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BACKGROUND

The primary goal of the Apollo Program is to place a manned vehicle on the surface of the moon, from which astronauts may egress, examine the lunar structure in detail, and return safely to the earth.

As a part of this effort, the NASA Manned Spacecraft Center has awarded a prime contract for the design and development of a space suit assembly which will satisfy these Apollo mission objectives. The primary function of the space suit assembly, of course, will be to provide a habitable environment for the extravehicular explorer while he is exposed to the extreme environments of free space and the lunar surface. Basically, the assembly (fig. 1) will consist of an anthropomorphic pressure garment including helmet, gloves, boots, a back-mounted portable life support system, which also contains the communication-telemetry package, an emergency oxygen system, and a thermal protective garment which will isolate the entire assembly from the external environmental extremes anticipated. The pressure garment, helmet, gloves, and boots also serve as back-up to the cabin pressurization system as did the Project Mercury suit.

MISSION DESIGN REQUIREMENTS

Although this report will deal primarily with the design and development of the portable life support system (PLSS), it is appropriate to review briefly the Apollo flight plan to appreciate fully the magnitude of the functional and interface requirements involved in the development of the PLSS.

The lunar spacecraft will be composed of three modules (fig. 2): a command module, which will be the home for the three astronauts for the majority of their journey; a service module, which, as the name implies, will service the command module with expendables, primary power, and thrust for course correction and return to earth; and a lunar excursion module, which will place the crew on the lunar surface.

One PLSS will be stowed in the command module and two units will be stowed in the lunar excursion module. The command module unit will be available for emergency free space maintenance and as back-up to several vehicle reentry and post landing systems. Shortly after a translunar orbit has been achieved, the modules will be maneuvered so that the lunar excursion module will mate with the apex of the command module. As the moon is approached, breaking rockets in the service module will place the entire vehicle into a lunar orbit. Two of the three astronauts will then enter the lunar excursion module for descent to the surface of the moon.

During the entire time in the lunar excursion module, both crewmen will wear their pressure garments. Shortly after landing, however, one crewman will don an extravehicular assembly, including the PLSS, thermal garment, lunar boots, and gloves, et cetera. After thorough checkout of the entire assembly, the spacecraft will be depressurized and the astronaut will egress to the lunar surface. There is a requirement for self-donning of the PLSS to allow the crew mate in the vehicle to effect a rescue of the lunar explorer, if necessary. This is the so-called "buddy system." The PLSS is designed to operate for 4 hours; however, the nominal mission will be 3 hours with 1 hour reserved for emergencies. Multiple excursions by each crewman will be possible by recharging the PLSS expendables from available spacecraft stores.

PLSS SELECTION

The size of the PLSS is to a large extent dictated by the length of mission and rate at which expendables are consumed. In the case of the Apollo PLSS, the choice of expendables is limited to those available aboard the spacecraft and the mission length is specifically defined as 4 hours in the flight plan. The difficulty in sizing the PLSS becomes apparent when an attempt is made to determine the rate at which the expendables will be consumed.

First of all, it is difficult to define exactly what tasks will be required during the 4-hour period on the moon. The scientific community has suggested several experiments which will undoubetdly be incorporated in the lunar missions; however, none of the proposed experiments are available in the detail necessary to establish the task analysis from a metabolic standpoint.

The encumbrance of the space suit assembly and resultant metabolic penalty in accomplishing the tasks can at this time only be estimated based upon data from existing state-of-the-art assemblies. Undoubtedly, the final space suit mobility will be significantly improved; however, the difference in metabolic costs is difficult to extrapolate. Finally, the effect of a one-sixth gravitational environment on metabolic rate is not known and appears extremely difficult to simulate on earth. Many authorities disagree as to whether the one-sixth gravity environment will aid or impede the astronaut (ref. 1).

The 4-hour mission profile selected to size the first Apollo prototype PLSS is based upon four levels of effort. The resting level is taken as 400 Btu's per hour metabolic heat. Light work is defined as 600 Btu's per hour, moderate work is 1200 Btu's per hour, and heavy work as 1600 Btu's per hour. By applying these metabolic expenditures to a typical mission plan (fig. 3), it is possible to select a reasonable average integrated metabolic rate. In this case, the average integrated load selected as a design point is 930 Btu's per hour. The question may well be asked, "What assurance does one have that the astronaut will not exceed these metabolic rates?" The answer is that he probably will at times; however, these higher loads should be short enough to be accommodated by temporary body storage. The astronaut may well have to stop and rest now and then as one would on a 4-hour hike here on earth.

