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ENVIRONMENTAL PHYSIOLOGY LABORATORY

FINAL REPORT ON RESULTS FROM NASA SMD III, PROJECT 76, EXPERIMENT 44, "METABOLIC AND CARDIOVASCULAR ADAPTATION–MONKEY" CONDUCTED AT NASA/JSC 14-25 MAY 1977

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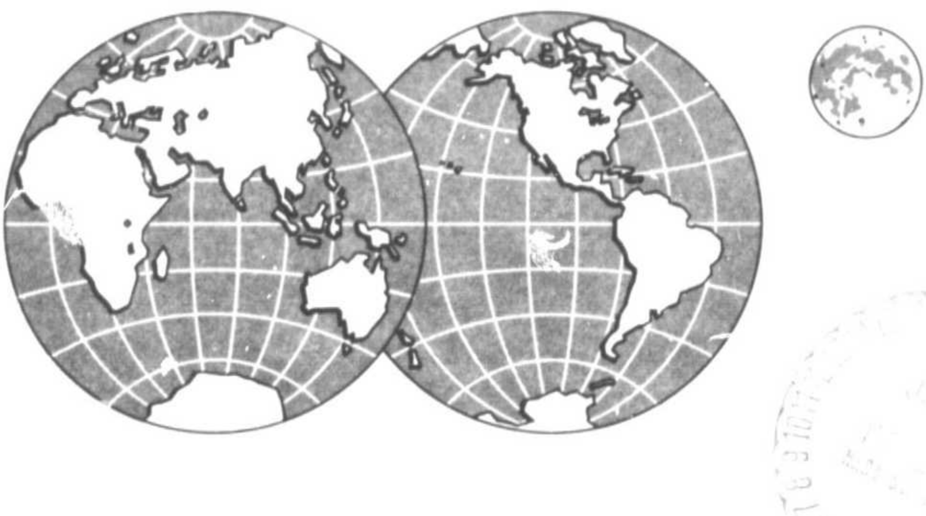

UNIVERSITY OF CALIFORNIA - BERKELEY

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FINAL REPORT ON RESULTS FROM NASA SMD III, PROJECT 76, EXPERIMENT 44, "METABOLIC AND CARDIOVASCULAR ADAPTATION - MONKEY"

CONDUCTED AT NASA/JSC 14-25 MAY 1977

Work performed under NASA Grant NSG-7262

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BACKGROUND

In August 1976 this laboratory (EPL) was invited by the NASA Ames Research Center (NASA/Ames) to collaborate as an experimenter group in a test of biomedical experiment feasibility for Spacelab flights, to be known as Space Mission Development III (SMD III). The test was to be conducted jointly by NASA/Ames and the NASA Johnson Space Center (NASA/JSC) in Houston, Texas during the spring of 1977. Assembly of the SMD III experiments payload was to be accomplished in the Spacelab configuration at NASA/Ames, and the assemblage was to be transferred to the Spacelab Simulator at NASA/JSC for the conduct of the test itself.

With NASA support since 1963, EPL has been developing and testing an experiment system designed to permit measurement of physiological parameters in subhuman primates during continuous, comfortable, couch restraint for periods of up to 30 days under space flight conditions[1-4]. A key element of the system is a fiberglass pod configured to contain an adult, 10-14 kg pig-tailed monkey *(Macaca nemestrina)* seated in a couch. The pod can be sealed hermetically, and is subdivided internally into upper and lower halves by means of a waist seal applied to the animal in the couch. The arrangement permits independent ventilation of the upper and lower portions of the animal,

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[1] Pace, N., J. T. Hansen, D. F. Rahlmann, N. J. Barnstein and M. D. Cannon. Preliminary observations of some physiological characteristics of the pig-tailed monkey, *Macaca nemestrina*. Aerospace Med., 35: 118-121, 1964.

[2] Rahlmann, D. F., J. T. Hansen, N. Pace, N. J. Barnstein and M. D. Cannon. Handling procedures and equipment for physiological studies on the pig-tailed monkey *(Macaca nemestrina)*. Lab. Animal Care, 14: 125-130, 1964.

[3] Pace, N., D. F. Rahlmann, A. M. Kodama, R. C. Mains and B. W. Grunbaum. A Monkey metabolism pod for space flight weightlessness studies. In: COSPAR Life Sciences and Space Research XII, P.H.A. Sneath (Editor). Akademie-Verlag, Berlin, 1974, pp. 129-132.

[4] Pace, N., A. M. Kodama, R. C. Mains, D. F. Rahlmann and B. W. Grunbaum. Continuous 30-day measurements utilizing the monkey metabolism pod. In: COSPAR Life Sciences and Space Research XV, R. Holmquist and A. C. Stickland (Editors). Pergamon Press, Oxford, 1977, pp. 213-218.

as well as the intermittent application of lower body negative pressure as desired.

The exhaust gas from the upper pod can be analyzed by mass spectrometer for oxygen and carbon dioxide concentrations to permit continuous measurement of respiratory gas-exchange rates and metabolic energy expenditure. Food and water are made available to the animal by means of metering devices so that a quantitative record of eating and drinking activities can be obtained. Urine and feces may be collected separately and quantitatively in the lower pod for subsequent biochemical analysis in elemental metabolic balance studies. Access ports on the upper and lower portions of the pod permit the application of procedures such as blood sampling or the administration of test substances or pharmaceuticals to the animal during an experiment. Attachment of physiological instrumentation to the animal by way of implanted electrodes or indwelling catheters is also readily performed.

It has been shown[4] that two or more fiberglass pods containing monkeys can be incorporated into the experiment system in such a way as to share the support instrumentation. For example, by use of an automatic valve sequencer the exhaust gas from each pod can be analyzed at frequent time intervals by a single mass spectrometer to provide respiratory gas-exchange measurements on several animals simultaneously. Thus, the statistical validity of experiments can be enhanced substantially by the use of multiple animal subjects under closely comparable conditions.

Following the initial period of development and testing in EPL, the monkey-pod experiment system was incorporated into a series of preliminary tests conducted by NASA to determine the feasibility of performing biomedical experiments under space flight conditions. A single-pod system was tested successfully as part of the NASA/Ames Shuttle Spacelab Concept Verification

In addition, the SMD III Experiment #44 mass spectrometer for measuring respiratory gas exchange of the Pod A monkey was shared with

- SMD III Experiment #59, B. Williams, Principal Investigator "Metabolic Adaptation - Rats"

Appropriate modification and assembly of the EPL 2-pod system into the Spacelab Project 76 configuration was carried out collaboratively by EPL and NASA/Ames personnel at NASA/Ames from October 1976 to January 1977. During this period, Mission Specialist Thornton and Payload Specialist Alexander visited EPL for preliminary briefing on the 2-pod system and on Experiment #44. In January 1977 they, with Payload Specialist Williams, went through Integrated Testing and initial Crew Training on the full SMD III Experiments Payload at NASA/Ames. Upon successful conclusion of these activities the SMD III Pre-Ship Review was held at NASA/Ames on 1-2 February 1977, and the decision was made to transfer the Experiments Payload to NASA/JSC for incorporation into the Spacelab Simulator. Shipment was made on 14 February 1977.

EPL personnel again collaborated with NASA/Ames and NASA/JSC personnel in the final 2-pod system installation for SMD III at NASA/JSC in February 1977, and on 1 April 1977 the EPL Experiment #44 personnel together with NASA/Ames experiments personnel and the animal subjects were flown to NASA/JSC. A series of tests was initiated to validate equipment readiness and experiment protocols, and to provide flight-crew training. These included a Science Verification Test on 6 April 1977, and a Two-Day Simulation Test on 10-11 May 1977. Fig. 1 shown the interior of the NASA/JSC Spacelab Simulator for SMD III and the positioning of the monkey pods.

The 6.3-day SMD III flight was performed during 17-23 May 1977 with the flight crew in residence in the Spacelab Simulator. However, in order to obtain the required preflight and postflight control data, the Experiment #44 monkey subject was installed in Pod A in the Spacelab Simulator on 14 May 1977, and remained there until 25 May 1977. Continuous physiological data return was obtained throughout this 11-day period. The SMD III flight crew took the direct responsibility for Experiment #44 from "Launch" at 0800 CST 17 May 1977 to "Landing" at 1404 CST 23 May 1977. EPL and NASA/Ames Experiment #44 personnel took the direct responsibility during the preflight and postflight periods. A preliminary report on the performance of the EPL 2-pod system was prepared and distributed in June 1977[9].

Acknowledgment must be made of the exceptional support provided by the host of NASA/Ames and NASA/JSC personnel who participated in the total build-up and successful execution of SMD III. The technical and administrative tasks involved were highly complex and formidable, but were competently met and conquered. While practicality precludes listing every contributor by name, special mention must be made of the outstanding performance of Mr. Rafael Miranda-Fontanez of NASA/Ames for his role in maintaining the high quality of the cardiovascular biotelemetry data return for Experiment #44. Special thanks are also due Dr. Melvin C. Buderer and Dr. William E. Feddersen of NASA/JSC who performed so effectively in their critical Spacelab Communicator role as the interface between flight crew and investigators for Experiment #44. The manifold assists provided by Dr. Bonnie P. Dalton of NASA/Ames throughout the project are very much appreciated. Finally, but by no means least, the scientific and engineering leadership brought to bear by Mr. William E. Berry, SMD III Project Manager, Dr. Paul X. Callahan, ARC SMD III Science Manager, and Dr. John A. Rummel, JSC SMD III Science Manager, is deserving of the highest praise.

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[9] Rahlmann, D. F., R. C. Mains, A. M. Kodama, E. P. McCutcheon and N. Pace. Preliminary Report on Results from NASA SMD III, Project 76, Experiment 44, "Metabolic and Cardiovascular Adaptation - Monkey", Conducted at NASA/JSC 14-25 May 1977. Report No. EPL 77-1, Environmental Physiology Laboratory, University of California, Berkeley, June 1977, pp. 1-22.

Test II (CVT II) conducted at NASA/Ames during April 1974[5]. Three months later, in July 1974, the same system was successfully tested as part of the NASA/Marshall General Purpose Laboratory Concept Verification Test III (CVT/GPL III) at the Marshall Space Flight Center, Alabama[6].

The experiment system was expanded to include a second monkey pod, and during May 1976, through the efforts of Dr. B. D. Newsom, NASA/Ames made space available for flight tests of the EPL 2-pod system on the NASA CV-990 airborne laboratory, "Galileo II". The primary objective of the NASA flight program at this time was a test of the "delayed flaps" landing approach technique, and involved a total of 58 take-offs and landings at a number of different airports with monkeys in the 2-pod system functioning aboard the aircraft. In addition to the multiple take-offs and landings, two Kepplerian parabolic trajectory maneuvers were executed on the final day of the program to provide several seconds of zero-*g* experience with the pod system.

One of the 2 monkey subjects had previously been prepared with a NASA/Ames cardiovascular biotelemetry device[7], surgically implanted by Dr. Ernest P. McCutcheon who was a collaborator in the flight experiments. Respiratory gas-exchange measurements were carried out continuously on both animals during the flights, and cardiovascular responses to lower body negative pressure were measured on several occasions in flight. The overall performance of the

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[5] Rahlmann, D. F., A. M. Kodama, R. C. Mains and N. Pace. Results from the EPL Monkey-Pod Experiment Conducted as Part of the 1974 NASA/Ames Shuttle CVT-II. Report No. EPL 74-1, Environmental Physiology Laboratory, University of California, Berkeley, June 1974, pp. 1-45.

