Observations in the SAM Two-Man Space Cabin Simulator

I. Logistics Aspects

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PRIOR to the time that man goes into space, much background work and laboratory testing must be completed. A large number of variables must be identified and their separate and combined impacts on the biological portion of the vehicle system assessed. These variables range from physiological parameters to emotional aspects of isolation, confinement and danger. Some of these variables can be studied separately and in various combinations in ground-based space cabin simulators. This forms the basis for this group of papers (I, II, III and IV)—a discussion of the various, aspects of sealed cabin experimentation being conducted at the School of Aviation Medicine, USAF Aerospace Medical Center.

The selection of the type of atmosphere to be used in a space vehicle is one of the early decisions that must be made in the design and development of any life support system for manned space operations. It is important that any such decision be based on as much experimental data as possible, a requirement that has influenced our thinking and experimental design a great deal. It appears logical to assume that a total pressure somewhat less than sea level pressure would be desirable in a space cabin. Since previous experimentation at the School of Aviation Medicine in the one-man simulator had been conducted at 18,000 feet,[11] it was believed that this would be an excellent starting point for this series of experiments. This altitude offers a certain amount of bends protection to the astronaut in case of decompression and the subsequent use of protective equipment.

The use of cabin pressure lower than 380 mm. Hg also has been suggested by various investigators to be desirable from an engineering point of view.[2,5] If one could utilize a 100 per cent oxygen atmosphere at a greatly reduced cabin pressure,[1] the problem of control and maintenance of cabin atmosphere would be somewhat minimized.

The purpose of this series of experiments in the two-man space cabin simulator, therefore, is to study the reactions and performance of crew members to various potential space cabin atmospheres and environmental conditions, ranging from ambient pressure ($\sim$ 750 mm. Hg) and atmosphere, to 33,500 feet ($\sim$ 190 mm. Hg) and, essentially, a 100 per cent oxygen atmosphere. This paper and its companion papers[4,8,9] will be concerned with data obtained from the first two experiments in this series. The first was conducted at an altitude of 18,000 feet with a 40 per cent oxygen, 60 per cent nitrogen atmosphere and lasted 30 days, 8 hours and 21 minutes. The second was conducted at an altitude of 33,500 feet with essentially a 100 per cent oxygen atmosphere and lasted 16 days, 21 hours and 27 minutes.

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METHODS AND PROCEDURE

Description of Simulator.—The two-man space cabin simulator is a hermetically sealed cabin containing all the necessary environmental control and life support equipment on-board, with the exception of the heat exchanger and power supply. A detailed description of the overall cabin system and sub-systems has been presented elsewhere by Nelson.[10] It should be pointed out that the cabin was not designed as an operational vehicle but as a research tool. In this capacity, it provides us with a large amount of data relevant to the problem of maintaining man in space.

An artist's conception of this simulator is shown in Figure 1. The simulator is an elliptically-shaped steel cylinder that is 12 feet long, 8 feet high and 5 feet wide. The total bound volume is 380 cubic feet. At a 10 psi pressure differential (28,500 feet altitude), the leak rate of ambient gases into the simulator produces a pressure change of 2.4 mm. per 24-hour period. If this pressure change were converted to a volume change, it would be equivalent to approximately 1 to 1.3 liters of ambient gas leaking in per hour, depending upon the exact free air space within the simulator.