DESIGN CONCEPT

The PLSS concept chosen for this application is basically similar to the Project Mercury Environmental Control System (fig. 4). It is, however, a more sophisticated package because of the many more functions it performs. The PLSS is a closed-loop gaseous-ventilation system, which relies upon a fan-motor to circulate oxygen through the space suit at 17 actual cubic feet per minute. A gaseous oxygen system maintains suit pressure at 3.7 ± 0.2 psia, and carbon dioxide levels are controlled to under 7.6 millimeters of mercury with a chemical absorbent. Heat is rejected by the vaporization of water from a liquid to a gas boiler.

The PLSS liquid-to-gas water boiler rejects heat from three sources: astronaut metabolism, internal systems heat loads, and net heat "leaks" into the space suit through the thermal garment from external sources. Of course, net heat "leaks" out of the assembly will also occur at various times in the mission. However, these outboard "leaks" will also be small and will only serve to improve the internal thermal situation.

The water boiler is sized to accommodate a total average integrated load of 1,570 Btu's per hour, of which 930 Btu's per hour are metabolic. The remaining load, 640 Btu's per hour, is alloted for external leakage and system-generated heat loads. For short periods of up to 10 minutes, the boiler will also accommodate peak metabolic loads of up to 1,600 Btu's per hour.

The majority of the metabolic load is collected in the boiler as latent heat by condensing vaporized perspiration. The average integrated perspiration rate is approximately 0.9 lb per hour.

Thermal control is accomplished by a thermally activated back-pressure poppet valve which senses boiler core temperature and adjusts the poppet setting to provide a constant suit inlet temperature of close to 45° F.

This type of control serves two major purposes in this case. It reduces the requirement for a manual valve and also reduces the chances for over or under compensation, which could result in freezing of the boiler and thereby a loss of capacity.

Moisture collected by the ventilation gas stream at a nominal rate of 0.9 to 1.0 lbs per hour will be condensed on the gas side of the boiler and trapped in a wick-type water separator at the boiler outlet. This water will then be recycled to the boiler water reservoir. Obviously the size of the boiler water reservoir can be significantly reduced by the recycling of roughly 4.0 lbs of water.

The contaminant control canister, which contains approximately 2 lbs of lithium hydroxide and 2 ounces of activated charcoal, maintains acceptable carbon dioxide and odor levels. The canister design is somewhat like an automobile oil filter, in that flow is introduced to the center of a cylindrical cartridge and collected at the periphery. This design effects a substantial reduction in pressure drop characteristics over axial-flow canister designs. This reduction is caused primarily because the area of the absolute filter material is eight times that of plane circular axial filter, reducing pressure drop proportionally. The reduction in pressure drop, of course, reduces the fan power requirement, which in turn directly reduces the weight and volume of the battery, et cetera.

The quantity of lithium hydroxide, at first glance, appears to be oversized. The original Mercury canister contained only 4.6 lbs of lithium hydroxide for an operational life of 34.5 hours. It must be pointed out that the PLSS flow rate and ventilation velocity is nearly twice that of the Mercury ECS, which significantly lessens the utilization efficiency of the canister. In fact, at the end of 4 hours, only about 50 percent of the lithium hydroxide has been reacted. A typical mission profile of carbon dioxide partial pressure plotted against time is shown in figure 5. Obviously, the last 10-minute metabolic spike associated with reentry into the lunar excursion module dictates canister size.

The high pressure oxygen subsystem consists of a recharge fitting and and check valve, an absolute filter, the primary oxygen pressure vessel, and the primary regulator assembly (fig. 6). The primary oxygen tank is a cylindrical stainless steel vessel, operating at a nominal pressure of 900 psia. The tank contains approximately 0.76 lb of oxygen for metabolic consumption and a nominal assembly leakage of 200 standard cc/min. The primary regulator is a single-stage device incorporating a manual shutoff valve and a pressure schedule selector to reduce the overall package envelope. The pressure schedule selector allows the astronaut to change the suit pressure regulation manually from 3.7 psia to 5.0 psia, should the astronaut experience a case of dysbarism. Although decompression sickness is unlikely after several days of denitrogenation, it is considered a possibility at the first exposure to 3.7 psia and heavy exercise (ref. 2). This regulator is referenced to ambient pressure to allow pressurization of the space suit in the pressurized cabin during assembly leak check. A constant bleed orifice short circuiting the regulator is sized to provide oxygen for leakage and minimum metabolic consumption in event of a regulator failure.