[6] Rahlmann, D. F., A. M. Kodama, R. C. Mains and N. Pace. Results from the EPL Monkey-Pod Experiment Conducted as Part of the 1974 NASA/MSFC CVT/GPL III. Report No. EPL 74-2, Environmental Physiology Laboratory, University of California, Berkeley, October 1974, pp. 1-52.

[7] McCutcheon, E. P., R. Miranda, T. B. Fryer and E. L. Carlson. An inductively powered implantable multichannel telemetry system for cardiovascular data. In: Proceedings of the 3rd International Symposium on Biotelemetry, H. P. Kimmich and T. B. Fryer (Editors). Academic Press, New York, 1976, pp. 71-74.

2-pod experiment system was deemed to be highly satisfactory, and the results were presented in a detailed report[8].

In October 1976 an official decision was reached by the NASA/Ames and NASA/JSC SMD III Intercenter Review Board to conduct 3 separate monkey experiments and to support a rat experiment with the EPL 2-pod system as part of SMD III under the rubric "Project 76". Scientific coordination responsibility for Project 76 was assigned to Dr. E. P. McCutcheon of NASA/Ames as Cognizant Investigator. Engineering coordination responsibility was assigned to Mr. James P. Connally of NASA/Ames as Project Engineer. Both of these individuals had previously played key roles in the success of the CV-990 flight experiment, and both greatly facilitated the development and successful implementation of SMD III, Project 76. The SMD III Intercenter Review Board also announced their selection of Dr. William E. Thornton of the NASA/JSC Astronaut Office as Mission Specialist for SMD III, Dr. W. Carter Alexander of NASA/JSC as Payload Specialist, and Dr. Bill Williams of NASA/Ames as Payload Specialist. Dr. Alexander was assigned particular responsibility for the implementation of the Project 76 monkey experiments during the simulated flight scheduled for May 1977. All three flight crew members contributed importantly to the success of Project 76, and merit high commendation.

The 3 monkey experiments comprising Project 76 were

- SMD III Experiment #44, N. Pace, Principal Investigator
  "Metabolic and Cardiovascular Adaptation - Monkey"
  Pod A *Macaca nemestrina*

- SMD III Experiment #18, E. P. McCutcheon, Principal Investigator
  "Cardiovascular Dynamics - Monkey"
  Pod B *Macaca nemestrina*

- SMD III Experiment #33, H. Leon, Principal Investigator
  "Hemolysis - Monkey"
  Pod B *Macaca nemestrina*

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8 Rahlmann, D. F., A. M. Kodama, R. C. Mains and N. Pace. Results from the EPL Monkey-Pod Flight Experiments Conducted Aboard the NASA/Ames CV-990, May 1976. Report No. EPL 76-1, Environmental Physiology Laboratory, University of California, Berkeley, July 1976, pp. 1-137.

PHYSIOLOGICAL RESULTS

The subhuman primate subject of Experiment #44 was a male, adult, pig-tailed monkey *(Macaca nemestrina)* from the EPL colony, serial number 423. The animal was transferred to the NASA/Ames colony on 16 November 1977, and a NASA/Ames inductively powered multichannel biotelemetry system[7] was surgically implanted on 17 February 1977, 3 months before the start of SMD III on 14 May 1977.

The biotelemetry unit comprised transducers for continuous monitoring of electrocardiogram, mean aortic pressure, mean left ventricular pressure, and intrathoracic temperature, as well as a radiofrequency transmitter and a battery power supply inductively rechargeable through the body surface without disturbance to the animal. Recovery from surgery was uneventful, and on 1 April 1977 the animal was transferred by air to the NASA/JSC colony.

Throughout the experimental period monkey 423 subsisted on the standard colony regimen of Purina Monkey Chow and water provided *ad libitum.* The animal had attained a stable body mass of 10.0-10.5 kg before entering the experiment, and maintained this level for the duration of the experiment.

On insertion into Pod A on 14 May 1977 the body mass was 10.11 kg. On removal from Pod A on 25 May 1977 the body mass was 10.45 kg. The animal consumed 2.11 kg of food pellets during the 11-day stay in the pod. The caloric equivalent of the food was 4.0 kcal/g, so that the animal took in a total of 8,440 kcal of food energy during the experiment.

The ambient cabin temperature within the Spacelab Simulator, in which Pod A was located, ranged from a low value of 19.4°C to a high value of 22.3°C, as shown in Table 1. The mean cabin temperature during the entire 11-day experiment was 20.8°C. The upper pod was ventilated continuously with an inflow of fresh cabin air at a measured rate that ranged from 8.07 to

8.64 liters/min, as shown in Table 2. The mean upper pod ventilation rate for the 11-day experiment period was 8.39 liters/min with a standard deviation of ± 0.12 liters/min. This level of upper pod ventilation served to maintain the internal upper pod temperature within a range of from 20.7°C to 23.4°C during the experiment, as may be seen in Table 3. The mean upper pod temperature was 22.1°C with a standard deviation of ± 0.6°C. Thus, the upper pod temperature averaged 1.3°C higher than the cabin temperature during the experiment.

The upper pod ventilation rate employed was predicated on the requirement for maintaining a reliably measurable oxygen and carbon dioxide concentration differential between fresh air intake and exhaust gas from the upper pod in order to measure respiratory gas exchange. This requirement did not apply to the lower pod; hence, a higher ventilation rate of 10-15 liters/min was used, which sufficed to keep the lower pod temperature essentially the same as the cabin air temperature.

The instrument used for measurement of the upper pod exhaust gas concentrations was a mass spectrometer developed by the Perkin-Elmer Corporation for the NASA Skylab Project, which has the requisite sensitivity and stability for physiological gas measurements of this kind[10]. Fractional concentrations of oxygen and carbon dioxide in the upper pod exhaust gas were recorded once every 4 min, and hourly means were computed from these values throughout the 11-day experiment. Oxygen concentration in the upper pod ranged from 18.93% to 20.04%, as shown in Table 4, with a mean value of 19.41% and standard deviation of ± 0.20%. Carbon dioxide concentration in the upper pod ranged from 0.52% to 1.27%, as shown in Table 5, with a mean value of 0.85% and

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[10] Michel, E. L., J. A. Rummel and C. F. Sawin. Skylab experiment M-171 "Metabolic Activity" - results of the first manned mission. Acta Astronautica, 2: 351-365, 1975.

standard deviation of ± 0.13%. The barometric pressure ranged from 755.9 torr to 762.3 torr, with a mean value of 759.1 torr and a standard deviation of ± 2.1 torr during the course of the experiment. Thus, the ambient atmosphere for the monkey in Pod A comprised partial pressures of about 145-150 torr oxygen and 5-6 torr carbon dioxide, equivalent to an altitude of 500 m above sea level.

Respiratory gas exchange rates for the Pod A monkey were computed from the differences between the 4-min fractional oxygen and carbon dioxide concentrations of the pod exhaust gas and the fractional composition of normal cabin air, together with the upper-pod gas flow rates. Oxygen consumption rate ($\dot{V}_{O_2}$) was found to range from 3.78 liters/hr STP to 7.23 liters/hr STP during the course of the 11-day experiment, as shown in Table 6. The mean oxygen consumption rate for the total period was 5.10 liters/hr STP ± 0.70 liters/hr STP standard deviation. Carbon dioxide production rate ($\dot{V}_{CO_2}$) ranged from 3.02 liters/hr STP to 6.35 liters/hr STP, as may be seen in Table 7. The mean carbon dioxide production rate was 4.24 liters/hr STP with a standard deviation of ± 0.68 liters/hr STP.

The respiratory quotient, or respiratory ratio, was computed as $\dot{V}_{CO_2}/\dot{V}_{O_2}$ for each 4-min reading and was expressed as hourly mean values in Table 8. The respiratory quotient ranged from 0.703 to 0.997 in the course of the 11-day experiment, with a mean value of 0.831 and standard deviation of ± 0.063.

The intrathoracic temperature measured by the implanted biotelemetry unit was recorded at 1-min intervals, and hourly mean values were computed for the 11-day duration of the experiment as shown in Table 9. The intrathoracic temperature ranged between 36.13°C and 39.03°C, with a mean value of 37.55°C and standard deviation of ± 0.68°C.

Heart rate, mean aortic pressure, and mean left ventricular pressure were likewise measured by the implanted biotelemetry unit, recorded at 1-min intervals, and computed as hourly mean values. Heart rate was found to range from 106 beats/min to 196 beats/min during the course of the 11-day experiment, as seen in Table 10. The mean heart rate during the entire experiment was 152 beats/min, with a standard deviation of $\pm$ 20 beats/min. Mean aortic pressure ranged between 102 torr and 171 torr, as seen in Table 11, with an 11-day mean value of 131 torr $\pm$ 14 torr standard deviation. Mean left ventricular pressure exhibited a range between 58.8 torr and 96.8 torr, as shown in Table 12. The overall 11-day mean value of mean left ventricular pressure was found to be 78.3 torr with a standard deviation of $\pm$ 7.6 torr.

The mean hourly values for oxygen consumption rate and carbon dioxide production rate for the entire 11-day experiment are plotted in Fig. 2, together with the respiratory quotient values. Also shown by a dashed line in each case is the mean hourly value for the 48 hr just prior to Launch. The monkey pod was illuminated from 0700 to 2100 and darkened from 2100 to 0700 each day of the experiment.

A similar plot of the mean hourly values for the three cardiovascular parameters measured, heart rate, mean aortic pressure, and mean left ventricular pressure, is shown in Fig. 3. Again, the dashed line in each case indicates the mean hourly value for the 48 hr just prior to Launch.

The mean hourly values for the intrathoracic temperature or the animal, the upper pod air temperature, and the Spacelab Simulator cabin air temperature are plotted in Fig. 4. The dashed line in each case once more indicates the mean hourly value for the 48 hr just before Launch.

In order to bring out diurnal differences, the respiratory gas-exchange parameters, the cardiovascular parameters, and the temperature parameters except for cabin air were expressed in each case as mean hourly values for the 14-hr light periods, 0700-2100, and the 10-hr dark periods, 2100-0700, during the course of the 11-day experiment. These mean day and night values are shown in Fig. 5, where it may be seen that many, but not all, of the parameters displayed a clear diurnal variation.

The differences between the day values and the night values for the 11 days were compared by t test, and the results are shown in Table 13. It is evident that oxygen consumption rate, carbon dioxide production rate, heart rate, intrathoracic temperature and upper pod air temperature all displayed highly significant diurnal variation statistically ($P < .05$), whereas respiratory quotient, mean aortic pressure and mean left ventricular pressure did not exhibit demonstrable diurnal variation.

In addition to diurnal variation, the physiological parameters measured revealed several general trends. The effect of the diurnal variation could be compensated by examining 24-hr sets of mean hourly values for each parameter during the 11-day experiment. Thus, a comparison by t test was made of the hourly values during the 48-hr preflight period from 0800 on day 135 to 0800 on day 137, with the hourly values during the 144 hr comprising the bulk of the flight period from 0800 on day 137 to 0800 on day 143, and with the hourly values during the 48-hr postflight period from 0800 on day 143 to 0800 on day 145. The results of these comparisons for each parameter are given in Table 14.

As is evident from inspection of Fig. 2 and the data in Table 14, the oxygen consumption rate of the animal displayed a significant increase of about 20% starting on the evening of day 140 and through day 141. The increase then abated, and oxygen consumption rate was back to the preflight levels during the postflight period.

