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U.S. Space Flight Experience: Physical Exertion and Metabolic Demand of Extravehicular Activity - Past, Present, and Future

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Extravehicular activity (EVA) has been part of the U.S. space program since the Gemini Program, when astronaut Edward White took the first space walk on Gemini IV in June of 1965 (ref.1). During the Gemini Program, five astronauts performed EVA's on five separate missions. Considerable difficulty was experienced by the crewmembers in performance of their EVA tasks. In fact, two of the EVA's had to be terminated before accomplishment of the EVA objectives because of overexertion and overheating problems. The crewmembers experienced elevated heart rates that peaked above 170 bpm, and, because of exhaustion and overheating, the astronauts could not complete their tasks (ref. 2). Some of the problems experienced could be attributed to the Gemini suit design. The Gemini space suit was designed to control astronaut body temperature with a cooling system that consisted of only a circulating gas system. The exchange of gas or oxygen being pumped into the suit was the only mechanism available to dissipate the heat produced by the astronaut. Although metabolic rates were not measured directly, it was obvious on several occasions that metabolic rates exceeded the thermal control and carbon dioxide washout capacities of the suit life-support system (ref. 3). With overheating, water vapor condensed on the inside of the helmet visor and thereby limited visibility and further added to the problems and frustration of the Gemini EVA crewmen. The suit was also found to be very stiff and cumbersome with limited flexibility about normal anatomical joint areas such as the elbow, the wrists, and the hands. Some of the Gemini EVA problems could also be attributed to the limited one-g EVA training provided the Gemini astronauts. No under-water training was available until prior to Gemini XII, the last Gemini EVA mission.

Physiologic monitoring of the Gemini EVA astronauts was by way of a one-lead electro-cardiograph with heart rate being the only parameter recorded. Table I is a summary of the Gemini EVA missions and heart rates of the crewmen. The problems encountered with the Gemini EVA's led to considerable concern regarding future EVA's. It was realized that adequate body restraints, realistic preflight zero-g simulation training in a water tank, and detailed preplanning of activity were essential to ensure task performance and to reduce fatigue (ref. 5). The Gemini experience also led to the develop-ment of what is called the liquid-cooling garment

TABLE I.- GEMINI EVA EXPERIENCE

[From ref. 4]

Flight	Experience	Duration, hr	Heart rate, bpm	
			Mean	Peak
Gemini IV	Overheating during hatch closing; objectives completed	0.60	155	175
Gemini IX	Visor fogging; hot at ingress; objectives not completed	2.11	155	180
Gemini X	No problem with heat or work rate; objectives completed	.65	125	165
Gemini XI	Exhausting work; no specific men-tion of heat; objectives not completed	.55	140	170
Gemini XII	Good restraints; no problems; objec-tives completed	2.10	110	155

(LCG). The LCG is a set of full-body long underwear with a closed system of flexible tubes sewn into it. The tubes are part of a circulating system that allows liquid to flow through the underwear, providing a cooling mechanism. The astronaut can control the relative temperature of the garment and his temperature by controlling the flow of this cooling liquid.

In planning ahead for Apollo, the primary objective was to land safely on the Moon and explore its surface during a series of lunar EVA's. During the Apollo Program, 6 lunar surface missions and 14 EVA's were accomplished (ref. 6). The metabolic rates from the lunar EVA's are shown in table II. The metabolic rates are presented for four different task categories - (1) scientific package deployment, (2) geological station activity, (3) overhead activity such as working around the lunar module and ingress and egress activity, (4) lunar roving vehicle (LRV) operations - and for all activities, which is an overall average for the entire EVA. The average metabolic rate in kilocalories per hour for the scientific deployment was 244; for geological station activity, 244; for overhead activity, 270; for LRV operations, 123; and for all activities, an average of 234 (ref. 7). As can be noted, driving around the lunar surface in the LRV was by far the least stressful activity.

There are basically three methods for obtaining metabolic rates during EVA. The first method utilized was that of the liquid-cooling garment, which provided essentially a calorimeter to measure heat production. By knowing the amount of body heat produced by an astronaut and taken up by the suit LCG, one can then convert the heat to a metabolic rate. Secondly, there were the oxygen bottle pressure gauge readings. They allowed determination of oxygen utilization from the pressure differentials recorded during the time the astronaut was breathing oxygen on the EVA suit system. Astronauts would also do space-suit familiarization runs on the ground in one g prior to the mission in which a graph of the relationship between oxygen uptake and heart rate would be plotted. Investigators could then look at the EVA heart rate and get some estimation of the corresponding metabolic rate. For the tables illustrated, a combination of the temperature and the oxygen pressure differential methods was used.