The PLSS, as previously pointed out, utilizes a fan-motor as a prime mover. In this case, a compact brushless direct-current motor rotates a centrifugal fan at 33,000 rpm providing 12 inches of water pressure head. The astronaut will have a flow control capability by a throttle valve located in the suit inlet umbilical. It is most probable that this manual flow control will be used only during periods of minimum activity and maximum external heat leak when the astronaut feels chilled.

Biomedical and environmental sensors will permit the crewman to monitor his own status. Also, ground stations will monitor his status by telemetry. Self-monitoring will include visual display of suit pressure, oxygen quantity, elapsed time, and cumulative radiation dose. Audible devices will also warn the astronaut of high oxygen usage (indicative of a leak) and suit pressures under 3.1 psia.

Ground stations will, of course, be in constant two-way voice communications and will receive five channels of environmental information and two channels of biomedical data including body temperature and an electrocardiogram reading.

FIRST PLSS PROTOTYPE EVALUATION

The first prototype Apollo PLSS was delivered to NASA in late October 1963 (fig. 1). Since this time, the unit has undergone an extensive in-house evaluation test program. A test on this first unit has been centered primarily around an evaluation of the suit-man interface. Such areas as donning, mobility, comfort, and control accessibility have been thoroughly explored.

As anticipated, the most difficult problem areas are centered around visual limitations of the man in a pressurized suit and the fact that all the interface areas with the PLSS are on the back of the suit.

For example, it was found to be virtually impossible to don the PLSS unassisted, because once the astronaut has his back to the unit he can neither see nor feel the restraint harness to pull it over his shoulders. It appears that prearranging the harness out in front of the crewman by fastening the disconnect points to the vehicle will be a necessity. The same is true of the controls and displays, which must be accessible at all times. It is extremely difficult to locate the controls where they can be reached and/or seen, without cluttering up the front of the space suit and exposing them to inadvertent operation.

One particularly interesting observation resulting from this evaluation, is the fact that the suited man, pressurized to 3.5 psig could not feel the weight of the PLSS even in the 1g environment. It is apparent that the suit transmits the weight directly to the floor. The majority of subjects in these tests also stated that their ability to perform certain maneuvers such as deep knee bends, et cetera, seemed improved.

CONCLUSION

The weight of the first prototype portable life support system is approximately 50 pounds fully charged. It is not likely that this weight will be reduced significantly in later units. A system which would accomplish the primary lunar mission could probably be developed for under 40 pounds. However, requirements for common utilization of hardware and glove-tight interfacing with two individual modules cost pounds. And, although the decision for interchangeability, et cetera, is generally made in the interest of saving overall mission weight and volume, it also complicates design and performance of the unit. Care must be taken to prevent secondary functions from being carried to the point that they begin to compromise the reliability of the system and the capability to perform its primary function.

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2. Henry, F. M.: Aviators "Bends" Pain as Influenced by Altitude and Inflight Denitrogenation. WADC Technical Report 53-227, March 1953, p. 22.