Carbon dioxide production rate tended to follow the same pattern, except that there was apparently a gradual overall reduction in production rate during the course of the 11 days, as evidenced further by a gradual decline in respiratory quotient during the experiment. The reason for the decline is not clear, inasmuch as the food intake during this period appeared to be adequate. As mentioned earlier, the Pod A monkey took in a total of 8,440 kcal during the 11-day period, and exhibited a slight gain in body mass of 0.34 kg. At the same time, the animal consumed a total of 1,306 liters of oxygen. Assuming a caloric equivalent of 4.85 kcal of food energy liberated per liter of oxygen consumed, the animal produced a total of 6,330 kcal in 11 days. Thus, the animal apparently took in 2,110 kcal of excess food energy. If the excess energy had all been stored as fat a net gain of 0.23 kg in body mass would have been expected, in good agreement with the net gain of 0.34 kg observed.

Fig. 3 and the data in Table 14 indicate that heart rate, mean aortic pressure and mean left ventricular pressure all exhibited a statistically significant increase during the flight period. These increases coincided roughly in time with the increase in oxygen consumption rate, and the degree of correspondence is brought out by Fig. 6. Here, each 24-hr mean value for oxygen consumption rate, heart rate and mean aortic pressure is plotted as a percentage value of the 48-hr preflight mean value, and both similarities and dissimilarities are evident in the time-course patterns displayed.

Oxygen consumption rate showed a tendency to start increasing on day 139-140, reached a peak value during day 140-141, and then returned to preflight levels during the 48-hr postflight period. Heart rate seemed to start increasing a day earlier but also reached a peak value on day 140-141, and then declined only gradually during the remainder of the study and was still elevated over preflight levels during the 48-hr postflight period.

Mean aortic pressure apparently increased abruptly during day 139-140, and remained significantly elevated at the higher level for the remainder of the study. Carbon dioxide production rate, not shown in Fig. 6, behaved in similar fashion to oxygen consumption rate, except for the previously noted decline in absolute level so that the postflight values were significantly lower than the preflight values. Mean left ventricular pressure, also not shown in Fig. 6, behaved in closely parallel fashion to mean aortic pressure.

Although the changes in the gas-exchange and cardiovascular parameters were not large, they were significant. A possible common explanation for the changes may be that the general physical activity of the animal increased midway through the flight period. While the extra physical activity abated toward the end of the experiment, concomitant sympathetic nervous activation may have persisted for a longer time. Alternative explanations are of course possible.

The behavior of the intrathoracic temperature of the Pod A animal, seen in Fig. 4 and in the data of Table 14, is of considerable interest. A slow, general rise appeared to begin during the night of day 139, despite the relative constancy of the ambient pod air temperature, agreeing well with the increased heat production by the animal signaled by the simultaneous increase in oxygen consumption rate. However, the body temperature continued to increase during the later stages of the experiment while the oxygen consumption was returning to the preflight levels, so that mean intrathoracic temperature during the 48-hr postflight period was 1.3°C higher than the mean during the 48-hr preflight period. If the animal had truly become hyperthermic, oxygen consumption rate should have shown an increase.

At least two explanations may be considered for the seemingly paradoxical intrathoracic temperature results. It is possible that the continuing sympathetic activation suggested by the behavior of the cardiovascular parameters included a corresponding state of vasoconstriction of the vasculature of the skin, with a reduction in heat transfer out of the body and consequent slight elevation in deep body temperature. Alternatively, it is possible that a slight drift could have occurred electronically in the circuitry of the thermistor temperature transducer in the course of the experiment. Practical circumstances permitted calibration checks on the cardiovascular transducers of the biotelemetry unit at the end of the experiment, but not on the temperature transducer.

The degree of statistical correlation between the various parameters measured was examined by computing the Pearson r correlation coefficient for the 256 hourly values in each member of pairs of parameters. The correlation matrix which resulted is shown as Table 15.

Oxygen consumption rate was statistically significantly correlated ($P < .05$) to varying degree with all the other parameters measured. As might be expected, it was highly correlated with carbon dioxide production rate ($r = 0.89$), moderately well correlated with heart rate ($r = 0.66$), and slightly correlated with mean blood pressure and intrathoracic temperature. There was even a very small, but significant, correlation with upper pod temperature. Carbon dioxide production rate, while statistically significantly correlated with the cardiovascular parameters and temperature parameters in most instances, exhibited consistently lower levels of correlation than those with oxygen consumption rate.

Heart rate showed a moderately strong correlation with mean aortic pressure, mean left ventricular pressure, and intrathoracic temperature, but no significant correlation with upper pod temperature. Mean aortic pressure, again as fully expected, displayed a very high correlation (r = 0.92) with mean left ventricular pressure, and both pressure parameters correlated moderately well with intrathoracic temperature.

Of particular interest was the finding that intrathoracic temperature was not significantly correlated with upper pod temperature, while it showed a small, but significant, negative correlation with mean aortic pressure and mean left ventricular pressure. A possible explanation may well be that an important component in the thermoregulatory mechanism for maintenance of body temperature in the face of variation in ambient temperature is the skin vasomotor response. Thus, one would expect the degree of skin vasoconstriction to be negatively correlated with ambient air temprature, thereby accounting for the negative correlation observed between blood pressure and ambient air temprature. Such an explanation would also be consistent with one of the explanations offered above for the anomalous time course of the absolute level of intrathoracic temperature during the course of the experiment.

GENERAL DISCUSSION

Experiment #44 of SMD III Project 76 was successful in demonstrating that metabolic and cardiovascular parameters of fundamental importance in delineating the physiological effects of weightlessness can be measured continuously in a comfortably restrained subhuman primate during a typical Spacelab mission. Although Experiment #44 utilized only Pod A of the EPL 2-pod experiment system, and the results from Experiments #18 and #33 on the Pod B monkey and Experiment #59 on rat metabolism are being reported separately, it may also be stated that the EPL 2-pod system in general performed well. However, a number of improvements in experiment design, procedures and apparatus would be required for most effective research use of the system in Spacelab.

The initial requirements submitted in connection with Experiment #44 clearly stipulated that the experimental period should begin 7 days before "Launch" to provide an appropriate preflight control period of measurements, and should continue for 7 days after "Landing" to provide an adequate postflight measurement period. However, practical SMD III management constraints resulted in curtailment of the pre- and postflight periods to 2 days each. From the results presented in the preceding section, it is evident that longer pre- and postflight measurement periods were necessary for full interpretation of the findings. Thus, appropriate provision should be made in Spacelab mission planning for adequate pre- and postflight periods as an integral part of experiments that require such controls.

Another basic requirement for Experiment #44 as originally proposed was that two animals be used as subjects, in order to provide some statistical validity for the findings. It is rudimentary in biological research that experiments should involve more than one subject, because of the well-established phenomenon of individual variation among members of the same species. It is also elemental that the greater the number of subjects examined in a given experiment, the greater is the predictive potential of the findings for the species as a whole. While practicality usually limits subject number to a few individuals in many physiological experiments, one subject is only marginally useful in defining the characteristics of a population while two subjects provide at least some indication of individual dispersion. Thus, appropriate provision should be made in Spacelab mission planning for multiple subjects for experiments.

A puzzling feature of the results from Experiment #44 was the occurrence of an apparent physiological transient that began on about the 3rd day of the flight, day 139, which indicated increased physical activity and sympathetic nervous system alerting of the animal subject. It is possible that this may have been the result of an environmental stimulus such as increased flight crew activity within the Spacelab Simulator during this period. That experimental animals are sensitive to unusual environmental activity is well known, and the experimenter is usually able to note such aberrations and take them into account. Under the Spacelab format adopted by NASA of a few flight crew members performing a variety of experiments remotely for a number of primary investigators, it is difficult for the latter to perceive and judge all details of the actual environmental conditions under which the experiments are being performed. Thus, particular attention must be given in Spacelab mission planning to rigorous definition and control of experiment total environment, including careful flight-crew activity training. This is especially important with respect to animal experiments.

The appearance of the physiological transient during Experiment #44 also points up the central importance of adequate ground-control experiments for experiments designed to study the effects of weightlessness. Such control experiments should be conducted in as close a simulation of the flight environment as possible, save for the presence of weightlessness, and serve the function of providing a suitable physiological base line against which to judge the effects of weightlessness *per se*.

It is also possible that a contributory factor in the occurrence of the physiological transient observed during Experiment #44 may have been the relative inexperience of the subject animal in the pod environment. Again, practical management constraints on the preparations for SMD III precluded sufficient prior training of the potential subjects for the experiment. It has been the experience of this laboratory that the animals become much more stable physiologically after the first few pod sessions, but for various reasons beyond our control the monkey used in Experiment #44 was only partially trained with respect to the pod environment. Thus, it is important that due consideration be given in Spacelab mission planning to the provision of sufficient lead time for the development of an adequate pool of well-trained animals from which the final selection of flight subjects is to be made.

Several mechanical improvements or alterations continue to be required before the monkey-pod experiment system can be considered fully flight ready. As has been pointed out previously, a need exists to provide reliable food and water dispensing mechanisms that will permit continuous recording of eating and drinking activity in the weightless state. The present feeding and watering devices depend on a gravity supply and are not suitable for flight. However, monkey feeding and watering devices were developed for NASA Biosatellite III that worked successfully under zero-*g* conditions, so a novel development is not necessary. Also, a limitation on the number of data channels available in SMD III precluded continuous, real-time, quantitative indication of eating and drinking activity of the Experiment #44 monkey. Such information is not only required for detailed analysis of the scientific results, but it is also needed as an indicator of the physiological well-being of the subject animal during the course of the experiment.

The pod ventilation system employed during SMD III consisted simply of drawing in Spacelab Simulator cabin air, and dumping the exhaust gases outside the Simulator. It is likely that a pod gas management subsystem will be needed for flight experiments, in which the exhaust gases may be suitably processed by filtration, adsorption and the like for recycling into the Spacelab stmosphere.

Finally, additional attention must be paid to the development of an optimal diet for monkey metabolism experiments in Spacelab. During SMD III, pellets of standard monkey chow were used but, as has been pointed out previously, these had several major drawbacks. The pellets used tended to crumble and interfere with the mechanical feeder function during the course of the experiment. More seriously, the standard formulation of monkey chow includes a relatively large percentage of relatively low-grade protein nutritionally, and an unnecessarily high calcium content for adult animals. Thus, excessive nitrogen and calcium are excreted by the animal, thereby significantly reducing the accuracy of elemental metabolic balance studies. Efforts to develop a fully acceptable diet formulation to circumvent these problems are currently in progress in this laboratory.

Mention should be made of the highly effective manner in which the data handling, storage, and preliminary reduction functions for Experiment #44 were discharged during SMD III by NASA and Technology Incorporated personnel. The large mass of numerical data generated by Experiment #44 would have been a severe burden on this laboratory before the results could have been interpreted, and the data processing help provided represented a significant contribution to the success of Experiment #44.