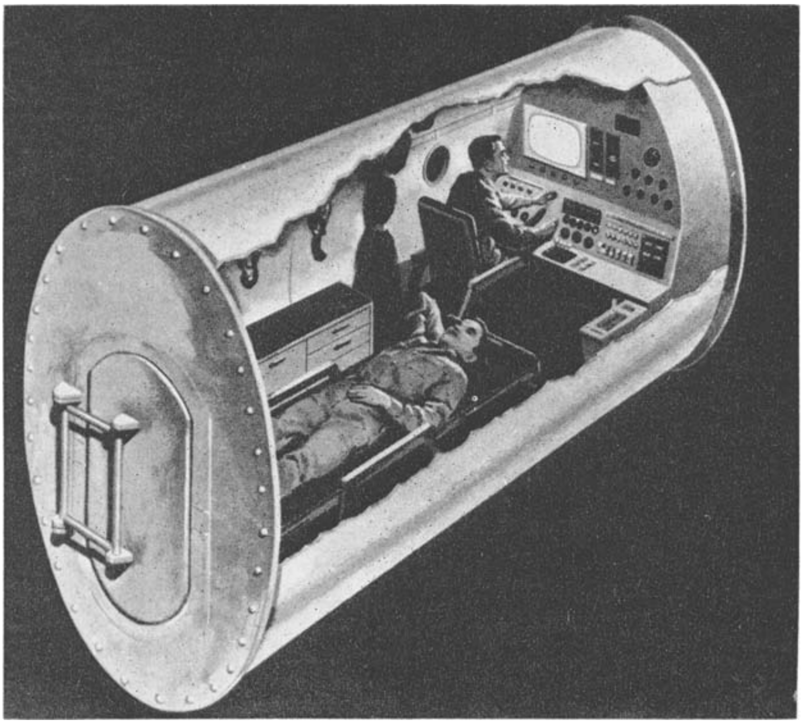

Fig. 1. Artist's conception of two-man simulator.

TABLE I. DESIGN RANGE AND DEGREE OF ACCURACY IN ENVIRONMENTAL CONTROL SYSTEMS

Variable	Range	Variation
Total pressure, mm Hg	200-Ambient	±5
Oxygen partial pressure, mm Hg	10-400	±3
Carbon dioxide partial pressure, mm Hg	0-80	—
Temperature, °F	60-80	±1
Relative humidity, per cent	40-70	±2

The system was designed for control of pressure, oxygen partial pressure, carbon dioxide partial pressure, temperature and relative humidity within the range and degree of accuracy shown in Table I. Oxygen is maintained either by an internal liquid oxygen source consisting of three 25-liter converters with a total daily boil-off of 2.4 liters liquid or by an external gaseous supply. Carbon dioxide currently is removed from the atmosphere by baralyme. Temperature and relative humidity are controlled by the use of cooling coils and reheaters.

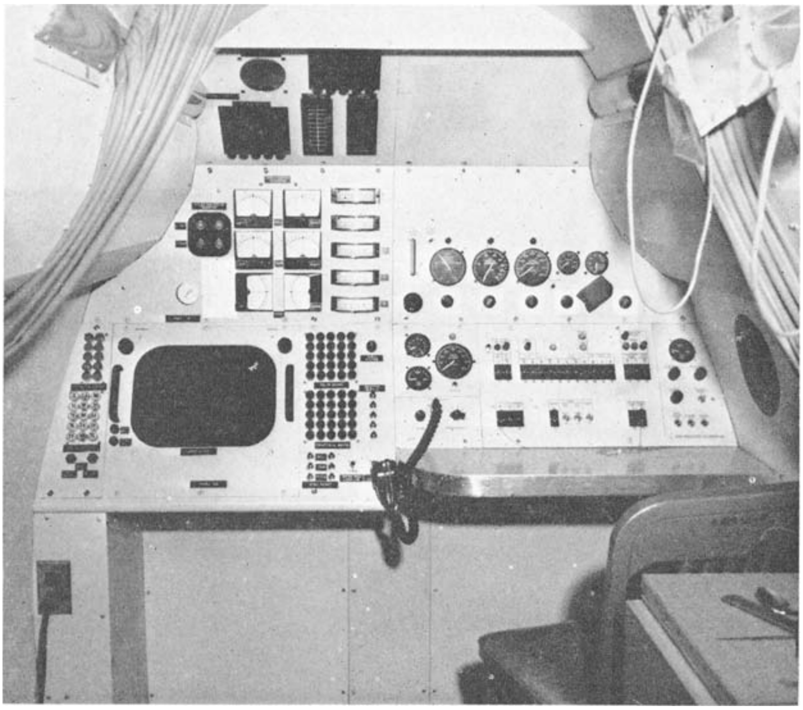

Fig. 2. Close-up view of work area of two-man simulator.

