A SUMMER TRIP TO NOWHERE

Ninety days in "an artificial environment"

by John Hall

A letter soliciting applications from "healthy male graduate students in the engineering, physical, biological, and social sciences to participate as scientist-astronaut crew members in a ground-based program" arrived in my mail one November morning in 1969. Answering it launched me—and some 50 other southern California graduate students—on a round of questionnaires, personal interviews, medical examinations, and psychological evaluations. Seven of us survived the selection process and became the prime and backup crews for a 90-day "holiday" confined in a Space Station Simulator (SSS) located in a large laboratory at McDonnell-Douglas Astronautics Corporation's plant in Huntington Beach.

Aside from the obvious criteria for selecting personnel able to sustain a relatively long period of confinement and remain in good physical and mental health, the selection process we went through is best summed up in the observation that the candidates who showed the most interest and perseverance in cooperating with the schedules of training emerged by mid-February as the team. The four "chambernauts" chosen as the prime crew included three graduate students from Caltech—Steve Dennis, from biology; Wilson Wong, from aeronautical engineering; and myself, from geology. Our fourth crewman was Terry Donlon, a UCLA graduate student in medical radiation physics.

The test, which took place from mid-June to mid-September, was set up to employ an advanced regenerative life support system (LSS) and to demonstrate that the system could be operated continuously for the 90 days, without resupply, to provide a habitable environment.

A previous 60-day simulation had tested a number of elements in the life-support loop, to which were now added a radioisotope-heated vacuum distillation system for the recovery of potable water from urine and humidity condensate, a solid amine resin carbon dioxide concentrator, a flight-weight alkaline electrolyte water electrolysis unit, a "shredder-type commode with vacuum dehydrated fecal storage," an improved reactor for reclamation of water from carbon dioxide and combustion of atmospheric toxins, and a microwave oven for food preparation.

If any of these new subsystems should fail, we were to repair them. Since no materials were to be passed into the chamber, the equipment repair we could perform was limited to procedures that might be done on a long space flight mission. Biological and medical samples could be passed out through an airlock in such a way that the chamber would not be contaminated from the outside.

As we began training, the SSS was a nearly empty double-walled horizontal cylinder, 12 feet in diameter and 40 feet long. An acoustic barrier and fireproof bulkhead separated the interior into two compartments. The first, adjacent to the airlock, would house the main living area, biological sampling area, and sleeping quarters; the second would eventually contain all of the LSS equipment. The space between the inner and outer chamber walls, as well as the airlock and pass-through ports, would be evacuated to several millimeters of mercury below the cabin pressure to ensure that all leakage would be outboard. Several inches of thermal insulation around the entire system would minimize thermal and acoustic transmission.

As the various subsystems of the LSS began to arrive and were installed in the chamber, we learned how to operate them, how they were most likely to fail, and how to repair them. We began to see the pieces of equipment in terms of their role in the over-all life support scheme and to appreciate their performance capabilities under various conditions of operation.

The general operation of the LSS consisted of cycling our urine through either an evaporative wick and condenser system or the plutonium 238 thermal vacuum distillation/vapor filtration boiler and condenser. The reclaimed water would be stored in zero-G design holding tanks and assayed for chemical and biological contamination prior to reuse.

To illustrate the economy of reclaiming body wastes, a crew of four men each consuming three quarts of water per day would require something over a ton of water for a 90-day mission, ignoring any provisions for washing. But through reclamation of processed urine and humidity condensate we in fact would operate with only several hundred pounds of water on board.