It should be noted that the overall average lunar EVA metabolic rate of 234 kcal/hr is actually lower than that anticipated by investigators on the basis of Gemini experience. The EVA crewmembers' heart rates generally ran in the 100- to 110-bpm range for normal activities and would occasionally increase to the 150- to 160-bpm range during especially strenuous activity such as lunar core sampling and Moon rock collection. None of the EVA crewmen had significant complaints about the difficulty of performing lunar EVA. On a couple of occasions, Mission Control had to tell the astronauts to slow their work rates because of increasing heart rates. Other than these minor precautionary measures, there were essentially no complaints or problems with the crewmembers' ability to perform, nor with their performance of, the Apollo lunar EVA's.

Crewmembers also performed zero-g EVA's during Apollo missions. The metabolic rates from Apollo zero-g EVA's (ref. 7) are listed in table III. The zero-g EVA's were primarily to obtain film canisters from the lunar module before it was released and the crew returned to Earth in the Apollo entry vehicle. On these EVA's, one person basically stood in the hatch and observed while the other EVA crewmember obtained the film canisters. The consistent differential in the metabolic rates of the two crewmembers reflects the different activity levels as can be noted from the table. The zero-g EVA metabolic rates were also well within comfortable metabolic working limits, and there were no complaints nor any reported difficulty in performing the EVA's. The Apollo zero-g EVA's were of relatively short duration, lasting an average of 63 minutes.

In 1973, the United States launched the Skylab orbital workshop (OWS), a man-tended orbiting scientific laboratory. To date, it has been our only experience in long-duration space flight. On the three Skylab missions, SL-2, SL-3, and SL-4, astronauts manned the OWS for a duration of 28, 59, and 84 days, respectively. During the Skylab Program, 10 EVA's were performed. A number of the EVA's were for film canister retrieval, similar to those on Apollo. However, a few were performed for unexpected manual repair of the spacecraft and experiments; for example, deploying jammed solar array panels, erecting a solar umbrella, and repairing an Earth resources antenna. Some of the Skylab EVA's occurred very late in the mission just prior to the crew's return. Table IV contains an overview of the metabolic rates from the Skylab EVA's. Again, a number were film retrieval EVA's, wherein one person would stand in the hatch and watch the other person retrieve film. This activity difference is readily apparent from the table by the differential in metabolic rates between paired EVA crewmen; as, for example, EVA's 2, 3, and 4 on SL-4.

In discussions with Skylab EVA astronauts Joseph Kerwin, science pilot on SL-2, Owen Garriott,

TABLE II.- METABOLIC EXPENDITURES DURING APOLLO LUNAR SURFACE EVA'S

Apollo mission	EVA no.	Crewmen	Metabolic rate, kcal/hr					EVA duration, hr
			Experiment deployment	Geological station activity	"Overhead"	LRV operations	All activities	
11	1	CDR[a]	195	244	214	None	227	2.43
		LMP[b]	302	351	303	None	302	2.43
12	1	CDR	206	243	294	None	246	3.90
		LMP	240	245	267	None	252	3.90
	2	CDR	None	218	215	None	221	3.78
		LMP	None	253	248	None	252	3.78
14	1	CDR	182	294	219	None	202	4.80
		LMP	226	174	259	None	234	4.80
	2	CDR	118	238	213	None	229	3.58
		LMP	203	267	231	None	252	3.58
15	1	CDR	282	275	338	152	277	6.53
		LMP	327	186	293	104	247	6.53
	2	CDR	243	293	287	149	252	7.22
		LMP	265	189	266	99	204	7.22
	3	CDR	261	242	311	138	260	4.83
		LMP	230	188	234	106	204	4.83
16	1	CDR	207	216	273	173	219	7.18
		LMP	258	268	275	159	255	7.18
	2	CDR	None	223	249	112	197	7.38
		LMP	None	244	236	105	209	7.38
	3	CDR	None	231	235	124	204	5.67
		LMP	None	242	264	103	207	5.67
17	1	CDR	285	261	302	121	275	7.20
		LMP	278	300	285	113	272	7.20
	2	CDR	None	261	302	121	207	7.62
		LMP	None	300	285	113	209	7.62
	3	CDR	None	261	302	121	234	7.25
		LMP	None	300	285	113	237	7.25
Mean			244	244	270	123	234	
Total time, hr			28.18	52.47	52.83	25.28	158.74	

[a]CDR = commander.
[b]LMP = lunar module pilot.

