The Skylab Medical Experiments Altitude Test (SMEAT)

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The Skylab Program represented a new level of complexity in space activities and required increased testing and support before flight. The Skylab Medical Experiments Altitude Test (SMEAT) was conducted both to test mission preparations and to observe any physiological changes that might be attributed to the planned atmosphere at 5 psia (70% O2/30% N2) while still in an Earth gravity situation. SMEAT was a high-fidelity simulation of a 56-d Skylab mission, conducted in an altitude chamber (**Fig. 1** and **2**) at the Manned Spacecraft Center (presently the Johnson Space Center) in the summer of 1972.[3] The development of the Skylab medical experiments, initiated in the mid-1960s, included a decision to design the experimental program along classical lines of medical and physiological research.

Skylab is the only NASA program in which biomedical experimentation was the main priority. Fourteen experiments were planned, covering most biomedical disciplines. Three astronauts (Robert Crippen, William Thornton, and Karol Bobko) were the subjects for the SMEAT study (**Fig. 3, 4,** and **5**). SMEAT was a separate mission to the extent that it approximated the full simulation of a space mission. A primary Skylab objective was to observe physiological change as a function of time in space. Earlier flight programs had generally been limited to pre- and postflight evaluations only.[1]

SMEAT had six specific objectives:

1. Obtain adequate baseline data for up to 56 d for those medical experiments that might be affected by the Skylab environment;
2. Evaluate selected experiment hardware systems and ancillary equipment;
3. Evaluate data reduction and handling procedures;
4. Evaluate preflight and postflight medical support operations, procedures, and equipment;
5. Evaluate in-flight experiment procedures and crew checklists. SMEAT utilized actual flight prototype hardware that was configured as planned for the Skylab workshop;
6. Provide realistic training for the Skylab medical operations team.

The SMEAT program was conducted in three phases:

1. Prechamber initiated 6 mo prior to the chamber test;
2. 56-d chamber test (initiated 26 July 1972);
3. 18-d postchamber test period.

Skylab mission procedures were simulated during SMEAT to the fullest extent possible. For example, all communications with the crew were relayed through the Mission Control Center CAPCOM communication. One example that demonstrates the high fidelity of SMEAT is the food provided for the simulation. A 6-d menu cycle was developed, and the crew consumed the Skylab diet for 28 d prior to the chamber study, for 56 d during the simulation at altitude, and for 18 d during posttest.

SMEAT biomedical experiments included 14 studies that had been approved for the Skylab Program:

1. Lower Body Negative Pressure—Experiment M092
2. Vectorcardiogram—Experiment M093
3. Hematology/Immunology Studies:
   a. Cytogenic Studies of the Blood—M111
   b. Investigation of Man's Immune System—M112
   c. Blood Volume and Red Cell Lifespan—M113
   d. Red Blood Cell Metabolism—M114
   e. Special Hematological Effects—M115
4. Mineral Balance—Experiment M071
5. Specimen Mass Measurement—Experiment M074
6. Bone Mineral Measurement—Experiment M078
7. Metabolic Activity—Experiment M171
8. Bioassay of Body Fluids—M073
9. Sleep Monitoring—Experiment M133
10. Time and Motion—Experiment M151

As a detailed example of how SMEAT was carried out, Medical Experiment M-171 will be described, in which the author served as the Principal Coordinating Scientist and had a major role in hardware development.

Historically, NASA considered three vendors for the Metabolic Analyzer equipment. Each provided a breadboard unit that was evaluated in the Environmental Physiology Laboratory under leadership of Dr. John Rummel (Co-I for M-171). NASA politics ultimately impacted the final selection of Marshall Spaceflight Center to develop the Metabolic Analyzer and that six units would be provided for each experiment subsystem, to be designated as: Design Verification Test Units #1 and #2, a Flight Trainer, a Qualification Unit, and Flight Units #1 and #2. This decision assured that ample hardware was available to support all phases of the program from early development through flight.

The equipment required to perform Experiment M-171 included:

- The M-171 Metabolic Analyzer (MA) with its associated accessories and the Cycle Ergometer;
- Hardware shared from Experiment M-092 that was used to provide blood pressure measurements;
- The Vectorcardiogram system (VCS) from Experiment M-093, which provided exercise heart rate; and
- A thermistor provided to obtain a measure of body temperature.