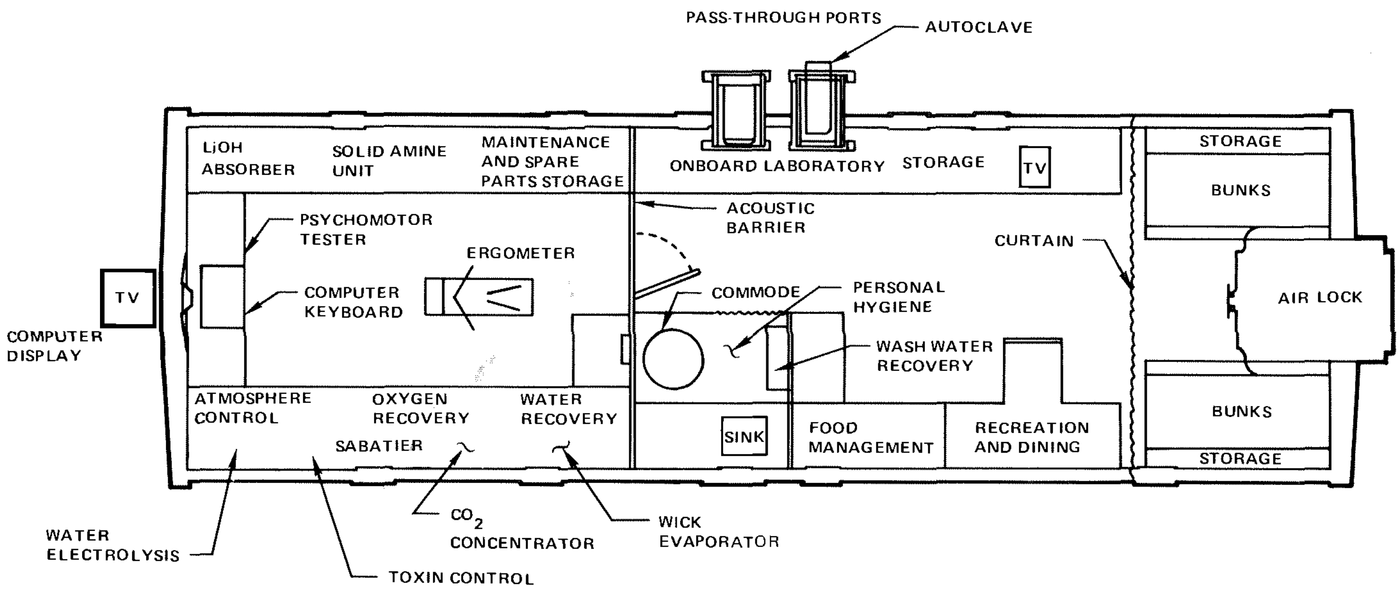
On even longer missions with larger crews, such as space trips to the planets, the economy of these regenerative systems becomes very important. Neither of our water reclamation systems was 100 percent efficient, but even allowing for the water losses incurred in processing and by

Terry Donlon and John Hall, on screen, confer with members of the ground crew outside the simulator. A battery of monitors followed the crew's activities throughout the run.

the requirements for passing samples outside the chamber for analysis, the metabolic production of water from the hydrogen in our food would result in a net water gain.

The food consisted primarily of freeze-dried items, permitting savings both in weight and storage space. Still, the total food for 360 man-days weighed over 500 pounds and took up 60 cubic feet of storage.

Regeneration of expired carbon dioxide as oxygen completed the mass balance. The gas would first be concentrated by molecular sieve or solid amine resins from which it would be thermally desorbed. Our LSS then would consume the carbon dioxide by reaction with molecular hydrogen on a hot nickel catalyst to produce water and methane. This scheme, familiar to chemists as the Sabatier Reaction, is exothermic. With an appropriate reactor and reaction mixture the process is entirely self-sustaining, and water is removed from the other products by a condenser. The methane and some unreacted carbon dioxide are discharged overboard, and the water pumped into storage. Finally, an electrolysis unit provides the molecular hydrogen needed for the Sabatier Reaction and oxygen gas for rebreathing. Nitrogen and oxygen makeup to the atmosphere is controlled by a small mass-spectrometer sensing unit.



The floor plan of the 40-foot-long "home" for the four crewmen is a testimonial to careful planning and ingenuity in stowing a large amount of equipment into a compact area.

Another purpose of the 90-day run was to ascertain if any adverse effects on psychomotor response might occur. Toward this goal much of our training time was spent learning to perform on a variety of reaction-time devices which scored such things as neurophysiologic response delay in various modes, coordination, and short-term memory.

Weekly blood sampling sessions for several months prior to the run gave us all some expertise in the biomedical procedures we would later be using and allowed establishment of a baseline on our blood biochemistry.