TABLE III.- APOLLO ZERO-G EVA'S

Flight	Crewman	Metabolic rate, kcal/hr	Duration, min
Apollo 9	Schweickart	151	59
Apollo 15	Worden	<237	40
	Irwin[a]	<117	40
Apollo 16	Mattingly	<504	85
	Duke[a]	(b)	85
Apollo 17	Evans	<302	67
	Schmitt[a]	<143	67
Total time			443

[a]Standup EVA.
[b]Not measured.

SL-3 science pilot, and Gerald Carr, commander of SL-4, it was learned that all believed there was no significant increased difficulty in doing EVA's late in the mission. With their in-flight exercise program, they felt they had maintained sufficient physical conditioning such that the late mission EVA's did not present any unexpected difficulties.

Part of the improvement in EVA capabilities was attributable to improved ground-based one-g training. After the Gemini experience, training facilities and programs were developed utilizing large, specially designed water tanks. The astronauts donned their actual space suits and performed simulated EVA procedures underwater. The existing underwater training facility at the NASA Lyndon B. Johnson Space Center in Houston, Texas, is a 60-foot pool named the Weightless Environment Training Facility, or WETF. The use of the WETF remains today as the primary training method for astronauts preparing for Space Shuttle EVA's. The astronauts are

TABLE IV.- SKYLAB EVA METABOLIC RATES[a]

Skylab mission	EVA no.	Duration, hr	Metabolic rate, kcal/hr		
			CDR[b]	PLT[c]	SPT[d]
SL-2	[e]1	0.61	None	330	260
	2	3.38	315	None	265
	3	1.56	280	None	None
SL-3	1	6.51	None	265	240
	2	4.51	None	310	250
	[e]3	2.68	225	None	180
SL-4	1	6.56	None	230	250
	2	6.90	155	205	None
	3	3.46	145	None	220
	4	5.31	220	None	185

[a]Total time - 81.4 hours; mean metabolic rate - 238.42 kcal/hr.
[b]CDR = commander.
[c]PLT = pilot.
[d]SPT = science pilot.
[e]Gas cooling only.

weighted in the water tank so that they are neutrally buoyant, but differences still exist between conditions in the WETF and actual zero-g conditions. Since gravity is still present, if a subject turns upside down, blood still rushes to his head and he will fall to the top of his suit; however, he remains neutrally buoyant and free-floating. Another noticeable difference exists in the viscosity of the water as compared to the absence of any in the vacuum of space. In the WETF, the astronauts quickly learn to work within nature's physical law relative to neutral buoyancy and weightlessness. For example, they learn that if they apply a force to or torque against an object without themselves being restrained, they will rotate instead of the object they are trying to turn. The astronauts all relate that there is a definite learning process involved in WETF EVA training that correlates with actual EVA work in zero g. It is recognized that a difference in the ease with which astronauts perform nominal EVA's is related to the amount of preflight WETF suit training accomplished. The U.S.S.R. cosmonauts were actually the first to use a water tank to train for EVA, and they continue to use it today as their primary EVA training facility.

The EVA suits have been greatly improved since the Gemini Program. Engineering design improvements and the use and development of advanced materials and fabrics have resulted in increased suit flexibility, mobility, and visibility. The current suit design has positive 4.3-psi differential pressure relative to the outside environment (ref. 8). In the pressureless vacuum of space, the astronauts' suits are therefore pressurized to 4.3 psi. Consequently, because of the pressure differential with the outside environment, the suit, like an expanded balloon, will seek and take the position of least resistant tension. Hence, the astronauts' extremities will tend to assume an extended position when relaxed. To bend or flex an arm or a finger, the crewmember must bend against the suit pressure that tends to maintain an extended position. Consequently, in order to remain in any other position, the astronaut has to maintain active isometric muscle contraction. The EVA suits have joints in the fingers and at the wrists, the elbows, and the shoulders, but no joints below the waist. A lot of "hands on" training is involved in learning how to use and work with the suit to avoid expending wasted energy in what amounts to fighting the suit. Because of the described tension developed by the pressure of the suit, the EVA crewmembers' upper extremities are required to be working almost constantly either in active movement or in an isometric contraction mode.