PROTOTYPE APOLLO SPACESUIT ASSEMBLY

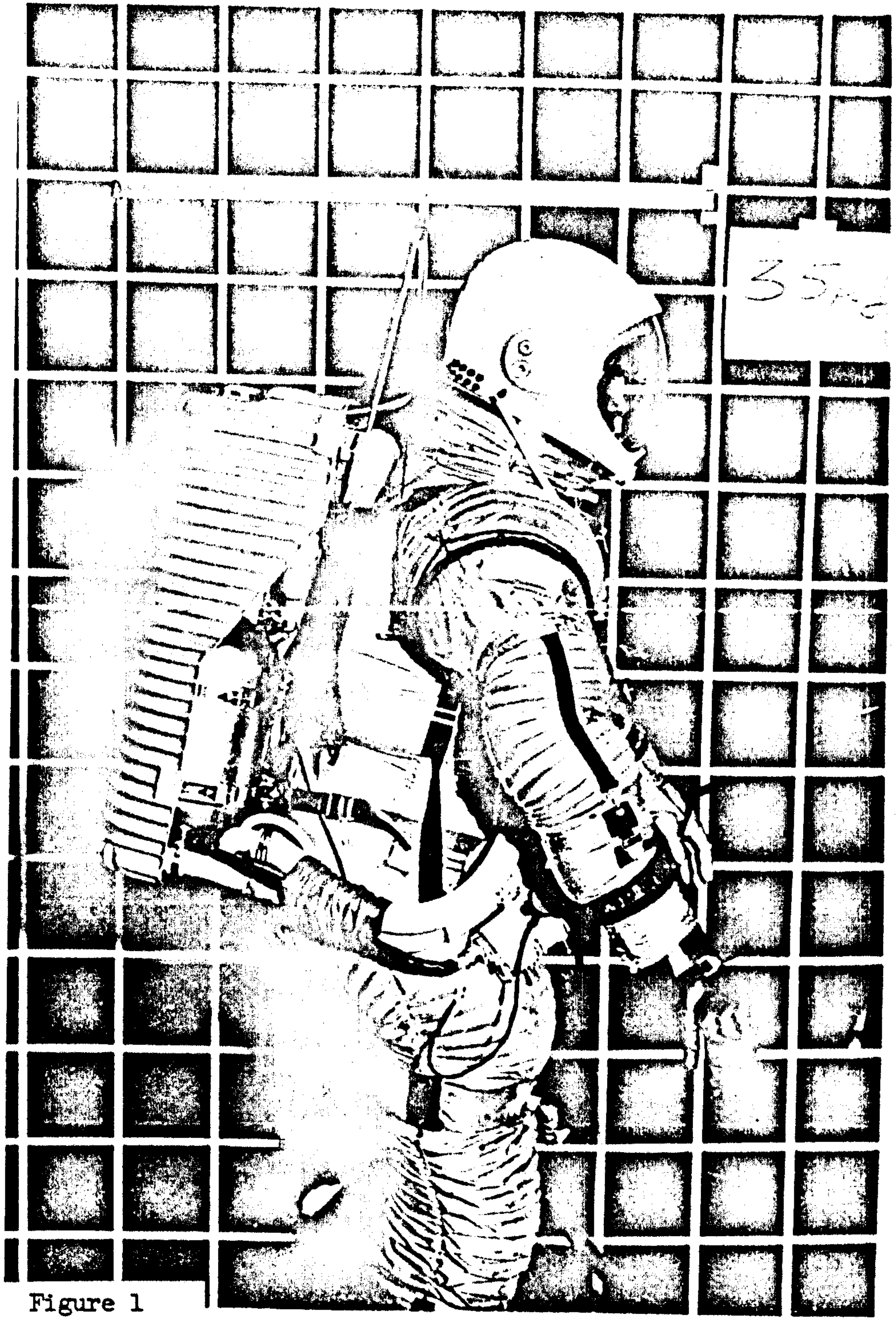

Figure 1

APOLLO SPACECRAFT