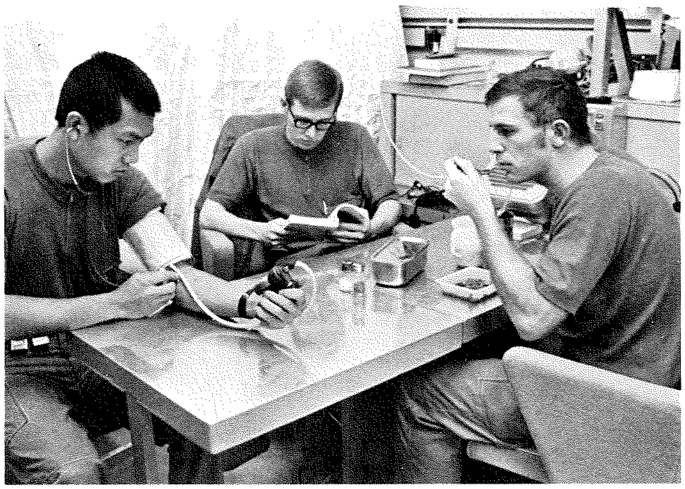
The original target date for commencing the run was April 29, but it was postponed several times. In late April Wilson and Terry, along with backup crew members Larry Hootman and Jim Shoemaker, participated in a five-day systems checkout "at altitude." This preliminary test revealed contamination in the potable water system which rendered the drinking supply completely unpalatable though chemically and bacteriologically safe. They also discovered during this period that adapting to the less-than-spacious seating of the zero-G commode presented some excretory difficulties. Dubbed "the slinger" by its manufacturer, this device left one with the sensation of being perched atop a garbage disposal unit. We who watched from the outside during the five days soberly made book as to how long it would take the inside crew to adjust.

All of these preliminaries out of the way, the day of ingress approached, and with it came mounting excitement and some second thoughts. Ten times I went through my choices of reading material. In the end I decided to limit professional materials to one anthology of recent articles, and to mollify my libido with *Fanny Hill.* Far more enticing during the actual run were a host of psychological and travel excursions:*Inside South America; Mood, States and Mind; Log from the Sea of Cortez; Amazon Headhunters; In Cold Blood; Cancer Ward;* and *Nansen in the Frozen World*—to name only a few.

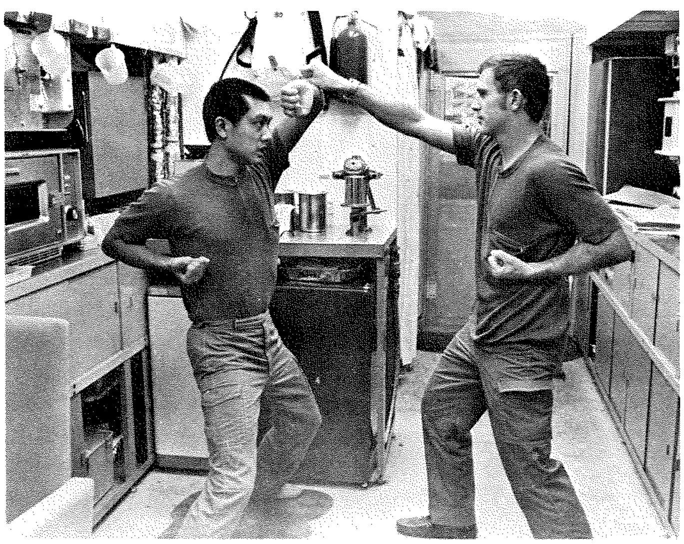
One by one the remaining items on the large chart which represented our "countdown" were crossed off. Finally on the fogged and drizzly morning of June 13, the rap of Wilson's fist at my apartment door alerted me to the fact that I had overslept.

Our last breakfast was hosted at the McDonnell-Douglas facility by chef Dave Myers, who had had the responsibility for training us in medical and microbiological sampling procedures. Depositing with him some last-minute samples of our body fluids, we concluded the handshaking formalities and filed into the air lock. The door slammed shut behind us, and the unperturbed face of our doctor Jim Wamsley smiled back through the outer porthole. A hiss signalled the pressure pumpdown as we approached the cabin pressure of 10 pounds per square inch, equivalent to about 10,000 feet altitude. The atmosphere was mildly oxygen-enriched (about 3.1 pounds per square

The days assumed the title of a particular task to be performed, or of some major food of the day. So we had blood day, eye day, and lobster day.



Crew members kept a photographic record of their activities inside the simulator. Here, Wilson Wong is taking his own blood pressure as part of the physiological data recording, while Stephen Dennis reads and John Hall tackles a meal of reconstituted freeze-dried food.