Table 1. Spacelab Simulator cabin temperature in degrees Celsius during SMD III Experiment #44. Values are hourly means of 1-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

	Calendar Day											
CST	134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		19.8	20.1	21.9	21.4	21.1	21.2	20.6	20.4	20.9	20.6	19.9
0100-0200		19.7	20.1	22.1	20.9	20.8	20.7	20.2	20.0	20.0	20.6	19.7
0200-0300		19.7	20.1	22.0	20.5	20.1	20.5	20.0	19.7	19.7	20.6	19.7
0300-0400		19.7	20.0	22.1	20.3	19.7	20.3	20.0	19.7	19.5	20.7	19.7
0400-0500		19.8	20.2	21.5	20.5	19.7	20.1	19.9	19.5	19.9	20.6	19.7
0500-0600		19.7	20.2	21.9	20.7	19.5	20.1	19.9	19.5	21.1	20.5	19.8
0600-0700		19.6	19.9	22.0	20.3	19.5	20.0	19.9	19.4	21.5	20.6	19.8
0700-0800		19.6	20.5	21.8	20.6	19.4	19.9	20.2	19.8	20.9	20.4	20.7
0800-0900		19.7	21.1	21.9	20.5	19.9	20.1	20.5	21.1	20.7	20.3	21.3
0900-1000		19.6	21.2	21.7	21.2	21.1	20.5	20.8	20.7	20.9	20.4	20.9
1000-1100		20.6	21.1	21.8	21.1	20.8	20.4	21.0	21.0	21.4	21.1	
1100-1200		20.7	21.2	21.7	21.3	20.7	20.4	22.2	21.1	20.2	21.8	
1200-1300		20.7	21.4	21.2	21.5	20.5	20.3	22.2	21.1	20.9	21.3	
1300-1400		20.7	21.0	21.7	21.4	20.2	20.5	21.9	21.3	21.5	20.3	
1400-1500		20.7	21.2	21.5	21.0	20.5	20.7	22.1	21.1	20.7	20.3	
1500-1600		20.8	21.3	21.6	21.1	20.8	21.0	22.1	20.9	21.2	21.3	
1600-1700		20.7	21.5	21.6	20.2	20.8	21.3	22.1	21.6	21.5	21.5	
1700-1800		20.5	21.5	21.5	19.6	21.0	20.9	21.9	22.0	21.9	21.5	
1800-1900	20.1	20.2	21.6	21.6	21.3	21.1	20.9	21.7	22.3	22.1	21.6	
1900-2000	20.0	20.3	21.8	21.6	21.3	21.2	20.8	21.4	22.1	22.2	21.1	
2000-2100	20.1	20.3	21.5	21.4	21.2	21.4	20.7	21.3	22.0	22.3	19.9	
2100-2200	19.9	20.2	21.9	21.6	21.6	21.3	20.9	21.1	21.8	21.0	19.7	
2200-2300	19.9	20.4	21.6	21.4	21.5	21.5	21.0	21.2	21.4	20.7	20.3	
2300-2400	19.8	20.2	21.5	21.5	21.3	21.4	21.0	21.1	20.7	20.7	20.2	

Table 2. Upper Pod A ventilation rate in liters per minute during SMD III Experiment #44. Values are hourly means of 4-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		8.39	8.38	6.31	8.48	8.52	8.45	8.57	8.52	8.36	8.18	8.36
0100-0200		8.38	8.37	8.29	8.45	8.50	8.45	8.57	8.50	8.35	8.17	8.32
0200-0300		8.37	8.36	8.29	8.43	8.49	8.46	8.57	8.50	8.33	8.16	6.23
0300-0400		8.36	8.36	8.28	8.41	8.47	8.44	8.58	8.49	8.30	8.11	8.26
0400-0500		8.35	8.36	8.26	8.39	8.46	8.44	8.59	8.48	8.28	8.10	8.24
0500-0600		8.35	8.36	8.26	8.37	8.45	8.42	8.57	8.48	8.28	8.08	8.22
0600-0700		8.36	8.37	8.25	8.34	8.46	8.43	8.59	8.47	8.27	8.07	8.20
0700-0800		8.36	8.38	8.25	8.34	8.47	8.43	8.59	8.47	8.27	8.07	8.18
0800-0900		8.38	8.41	8.24	8.33	8.50	8.44	8.60	8.49	8.28	8.08	8.20
0900-1000		8.38	8.42	8.24	8.33	8.54	8.46	8.61	8.49	8.28	8.08	8.21
1000-1100		8.39	8.42	8.23	8.34	8.56	8.47	8.63	8.49	8.29	8.10	
1100-1200		8.39	8.37	8.26	8.37	8.56	8.45	8.63	8.49	8.30	8.10	
1200-1300		8.39	8.36	8.27	8.37	8.54	8.45	8.63	8.48	8.30	8.24	
1300-1400		8.39	8.36	8.27	8.35	8.53	8.43	8.63	8.48	8.31	8.37	
1400-1500		8.39	8.35	8.48	8.40	8.45	8.37	8.63	8.40	8.31	8.37	
1500-1600		8.40	8.36	8.63	8.44	8.36	8.35	8.64	8.43	8.31	8.39	
1600-1700		8.41	8.38	8.64	8.43	8.36	8.35	8.51	8.41	8.30	8.38	
1700-1800		8.40	9.37	8.63	8.41	8.34	8.34	8.51	8.40	8.28	8.35	
1800-1900	8.48	8.39	8.36	8.61	8.42	8.33	8.35	8.51	8.40	8.27	8.32	
1900-2000	8.49	8.40	8.36	8.60	8.41	8.33	8.39	8.52	8.39	8.26	8.29	
2000-2100	6.39	8.39	8.35	8.60	8.43	8.33	8.44	8.52	8.40	8.25	8.26	
2100-2200	8.39	8.38	8.34	8.58	8.50	8.34	8.48	8.52	8.41	8.25	8.25	
2200-2300	8.40	8.39	8.33	8.56	8.55	8.34	8.52	8.52	8.41	8.22	8.23	
2300-2400	8.39	8.39	8.31	8.54	8.55	8.40	8.57	8.52	8.39	8.19	8.37	

Table 3. Upper Pod A internal temperature in degrees Celsius during SMD III Experiment #44. Values are hourly means of 1-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		21.2	21.4	23.0	22.7	22.6	22.2	22.2	21.9	22.0	21.9	21.3
0100-0200		21.1	21.5	23.2	21.8	22.2	21.8	22.1	21.3	21.4	21.9	21.1
0200-0300		21.1	21.7	23.2	21.7	21.6	21.7	21.9	21.1	21.1	21.9	21.0
0300-0400		21.2	21.7	23.3	21.5	21.3	21.4	21.9	21.0	20.9	21.9	21.0
0400-0500		21.1	21.8	22.7	21.5	21.1	21.4	21.7	20.8	21.0	21.9	21.0
0500-0600		21.2	21.7	22.9	21.7	21.1	21.3	21.5	20.8	21.8	21.9	20.9
0600-0700		21.6	21.8	23.2	21.5	20.8	21.3	21.7	20.7	22.3	21.9	20.9
0700-0800		21.6	22.0	23.0	21.6	20.9	21.5	22.0	20.9	22.2	21.9	21.5
0800-0900		21.9	22.2	23.0	21.5	21.3	21.7	22.2	22.1	22.1	21.8	22.1
0900-1000		21.7	21.5	23.0	22.2	22.4	21.7	22.5	22.0	22.3	21.7	22.0
1000-1100		22.3	22.3	23.0	22.5	22.1	21.9	22.5	22.1	22.5	22.1	
1100-1200		22.3	22.2	23.0	22.6	22.2	21.9	23.3	22.1	21.6	22.7	
1200-1300		22.3	22.5	22.8	22.7	22.0	21.9	23.4	22.3	21.9	22.4	
1300-1400		22.3	22.3	23.0	22.5	21.8	22.1	23.3	22.1	22.4	21.6	
1400-1500		22.3	22.5	22.7	22.1	21.7	22.1	23.3	21.9	22.1	21.7	
1500-1600		22.0	22.6	22.6	22.1	21.7	21.9	23.0	22.1	21.9	22.3	
1600-1700		22.0	22.7	22.8	21.5	22.0	22.4	22.7	22.2	22.6	22.6	
1700-1800		22.0	22.8	22.8	21.1	22.2	22.3	22.9	22.7	22.8	22.7	
1800-1900	22.7	21.8	23.1	22.7	22.3	22.2	22.3	22.7	22.9	23.0	22.6	
1900-2000	22.1	21.8	22.8	22.8	22.4	22.3	22.2	22.8	22.9	23.1	22.4	
2000-2100	21.8	21.7	23.0	22.8	22.7	22.5	22.5	22.7	23.1	23.1	21.7	
2100-2200	21.6	21.5	23.1	22.9	23.1	22.6	22.6	22.8	22.9	22.5	21.3	
2200-2300	21.5	21.7	22.8	22.6	22.9	22.6	22.7	22.6	22.6	22.1	21.6	
2300-2400	21.3	21.5	22.7	22.7	22.7	22.6	22.7	22.2	22.2	21.9	21.6	

Table 4. Fractional per cent oxygen in Upper Pod A exhaust gas during SMD III Experiment #44. Values are hourly means of 4-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day											
	134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		19.58	19.70	19.52	19.59	19.56	19.44	19.24	19.29	19.34	19.43	19.57
0100-0200		19.66	19.72	19.55	19.59	19.50	19.33	19.14	19.45	19.26	19.52	19.59
0200-0300		19.66	19.64	19.44	19.60	19.57	19.23	19.15	19.29	19.09	19.49	19.53
0300-0400		19.61	19.58	19.56	19.62	19.50	19.29	19.13	19.43	19.39	19.41	19.56
0400-0500		19.71	19.49	19.57	19.62	19.60	19.24	18.93	19.44	19.39	19.41	19.52
0500-0600		19.63	19.67	19.51	19.55	19.49	19.29	19.17	19.25	19.25	19.41	19.56
0600-0700		19.36	19.48	19.55	19.56	19.59	19.21	18.93	19.49	19.13	19.50	19.55
0700-0800		19.38	19.50	19.65	19.60	19.40	19.09	19.08	19.37	19.21	19.35	19.50
0800-0900		19.21	19.11	19.56	19.51	19.16	19.21	19.10	19.21	19.14	19.31	19.14
0900-1000		19.47	19.59	19.61	19.41	19.26	19.23	19.17	19.29	19.30	19.32	19.33
1000-1100		19.45	19.57	19.51	19.36	19.38	19.24	19.11	19.16	19.28	19.26	
1100-1200		19.53	19.51	19.21	19.41	19.39	19.16	19.15	19.20	19.25	19.44	
1200-1300		19.48	19.50	19.26	19.58	19.47	19.19	19.09	19.25	19.22	19.37	
1300-1400		19.32	19.34	19.43	19.56	19.46	19.17	19.17	19.39	19.20	19.41	
1400-1500		19.42	19.35	19.64	19.56	19.35	19.20	19.33	19.34	19.18	19.43	
1500-1600		19.55	19.48	19.73	19.57	19.84	19.58	19.21	18.94	19.36	19.39	
1600-1700		19.37	19.28	19.30	19.39	19.97	19.25	19.13	19.15	19.42	19.49	
1700-1800		19.56	19.34	19.46	19.50	20.04	19.11	19.20	19.13	19.58	19.47	
1800-1900	19.22	19.63	19.53	19.48	19.24	19.95	19.07	19.11	19.11	19.40	19.45	
1900-2000	19.50	19.46	19.56	19.52	19.48	19.98	19.14	19.17	19.03	19.43	19.43	
2000-2100	19.52	19.69	19.56	19.50	19.38	19.83	19.07	19.17	19.07	19.47	19.52	
2100-2200	19.63	19.70	19.57	19.53	19.21	19.68	19.04	19.04	19.19	19.50	19.39	
2200-2300	19.38	19.54	19.57	19.54	19.54	19.54	19.17	19.42	19.19	19.56	19.58	
2300-2400	19.68	19.69	19.61	19.54	19.53	19.49	19.10	19.38	19.27	19.57	19.60	