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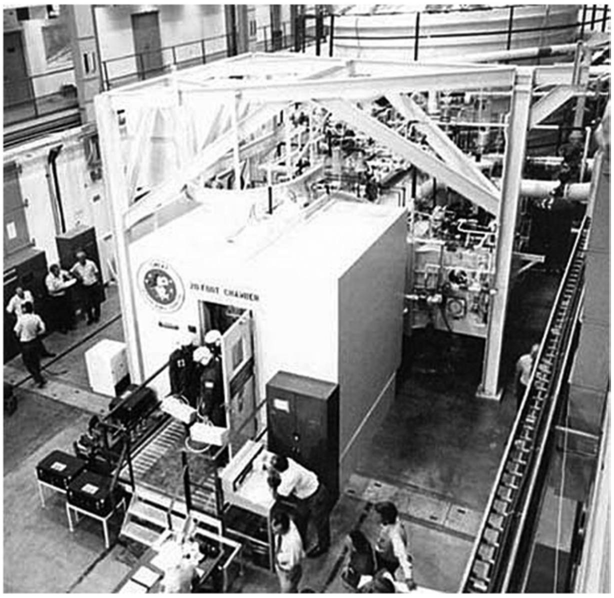

Fig. 1. The airlock to the Crew Systems Division 20-ft altitude chamber in Building 7 at NASA JSC used for the SMEAT Program. Photo credit: NASA

The Metabolic Analyzer system included:

1. An analog computer built from Burr-Brown modules that literally implemented the required computational equations, step by step;
2. A compact, cylindrically configured Perkin-Elmer mass spectrometer. It was a magnetic sector, fixed collector instrument that measured partial pressures of N_2, O_2, CO_2, and H_2O;
3. Cylinders of calibration gases. One was used to check the span of the mass spectrometer gains for each channel; the second was a mixture that simulated mixed expired air during typical exercise;
4. Two rolling seal spirometers that measured inspired and expired respiratory volumes, breath by breath. In order to obtain the rapid response necessary for high exercise ventilation levels, the emptying of each spirometer was through a large Saturn rocket fuel flow control valve. These valves were triggered by an electronic signal and actuated by pressurized N2;

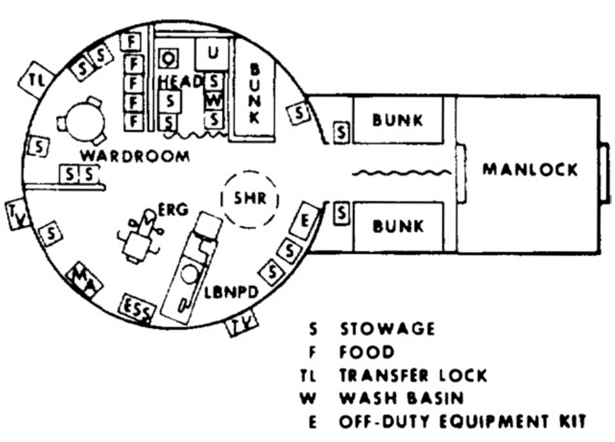

Fig. 2. Plan view of the SMEAT chamber. Photo credit: NASA

Fig. 3. S72-41,858 (15 June 1972)—Astronauts Robert L. Crippen and Dr. William E. Thornton stand at the cabinet containing the off-duty recreation equipment in the SMEAT chamber. Photo credit: NASA

5. A subject mouthpiece attached to a bidirectional respiratory valve, that in turn was interfaced with the MA by large diameter corrugated tubing; and finally
6. A 3-liter hand pump used to simulate human breathing.

Calibration of the MA was essential and performed prior to each day of operation and involved a sequence of steps. First, the mass spectrometer was calibrated by flushing its inlet with the internal gas mixture. Next ambient cabin air was sampled and its analysis was stored electronically to represent inspired air. Then the mass spectrometer was set up to sample the gas mixture that simulated expired air. Finally, the hand pump was used at various settings and pumps per minute to simulate human breathing. These steps resulted in predetermined "known" values for Vo_2, Vco_2, and MV (minute volume). After anticipated results had been verified, subject testing could be initiated.