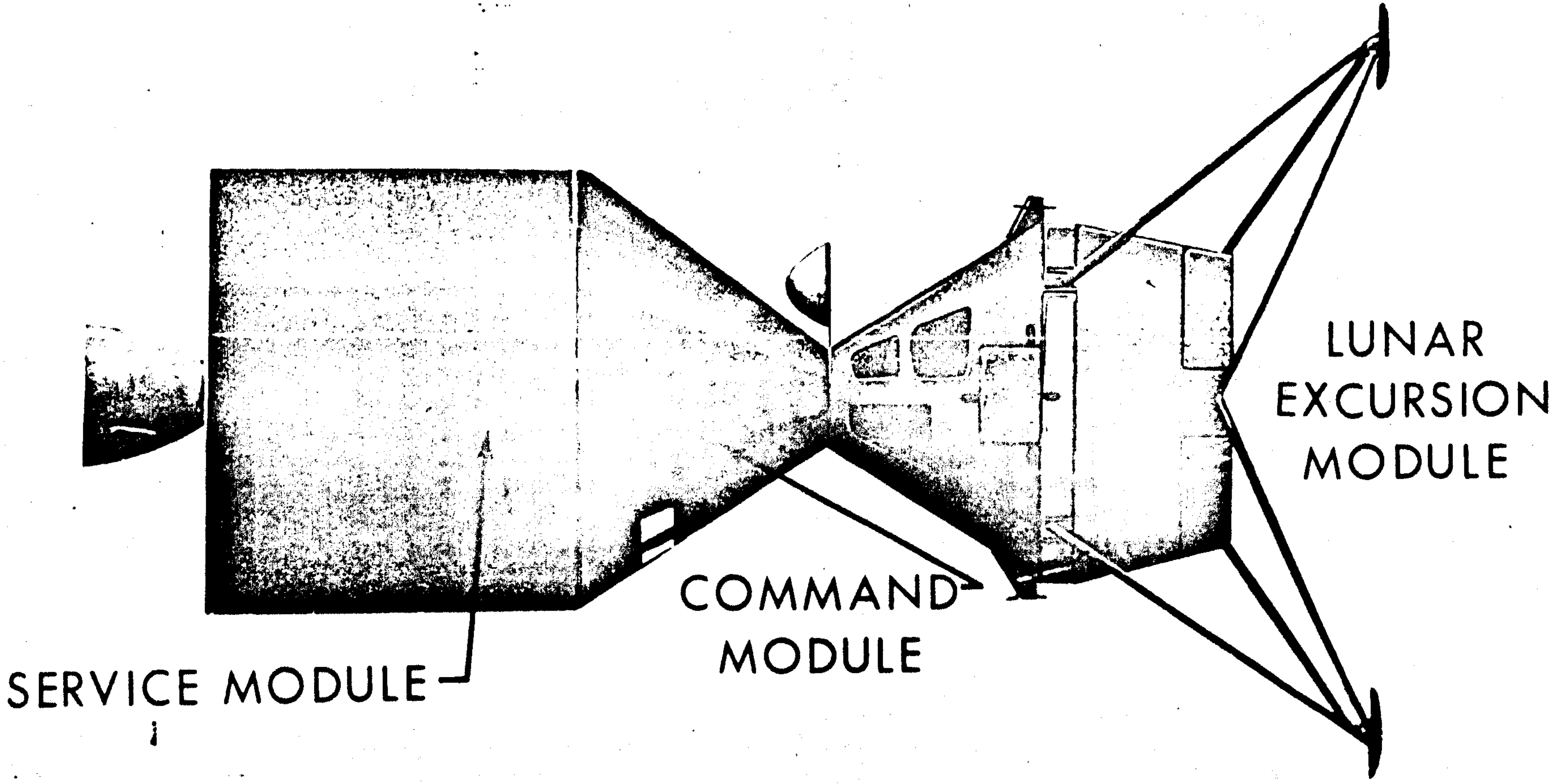

Figure 2

TYPICAL MISSION ACTIVITY PROFILE