The simulator is divided roughly into two separate areas—the rest area and the work area. The rest area is used for water purification, oxygen, food and water storage, work table and sleeping. The work area shown in Figure 2 is utilized as the control center of the vehicle. The left side of the control panel contains the psychomotor performance equipment which is described in detail in Part III.[8] The right side of the panel contains the environmental system controls, transfer switches, indicator lights and analyzer calibration equipment. The outside monitor console (Fig. 3) houses the primary indicators identical to those inside the simulator plus necessary over-riding controls, recording devices and necessary monitoring equipment including closed circuit television.

Crew Members.—The two men who participated in these two experiments were both Air Force jet pilots with a background in some field of science in college. A description of each man is given in Table II. Prior to final selection, each individual was subjected to exhaustive physical and psychiatric screening. Following final selection, approximately one week was allotted for an intensive indoctrination and familiarization in the simulator.

Environmental Conditions.—The environmental conditions maintained during the 30-day flight and the 17-day flight are shown in Table III. The simulator atmosphere during the 30-day flight was a four gas system, being composed of oxygen obtained from on-board liquid oxygen, nitrogen, carbon dioxide and water vapor. During the 17-day flight, nitrogen was essentially absent, or at least present in amounts not exceeding 2-3 mm. Hg partial pressure, making the atmosphere of oxygen, carbon dioxide and water vapor a three gas system. Oxygen was obtained from external gaseous supply for this experiment.

TABLE II. DESCRIPTION OF CREW MEMBERS

	Subject A	Subject B
Age (years)	30	36
Height (cm)	169.5	172
Weight (kg)	68.52	72.05
Educational background	B.S. (Chemistry)	B.S. (Biology)
Pilot hours (total)	1300	4970
Reciprocating	200	4400
Jet	1100	570

The major source of variation in the total pressure and partial pressure of oxygen during the 30-day flight was the accidental discharge of an emergency oxygen bottle. Except for this one occurrence, the oxygen partial pressure was very constant. The partial pressure of carbon dioxide rose in a more or less linear fashion to the peak of 13.9 mm. Hg at the end of the twenty-second day of the flight. At that time, a baffle plate in the absorber system was removed, allowing a greater air flow through the baralyme beds. This resulted in a fairly rapid drop to about 3 mm. with an apparent stabilization around this point. The maximum temperature occurred when the temperature control system was turned off for repair of a circulating pump in the refrigeration system. Relative humidity data are not available for the 30-day flight due to a failure in the humidity sensing system.

TABLE III. SUMMARY OF ENVIRONMENTAL CONDITIONS

	30-Day	17-Day
Pressure (mm Hg)	383 Max.—410 Min.—374	189 Max.—211 Min.—187
PO_2 (mm Hg)	150 Max.—209 Min.—138	176 Max.—188 Min.—168
PCO_2 (mm Hg)	6.43 Max.—13.9 Min.— 1.3	3.0 Max.—6.8 Min.—0.9
Temperature (°C)	22.6 Max.—26.2 Min.—20.0	21 Max.—23.0 Min.—20.0
RH (per cent)	—	50 Max.—69 Min.—34

Less variation was experienced during the 17-day flight, as evidenced by the data in Table III. On one occasion, however, the total pressure and partial pressure of oxygen were intentionally increased to 247 and 244 mm. Hg, respectively. This was necessitated by discomfort on the part of one of the crew members, which is discussed in Part II.[9] This intentional increase was not used in figuring the average environmental data.

Body Weight.—Body weight was determined by the use of regular clinical scales before and after both flights. The scales were routinely calibrated to insure their accuracy relative to previous weights.