In the Space Shuttle Program, the first EVA took place on the STS-6 mission in April 1983 The primary purpose of the first Space Shuttle EVA was to demonstrate EVA capability and to evaluate the function of the suit and various tools and restraint devices. At all times during EVA, the astronauts are tethered or attached to the Orbiter. They hook themselves to a small cable tether that is attached to a slidewire running down both sides of the Orbiter payload bay. On STS-6, the tether provided about 1 pound of pull or reeling-in force, which the EVA crewmembers found annoying and uncomfortable in the weightless environment. Conversely, during the preflight training in the WETF, the 1-pound pulling force had been hardly noticeable because of the viscosity of the water, illustrating the difference between one-g training and the actual zero-g experience. Since the STS-6 EVA, the reeling force of the tether has been reduced.

There have been a number of different and varied Space Shuttle Program EVA mission objectives. The purpose of STS 41-C, the third Space Shuttle EVA mission, was to rendezvous with and repair the Solar Maximum Mission satellite (Solar Max) utilizing the manned maneuvering unit (MMU). The MMU is a self-contained backpack that allows the astronaut to propel and maneuver himself untethered away from the Orbiter by use of the MMU gas jets. The mission plan was to rendezvous with Solar Max, fly with the MMU to the satellite, dock with the satellite, bring it back to the payload bay, repair it, and return it to space. Because of blueprint errors in the docking port on Solar Max, astronaut George Nelson was not able to dock and attach to it. Consequently, astronaut Terry Hart, operating controls from inside the Orbiter, literally had to grab the satellite in midair with the use of the remote manipulator arm. The satellite was then placed inside the payload bay, and the EVA astronauts went back out to repair it. To repair the satellite, they had to change out a small control panel, which meant fairly fine movements of their hands and fingers. Because of the EVA suit pressure exerting a force tending to open or extend the fingers, considerable concentrated effort is required in doing fine manipulative work on EVA. From attempting to dock with a large orbiting satellite to performing fine manual repairs, the STS 41-C mission is a good example of the differences in the type of work EVA astronauts have to perform.

Space Shuttle mission STS 51-A, the first satellite retrieval mission, further demonstrated the varied and valuable capabilities of EVA. Because of upper stage rocket firing malfunctions, two satellites launched on a previous Space Shuttle mission did not achieve the required altitude for geosynchronous orbit. If left as they were in low Earth orbit, the satellites would have eventually fallen into the Earth's atmosphere and would have been destroyed. The mission plan of STS 51-A was to retrieve the satellites, secure them in the payload bay, and return them to Earth for repair and reuse. For the satellite retrieval, the astronaut flew the MMU with a "stinger" mechanism attached to the front of it, impaled the rocket nozzle end of the satellite, and, with a spring-loaded grapple mechanism, latched on to the spinning satellite. The mission plan then had the astronaut fly the MMU with the attached satellite back to the Orbiter payload bay. Next, the original plan called for the second EVA astronaut to attach a holding mechanism to the other end of the satellite. From this holding device, the Orbiter remote manipulator would hold the satellite while a mounting platform was placed on the other end of the satellite. The satellite would then be placed, mounted, and secured in the Orbiter payload bay. Again, because of blueprint error, the planned holding mechanism would not fit on the satellite and consequently the EVA crewmen were not able to attach it. The crew therefore had to improvise a plan, which required that the astronaut hold the satellite in his hands while the mounting platform was bolted in place. The satellite weighed 1500 pounds on Earth but was weightless in zero g. It still had 1500 pounds of mass, however, and the laws of physics and inertia remain valid in zero g; that is, any movement imparted to the satellite would then have to be counteracted in order to stop its motion. Consequently, astronaut Joseph Allen, who at 5 feet 4 inches and 135 pounds was the smallest male astronaut, had to maintain the ability to hold and maneuver the satellite into position while the other EVA astronaut, Dale Gardner, worked on the other end attaching the mounting platform. Any uncontrolled satellite movement had the potential consequence of striking and possibly damaging the Orbiter. Allen had to maintain the satellite positioning for more than one revolution of the Earth, or approximately 100 minutes, while Gardner performed his tasks. Actually, Gardner's duties were probably more physically demanding in that he had to ratchet on nine bolts attaching the mounting platform to the bottom of the satellite so that it could then be secured into the payload bay. The experience encountered on this mission, as with the previously described Solar Max repair mission, demonstrates that EVA missions are not always nominal and that the human capability to improvise is very important. However, the experience on this mission also demonstrates that unexpected problems can add to the physical as well as the mental stresses involved during EVA and that the astronauts should be properly prepared to deal with them.

