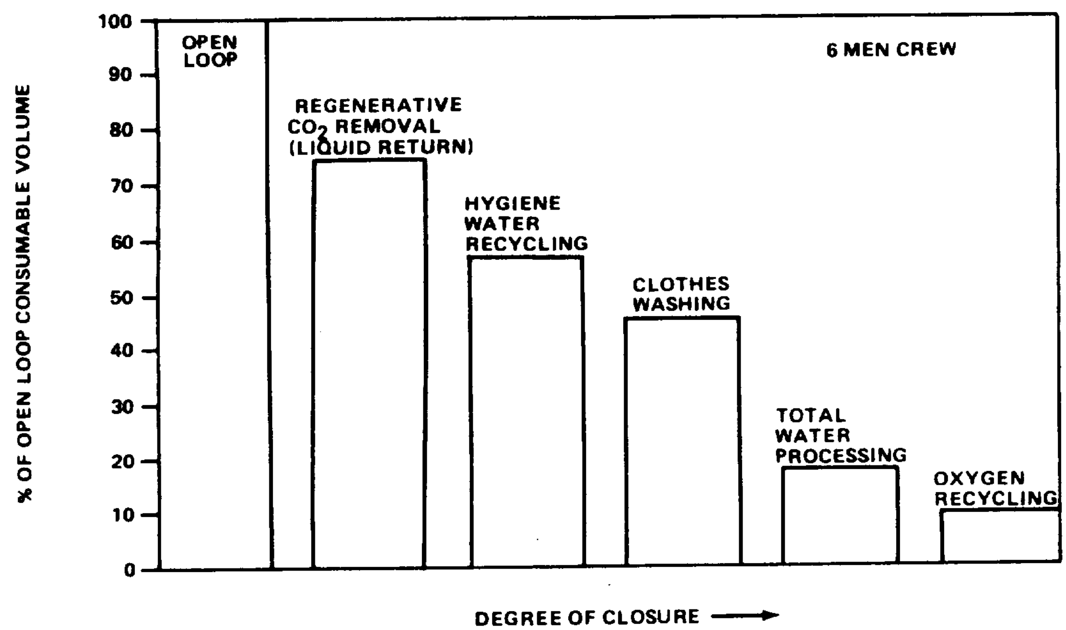
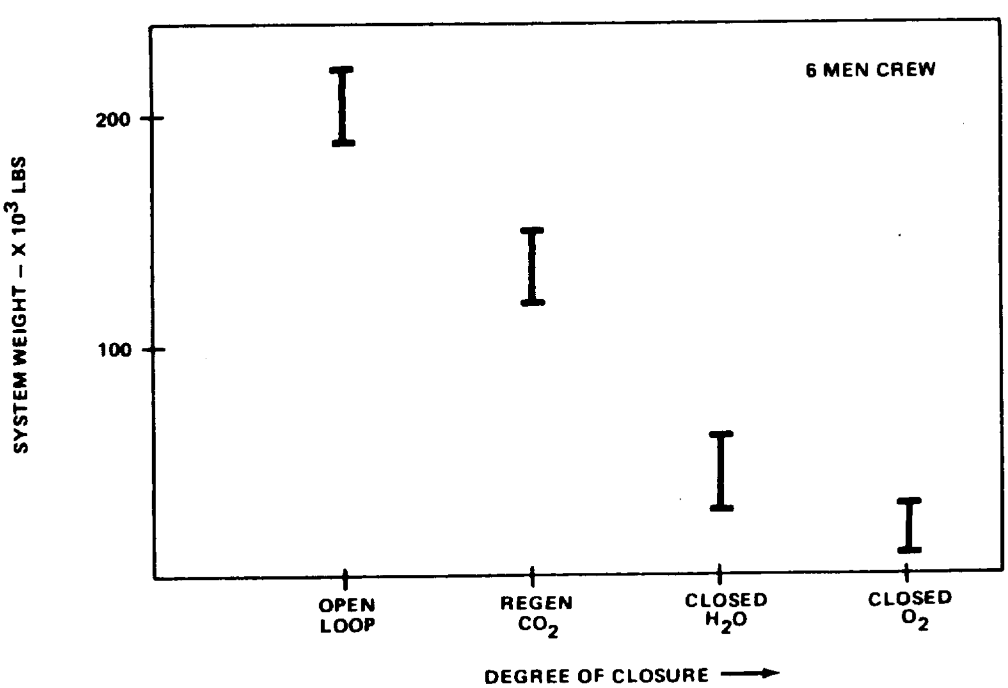


FIGURE 4. TOTAL WEIGHT VS EC/LSS SYSTEM CLOSURE



The issue of system closure for the ECLSS will become a major design driver for the overall vehicle. The Trans-Mars Vehicle will be more heavily affected than Mars surface equipment since some of the consumables will be available on the Martian surface. Ideally, it would be desirable to close the system as much as possible. However, system inefficiences, structural leakage of gases, consumed gases/liquids, and emergency supply of consumables will always dictate that a storage facility for consumables be required. The actual size of such a facility will require further study. Other factors influencing the design will be the EVA requirements and the design of non-venting/closed EVA systems. The largest part, both by weight and volume, of such a facility will be driven by the water requirements.

One of the key parameters concerning the redundancy issue is the crew safe haven philosophy. Also, the overall architecture of the vehicle will have direct bearing on the type of ECLSS subsystems that will eventually be implemented. For example, the use of several separate modules to form the habitat area would in essence allow nonredundant loops in each module with repair capability of the failed loop. The crew would temporarily be restricted to the active module(s) while repair was being performed. The use of a singular module, although structurally more weight efficient, will place very stringent safety requirements on the design. The resultant repair/maintenance philosophy would be different from that of a multiple module design.

One other issue that will effect the design of the ECLSS is the potential requirement of artificial "g" during the flight from LEO to Mars and return. The level of gravity proposed will dictate the type of system design that may be implemented. If the gravity is comparable to that expected on the Martian surface (1/3 that on Earth), the system used might be similar to that which will be used on the Martian surface. The primary effect a higher gravity environment has on the ECLSS is in the area of fluid acquisition/feed systems and vapor/liquid separation devices.

TECHNOLOGY

The major areas of technology in the ECLSS that will have to be advanced for a manned Mars mission are: regenerative systems, consumable storage/generation, and waste/trash management. Table 4 provides a list of some of the key ECLSS technology items that will need to be addressed prior to commitment of a design for a manned Mars mission. Some of the issues will be worked by the Space Station technology program. However, the aspects of operational life requirements of approximately three years without resupply/refurbishment will place additional requirements on the applicable Space Station hardware. Also, the potential of artificial "g" during transit flight to Mars and the gravity on the Martian surface will provide the opportunity to use systems that take advantage of the gravitational force. The areas that will require major emphasis are waste management and systems for extracting the consumables from the Martian atmosphere.

SUMMARY

The major issues that need further emphasis are the degree of closure that can be effected by the ECLSS and the operational reliability of the hardware. The minimization of redundancy and spares will be an important factor due to the vehicle weight sensitivity for a Mars mission.

A manned Mars mission will be a very challenging undertaking for the design/development of the ECLSS. Current and advanced technology will be required to meet the mission objectives. A lot of the development work being conducted and planned by S/S will be directly applicable to this mission. The Trans-Mars Vehicle's ECLSS design could be very similar in design to that of the S/S. The MEM and Mars base facility ECLSS designs remain as open issues because of the many undefined variables mentioned earlier.