Criteria for Design of the Mercury Environmental Control System, Method of Operation and Results of Manned System Operation

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PROJECT MERCURY, under the direction of the National Aeronautics and Space Administration, is the United States' effort to place a man in orbital space flight. The major requirements for the program include the Army Redstone and the Air Force Atlas boosters, the McDonnell Capsule—the payload, and the ground complex which includes the pad operation, tracking stations and recovery system.

The announced objectives of the project are to: (1) place a manned space capsule in orbital flight around the earth, (2) investigate man's performance capabilities in a true space environment, and (3) recover the capsule and man safely.

Man will be launched into an orbit around the earth in the not-too-distant future. In order to accomplish this scientific feat, it is necessary to provide the astronaut with a controllable environment that satisfies his physiologic tolerances. The object of this paper is to outline the criteria for the design of the life support system, describe the operation of the McDonnell system for the Project Mercury capsule, and give results of manned operation at simulated altitudes.

In the development of the environmental system, simplicity of design was a very important consideration, primarily because of reliability requirements and also because of critical delivery requirements. In view of these requirements, a decision to use an artificial atmosphere composed of essentially 100 per cent oxygen rather than a more complex mixed gas system was made early in the program.

Due to the O_2 environment in which man has always lived, his evolutionary processes have adapted him well to our atmospheric concentration. Man can tolerate some deviation from his natural environment and research has attempted to demonstrate these limits.

It has been established that if a man is to breathe 100 per cent oxygen, his limits would be between 16,000 (412 mm. Hg) and 38,000 feet (155 mm. Hg) altitude depending upon the individual. The suitability of high oxygen concentrations at lower altitude has not been well established for extended periods of time. Since these are tolerances depending to a great extent upon individual differences for conservative operational purposes, we must reduce the range to limits which are approximately 20,000 (349 mm. Hg) to 33,000 (196 mm. Hg) feet altitude. This already narrows the possible pressure down to a 3 psi range.

The total pressure required to keep most flight crew people out of the "bends"-susceptible altitude for at least up to a day is approximately 27,000 feet (258 mm. Hg). We are now in a range between 20,000 and 27,000 feet.

Fire hazard becomes a more important consideration as the concentration of oxygen increases. The desire here would be to have as low a total pressure as possible. Since the minimum pressure desirable for the man is 258 mm. Hg or 27,000 feet, it was selected as the final capsule total pressure.

This reduced pressure is very desirable because it avoids a high structural weight penalty for the capsule as well as minimizing leakage

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rates. The leakage rate becomes a very important item when replacement is from a stored supply.

The only problem made more difficult by the reduced pressure is removing heat from the man and equipment.

The task of assigning a realistic average body heat production for a twenty-eight-hour flight received considerable attention. The astronaut's metabolic rate during the mission is the real key for determining the quantity of supplies to be stored on board. Once one assigns a value to metabolic rate, then the design figure for the oxygen supply volume, carbon dioxide absorber size, coolant material supply, and requirements for drinking water and food can be established. Because of all these accumulating factors, the importance, weight wise, of assigning a realistic figure is obvious. From past experience of measuring men during simulated flights in a pressure suit, both pressurized and unpressurized, and considering the restriction to movements within the capsule, it was concluded that an average 400 BTU/hour (100 kg. Cal./hr.) would be the design figure. In order to produce this much heat per hour, it will take 345 ml./min. STP of oxygen or 1.825 pounds per twenty-eight-hour flight time. This assumes a respiration quotient (R.Q.) of 0.82 which can vary. We compensate for leakage by adding oxygen and our design assumes a leakage rate of 300 ml./min. STP. The oxygen supply bottle is designed to hold 4 pounds which provides an additional 155 ml./min. margin for leakage and/or oxygen consumption. When man uses oxygen at the rate of 345 ml./min. STP with an R.Q. of 0.82, he must be producing CO_2 at the rate of 283 ml./min. STP. In designing the CO_2 absorber, we sized it for a 400 ml./min. CO_2 production.