TABLE IV. TYPICAL DEHYDRATED FOOD ITEMS

Pork chops	Peas
Chicken and rice	Carrots and peas
Cubed steak	Green beans
Swiss steak	Grapefruit-orange juice
Sliced roast beef and gravy	Peaches
Fish patties	Fruit cocktail
Roast pork	Pineapple
Oatmeal	Chocolate pudding
Mashed potatoes	Chicken and rice soup
Buttered rice	Cocoa
Carrots	Milk

Energy Intake.—Dehydrated, pre-cooked foods obtained from the Quartermaster Food and Container Institute, Chicago, Illinois, made up the bulk of the diet. There were a few items such as prefried bacon, cookies and candy that were not in a dehydrated form. A listing of some representative food items is shown in Table IV. These foods require only the addition of either hot or cold water, depending on the food item, for reconstitution. After soaking for a few minutes, they are ready for consumption.

Energy intake was determined by providing weighed food packages of known caloric composition. The men were allowed to consume the food *ad lib* with the requirement that they consume all the food in the package once it had been opened. Food consumed was then reported on a daily basis.

Water Requirements.—Water requirements were met by both stored supplies on board at the start of the flight and by waste water recycled during the flight. The recycled water was purified by a vacuum distillation apparatus constructed by our machine shop. The still is constructed of stainless steel and the condenser and receiver of acrylic plastic. Heat is applied by means of an externally wrapped resistance wire. The water production rate is approximately 300 cc/hour at a power input of approximately 220 watts. Water from all sources (urine, wash water and water condensed from the cabin atmosphere) was pooled in the pretreat tank. It was treated with acid to reduce the pH to 2-3 and then passed through a filter. From the filter, the urine passes to the still where the distillation was accomplished at 35-37°C. The gaseous phase was passed through activated carbon maintained at approximately 45°C and then condensed. The condensate was checked for purity by making tests on each batch of water. Odor, appearance, ammonia content, absorption spectra in the range of 220 to 340 mu and bacteriological examination were used as criteria of acceptability. During the 30-day flight, the men derived about 50 per cent of their water supply from this source. During the 17-day flight, 68 per cent of the water supply was from recycled waste water. These percentages were determined by dividing the overall initial supply of water into