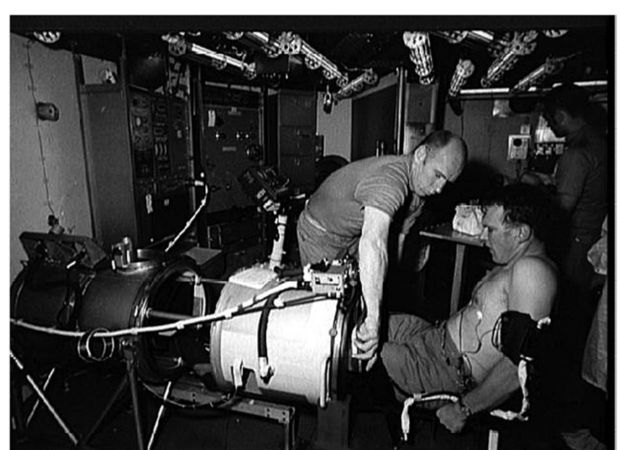

Fig. 4. S72-43,282 (15 June 1972)—Astronaut Karol J. Bobko, SMEAT pilot, is being configured for a test in the Lower Body Negative Pressure experiment. Dr. William E. Thornton, SMEAT science pilot, assists. In the right background is astronaut Robert L. Crippen, SMEAT commander. Photo credit: NASA

Fig. 5. SMEAT crewmembers (L-R) Robert Crippen, William Thornton and Karol Bobko standing near the M-171 Ergometer. Photo credit: NASA.

Prior Gemini and Apollo flight exercise studies were primarily pre- and postflight. These employed a heartrate control protocol, which resulted in widely varying workloads that made it difficult to evaluate metabolic activity. Therefore, a workload control protocol was selected for M-171. Preflight baseline tests were performed on each crewman to determine workloads that approximated 25, 50, and 75% maximum aerobic capacity. The preparatory phase of each test included calibration of the MA, verifying vectorcardiogram electrode isolation, and making vital capacity and body temperature measurements.

The MA used for SMEAT was DVTU #2 that had only minor, insignificant differences from the Flight Unit. The cycle ergometer was an electrically braked device. Manually set workloads were independent of pedaling rate between 50 and 80 cycles per minute. The SMEAT ergometer was the Flight Trainer unit. The ergometer load module failed during the second day of SMEAT. Another load module was substituted until the original was repaired, recalibrated, and replaced in the test chamber. After conclusion of SMEAT, it was determined that a faulty bearing had been responsible for the failure. This was corrected in the Flight Unit.

Results of SMEAT M-171

The following are some of the results of SMEAT M-171:

1. Vital capacity measurements were discontinued due to sensitivity of triggering for dumping the rolling seal spirometer. It seemed impossible to match the response needed for high level exercise volumes to that necessary for a slow maximum exhalation to determine vital capacity.
2. Body temperature measurement was intended only to determine whether the subject was storing significant heat from pre- to postexercise. No significant differences were noted in SMEAT and the requirement was dropped. Additionally, the thermistor used had a small current leakage that upset the crewmembers.
3. BPMS data were somewhat inconsistent. One suggested explanation was that the cuff bleed rate at 14.7 psia was faster than at 5.0 psia, making the measurement more susceptible to arm motion during cycle exercise. A procedural change was made to request that the crewmember remove his cuffed arm from the handlebars during the measurement.
4. Although personal exercise regimens were suggested by the M-171 investigator, each crewmember adjusted his regimen to suit his needs. This was an area that required improvement before actual Skylab missions. Additional exercise devices were provided over the course of the Skylab missions.
5. The SMEAT version of the M-171 study proved to be very beneficial for the development of the experiment prior to Skylab missions. All of the initial SMEAT objectives contributed valuable information that improved M-171.
6. No adverse physiological changes were noted that could be attributed to the simulated Skylab atmosphere.

Data Analysis of SMEAT M-171

The fixed workload protocol resulted in unprecedented, detailed analyses of the metabolic response to exercise. For example, linear correlations between many sets of parameters provided insight into exercise responses. Correlations between many important parameters included:

1. Oxygen consumption as a function of workload;
2. Heart rate in response to increasing workloads; and
3. Systolic and diastolic blood pressure changes in response to increasing workloads.

The SMEAT project identified several hardware and procedural anomalies that had to be resolved prior to successful implementation of the flight experiments. Without any doubt, the Skylab Program would not have produced such high-quality results[2] if SMEAT had not been a prerequisite.

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