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The History of In-Flight Exercise in the U.S. Manned Space Program

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In the days before manned space flight, the physiologic consequences of weightlessness on the human body were totally unknown. Today, we find it surprising, if not amusing, to think that before the first U.S. astronaut was launched, some scientists predicted, and even President John F. Kennedy's advisory committee on space expressed concern, that the human body would not be able to withstand the rigors imposed on it during space flight and that our astronauts would not survive. As a result of these uncertainties, prospective astronauts for Project Mercury underwent comprehensive and very extensive medical testing. As Tom Wolfe documented in his book "The Right Stuff," and as was subsequently graphically depicted in the movie of the same name, every conceivable physical parameter was tested, every possible laboratory value was measured, and every orifice was probed in an attempt to find any identifiable medical or physiological flaw in the candidates. Consequently, the astronauts who survived the selection process were viewed by many as a breed of supermen. The maintenance of physical conditioning and exercise became an unwritten rule in the astronaut cadre. This esprit de corps arose partly because of the unknown possibility that physical fitness and athletic ability might become a crew selection criterion and also possibly out of the desire to maintain this superimage.

During Project Mercury, little attention was paid to in-flight exercise. The Mercury manned flight program began with two suborbital flights, progressed to John Glenn's three Earth orbits on Mercury 6, and ended with Gordon Cooper's 34-hour flight on Mercury 9. The short duration of these flights and, more importantly, the fact that these flights took place in a very small, compact, and cramped vehicle precluded the need or the ability to perform in-flight exercise.

From Project Mercury, we progressed to the Gemini Program and the development of two-man spacecraft, the first of which was launched in March of 1965. The vehicles remained extremely small and available space for unrestricted movement was still severely limited. It was, however, on the second manned Gemini mission, Gemini IV, that the first experiment using an in-flight exerciser was performed. The objective of this experiment was to make day-to-day evaluations of the cardiovascular response to a calibrated workload under space-flight conditions. The exercise device consisted of a pair of rubber bungee cords attached to a nylon handle at one end and to a nylon footstrap at the other. The flight bioinstrumentation system was utilized to obtain pulse rate, blood pressure, and respiratory rate. The exercise device required about 70 pounds of force to stretch the rubber bungee cords maximally through an excursion of 12 inches. The exercise periods lasted 30 seconds, during which time the astronauts stretched the bungee cords through one contraction and relaxation cycle per second. Each of the astronauts performed approximately 15 exercise bouts during the 4-day mission. In flight, the heart rate of the command pilot and the pilot reached 105 bpm during exercise. There was no significant difference from their preflight values for exercise heart rate or for recovery heart rate. From this minimal level of exercise, the investigators concluded that there was no evidence of "deconditioning" at any time during the Gemini IV mission. In the postflight physical exam, using a Harvard step test as an index of physical fitness, no decrement in physical condition was found. Consequently, use of the bungee device was continued on Gemini flights, including Gemini VII, which at that time was our longest stay in space, 14 days. For this 14-day flight, a simple isometric routine was designed and astronauts performed the routine about three times a day along with the bungee apparatus. This in-flight exercise program did not serve as a conditioning program but did relieve disuse discomfort stemming from both weightlessness and the relative immobilization caused by the cramped quarters.

After the Gemini Program, we moved into the Apollo Program with a three-crewmember spacecraft. The goal of Apollo was to go to the Moon, explore the lunar surface, and return safely to Earth. The Apollo Program was initially structured to have a competent exercise device on board a somewhat larger spacecraft. A small box ergometer with pedals on either side was developed; however, it contributed to spacecraft weight problems and the exercise program was canceled. Consequently, only a very informal exercise program existed through the Apollo Program. The only on-board exercise device was one of the rope-and-pulley variable-friction machines. The crew used this item sporadically, again primarily for relief of the discomfort of cramped confinement. During Apollo, two of the crewmembers on each of the six lunar landing missions received additional exercise during their lunar extravehicular activities (EVA's). The activities included collecting geological core samples, setting up experiments, and gathering various lunar samples and Moon rocks. It was during the Apollo Program that evidence began to appear and a pattern to evolve of deconditioning, weight loss, loss of muscle mass, and, in particular, decreased exercise capacity during the immediate postflight period in 20 of the 27 Apollo crewmembers tested. The exercise capacity was measured on ergometers before and after flight. Significant concerns were raised regarding space-flight "deconditioning" and about the use of exercise as a prophylactic measure, especially in planning for the upcoming long-duration Skylab missions.