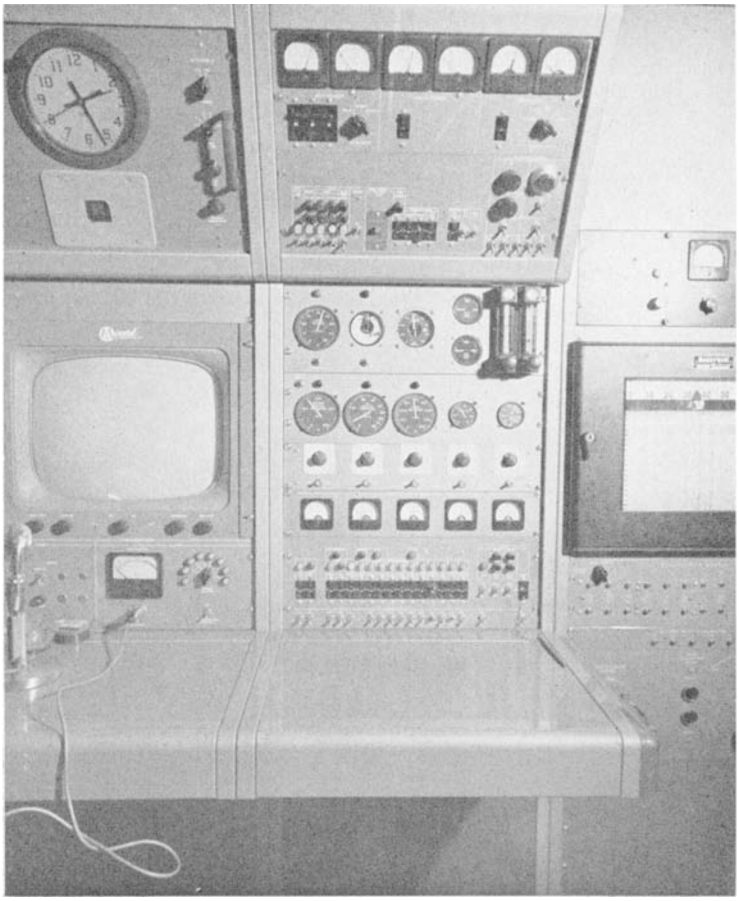

Fig. 3. Outside monitor console of two-man simulator.

the water actually used by the crew members. The still in the prototype phase operated at 60 per cent efficiency in the 30-day flight and at 80 per cent efficiency in the 17-day flight.

The men in the simulator kept accurate records of all liquids used and also of the volume of urine produced. These records were then handled on a daily basis to provide data on water requirements. In the 17-day experiment, 10 per cent of the volume of each voiding was collected for biochemical analyses.

RESULTS

Body weight data for both flights are shown in Table V. In the 30-day flight, the men lost 3.64 and 2.85 kilograms, respectively. During the 17-day flight, these same individuals experienced a weight loss of 2.05 and 1.93 kilograms, respectively. The exact composition of this weight loss is not known. Body water data as determined by the antipyrine method in the 30-day flight and by the deuterium oxide method in the 17-day flight indicated a loss in total body water. This, plus nitrogen balance data in the 17-day flight, would suggest that the weight change was primarily water combined with some rearrangement in body composition.

A summary of the energy intake data is presented in Table V. The measured intake values of 1406 and 1890 kilocalories for Subject A and 1667 and 1940 kilocalories for Subject B are somewhat below previous estimates for energy requirements in similar situations,[3,6] but in general agreement with an 1855 kilocalorie observation in an earlier experiment.[12] The exact energy requirement is questionable, however, due to the measured weight loss and the current inability to define adequately this weight loss as pointed out above.

TABLE V. AVERAGE DAILY ENERGY INTAKE DATA

	Initial Weight (Kg)	Energy Intake (Kcal)	Kcal/Kg Body Wt.	CH_2O %	F %	P %
Subject A						
30-day	68.52	1406	20.52	57	25	18
17-day	67.61	1890	27.95	52	33	15
Subject B						
30-day	72.05	1667	23.14	52	31	17
17-day	72.05	1940	26.92	51	33	16

TABLE VI. SUMMARY OF WATER DATA

	Subject A		Subject B	
	30-Day	17-Day	30-Day	17-Day
Water used (ml/day)	1601	2084	1974	2065
In liquids	972	1545	1135	1400
Food rehydration	479	403	610	538
Personal hygiene	150	136	229	127
Water intake	1451	1948	1745	1938
Water in food	57	53	44	37
Water of oxidation	178	237	210	245
Total water available	1686	2238	1999	2220
Water excreted	1114	1374	970	1008
Urine	1059	1304	902	939
Feces	55	70	68	69
Insensible and sensible loss	??	??	??	??

The percentage of calories derived from carbohydrate, fat and protein averaged 53, 30.5 and 16.5 per cent, respectively, during both flights.

An average weight of 1.14 lbs./man/day was required for both food and container. This value probably approaches the minimum weight that can be expected in practical usage and is certainly much less than the weight incurred by using canned[11] or frozen foods.

A summary of the water intake/output data is presented in Table VI. The average daily water usage for both men for both flights was 1931 ml. This includes water used for personal hygiene, but does not include that water derived from foods as preformed water and water of oxidation. The average water *intake* from all sources including water in food and water of oxidation was 2036 ml. per day. This water intake, coupled with this particular dietary regimen, resulted in an average water excretion from the kidney and in feces of 1116 ml. per day.