Lithium hydroxide is used to consume the CO_2 because of the excellent absorption ratio. An efficiency of 75 per cent was used in calculating the required quantity. A laboratory test was run on the canister in which 400 ml./min. STP of CO_2 and 2.27 grams H_2O/min. was added to the system. The partial pressure level of CO_2 was maintained below 2 mm. Hg for over thirty hours and it required thirty-six hours to reach the 8 mm. Hg partial pressure level which was the upper design level.

The heat within the capsule is removed from the system by evaporating water which has the best heat of evaporation vs. weight ratio of any conveniently available liquid. The cabin or suit temperature is conveniently controlled by manually varying the rates of water flow into the respective heat exchangers. Since the vapor pressure of water at comfortable environmental temperatures are such that boiling does not occur below approximately 100,000 feet, depending on the temperature, water is not suitable for cooling below this altitude. The flight time below 100,000 feet is very short and the thermal inertia of the system will maintain the temperature within safe limits.

The humidity is not controlled independently of temperature in the suit system. As the temperature is reduced in the heat exchanger, the water is condensed into droplets. A sponge downstream of the heat exchanger removes the liquid water. At this temperature, the gas is saturated. The greatest temperature rise is in the suit and, even though the man is adding water to the gas, the relative humidity is decreasing. The gas will leave the suit at a lower relative humidity than when it entered.

The system will operate under one "g", increased "g's", and in a weightless condition. Much consideration has been given to a system design in which a catastrophic failure could not occur from the failure of a single component. At the same time it was necessary to keep the design as simple as possible.

The astronaut, wearing his pressure suit, enters the capsule approximately two hours before launch time. The suit is connected to the environmental control system by flexible hoses connected at the waist and helmet. The helmet visor is closed and the system is purged with 100 per cent oxygen until the suit system contains nearly 100 per cent oxygen. At this same time, the suit and cabin system fans are started and freon is passed through the water side of the suit and cabin system heat exchangers for cooling during the pre-launch period. The freon flow is controlled to maintain the desired temperature and continues until the umbilical is separated before launch. After the entrance hatch is closed the cabin is purged with 100 per cent oxygen. From this time until his return to 20,000 feet, the astronaut is separated from the earth's ecologic system.