Wong and Hall take karate stances—for purposes of exercise only. In addition to such informal activity, each crew member put in 15 minutes a day pedaling on a stationary bicycle.

inch)—a condition which necessitated NASA's stringent regulations regarding elimination of combustibles from the cabin. Once during the run the potential for flammability in even this mildly oxygen-enriched atmosphere was dramatically brought home to me when a piece of cotton rag (normally stored in metal boxes) brushed the tip of a hot soldering iron I was using and immediately began to char without catching flame. In a matter of seconds before I could suffocate the ignition, the rag had turned to ashes and sent acrid smoke through the equipment room.

This accident points up another consideration in closed environment design. Any number of items which are basic construction materials—paints, woods, adhesives—outgas and release organic vapors, especially when taken to altitude. In a spacecraft the air cannot be used as a sewer, for simple dilution results in rapid buildup of potentially noxious substances which may adversely affect the health and well-being of the crew or even affect LSS equipment performance.

At the beginning of the run, we were called on to start and operate the systems, and the first several days passed quickly. Crew scheduling provided for two persons to be up at all times. Wilson and I operated on a swing shift, getting up at 9 p.m. With none of the normal clues to day or night, and living under essentially constant illumination, I was occasionally confused as to time of day, entering times off my normal wristwatch as 0900 (9 a.m.) for example, when it was really 2100 at night. The constant background noises of pumps cycling, blowers whining, and relays clicking were a further disturbance in making the adjustment to our new sleep cycle, and they remained a source of annoyance through the run.

With time and repetition we found that days assumed the title of some particular task which was to be performed on them, or of some major food of the day. For example, the audiometric testing was done each Saturday morning, and biomedical sampling every Tuesday—so that we would refer to "blood day," "eye day," or "lobster day," for example.

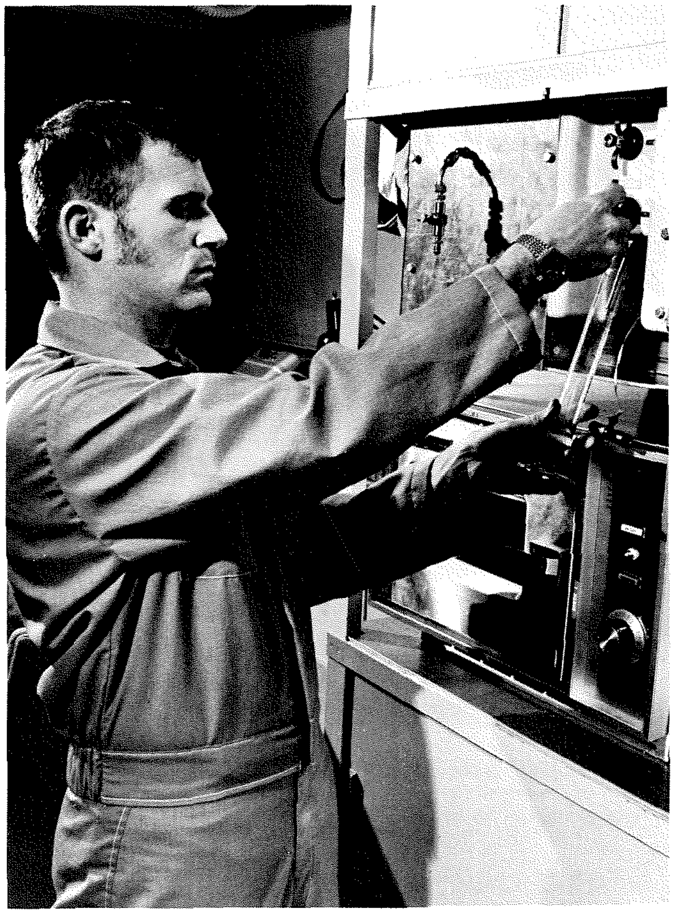
Our food menu rotated on a ten-day schedule with each four-man meal packaged separately. We all quickly developed food likes and dislikes, either of which served to characterize a particular day. Among our favorite items were beef tenderloin steak, the freeze-dried vegetables and fruit, and such desserts as fruitcake. The least appreciated included scrambled eggs (eventually boycotted by several of the crew), freeze-dried noodles, and a sweet canned gelatin dessert which only one person would eat. There was not much opportunity for modifying the prepackaged fare, and the consequences of any improvisation that was undertaken could be great, as I demonstrated one evening. Combining scrambled eggs with beef stew, broccoli, and beef with rice, I created a grand-appearing concoction which I then anointed with ketchup and devoured. Several hours thereafter my stomach was tied in knots, and my sleep became a stream of troubled nightmares involving decapitation, drowning, and death by fire as best I recollect.