The amount of water lost by way of the lungs and skin as insensible water loss is unknown. Kuno[7] has estimated this to be on the order of 900 ml./man/day. This estimate, however, is based on a sea-level condition and the influence of altitudes of 18,000 and 33,500 feet is not clearly understood. If these individuals in the simulator were in water balance, an average value of approximately 920 ml./man/day could be assigned to this insensible loss. Since body water data indicated they were not in balance and since individual variability could be fairly large, the problem of insensible loss is still open to question.

Oxygen requirements have been estimated from the average energy intake obtained during both flights, using the value of 4.825 Kcal/liter oxygen required. This calculation yields a requirement for oxygen of approximately 360 liters/man/day or 1.13 lbs/man/day. If the weight loss observed does represent tissue loss, this oxygen requirement would then be increased.

DISCUSSION

The results from these two experiments strongly indicate the necessity for this type of data in order to minimize the amount of estimation involved in designing life support systems. It is essential that body weight be controlled or the composition of any weight change determined if the energy requirements of man in this situation are to be accurately defined. The importance of defining the energy requirements cannot be underestimated, since this directly influences the oxygen requirement, the amount of carbon dioxide produced and the amount of heat produced. It also indirectly influences the requirement for water and the amount of waste liquid produced.

The use of pre-cooked dehydrated foods, when combined with a water purification system, appears to be a logical solution to the problem of nutrition in regards to space flight. The fact that these foods weigh approximately half as much as ordinary foods, require no special storage facilities and are quick and easy to prepare would seem to justify their use. They would require special techniques for rehydration under weightless conditions which conceivably could be a liability, however.

The level of energy intake observed during these two flights should be considered to be the minimum that would be encountered. It should be pointed out that two additional factors will have their effect in the operational situation: weightlessness and emotions. The magnitude and direction of these two factors are unknown at this time.

The water purification system was designed to have a flow rate in excess of that necessary to meet the minimum daily requirements. This was felt to be necessary to allow for cleaning and repairs in the event of a malfunction. The device is very simple to operate and is designed in such a manner as to facilitate cleaning.

Additional experimentation will have to be accomplished to further define man's adaptability to living under other than "normal" atmospheric conditions. Successful completion of these studies should bring about a greater degree of understanding between those concerned with the man and those with the machine.

SUMMARY

Two pilots were maintained in a two-man space cabin simulator for 30 days and for 17 days. The 30-day flight was at an altitude of 18,000 feet with 40 per cent oxygen—60 per cent nitrogen atmosphere. The 17-day flight was at an altitude of 33,500 feet with essentially a 100 per cent oxygen atmosphere. The men consumed an average of 1726 Kcal./man/day

during both flights. This food plus container weight averaged 1.14 lbs./man/day. The daily liquid requirement was 1931 ml./man/day. Oxygen consumed, based on the energy intake, averaged 360 liters or 1.13 lbs./man/day.

ACKNOWLEDGMENT

The devotion to duty and the personal sacrifice of those individuals who served as crew members during these flights is greatly appreciated by the authors.

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Lung Changes After Sea Water Aspiration

DENIS F. J. HALMAGYI, University of Sydney, Australia. *J. Appl. Physiol.*, 16:41-44, 1961

In rats given sea water intratracheally, weight of the lungs increases notably. Increase in mean relative lung weight within one minute after administration of 0.1 cc. of sea water per 100 gm. of body weight corresponds to the amount of fluid introduced. After twenty minutes, relative lung weight is 4 times the quantity introduced. The increase appears to be due to withdrawal of an amount of plasma water equivalent to the sea water, which is about 4 times more concentrated than body fluids. Once the osmolarity of the fluid in the lungs is restored, the lungs take a long time to get rid of the increased volume. Sea water also causes extensive intraalveolar hemorrhage. Introduction of fresh water intratracheally does not produce changes in the lungs of rats. Fatal respiratory arrest sometimes occurs after salt water and cold fresh water aspiration.—From *Modern Medicine*, June, 1961.