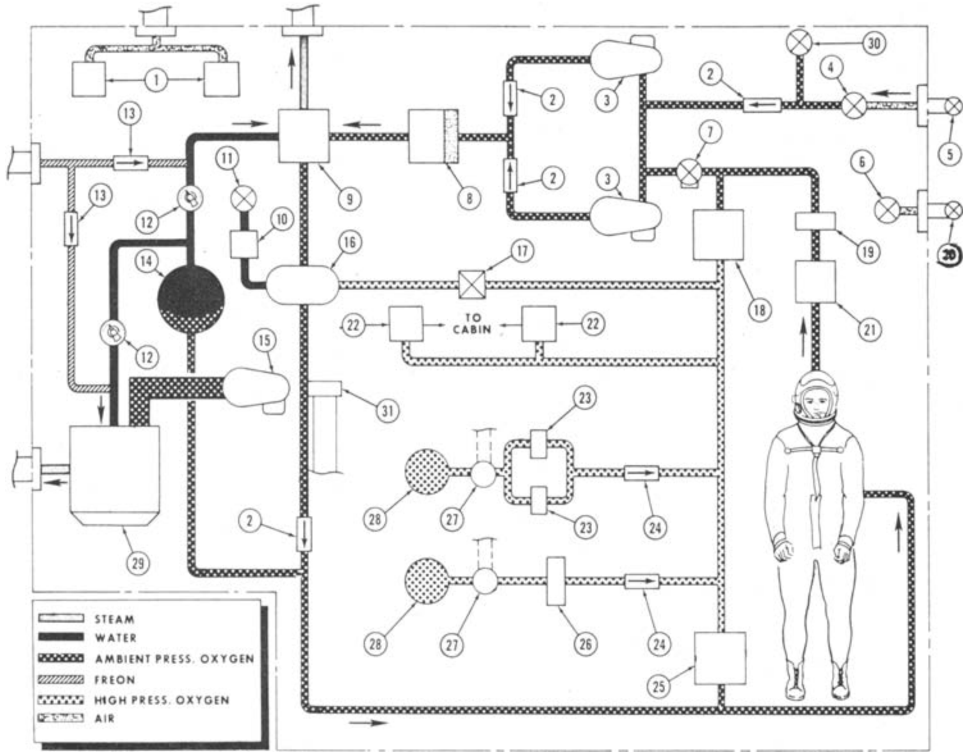

Fig. 1. Mercury Environmental Control System: (1) Cabin press relief and emergency decompression valve, (2) Oxygen check valve, (3) Suit circuit blower, (4) Inlet air valve, (5) Snorkel inflow valve, (6) Post-landing outflow valve, (7) System S/O emergency valve, (8) Suit CO_2 absorber and odor control, (9) Suit circuit heat exchanger, (10) Condensate tank, (11) Condensate removal valve, (12) Comfort control valve, (13) Freon 114 check valve, (14) Cooling water tank, (15) Equipment blower, (16) Suit circuit water absorber, (17) Solenoid switch valve, (18) Suit pressure regulator, (19) Suit pressure relief valve, (20) Snorkel outflow valve, (21) Solids trap, (22) Dual cabin pressure regulator and repressurization valve, (23) Oxygen press reducer, (24) Oxygen check valve, (25) Emergency oxygen rate suit valve, (26) Oxygen pressure reducer, (27) Oxygen pressure transducer, (28) Oxygen bottle, (29) Cabin equipment heat exchanger, (30) Ground oxygen inlet valve, (31) Carbon dioxide sensor.

The suit system operates by the following method (Fig. 1): The gas enters the pressure suit at the waist and flows through the suit ventilation ducts to distribute the gas over the astronaut's body for convective and evaporative cooling. The flow returns over his body to the helmet where part of the gas is used for breathing purposes. The gas then leaves the helmet and passes through a solids trap (21), goes by an over pressurization relief valve (19), through a system shutoff valve (7), and through one of two compressors (3) which increases the pressure approximately 10 inches water. The gas is then directed through the canister (8) which contains charcoal to absorb noxious odors, and lithium hydroxide to absorb CO_2. The CO_2 absorption is an exothermic reaction and as such adds to the system approximately 136 BTU/hr. depending on the quantity of CO_2 absorbed. The gas enters the heat exchanger (9) and the temperature is dropped to the astronaut's selected temperature . . . normally around 45°F. Since the condensed water is in a weightless state, the gas must be passed through a separator (16), which in this case is a sponge. The sponge is sized to hold all water the man might produce in thirty minutes at which time the water is squeezed from the sponge and collected in a tank (10). The gas at this reduced temperature (but near a saturated condition) is returned to the suit. This is the normal mode of operation for pre-launch and all phases of the flight until the return to 20,000 feet.

During the countdown period, the suit system works just as in orbit—the CO_2 is being absorbed, oxygen is replaced by the demand regulator (18), and the water is condensed in the heat exchanger and then removed by the sponge.

Upon launch, the pressure in the capsule and suit systems approximately follows ambient pressure until 25,000 feet is reached, at which time the cabin pressure relief valves (1) close to hold this pressure and remain closed until the capsule returns to 25,000 feet.

From launch to around 100,000 feet, depending on the internal temperature, there will be no cooling taking place in the heat exchangers. From 100,000 feet altitude until return to this altitude, the systems will be cooled by evaporating water in the heat exchanger and exhausting the vapor into space. The capsule pressure is maintained by adding O_2 as demanded by either of the two cabin pressure regulators (22). When operating with a closed suit circuit, the oxygen which the man uses is replaced, as demanded, by the pressure suit regulator (18) which has a demand function in addition to pressure regulation.

The oxygen supply consists of two bottles (28) containing four pounds of gaseous oxygen each at 7,500 psi pressure. The main supply has enough oxygen for an eighteen-orbit flight. The system has two reducers (23) for redundancy both of which are set to deliver oxygen at 100 psi. The emergency system is controlled by a separate reducer (26) set at 80 psi. This means the main bottle must be used first even in an emergency. Two fans are provided on the suit circuit either of which has the capacity to provide adequate ventilating flow. A pressure switch is provided to turn on the second fan if the first should fail.