Skylab was a large orbiting laboratory that to date has been the only long-duration space-flight experience in the U.S. space program. There were three Skylab missions, identified as SL-2, SL-3, and SL-4, carrying three crewmembers each on missions of 28, 59, and 84 days. Skylab missions were flown during the time period of May 1973 to February 1974. For the initial Skylab flight, a bicycle ergometer capable of a wide range of workloads was developed. Coupled with the bicycle was the capability for measuring heart rate, respiration, and blood pressure and for obtaining electrocardiograms. A mass spectrometer gas analyzer was also on board, capable of giving the crew and investigators oxygen and carbon dioxide parameters. The device was used in the experimental testing mode approximately every fifth day on all three Skylab flights. The data obtained provided a longitudinal look at exercise capacity as a function of time in weightlessness. The bicycle was also available in flight for use as a daily exercise device. All exercise done was carefully logged and reported. Consequently, a complete record of in-flight exercise was obtained. On the first manned Skylab mission, SL-2, the bicycle ergometer was the only exercise device on board. Because of problems with the design of the shoulder harness and the eventual discarding of it completely, it took the SL-2 crew approximately 10 days to learn how to ride the bicycle in zero g. From that point on, the astronauts had no difficulty in achieving the same feedout oxygen readings at the same workloads with approximately the same heart rates in flight as they had before flight. The problem with making comparisons with preflight norms was that the norms were established 6 to 12 months before flight, and because of significant improved conditioning of the astronauts prior to flight, the initial in-flight workload levels were artificially low and were subsequently corrected. The SL-2 crew improvised, with commander Charles Conrad diligently using the bicycle not only in its conventional mode but also as an upper body ergometer. After crew return, postflight testing revealed cardiovascular deconditioning and decreased upper and lower body muscle strength. As a result of this finding, along with the crewmembers' comments and recommendations, changes were made in the exercise program for SL-3. To facilitate increased upper body exercise, two devices, identified as Mark I and Mark II, were added on board. Mark I was a modified commercially available product named the Mini Gym. It was another rope-pull type of device that worked on a centrifugal braking action that approximated isokinetic exercise. The Mark II was a pair of handles between which five springs could be attached giving a maximum of 25 lb/ft that could be developed on extension. On SL-3, the crewmember's average exercise time on the bicycle was increased by more than 100 percent over that done on SL-2.

During this time, work was also begun on the development of a treadmill for Skylab 4. After returning from their 59-day mission, the SL-3 crew was found to be in better cardiovascular condition than was the SL-2 crew. Postflight muscle strength testing showed improvements in maintenance of arm strength, but significant leg strength decrements were still found. On SL-4, a Teflon treadmill devised by astronaut William Thornton, M.D., was flown on board. It consisted of a Teflon-coated aluminum walking surface attached to the Skylab isogrid floor. Four rubber bungees provided an equivalent weight of 80 kilograms and were attached to a shoulder and waist harness worn by the astronaut. By angling the bungees, the equivalent of a slippery hill was presented to the subject, who then had to climb it. Astronaut Gerald Carr, commander of SL-4, stated that he used the treadmill regularly to walk for approximately 15 minutes. He then would perform what amounted to basically a sprint on the device, the sprint being time limited to about 1 to 1-1/2 minutes because of overheating to his socks and feet. He also would use the harness/bungee setup to do squats and toe raises for additional leg muscle exercise. His recollection was that the other two crewmembers, Edward Gibson and William Pogue, used the device in a similar fashion. The SL-4 crew continued the use of the Mark I and II. In addition, they further increased the time on the bicycle to 130 percent of that of the first Skylab crew and added some improvised torso isometric exercises. After 84 days in space, the third Skylab crew returned in better condition than did the crews on the the other two missions, as evidenced by less strength loss, less weight loss, less leg volume decreases, and improved postflight exercise testing.