For snacks we relied on chocolate bars, nuts, and the like. Our chocolate bars—800 of them in all—took up a good deal of storage space, and early in the run we would jest about anyone ever being able to consume such a volume of sweets. Yet on the day of our egress only several dozen bars remained. It was a continual source of surprise to our outside medical observers that the crew maintained such a high caloric intake (some of us consumed over 3,000 calories per day), in view of previous confinement experiences and the Apollo flights, where some weight loss has been the general rule and food intake has commonly been less than 2,000 calories per day. I attribute this to the generally high quality and acceptability of our food and the generally high degree of crew motivation.

A typical day's fare might consist of a breakfast including ham and eggs, toast with jelly, and chocolate or coffee. Lunch would be a carrot-raisin salad, tuna casserole, pudding, and cookies. Dinner was generally the high point in the culinary scheme, featuring on a typical day pork tenderloin, asparagus, squash, breadsticks, strawberries, and cookies.

The daily inventory of food items consumed was sent out via computer data link along with psychologic and physiologic questionnaire information and equipment performance data. Occasionally communications with the computer would break down, and on our television monitor unintelligible gibberish would be displayed. I recollect one day when some consternation and surprise was expressed outside the chamber that the computer printout indicated the consumption of a 6,000 calorie daily diet for one of us, mostly in the form of some 400 teaspoons of raw sugar! Upon interrogation, the crewman denied having developed any great new affinity for sweets, and our computer was duly instructed to replace the errant decimal point.

Steve Dennis early established himself as the poet of our mission, and spent much of his free time writing verse and composing music on his harmonica. Occasionally he would terminate his computer transmissions, which were monitored by the outside observers, with rhymes which



To keep track of water consumption, John Hall measures the amount he is withdrawing from the potable water dispenser. Water, recovered from the crew's urine, perspiration, and wash water, was purified for reuse.

expressed our immediate feelings on some aspect of cabin living. For example:

Watch what you say
Watch what you do
That man with the notebook is watching you.
Don't take off your clothes
Don't pick your nose
'Cept in the bunk room where anything goes.
I'll tell you something
If you ain't heard the news
I got the non-interference talkin' NIPA blues.

Studying hard at the foot of the hills
This cat with a beard sold me these little pills
Gave one to my bird and I took the rest
When I woke up I was stuck in an SSS
If I ever get out
I'm gonna stick with the booze
I got the non-interference talkin' NIPA blues.

NIPA—Non-Interference Performance Assessment—was an Orwellian innovation of our project psychologists that the crew occasionally found annoying. The purpose of NIPA was to develop techniques for ground support personnel to use in detecting significant changes in an astronaut's emotional or performance characteristics during space missions.

In practice, closed circuit televsion cameras and microphones were arranged to allow outside personnel to monitor the cabin continuously and completely—except for the sleep and hygiene areas. The crew did not have any visual contact with the outside, and relied entirely on microphone headset communications.