Figure 1 is a graph of the heart rates of the astronauts during the second STS 51-A EVA. The duration of this EVA was 5 hours and 45 minutes. The astronaut, Allen, who performed the isometric-type exercise of holding the satellite is represented as EV1, the solid line. Gardner, who was responsible for ratcheting down the bolts to secure the satellite, is EV2, or the dashed line. On the graph, the areas of absent data are due to what is called LOS, loss of signal, where no data are received while the Orbiter is outside the range of the receiving stations. It is evident that astronaut Gardner consistently had the higher heart rate during the EVA. As can be noted on the graphs, for a considerable amount of time, his heart rate is elevated above 100 bpm with a maximum of 168. Heart rate was recorded for 3 hours and 55 minutes of the EVA. For approximately 1 hour and 40

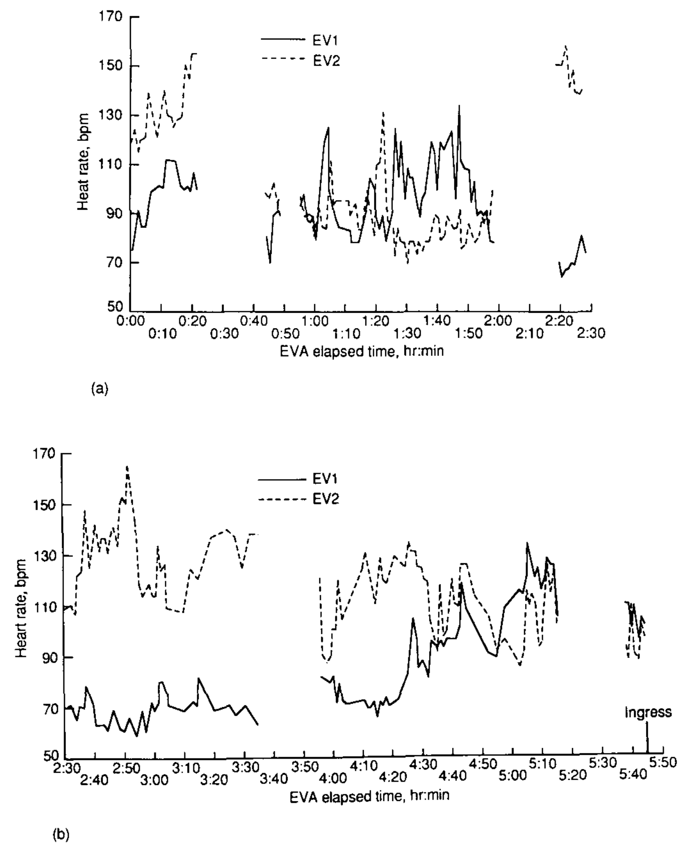

Fig.1.- Heart rates of crewmen EV1 (solid line) and EV2 (dashed line) during second STS 51-A EVA. (a) 0:00 to 2:30 elapsed time. (b) 2:30 to 5:50 elapsed time.

minutes, or 43 percent of the EVA time, astronaut Gardner's heart rate was greater than 65 percent of his maximum heart rate, 120 bpm. Again, when considering the overall physical demands involved, the 5-1/2-hour duration of the EVA should be considered.

The two latest EVA missions, STS 51-I and STS 61-B, are also examples of physically demanding and strenuous EVA's. On STS 51-I, there were two EVA's, with the objective once again being a satellite rendezvous and retrieval with repair of a 15 000-pound satellite. The satellite, called LEASAT, launched 4 months earlier on STS 51-D, had failed to activate and fire its rocket engine upon release from the Orbiter. On STS 51-D, in an attempt to activate it, two astronauts performed the first unplanned EVA in the U.S. space program. For the STS 51-D EVA, a "flyswatter" device was devised and fabricated by the crew on orbit and attached to the Orbiter remote manipulator arm by the EVA astronauts. The arm, with the attached flyswatter, was then used in an attempt to trip the activation switch on the satellite. Although there was good capture of the switch by the use of the flyswatter, activation of the satellite did not occur, an indication that the problem probably was a malfunctioning activation switch. As with the satellites on STS 51-A, LEASAT was in a low Earth orbit and would eventually be lost if it were not repaired. The STS 51-I EVA mission plan called for astronaut James Van Hoften, who is 6 feet 2 inches tall and weighs about 210 pounds, to stand anchored on the end of the Orbiter remote manipulator arm and physically grab the 15 000-pound satellite. He then had to maintain his grip on it, stop its approximate 1 rpm spin, and hold it in position while astronaut William Fisher assisted in securing it. The remote manipulator arm was used to place the satellite in the payload bay, where it was then repaired by the EVA crewmen with the replacement of the faulty activation switch. Finally, astronaut Van Hoften manually spun the satellite and physically placed it in orbit.