Table 5. Fractional per cent carbon dioxide in Upper Pod A exhaust gas during SMD III Experiment #44. Values are hourly means of 4-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		0.92	0.74	0.85	0.71	0.67	0.77	0.89	0.89	0.76	0.82	0.65
0100-0200		0.84	0.72	0.79	0.72	0.71	0.86	0.98	0.76	0.87	0.74	0.63
0200-0300		0.85	0.77	0.85	0.72	0.66	0.90	0.98	0.90	1.01	0.74	0.67
0300-0400		0.89	0.84	0.76	0.71	0.73	0.85	1.02	0.78	0.74	0.81	0.65
0400-0500		0.81	0.90	0.77	0.71	0.64	0.89	1.23	0.78	0.76	0.81	0.67
0500-0600		0.87	0.76	0.80	0.75	0.73	0.85	1.04	0.93	0.86	0.60	0.64
0600-0700		1.11	0.92	0.74	0.74	0.66	0.90	1.23	0.72	0.93	0.74	0.64
0700-0800		1.04	0.88	0.67	0.68	0.80	1.01	1.10	0.83	0.85	0.66	0.65
0800-0900		1.18	1.27	0.74	0.78	0.96	0.87	1.07	0.90	0.97	0.87	0.90
0900-1000		0.91	0.90	0.71	0.82	0.89	0.86	0.99	0.85	0.84	0.86	0.75
1000-1100		0.90	0.90	0.79	0.84	0.84	0.86	1.05	0.98	0.89	0.89	
1100-1200		0.84	0.93	0.98	0.81	0.81	0.89	1.00	1.00	0.94	0.78	
1200-1300		0.93	0.96	0.95	0.70	0.75	0.87	1.02	0.92	0.99	0.82	
1300-1400		1.11	1.07	0.84	0.71	0.77	0.87	0.92	0.79	1.05	0.85	
1400-1500		0.94	1.03	0.71	0.52	0.87	0.86	0.83	0.70	1.11	0.84	
1500-1600		0.96	0.86	0.71	0.67	0.81	0.70	0.92	1.08	0.88	0.82	
1600-1700		1.05	1.09	1.03	0.78	0.78	0.89	0.99	0.96	0.83	0.72	
1700-1800		0.85	1.02	0.87	0.69	0.70	0.99	0.96	0.97	0.71	0.73	
1800-1900	1.18	0.80	0.85	0.83	0.86	0.76	1.08	0.97	1.00	0.84	0.74	
1900-2000	0.94	0.97	0.83	0.78	0.72	0.79	1.02	0.89	1.07	0.81	0.75	
2000-2100	0.94	0.76	0.82	0.80	0.81	0.90	1.08	0.90	1.02	0.77	0.69	
2100-2200	0.87	0.76	0.81	0.78	0.92	1.02	1.09	1.02	0.86	0.75	0.80	
2200-2300	1.07	0.86	0.80	0.79	0.64	1.14	0.95	0.73	0.86	0.72	0.65	
2300-2400	0.82	0.73	0.73	0.77	0.68	0.95	0.98	0.79	0.82	0.71	0.62	

Table 6. Oxygen consumption rate in liters per hour STP of Pod A monkey during SMD III Experiment #44. Values are hourly means of 4-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicates by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		4.88	4.06	4.58	4.34	4.35	4.36	5.57	5.36	4.62	5.11	4.35
0100-0200		4.30	4.03	4.39	4.44	4.64	4.97	6.15	4.59	5.10	4.62	4.23
0200-0300		4.52	4.42	4.87	4.39	4.34	5.34	6.07	5.40	5.94	4.73	4.49
0300-0400		4.54	4.69	4.26	4.30	4.75	5.08	6.23	4.70	4.44	5.07	4.34
0400-0500		4.10	5.04	4.31	4.30	4.22	5.32	7.23	4.64	4.44	5.06	4.48
0500-0600		4.45	4.18	4.55	4.53	4.74	5.13	6.00	5.59	5.03	5.03	4.27
0600-0700		5.77	5.10	4.32	4.49	4.26	5.47	7.22	4.36	5.48	4.60	4.29
0700-0800		5.61	5.01	4.06	4.20	5.19	6.05	6.42	4.91	5.12	5.27	4.40
0800-0900		6.43	6.83	4.40	4.72	6.26	5.48	6.25	5.55	5.85	5.45	5.99
0900-1000		5.17	5.10	4.16	5.11	5.61	5.43	5.89	5.16	5.06	5.41	4.99
1000-1100		5.20	5.15	4.63	5.29	5.02	5.40	6.23	5.83	5.36	5.60	
1100-1200		4.79	5.22	5.95	4.98	5.03	5.69	5.88	5.61	5.67	4.76	
1200-1300		5.07	4.98	5.72	4.24	4.65	5.60	6.18	5.36	5.97	5.12	
1300-1400		5.81	5.65	4.85	4.44	4.81	5.69	5.74	4.69	6.28	5.34	
1400-1500		5.82	5.58	4.10	4.43	5.38	5.67	4.94	5.71	6.58	5.19	
1500-1600		4.86	4.94	4.04	4.42	4.67	4.35	5.52	6.74	5.64	5.27	
1600-1700		5.69	5.82	6.01	5.14	4.11	5.69	6.18	5.59	5.27	4.75	
1700-1800		4.73	5.48	5.17	4.60	3.78	6.35	5.77	5.62	4.43	4.82	
1800-1900	6.34	4.39	4.58	4.99	5.72	4.24	6.42	6.26	5.70	5.29	4.89	
1900-2000	4.99	5.23	4.45	4.74	4.75	4.08	6.03	5.94	6.10	5.10	4.97	
2000-2100	4.92	4.13	4.43	4.80	5.22	4.93	6.37	5.96	5.87	4.82	4.60	
2100-2200	4.43	4.11	4.33	4.62	5.93	5.78	6.52	6.60	5.27	4.75	5.25	
2200-2300	5.63	4.86	4.31	4.63	4.29	6.63	5.87	4.67	5.30	4.50	4.44	
2300-2400	4.21	4.08	4.15	4.60	4.35	5.50	6.25	4.98	4.98	4.41	4.21	

Table 7. Carbon dioxide production rate in liters per hour STP of Pod A monkey during SMD III Experiment #44. Values are hourly means of 4-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		4.56	3.63	4.15	3.55	3.32	3.84	4.51	4.48	3.77	3.95	3.17
0100-0200		4.12	3.49	3.84	3.58	3.55	4.30	4.99	3.83	4.30	3.52	3.05
0200-0300		4.15	3.77	4.18	3.54	3.28	4.53	5.02	4.55	5.03	3.55	3.24
0300-0400		4.36	4.13	3.68	3.49	3.62	4.26	5.23	3.90	3.62	3.86	3.11
0400-0500		3.98	4.43	3.71	3.50	3.17	4.44	6.31	3.91	3.71	3.83	3.24
0500-6000		4.29	3.71	3.88	3.67	3.62	4.26	5.33	4.70	4.22	3.81	3.05
0600-0700		5.50	4.52	3.60	3.61	3.26	4.52	6.35	3.59	4.61	3.49	3.06
0700-0800		5.13	4.31	3.24	3.33	4.00	5.10	5.67	4.17	4.19	4.08	3.09
0800-0900		5.87	6.35	3.59	3.79	4.84	4.39	5.47	4.52	4.80	4.14	4.36
0900-1000		4.50	4.44	3.42	4.00	4.53	4.31	5.07	4.27	4.14	4.11	3.64
1000-1100		4.43	4.44	3.81	4.15	4.23	4.34	5.41	4.94	4.40	4.25	
1100-1200		4.15	4.55	4.78	3.99	4.10	4.49	5.14	5.05	4.67	3.70	
1200-1300		4.58	4.72	4.66	3.41	3.76	4.36	5.25	4.64	4.93	3.92	
1300-1400		5.53	5.29	4.10	3.47	3.89	4.34	4.75	3.96	5.20	4.20	
1400-1500		4.62	5.10	3.50	3.40	4.39	4.19	4.26	4.70	5.46	4.12	
1500-1600		4.86	4.58	3.55	3.32	3.93	3.40	4.76	5.44	4.31	4.06	
1600-1700		5.21	5.43	5.28	3.87	3.75	4.39	5.03	4.80	4.06	3.56	
1700-1800		4.21	5.06	4.43	3.41	3.35	4.93	4.85	4.89	3.45	3.60	
1800-1900	5.94	3.94	4.17	4.22	4.30	3.65	5.35	4.94	5.05	4.09	3.63	
1900-2000	4.71	4.80	4.06	3.92	3.56	3.79	5.10	4.51	5.41	3.91	3.67	
2000-2100	4.67	3.73	4.03	4.05	4.03	4.38	5.45	4.57	5.11	3.71	3.33	
2100-2200	4.27	3.73	3.95	3.91	4.63	4.96	5.51	5.16	4.29	3.64	3.87	
2200-2300	5.34	4.23	3.94	3.97	3.22	5.55	4.83	3.66	4.32	3.47	3.20	
2300-2400	4.04	3.56	3.82	3.87	3.38	4.69	4.98	3.97	4.07	3.39	3.02	

Table 8. Respiratory quotient of Pod A monkey during SMD III Experiment #44. Values are hourly averages of 4-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		0.942	0.894	0.906	0.817	0.764	0.880	0.810	0.835	0.814	0.772	0.730
0100-0200		0.958	0.867	0.875	0.807	0.764	0.864	0.812	0.834	0.843	0.761	0.721
0200-0300		0.929	0.855	0.858	0.806	0.756	0.848	0.826	0.843	0.845	0.752	0.720
0300-0400		0.959	0.881	0.865	0.812	0.762	0.837	0.839	0.829	0.816	0.760	0.717
0400-0500		0.971	0.880	0.861	0.812	0.752	0.835	0.873	0.842	0.836	0.757	0.721
0500-0600		0.963	0.889	0.853	0.809	0.763	0.831	0.887	0.841	0.838	0.758	0.716
0600-0700		0.952	0.887	0.835	0.804	0.764	0.827	0.880	0.824	0.841	0.759	0.712
0700-0800		0.915	0.860	0.798	0.789	0.770	0.843	0.884	0.849	0.819	0.775	0.703
0800-0900		0.911	0.930	0.816	0.802	0.774	0.800	0.875	0.816	0.820	0.760	0.728
0900-1000		0.871	0.869	0.322	0.784	0.809	0.793	0.861	0.827	0.816	0.760	0.729
1000-1100		0.852	0.871	0.822	0.784	0.843	0.804	0.866	0.848	0.819	0.759	
1100-1200		0.866	0.883	0.803	0.802	0.816	0.790	0.874	0.903	0.821	0.776	
1200-1300		0.906	0.947	0.814	0.803	0.808	0.779	0.849	0.866	0.824	0.76[illegible]	
1300-1400		0.950	0.937	0.845	0.782	0.807	0.764	0.828	0.846	0.826	0.788	
1400-1500		0.821	0.914	0.853	0.767	0.816	0.740	0.862	0.826	0.829	0.793	
1500-1600		0.997	0.926	0.879	0.752	0.856	0.820	0.858	0.807	0.764	0.770	
1600-1700		0.917	0.939	0.879	0.754	0.913	0.771	0.816	0.859	0.771	0.748	
1700-1800		0.892	0.922	0.857	0.742	0.889	0.776	0.840	0.871	0.778	0.745	
1800-1900	0.936	0.897	0.912	0.846	0.752	0.867	0.833	0.790	0.888	0.772	0.742	
1900-2000	0.944	0.915	0.913	0.828	0.749	0.930	0.847	0.759	0.886	0.767	0.739	
2000-2100	0.951	0.901	0.909	0.845	0.771	0.918	0.856	0.767	0.871	0.768	0.723	
2100-2200	0.963	0.907	0.912	0.846	0.776	0.906	0.845	0.783	0.814	0.766	0.737	
2200-2300	0.947	0.872	0.913	0.856	0.750	0.894	0.828	0.783	0.814	0.771	0.717	
2300-2400	0.960	0.872	0.920	0.841	0.774	0.887	0.798	0.798	0.817	0.764	0.720	