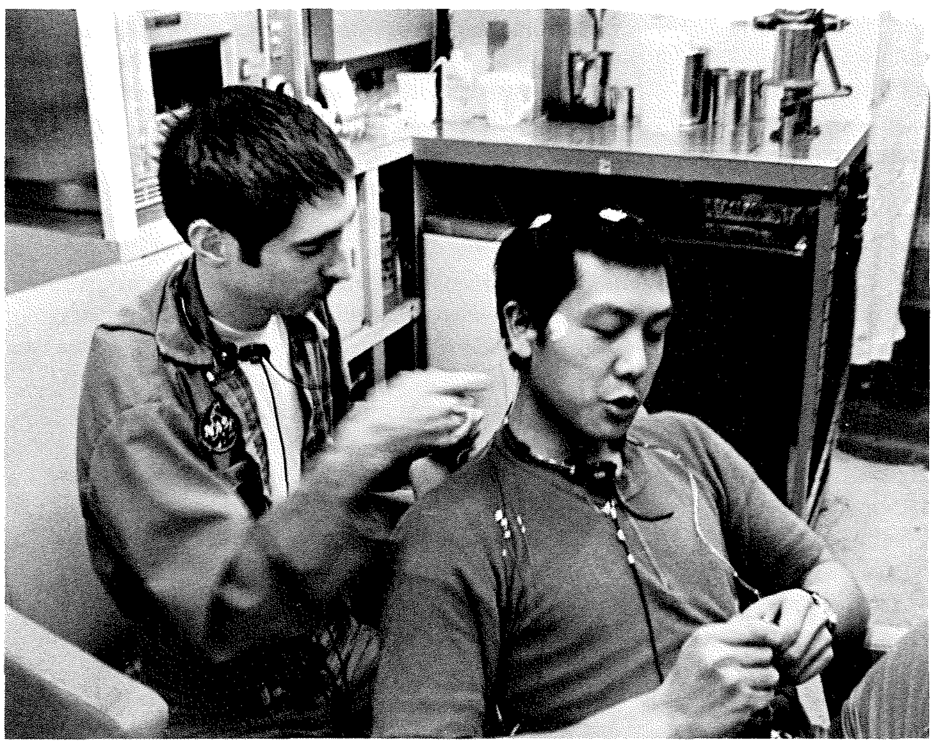
The NIPA observers, who were trained personnel with some background in psychology, were provided with a bank of television screen displays as well as acess to our bank of television screen displays as well as access to our told only that the NIPA observers were going to study crew behavior in relation to task performance. In consequence we often had the feeling of being watched with little appreciation toward what end. Thus, while NIPA was indeed "non-interfering," it was seldom unobtrusive.

In fact, what the NIPA personnel did was to code into the computer a number of fairly objective features of crew behavior, such as position in the cabin, frequency of conversations, persons involved in conversation, and the affect content of speech, toward the objective of discerning some behavioral parameters which might correlate with the caliber of crew performance. Since the crew accomplished all of the jobs requested of them during the run, this sort of straightforward correlation was not possible. However, NIPA did chart the changes in crew morale, and that information may be of some benefit in predicting performance changes during longer tests or actual space missions.

The onboard equipment included a number of cameras for documenting our activities, and after we had filmed representative samples of most of the daily activities and yet found much film remaining, Wilson Wong decided to produce a movie. As he zoomed in and out following our movements, we put together a gripping melodrama which begins with me emerging from one of the food storage cabinets with a tin hat and proceeding to climb the walls, while Steve torpidly responds to buzzes from the outside and keeps sleepily falling from his chair. Inane, yes, but the occasional variety offered by such outlets aided the passage of time.

Concerned that we might not be providing our psychologists with enough data on men under confinement stress, Wilson began sending his own narrative prose out among the weekly vials of blood. One week the appearance of several winged adult fruit flies inside the chamber was traced to larvae in some of the raisin stores. After a boycott of the raisins by several crewmen and the suggestion that we ought to get rid of all the raisins lest the rest of the larvae hatch out and invade our accommodations, I resolved the dilemma by a combination of microwave cremation and deep freezing. Pity for the deceased larvae brought forth a moving document from Wilson detailing the events of their annihilation.

Besides clowning, we enjoyed movies, television, and games; Scrabble rapidly became the most popular group recreational pastime. However, equipment shortcomings emerged early in the run, and at one point the urine reclamation boiler had to be fully disassembled and 80 pounds of urine stored in plastic containers, the



As one way of obtaining physiological and psychological data on the effects of long-duration confinement, electrodes were attached to the crewmen's heads for periodic electroencephalographic (EEG) readings while resting. Here, Terry Donlon puts the contacts on Wilson Wong.

Sabatier Reactor was disassembled for catalyst replacement, and a gas concentrator valve stuck, requiring wrenching every half hour; so no one could complain of being bored.

As we celebrated the passage of the 60th day—the previous U.S.A. record for a manned test of this sort—there was a general attitude of "it's all downhill now," and in retrospect I don't think we were ready for yet another 30 days of confinement. In these later days of the simulation the psychological aspects of the confinement experience became wearing. During the early days of the run the novelty of the situation and press of learning new skills had occupied everyone, and in mid-run the flurry of equipment repairs had kept us busy. Now, however, the elation of day-60 slowly fizzled out as we realized that there was indeed still a considerable time to go. The small maintenance tasks that were not absolutely necessary or included in the time-line schedule were shirked entirely. Cohesion of the crew as a group had stemmed more from the common experiences we had shared than from emotional affinities, and now with a diminished activity schedule small tensions escalated themselves until, around day-70, they began to seem intolerable.