To compound the problems of this EVA, the Orbiter remote manipulator arm was not functioning in its computer-assisted mode. This meant that the arm did not move smoothly, making it difficult to easily control the satellite. It abruptly moved and abruptly stopped so that astronaut Van Hoften had to exert additional force in overcoming inertia in moving the satellite and then in stopping it. As mentioned previously, the satellite had 15 000 pounds of mass and to quote Van Hoften, "We planned for the mission for 4 months, I knew it was going to be difficult, and I was ready for it and it was even more difficult than I thought it was going to be." He said that just the "grunting and groaning" of trying to move the satellite into proper position for astronaut Fisher compounded by the manipulator arm not working in its computer-assisted mode presented a significant challenge. When asked to give some indication on the Borg perceived exertion scale of 6 to 20 what level of exertion he felt he experienced, he stated that cardiovascularly, it was not that stressful. However, from a muscular standpoint, he rated the EVA at about a 17 or an 18 on the scale. On the next EVA, which took place the following day, the crewmembers changed out the activation switch on the satellite and replaced it with a new one. Then, to launch the satellite, Van Hoften again literally had to manhandle the satellite using a grip bar the astronauts had attached to its side. To provide some gyroscopic stability to the satellite, he had to spin it up to 3 rpm and release it. Van Hoften stated that just trying to spin the massive satellite so as to prevent contact with the Orbiter as well as to maneuver it into the correct position was physically very demanding. When at a safe distance from the Orbiter, the new switch was activated successfully, firing the satellite booster rocket and taking it to a geosynchronous orbit.

The last Space Shuttle EVA mission to date was STS 61-B, during which the EASE/ACCESS experiment was performed. The EVA's basically were construction engineering EVA's wherein the astronauts tested the ability to build structures in space similar to those anticipated on Space Station. The Assembly Concept for Construction of Erectable Space Structures (ACCESS) experiment was in simplistic terms very similar to a space-age erector set. The astronauts would assemble 93 stowed tubular aluminum struts into a three-sided truss that snapped together at nodes or junction points. After the 45-foot ACCESS assembly was complete, the astronauts tested their ability to maneuver and rotate the structure in the weightless environment. The Experimental Assembly of Structures in EVA (EASE) experiment was a series of six 12-foot beams that were assembled into a tetrahedron. During the first EVA, the astronauts did EASE while free-floating rather than being secured or anchored. One astronaut, the high man, would be free-floating and the other astronaut would be down below in the payload bay workstation. The low man would pull out one of the beams and transfer it up to the free-floating astronaut, who would then assemble the tetrahedron. Both crewmembers commented that it was very difficult to work free-floating without a stable, restrained base. It was difficult to try to hold on with one arm for maintaining position while manipulating the ends of the beams into their attachment nodes with the other arm in order to construct the tetrahedron.

Figure 2 shows Jerry Ross in the lower workstation and his position in foot restraints. The STS 61-B astronauts stated that the only time they got any leg exercise was when they would rock back in the foot restraint to look backward and then use the dorsi flexors of their legs to bring themselves back to the upright position. They commented that they received very little little midbody or thorax exercise. The muscles used were almost entirely upper body. They said that occasionally they would get some minimal abdominal exercise when they had to look down around their feet or below them.

The STS 61-B, EASE/ACCESS EVA crewmembers were also asked to rate their EVA's on the Borg scale of perceived exertion. They felt that from a cardiovascular standpoint, the EVA was not particularly demanding and rated it at about a 10 or an 11, which closely reflected their heart rates during the EVA. However, from a muscular standpoint, one crewmember rated the first EVA as a 20. He unequivocally stated that it was the most fatigued his arms, forearms, and hands had ever been. He rated the second EVA, in which EASE was accomplished while in a foot restraint, as an 18.

In the Space Shuttle Program, there have been 13 two-crewmember EVA's performed on 8 different missions. For the Space Shuttle EVA's, metabolic rates have been obtained by the three different methods: knowing the water temperature differential of the liquid-cooling garment, knowing the oxygen bottle pressure change, and correlating EVA heart rate with one-g measurements. Table V is a summary of the metabolic rates using the first two methods. With both of those methods, the metabolic rate is an average over the entire EVA. Until the last EVA mission, STS 61-B, the capability of downlinking periodic oxygen consumption rates did not exist. Consequently, the average metabolic rate over the entire EVA includes times of active EVA work as well as ingress, egress, and occasional times of inactivity such as occur when a crewmember may be required to