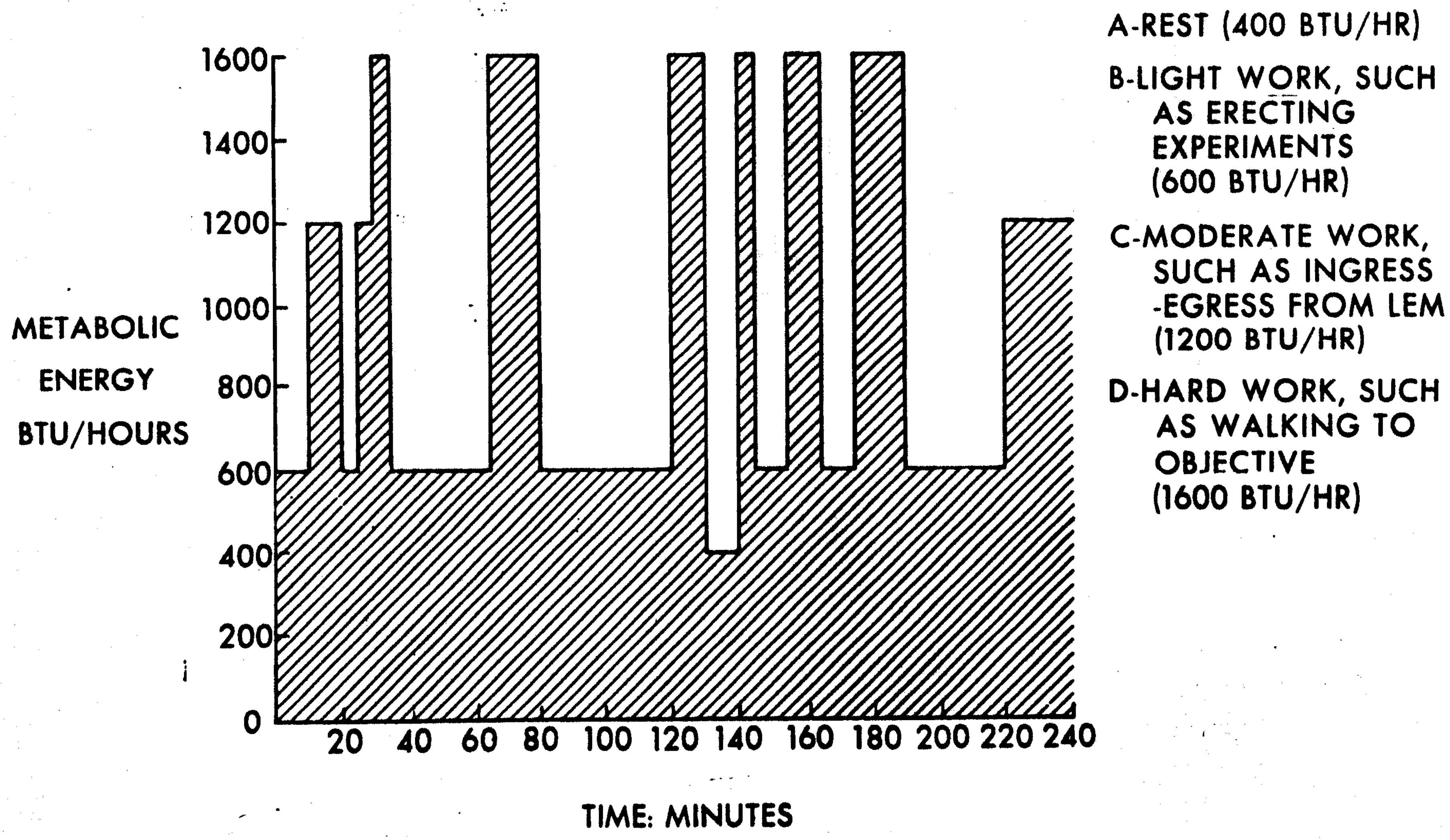

Figure 3

PORTABLE LIFE SUPPORT SYSTEM SCHEMATIC

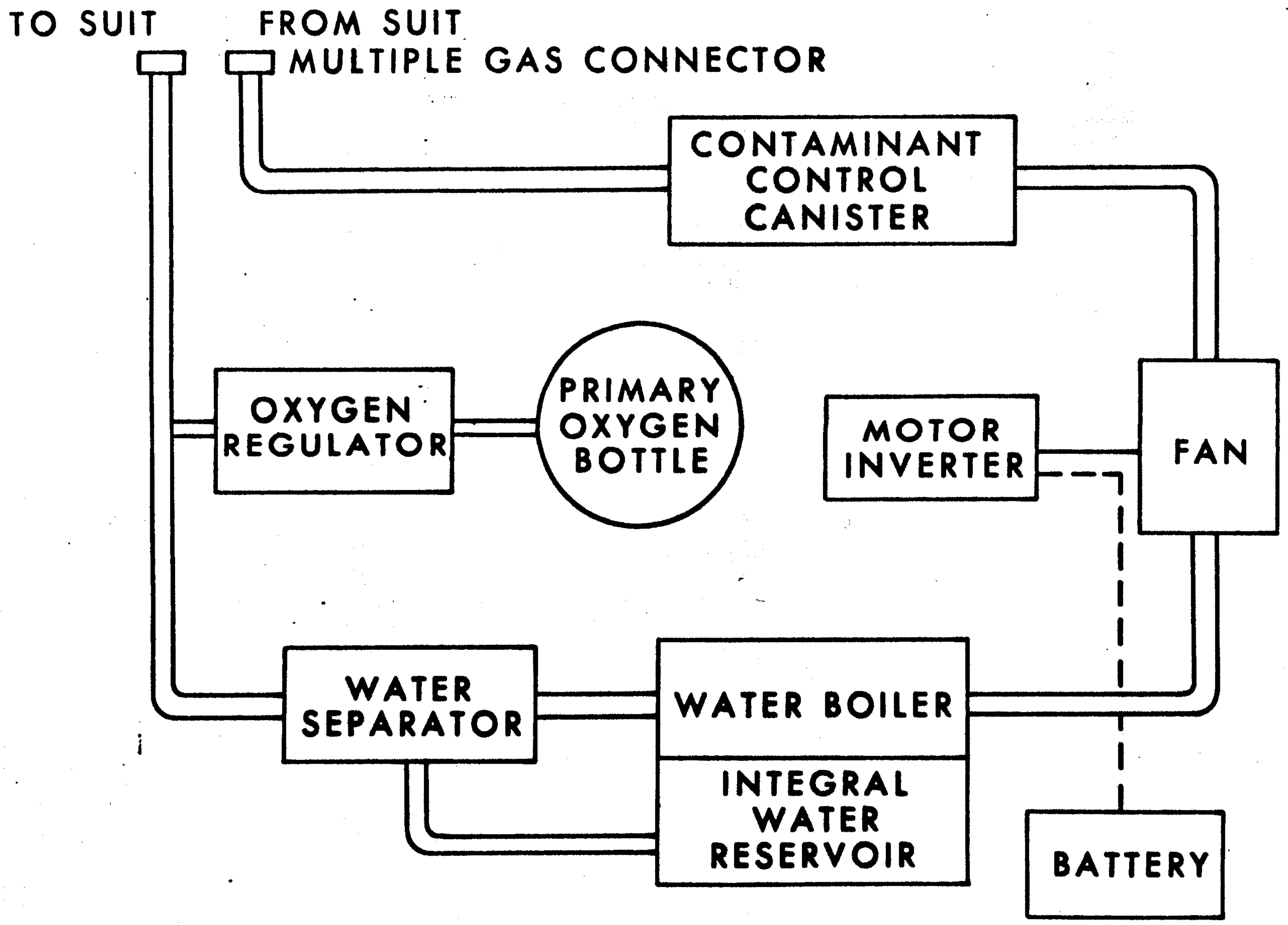