However, during our cohesion training sessions prior to the test, we had learned that the buildup of hostilities is always a risk in such small-group confined situations, and we had all expressed some resolve not to suppress the small annoyances, but rather to vent them as they occurred. Accordingly, we conducted an open discussion to iron out these sources of friction. This proved effective in restoring our proficiency, and the remainder of the run passed smoothly.

In long-term space ventures it is of course important that an astronaut crew be kept physically fit. Since we were not living under zero-G, we could not hope to duplicate the physiological stresses or exercise requirements of men in space. Yet we could establish the degree of exercise necessary to preserve cardiorespiratory conditioning under prolonged confinement conditions on earth. Furthermore, since task performance is undoubtedly correlated with a sense of physical well-being, I feel that the exercise program was important to the maintenance of crew morale and performance.

Our exercise consisted of 15 minutes each weekday pedaling on a variable-resistance bicycle ergometer against a load individually determined to result in a plateau heartbeat rate of 150 to 160 beats per minute. An improvement in conditioning would be indicated by a declining plateau heart rate against a set load over a number of exercise periods.

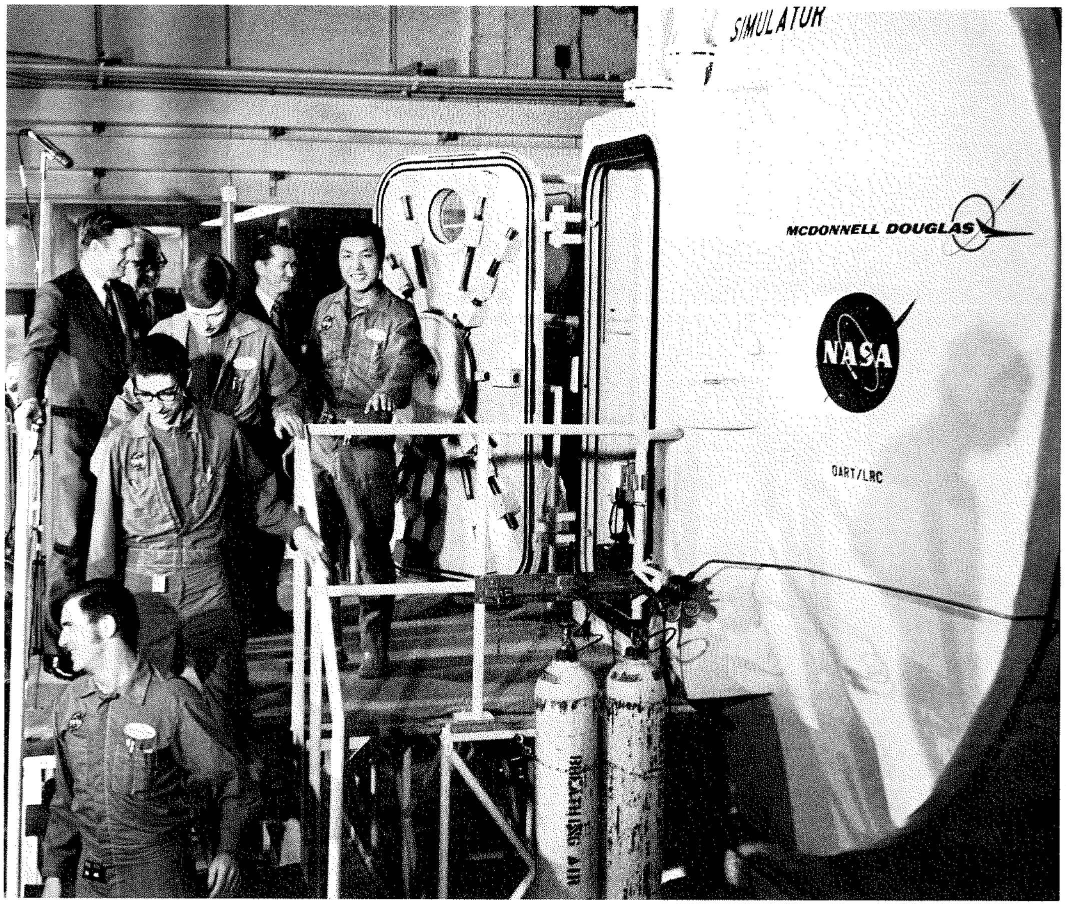
Because astronauts in space are not limited in their exercise, we also could undertake any ad lib exercise programs we desired. My own choice was to adopt a set of calisthenics and isometric exercises done each day for about 45 minutes. Though I felt myself to be in good physical condition before the test, my physical conditioning in fact improved inside the chamber. Treadmill tests before and after the simulation substantiate the observation that those of us who undertook some exercise program in addition to the bicycle all retained or improved cardiorespiratory conditioning, while limitation of exercise almost solely to the ergometer seemed to result in a slight decrease in physical conditioning.