Table 9. Intrathoracic temperature in degrees Celsius of Pod A monkey during SMD III Experiment #44. Values are hourly means of 1-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

	Calendar Day											
CST	134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		36.25	36.48	36.28	36.98	36.85	37.73	37.80	38.50	37.50	37.95	37.85
0100-0200		36.18	36.33	36.25	37.03	36.95	37.65	37.65	38.43	37.50	38.00	37.73
0200-0300		36.35	35.98	36.35	36.85	36.93	38.03	37.63	38.38	37.55	37.90	37.70
0300-0400		36.33	36.13	36.33	36.93	36.78	37.80	37.70	38.40	37.33	38.05	37.65
0400-0500		36.53	36.38	36.30	36.63	36.68	37.80	37.13	38.38	37.05	38.30	37.60
0500-0600		36.70	36.60	36.63	36.95	36.90	37.75	37.55	38.35	37.15	38.35	37.55
0600-0700		37.05	36.90	36.65	37.08	36.95	37.85	37.38	38.28	37.40	38.38	37.50
0700-0800		37.38	37.12	36.73	37.03	37.00	38.08	37.55	38.05	37.68	38.50	37.48
0800-0900		37.38	37.33	36.58	36.95	37.40	38.23	37.73	38.15	37.75	38.80	37.60
0900-1000		37.68	37.55	36.63	37.10	37.25	37.95	37.63	38.18	37.98	38.88	37.95
1000-1100		37.73	37.40	36.75	37.28	37.30	37.70	37.25	37.90	37.95	38.98	
1100-1200		37.58	37.30	37.38	37.43	37.38	37.60	37.75	38.38	37.60	38.73	
1200-1300		37.43	37.20	37.70	37.28	37.30	37.73	37.83	38.58	37.48	38.85	
1300-1400		37.28	37.50	37.33	37.05	37.10	37.55	37.83	38.40	37.90	38.90	
1400-1500		37.13	37.34	36.88	37.03	37.43	37.80	37.73	38.50	38.43	38.88	
1500-1600		36.98	37.19	36.73	37.00	37.40	37.75	38.16	38.18	38.58	39.03	
1600-1700		37.23	37.03	37.15	37.15	37.30	37.95	38.13	38.55	38.38	38.70	
1700-1800		37.58	36.90	37.58	37.28	37.68	37.35	38.35	38.68	37.98	38.55	
1800-1900	37.53	37.30	37.08	37.48	37.65	37.70	37.78	38.58	38.48	38.08	38.45	
1900-2000	37.28	37.20	36.65	37.03	37.50	37.69	37.93	38.53	38.70	38.20	38.58	
2000-2100	36.85	36.98	36.[illegible]5	36.85	37.40	37.68	37.83	38.58	38.95	38.13	38.40	
2100-2200	36.60	36.68	36.60	36.88	37.55	37.93	37.95	38.90	38.88	38.15	38.40	
2200-2300	36.53	36.73	36.45	36.85	37.15	37.75	38.13	38.73	38.15	38.00	38.28	
2300-2400	36.25	36.73	36.23	36.95	36.93	37.73	38.15	38.35	37.65	37.93	38.03	

Table 10. Heart rate in beats per minute of Pod A monkey during SMD III Experiment #44. Values are hourly means of 1-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		115	108	126	134	137	150	170	171	154	163	153
0100-0200		114	115	127	138	143	156	174	159	160	153	151
0200-0300		119	118	137	135	135	169	175	180	173	155	152
0300-0400		122	125	132	135	141	166	178	161	149	159	149
0400-0500		117	129	130	134	129	172	178	166	146	165	151
0500-0600		127	117	134	139	158	163	166	190	159	164	148
0600-0700		156	132	135	137	146	173	180	155	167	154	148
0700-0800		172	141	137	132	147	184	174	160	163	170	148
0800-0900		174	150	137	138	154	178	170	174	175	171	168
0900-1000		168	159	129	141	148	172	170	168	167	167	158
1000-1100		166	140	140	154	143	178	166	173	162	167	
1100-1200		163	131	154	174	141	178	166	172	148	155	
1200-1300		160	126	154	134	138	181	173	167	153	163	
1300-1400		157	133	144	136	138	179	173	152	172	164	
1400-1500		155	129	132	133	142	179	161	159	175	162	
1500-1600		136	125	122	141	142	190	148	180	175	163	
1600-1700		132	122	148	142	157	182	177	161	164	156	
1700-1800		126	120	145	137	153	183	172	166	152	156	
1800-1900	150	113	123	138	150	156	180	179	165	161	159	
1900-2000	134	125	118	133	147	159	190	187	168	158	160	
2000-2100	126	111	121	134	144	160	182	185	172	158	154	
2100-2200	114	106	122	131	163	158	181	196	166	155	168	
2200-2300	124	119	122	130	144	165	187	162	164	153	158	
2300-2400	106	111	117	133	140	164	185	161	156	150	152	

Table 11. Mean aortic pressure in torr of Pod A monkey during SMD III Experiment #44. Values are hourly means of 1-min readings. Calendar day 134 was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day											
	134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		123	111	126	120	126	132	130	137	129	156	142
0100-0200		120	116	127	123	116	145	138	138	137	143	142
0200-0300		126	119	135	119	118	148	135	147	133	149	141
0300-0400		121	129	123	115	124	146	138	124	120	149	141
0400-0500		115	127	126	120	118	135	141	133	129	146	143
0500-0500		122	118	125	118	125	133	140	141	138	146	141
0600-0700		156	127	124	124	130	145	141	138	134	138	144
0700-0800		171	138	127	119	135	153	140	146	129	147	145
0800-0900		168	149	128	126	139	145	138	146	140	135	152
0900-1000		139	160	131	126	123	129	133	140	135	133	136
1000-1100		124	142	137	126	127	139	136	148	126	136	
1100-1200		121	124	130	120	126	135	130	147	125	136	
1200-1300		118	117	127	114	128	142	135	136	135	136	
1300-1400		115	117	120	120	128	143	129	131	133	134	
1400-1500		113	118	123	125	136	137	126	139	148	134	
1500-1600		120	120	123	142	149	146	125	137	136	132	
1600-1700		111	121	142	124	151	134	149	126	131	133	
1700-1800		102	121	125	127	144	135	136	126	217	137	
1800-1900	119	106	126	126	123	145	124	137	124	133	140	
1900-2000	112	119	125	117	124	146	127	148	134	129	135	
2000-2100	112	107	121	119	121	151	133	138	133	134	135	
2100-2200	109	109	124	117	137	142	138	147	131	137	141	
2200-2300	126	116	124	118	133	151	146	130	133	144	138	
2300-2400	120	108	120	117	129	146	136	136	129	145	137	

Table 12. Mean left ventricular pressure in torr of Pod A monkey during SMD III Experiment #44. Values are hourly means of 1-min readings. Calendar day was 14 May 1977. "Flight" launch and landing times are indicated by lines.

CST	Calendar Day 134	135	136	137	138	139	140	141	142	143	144	145
0000-0100		68.5	65.4	72.4	71.1	76.8	79.7	76.8	85.9	78.3	95.4	87.1
0100-0200		66.8	67.2	73.2	72.1	75.8	84.1	78.8	88.1	82.3	87.3	86.7
0200-0300		68.8	69.6	76.7	69.4	73.9	84.7	77.6	89.2	81.1	90.8	86.3
0300-0400		66.6	72.6	71.9	67.9	80.0	84.9	79.5	84.6	73.6	92.3	86.2
0400-0500		62.5	73.1	73.9	71.7	75.2	84.7	82.8	89.7	78.1	89.9	86.8
0500-0600		65.9	68.9	73.6	69.5	76.5	80.6	82.7	84.2	83.2	90.5	86.2
0600-0700		85.4	72.0	72.8	73.9	73.8	86.0	83.1	88.7	79.1	85.4	87.9
0700-0800		91.4	80.3	74.6	71.0	82.1	88.3	81.8	90.0	74.3	89.7	87.9
0800-0900		92.9	88.5	73.2	74.5	82.9	83.1	81.6	87.9	80.0	83.5	91.8
0900-1000		75.4	96.8	72.3	73.9	74.3	74.5	80.1	85.0	80.5	82.6	83.2
1000-1100		69.5	81.3	77.6	71.[illegible]	75.2	79.7	82.5	84.6	78.5	85.0	
1100-1200		68.0	74.7	74.5	72.[illegible]	77.0	79.0	76.9	88.7	78.3	85.7	
1200-1300		66.5	72.1	71.8	67.9	78.4	81.8	79.1	82.3	84.6	94.7	
1300-1400		65.0	71.9	69.7	71.9	78.3	82.3	79.8	81.6	81.3	83.1	
1400-1500		63.5	71.7	72.2	73.8	83.1	79.8	76.7	87.0	88.6	83.4	
1500-1600		68.7	71.4	71.6	82.4	89.8	83.8	78.4	83.7	82.6	81.8	
1600-1700		63.6	71.2	80.6	73.4	90.3	77.1	87.7	76.1	81.1	83.5	
1700-1800		58.8	71.4	70.7	71.2	88.1	78.9	80.8	75.9	79.6	85.7	
1800-1900	66.7	61.8	73.2	68.9	72.3	87.7	73.6	81.4	73.9	81.8	87.1	
1900-2000	63.0	69.3	73.0	67.3	72.1	87.3	75.4	85.6	77.2	79.2	84.1	
2000-2100	62.7	62.6	70.3	69.1	71.8	90.1	78.3	85.0	78.8	82.6	83.0	
2100-2200	60.5	64.2	70.8	68.1	82.5	85.7	79.8	83.5	82.5	83.5	86.1	
2200-2300	70.5	68.8	71.9	69.5	80.6	89.6	82.5	77.1	81.2	87.7	84.3	
2300-2400	66.7	63.5	69.4	68.4	78.7	87.0	79.4	81.1	75.3	88.3	84.2	

Table 13. Diurnal variation of parameters measured during SMD III Experiment #44. The mean of the 11 light periods, 0700-2100 daily, is compared with the mean of the 11 dark periods, 2100-0700 daily, in each case.