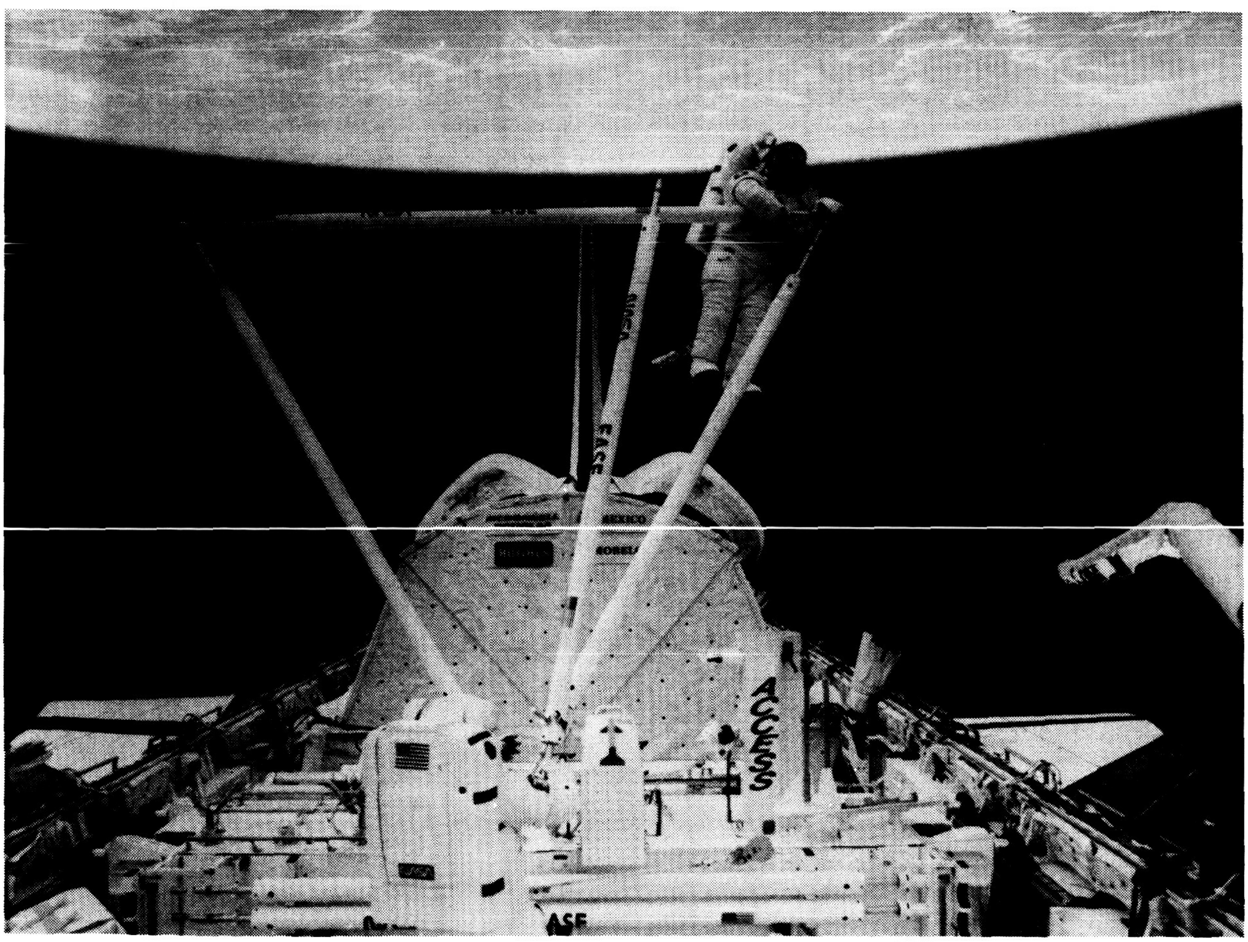

Fig. 2.- STS 61-B astronauts Sherwood Spring (upper right) and Jerry Ross (lower workstation) during EASE/ACCESS EVA.