The pollution control problem in the SSS was in many ways a microcosm of the same problems in our normal environment. Earth's resources are not infinite, and we cannot continue to rely on simple dilution in the air, soil, or waters for disposal of waste materials. In the SSS, reclamation of our limited resources meant not only that water and gases had to be regenerated, but also that garbage and trace contaminants had to be disposed of. Dry food wrappings and papers were baled and sealed in aluminum wrappings to prevent fire, while wet food wastes were disinfected and canned.

Because of the precautions exercised in cabin material selection, there was little danger of having to cope with problems of heavy metal pollution. The accumulation of hydrocarbons from outgassing of foods and metabolic activity was kept to low levels by the use of adsorbents in the atmospheric purifying systems and a catalytic burner which slowly processed the cabin air, combusting hydrocarbons to water and carbon dioxide. The human body is of course a source of small amounts of hydrocarbons, mostly methane, as a result of microbial activity in the gut. It also generates some carbon monoxide as a result of other physiological activities. Recent medical studies indicate that even very low carbon monoxide levels, which may deactivate only 2 percent of the body hemoglobin, cause certain impairments in mental functions such as arithmetic and judgment of time intervals. In one test our catalytic burner was shut down for several days, and levels of several parts per million of carbon monoxide were allowed to accumulate. While the crew suffered no specific chronic effects from the elevated CO levels, there is a suggestion in some of the psychomotor data that performance was adversely affected.

What did we accomplish? First, the wealth of design and equipment operational data alone justifies the exercise. No amount of bench testing could provide the same information.

Was this simulation successful? My answer is yes: The test objectives were met, and the equipment was



Astronaut Neil Armstrong was on hand to greet the SSS crewmen as they emerged from the simulator at the end of their 90-day run.

operated under conditions of limited weight, space, and energy consumption, as well as limited maintenance and repair. Moreover, from a medical and physiological viewpoint, the data will serve as an effective control in future experiments on the long-term effects of confinement and exposure to an atmosphere of elevated carbon dioxide partial pressure, such as will be encountered in at least the next generation of spacecraft.

Of course, there were many important differences between our experience and an actual space mission. Our environment was not particularly hazardous, and the safety of an abort was never more than a few seconds away. Hence the stress we experienced could not have duplicated that of a real astronaut's for whom equipment failure or meteorite puncture could have catastrophic results. Further, there was no opportunity for extravehicular activity, such as "space walks." Such opportunity might have a mixed effect, acting on the one hand to moderate tensions resulting from confinement, but on the other hand producing a more immediate realization of the confrontation between man and environment. Finally, there was not the sense of a "mission." However high the motivation of a simulation crew, no man can experience on earth the sensations felt by the first astronauts to arrive at a distant planet after a year or more of travelling to get there. I cannot doubt that astronaut crews on such long-term flights will possess an extra amount of drive and be willing to tolerate annoyances otherwise unacceptable.

The purpose of the 90-day Space Station Simulation and similar tests is not to stress men to their limits; rather, it is to provide an artificial environment in which men can work and live with the minimal stress and compromise of a "normal" type of existence. The 90-day run demonstrated the response of an astronaut-like crew to a long-term confinement experience.

In the immediate future many of the habitability responses encountered during the 90-day run are being incorporated into planning for the Skylab I, the Apollo Applications Laboratory being built by McDonnell-Douglas for launch by 1973. Eventually regenerative life support modules will be installed in the larger orbital space stations of the late 1970's, and in the interplanetary craft of the next decade. Toward these future endeavors re-engineered and improved life support equipment with increased automation will first have to pass longer tests of operation and performance. The next step may well be a 180-day Space Station Simulation. *I* still think *90* days is a long time.