	0700-2100 Day Mean	2100-0700 Night Mean	Difference	Per Cent Difference	P
Oxygen Consumption, l/hr	5.27	4.88	-0.39	-7.4	<.001
Carbon Dioxide Production, l/hr	4.38	4.04	-0.34	-7.8	<.001
Respiratory Quotient	0.832	0.830	-0.002	--	.83
Heart Rate, min^{-1}	154.9	147.9	-7.0	-4.5	.004
Mean Aortic Pressure, torr	130.8	131.6	+0.8	+0.6	.67
Mean Left Ventricular Pressure, torr	78.2	78.4	+0.2	+0.3	.89
Intrathoracic Temperature, °C	37.70	37.35	-0.35	--	<.001
Upper Pod Temperature, °C	22.29	21.86	-0.43	--	<.001

Table 14. Comparison of mean preflight, flight, and postflight values of the parameters measured during SMD III Experiment #44. The mean of the hourly values during the 48-hr period just prior to flight is compared with the mean of the hourly values during the 144-hr flight period, and with the mean of the hourly values during the 48-hr postflight period in each case.

	Pre-Flight 48 hrs Mean	Flight 144 hrs Mean	Post-Flight 48 hrs Mean	Significance of Difference: Pre-Flight vs Flight P	Significance of Difference: Pre-Flight vs Post-Flight P
Oxygen Consumption, l/hr	4.80	5.24	4.99	<.001	ns
Carbon Dioxide Production, l/hr	4.34	4.31	3.81	ns	<.001
Respiratory Quotient	0.89	0.82	0.76	<.001	<.001
Heart Rate, min^{-1}	132	158	159	<.001	<.001
Mean Aortic Pressure, torr	123	133	138	<.001	<.001
Mean Left Ventricular Pressure, torr	72	79	85	<.001	<.001
Intrathoracic Temperature, °C	36.9	37.6	38.2	<.001	<.001
Upper Pod Temperature, °C	22.3	22.1	22.0	ns	ns
Cabin Temperature, °C	20.9	20.9	20.8	ns	ns

Table 15. Correlation matrix for the parameters measured during SMD III Experiment #44. Pearson r, the degree of correlation, is shown for the pairs of parameters, each comprising 256 hourly mean values for the entire experiment. The level of significance of the correlation, P, is also shown in each case.

		Carbon Dioxide Production	Heart Rate	Mean Aortic Pressure	Mean Left Ventricular Pressure	Intrathoracic Temperature	Upper Pod Temperature
Oxygen Consumption	r	0.89	0.66	0.36	0.28	0.42	0.18
	P	<.001	<.001	<.001	<.001	<.001	<.01
Carbon Dioxide Production	r		0.40	0.18	0.05	0.17	0.19
	P		<.001	<.01	ns	<.01	<.01
Heart Rate	r			0.67	0.66	0.76	0.05
	P			<.001	<.001	<.001	ns
Mean Aortic Pressure	r				0.92	0.49	-0.12
	P				<.001	<.01	<.05
Mean Left Ventricular Pressure	r					0.62	-0.15
	P					<.001	<.01
Intrathoracic Temperature	r						0.05
	P						ns

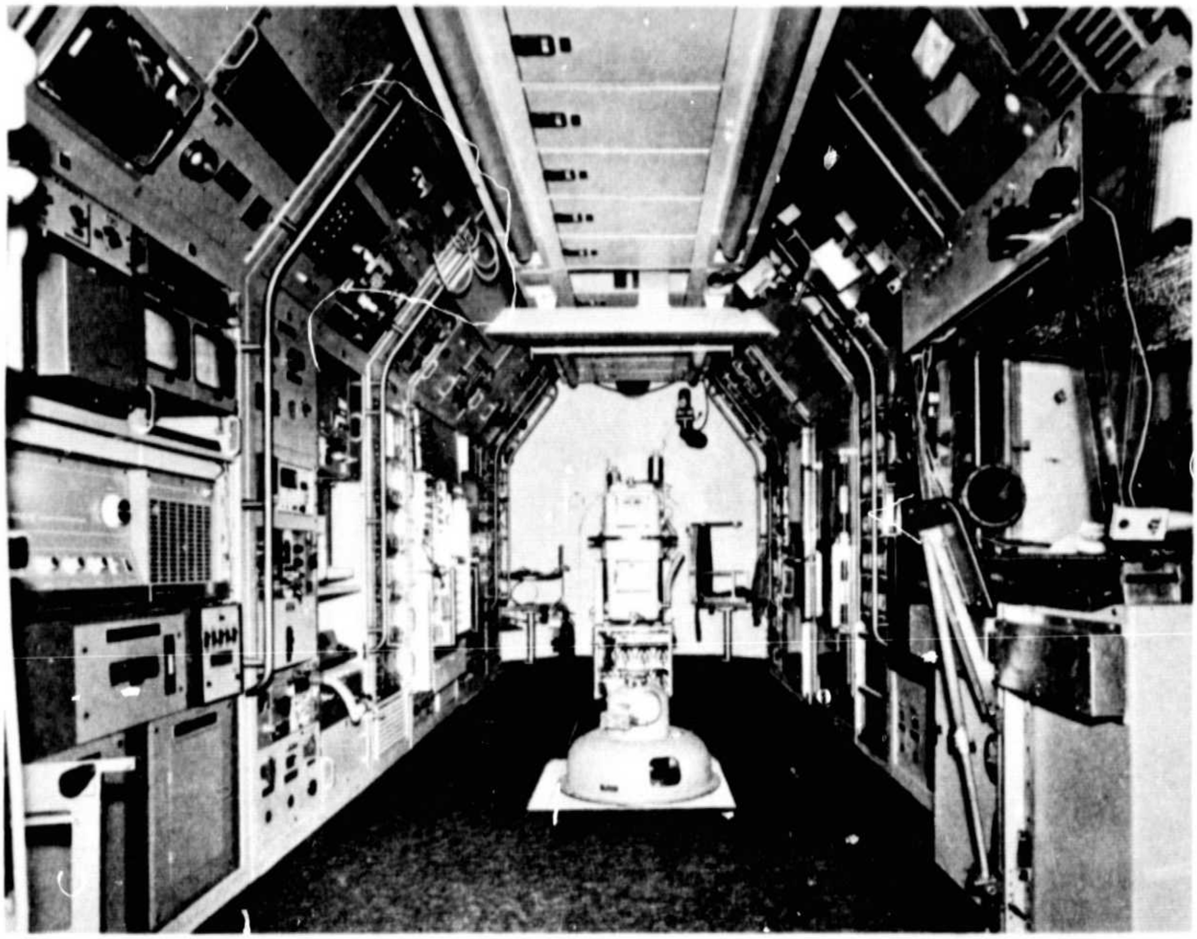

Fig. 1. Interior view of Spacelab Simulator at NASA/JSC during SMD III. Monkey Pod A is floor-mounted at the center rear of the Simulator, with Pod B out of sight immediately behind Pod A. Pod system experiment instrumentation occupies the last rack on either side of the Simulator.

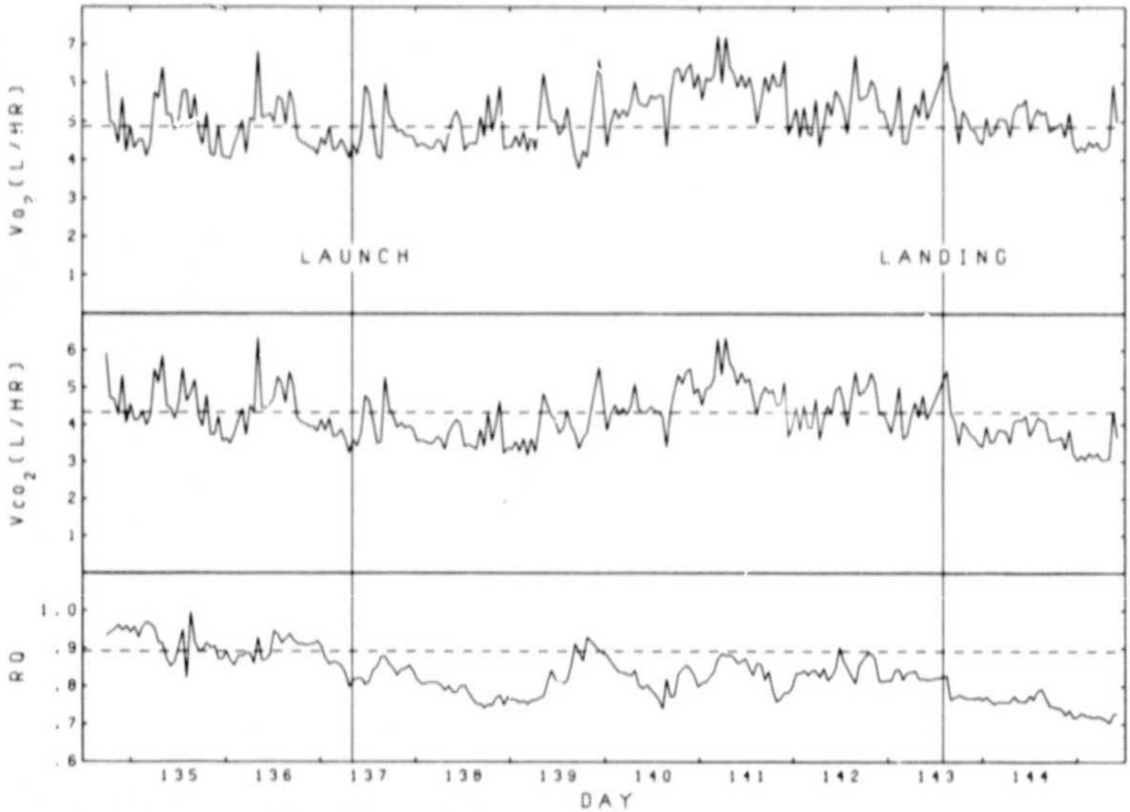

Fig. 2. Oxygen consumption rate ($\dot{V}_{O_2}$), carbon dioxide production rate ($\dot{V}_{CO_2}$), and respiratory quotient (RQ) for Pod A monkey during SMD III Experiment #44. Mean hourly values are plotted in each case. "Launch" occurred at 0800 on calendar day 137 (17 May 1977), and "Landing" occurred at 1404 on calendar day 143 (23 May 1977).