It was evident from the in-flight cardiovascular testing that all of the SL-4 crewmembers had actually improved their physical conditioning in flight. Commander Carr believed that other than for some unsteadiness caused by vestibular readaptation, he would have been physically able to perform emergency procedures including walking away from the spacecraft or vehicle under his own power if necessary.

After Skylab and the U.S.-U.S.S.R. Apollo-Soyuz flight, planning for the Space Shuttle Program proceeded. From the Skylab experience, a passive treadmill was devised by William Thornton, M.D., and developed and built by Henry Whitmore of Whitmore Enterprises. The Space Shuttle treadmill consists of aluminum plates with rollers on the end that are connected in a series to form a belt. The treadmill is nonmotorized and purely passive so that the astronaut must make the metal belt move by walking or jogging on it. The down-pull of the bungee/harness system can be manually adjusted by the astronaut to approximate his/her own body weight. The treadmill was first flown on STS-3 in 1982 and has been flown with a more recently improved, updated model on every subsequent Space Shuttle flight. By mission flight rules, all astronauts on a Space Shuttle mission have a daily exercise period allotted to them in their crew activity plan. The use of the exercise time is left to the discretion of the individual astronauts to be used as he or she may wish. There is no mission requirement to perform exercise in flight; however, the majority of the astronauts usually do exercise at some time during flight. The treadmill is generally used more frequently by the commander and the pilot, because these crewmembers have mission-critical duties during landing that require use of the legs to push rudder pedals, to steer, and to apply brakes. Other crewmembers on the relatively short Space Shuttle missions are sometimes willing to sacrifice their exercise time and endure some temporary deconditioning for the opportunity to take advantage of the unique sightseeing that space flight provides.

Other than comments related to the noise of the treadmill and concerns regarding the minute acceleration forces imparted to the Orbiter during its use that can disturb zero-g-critical experiments, no significant problems have been experienced with the Space Shuttle treadmill.

Extravehicular activity, or space walks, provide the only other significant in-flight exercise. The first EVA's during the Gemini Program were found to be very demanding with heart rates averaging about 150 bpm. With improved space-suit design and preflight training, EVA's have become somewhat less demanding from a cardiovascular standpoint. However, it should be recognized that essentially all of the physical work involved in EVA is performed by the upper extremities. The only real function of the lower extremities during EVA is to be anchored in foot restraints in order to facilitate working at various workstations without floating free. Some of the Space Shuttle EVA mission objectives have ranged from the manual retrieval of malfunctioning satellites to simulated space station construction activities to the fine electrical repairs of satellites. Some Space Shuttle EVA's have lasted as long as 7 hours. As a result of the duration and the varied nature of the EVA tasks and objectives, significant physical exertion can occur during EVA. This fact should be realized and taken into consideration in Space Station planning, especially during the anticipated EVA-intensive construction phase.

In this paper, I have attempted to give a historical perspective on in-flight exercise in the U.S. manned space program. We have learned a great deal in the 25 years since the inception of Project Mercury. But, as we look forward to a Space Station and long-duration space flight, we must recognize the challenge that lies ahead. The importance of maintenance of the crewmember's physical condition during long stays in weightlessness is a prime concern that should not be minimized. The challenge lies in the design and development of exercise equipment and protocols that will prevent or minimize the deleterious sequelae of long-duration space flight while maximizing valuable on-orbit crew time.