Figure 4

CO_2 PARTIAL PRESSURE RESPONSE TO CHANGES IN METABOLIC RATE

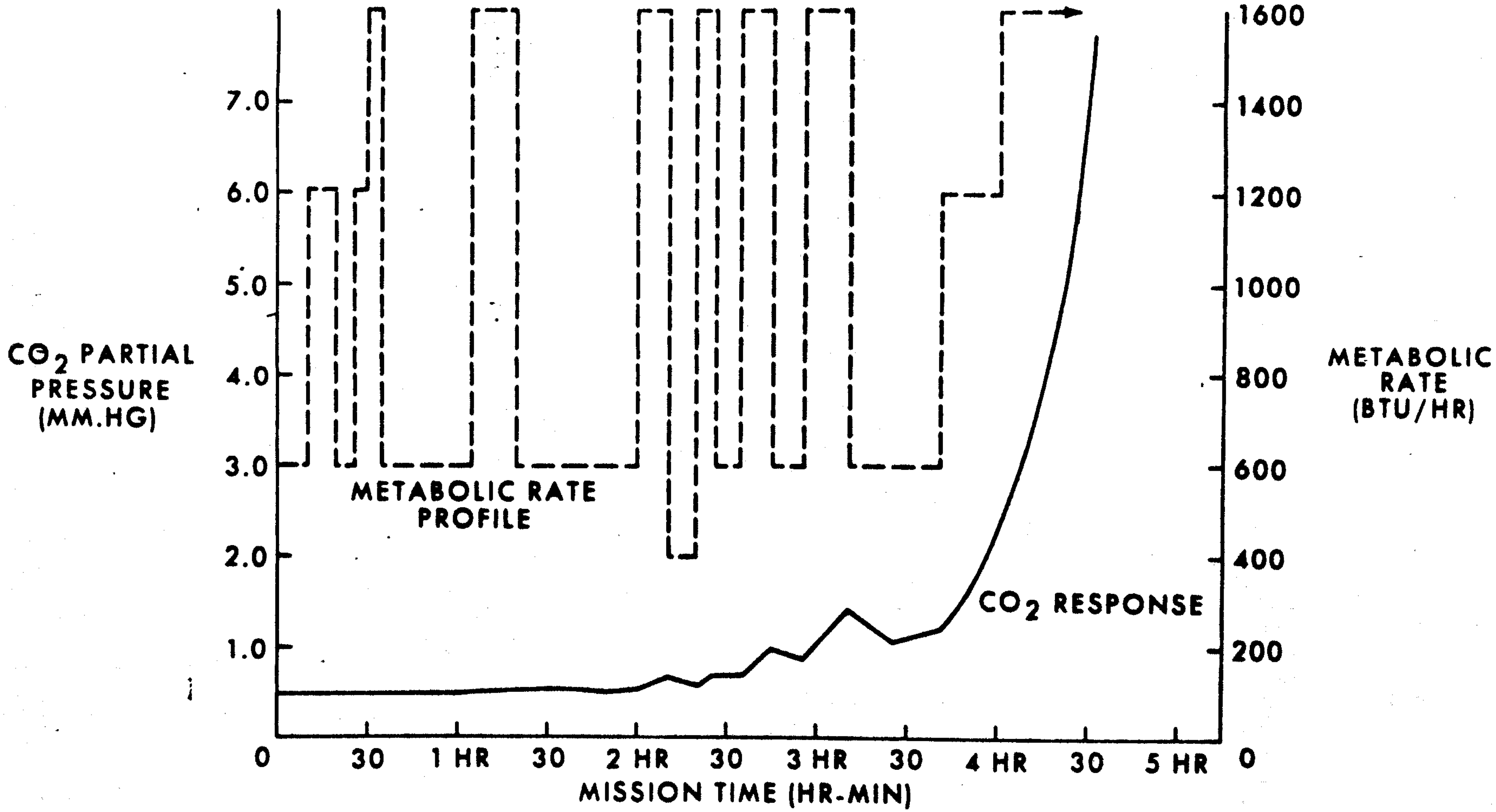