The water is supplied to the heat exchangers through manually controlled needle valves (12) from a water supply. Water is stored in a bladder container (14) with gas pressure on one side to insure positive operation under weightless conditions.

During launch, the astronaut will have his pressure suit helmet visor closed. The system is so designed that he can fly with the visor opened or closed in orbit. The visor must be closed manually if decompression occurs in the capsule. Most likely the astronaut will perform the complete mission with the visor closed except to eat or drink. Upon decompression if the visor is closed the astronaut will only notice the stiffening of the pressure suit. The suit system continues to operate exactly the same. Now the concern is for the leakage rate of the suit and environmental control system instead of the capsule wall. If the astronaut elects to continue his mission rather than abort, the leakage rate of the suit system must not exceed the capsule design figure. During decompression the cabin pressure control valves are automatically turned off when the pressure drops below 4 psi. Otherwise these valves would dump the total remaining oxygen supply.

If there is a leak in the environmental section of the suit system and the pressure drops to 3.5 psi, the major part of the system will be blocked off [system shutoff valve (7) and the check valve upstream from the suit] and the emergency constant flow valve (25) will deliver 0.05 lb./min. of oxygen for eighty minutes plus what remains in the normal bottle. This valve can be operated manually if the CO_2 rises to a dangerous level or if the fans stop. This constant flow must then supply the man with his breathing oxygen as well as remove his body heat for the remaining orbital time plus the re-entry time. This has been accomplished in a simulated flight and works satisfactorily.

On re-entry there is no change in the normal system until the capsule has descended to approximately 100,000 feet, depending on the temperature, at which time the water for cooling the heat exchanger stops boiling off. Upon reaching 25,000 feet the cabin pressure relief valves open and the capsule pressure increases with the ambient pressure. At 20,000 feet, the snorkel valves (4 and 6) open and air is pulled into the suit system over the astronaut and dumped into the capsule either through the visor opening if open or through the suit pressure regulator (18). This method of ventilation continues into the post landing condition and can be maintained for twelve hours or longer depending on the power supply. Survival equipment, including a raft, is available if the need or desire to leave the capsule arises. Food and water are provided for body needs as well as for experimentation in handling.

Instrumentation on the astronaut includes two electrocardiographic leads, respiration rate, and deep body temperature. Voice communication is also considered significant from the standpoint of determining the well being of the astronaut. Important environmental measurements are total pressure and oxygen partial pressure in the system.

Manned System Testing.—The test vessel consists of a steel capsule with a production environmental control system. The altitude chamber is controlled to an altitude of 30,000 feet except during the check of the automatic operation of the emergency oxygen rate valve at which time it is controlled to 34,000 feet. The water side of the heat exchanger is maintained below 2 mm. Hg.

Approximately 100 hours manned system testing at altitude was accomplished. These tests utilized five subjects with the longest period at altitude [5 psi 95 per cent pO_2 (oxygen-combining potential)] being twenty-eight hours. The nominal test time was four and one-half hours. A particularly severe test was conducted to simulate four and one-half hours of orbit followed by twelve hours of the post landing phase with ambient conditions of 85°F. and 85 per cent relative humidity. Various modes of system operation were demonstrated and consisted of normal and emergency operation of the suit circuit with the cabin decompressed. The heat pulse during re-entry was simulated for each of these modes.

Physiologic measurements identical to those in the basic capsule were made during the test runs. The pO_2 and pCO_2 were measured by a Beckmann Analyzer, and in addition, gas samples were taken for comparative analyses. The system provided adequate ventilation and temperature-humidity combinations to maintain the comfort level of the occupant during all phases of the tests at altitude. No adverse physiological effects occurred. In the simulated post landing phase, the subject started with a pulse of 60 and a deep body temperature of 98.2°F. and ended the twelve-hour period with a pulse of 110 and a deep body temperature of 101°F.

It is significant to note that during these closed system tests, the pCO_2 was maintained below 1 mm. Hg at all times and the pO_2 stabilized at values between 92 and 95 per cent depending on suit inlet temperature. The variation in pO_2 is primarily caused by the difference in pH_2O vapor.