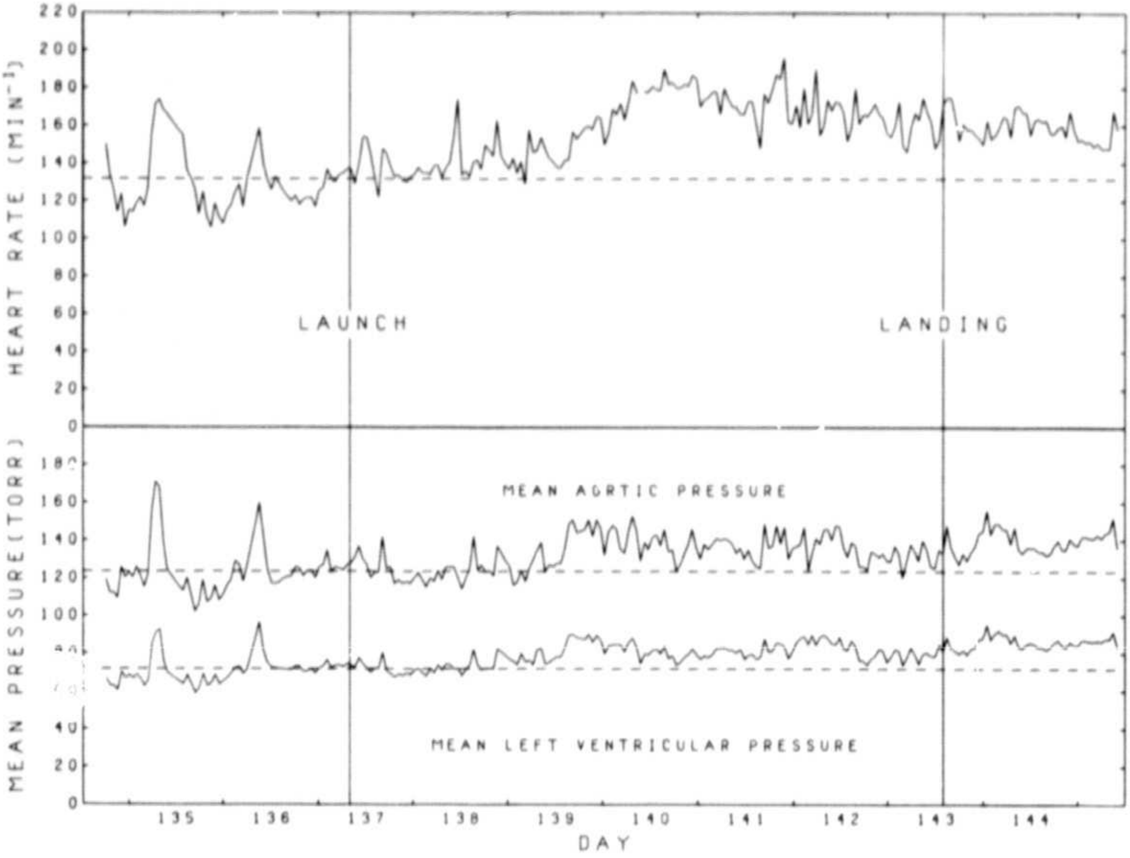

Fig. 3. Heart rate, mean aortic pressure, and mean left ventricular pressure for Pod A monkey during SMD III Experiment #44. Mean hourly values are plotted in each case. "Launch" occurred at 0800 on calendar day 137 (17 May 1977), and "Landing" occurred at 1404 on calendar day 143 (23 May 1977).

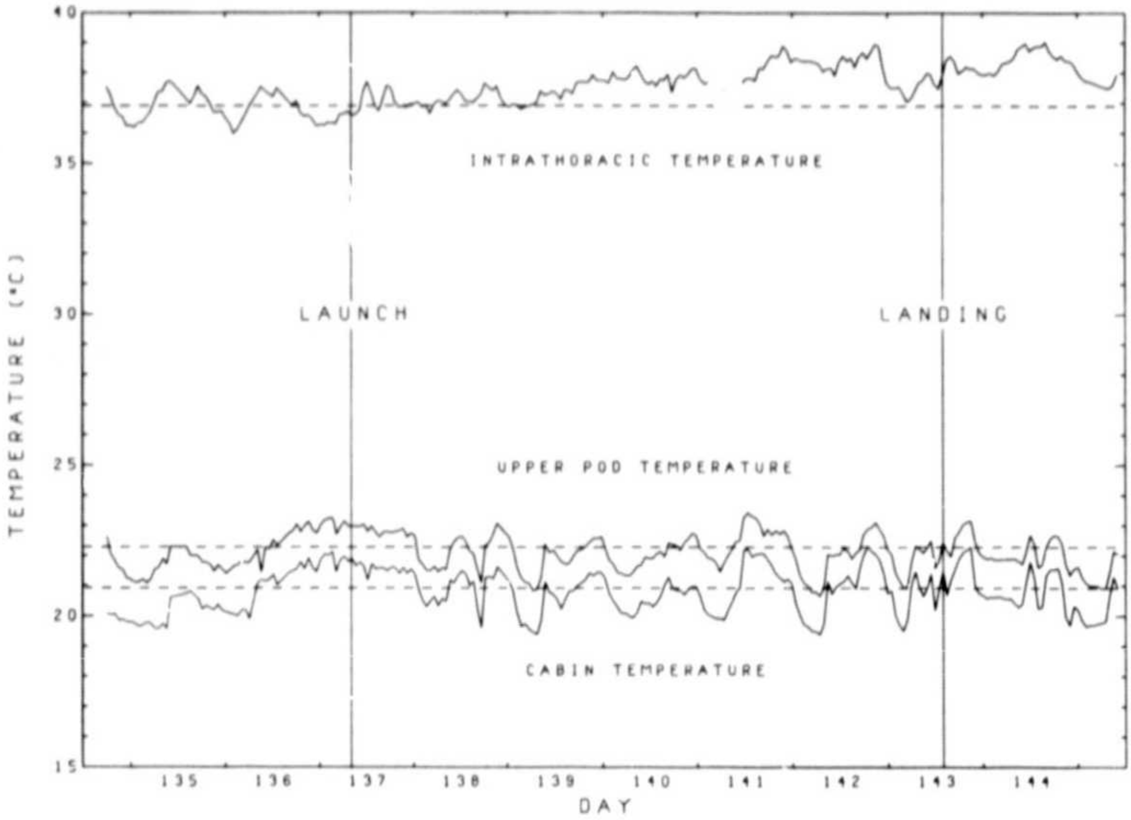

Fig. 4. Intrathoracic temperature for Pod A monkey, upper Pod A temperature, and Spacelab Simulator cabin temperature during SMD III Experiment #44. Mean hourly values are plotted in each case. "Launch" occurred at 0800 on calendar day 137 (17 May 1977), and "Landing" occurred at 1404 on calendar day 143 (23 May 1977).

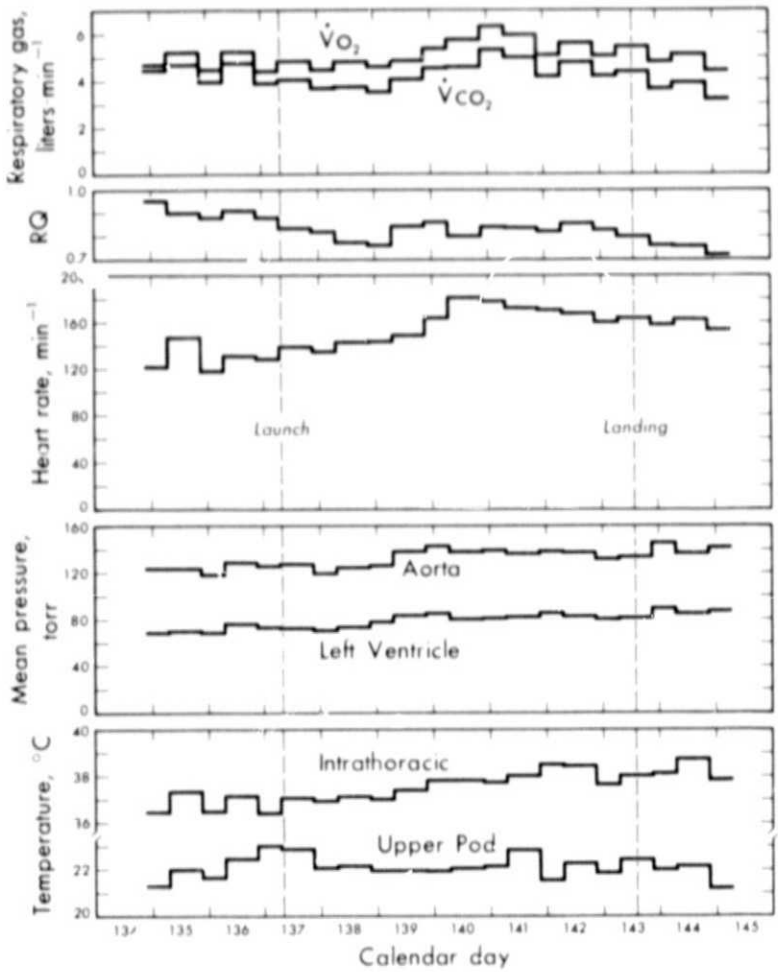

Fig. 5. Diurnal behavior of Experiment #44 parameters during SMD III when plotted as hourly means for the 14-hr light periods, 0700-2100, and the 10-hr dark periods, 2100-0700. "Launch" occurred at 0800 on calendar day 137 (17 May 1977), and "Landing" occurred at 1404 on calendar day 143 (23 May 1977).

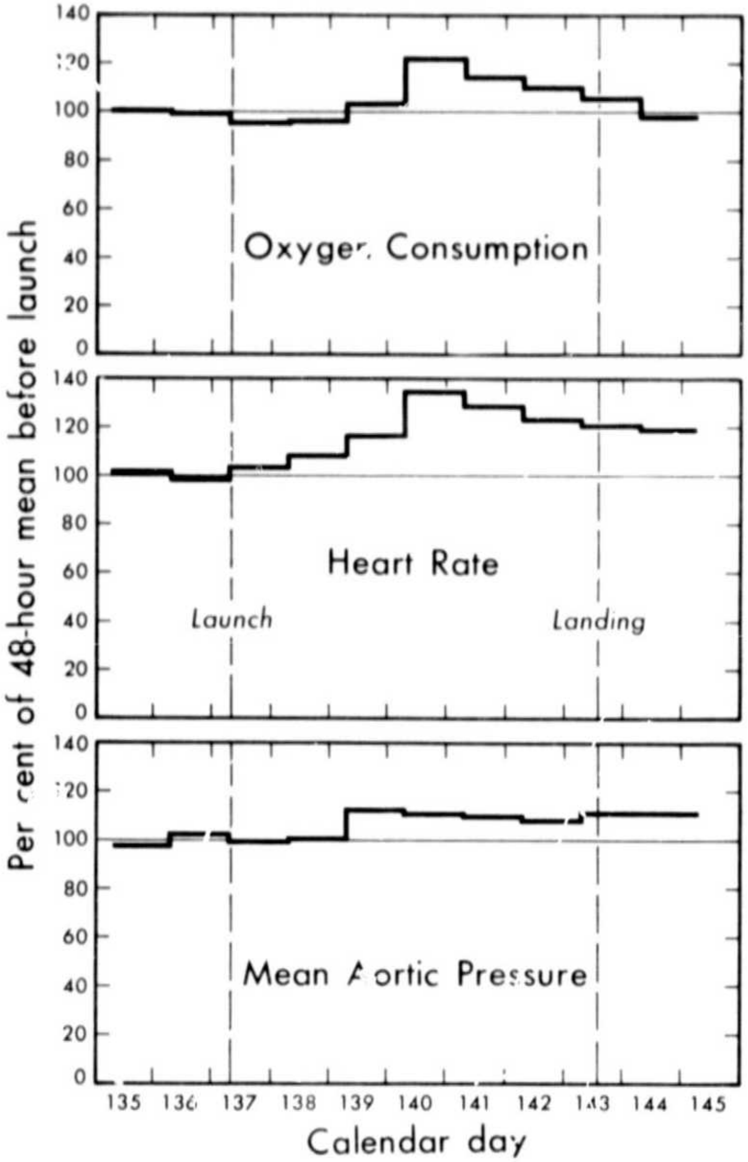

Fig. 6. Oxygen consumption rate, heart rate, and mean aortic pressure of Pod A monkey during SMD III Experiment #44. The 24-hr mean is plotted as a percentage of the mean value in each case for the 48 hr just prior to "Launch". "Launch" occurred at 0800 on calendar day 137 (17 May 1977), and "Landing" occurred at 1404 on calendar day 143 (23 May 1977).