Figure 5

HIGH PRESSURE OXYGEN SUBSYSTEM

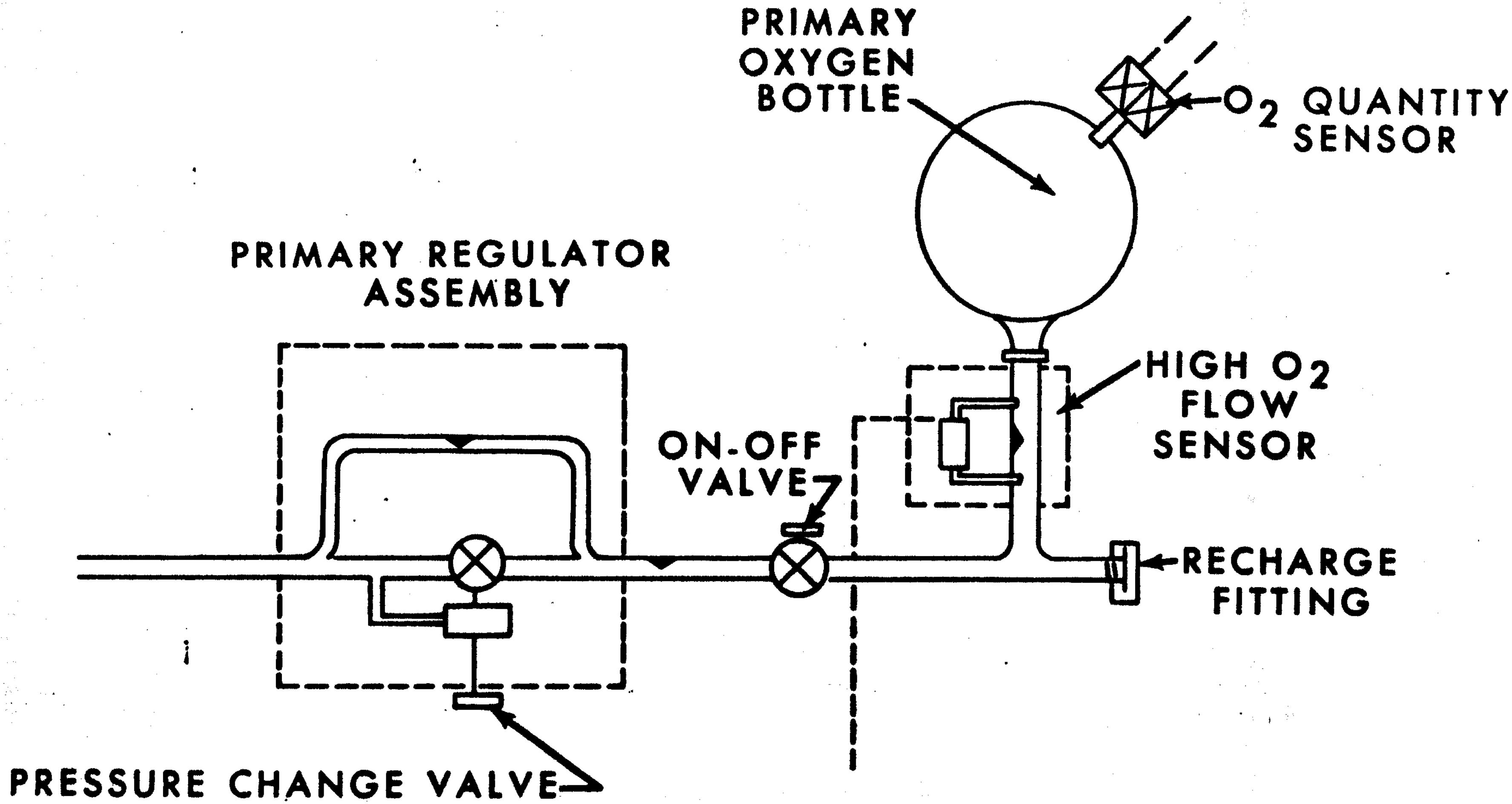

Figure 6