TABLE V.- SUMMARY OF AVERAGE METABOLIC RATES DURING SPACE MISSION EVA'S

(a) All missions

Mission	Metabolic rate, kcal/hr
Apollo	234
Skylab	230
Space Shuttle	199

(b) Space Shuttle missions[a]

STS mission	Duration, hr	EVA no.	Metabolic rates			
			EV1		EV2	
			kcal/hr	kcal/hr/kg	kcal/hr	kcal/hr/kg
STS-6	3.75	1	146	1.96	206	2.91
41-B	5.5	2	191	2.47	239	3.33
41-B	5.67	3	166	2.15	186	2.59
41-C	3	4	204	2.60	246	2.65
41-C	7	5	235	2.99	194	2.09
41-G	3.5	6	237	3.33	159	2.23
51-A	6	7	153	2.64	202	2.72
51-A	5.75	8	159	2.74	191	2.57
51-D	3	9	222	3.04	181	2.22
51-I	7.5	10	200	2.16	192	2.69
51-I	4.5	11	211	2.28	202	2.83
61-B	5.5	12	267	3.09	196	3.14
61-B	6.5	13	230	2.66	169	2.70

[a]Summary: total duration - 67.17 hours (134.34 crewmember hours); mean metabolic rates - 201 kcal/hr and 2.65 kcal/hr/kg.

wait while Mission Control makes evaluations or decisions. The average EVA metabolic rate for Apollo was 234 kcal/hr; for Skylab, 230 kcal/hr; and for Space Shuttle, 199 kcal/hr. The mean duration of the 13 Space Shuttle EVA's is 5 hours and 10 minutes. The highest absolute Space Shuttle metabolic rate was 267 kcal/hr for EV1 on STS 61-B, and, when corrected for weight, the highest was 3.33 kcal/hr/kg for both EV2, STS 41-B, and EV1, STS 41-G.

It should be realized that doing manual, hand-intensive work in the space suit is very strenuous, particularly on the upper extremities, and primarily the hands and forearms. When looking at the metabolic rate, one should recognize the work on EVA is almost exclusively upper body work. Consequently, the musculature of the upper extremities is the primary contributor to the metabolic rates generated during EVA. When looking at maximum oxygen uptake in ground-based aerobic capacity testing, one sees an approximately 30-percent decrease in maximum oxygen uptake during upper extremity testing when compared with conventional cycle ergometry or treadmill (refs. 9 to 11). One of the EVA astronauts who is a marathon runner in excellent physical condition stated that after his EVA, he felt a level of fatigue similar to that of running 12 to 15 miles.

In looking ahead to the 1990's and the plans for Space Station, a significant number of structure assembly EVA's are anticipated, especially during the construction phase of Space Station. One of the tentative plans calls for 2000 hours a year per crewmember of EVA. Most of the astronauts feel this objective would be very difficult to achieve and is an unrealistic plan. The only back-to-back Space Shuttle EVA to date took place on STS 51-I, where Van Hoften and Fisher did the LEASAT retrieval and repair. Van Hoften felt that knowing they had to do the EVA's back-to-back, he was able to do them successfully. However, he stated that if pressed and put into a position where he would have to do EVA's 5 days in a row, he felt it would be very taxing and difficult to maintain such a schedule. Some of the other astronauts have expressed reservations regarding back-to-back EVA's. With consecutive EVA's, they were concerned that some compromise in maximal effectiveness and performance would be encountered and accepted. They all felt future flight rules, especially for Space Station, regarding the frequency of EVA need careful consideration.

Another important related area to EVA is preflight conditioning. From my discussions with the EVA crewmembers, it was learned that all of them did do preflight conditioning. Their preflight training regimes varied but consisted primarily of upper body strength training combined with aerobic training. Without exception, all of them subjectively felt their preflight conditioning helped even if solely from a psychological standpoint. They believed that knowing they had the extra reserve capacity if needed afforded them added confidence in performing their EVA tasks. They all felt upper body exercising and training were very useful and beneficial, and at least one commented he wished he had done more preflight conditioning than he had.

There were only a few medical problems encountered by the crewmembers during the EVA's. The astronauts from the EASE/ACCESS EVA had some finger numbness, primarily from compression of the digital nerves in the web space between the thumb and the index finger where their gloves creased. Because of the hand-intensive work and manipulations they did during their EVA's, both crewmembers said they experienced parastesia of their thumbs lasting for as long as 2 weeks. Improved suit and glove design is one of the necessary and ongoing areas of technological development to facilitate improved EVA capability. Two crewmembers also noted mild pressure ear blocks upon repressurization following their EVA's. These were relieved after forced clearing of their ears by the valsalva maneuver.

In conclusion, from the EVA experience and data obtained to date, the following points should be stressed.

1. Nominal EVA's should not be overstressful from a cardiovascular standpoint.

2. Manual labor-intensive EVA's such as planned for the construction phase of Space Station can and will be demanding from a muscular standpoint, primarily for the upper extremities.

3. Off-nominal unplanned EVA's can be physically demanding both from an endurance and from a muscular standpoint.

The crewmembers should be physically prepared and capable of performing these EVA's at any time during the mission.

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