

Chapter 17: The NASA Connection

My first association with NASA was when I met Captain James Lovell. This was an amazing experience for me since my Israeli background in sports had never included an opportunity to meet an actual NASA astronaut. I grew up in Israel, where we had our heroes in the Air Force, but no astronauts in a space program. Meeting such an accomplished astronaut as James Lovell was both awe inspiring and slightly intimidating.

When I returned to Amherst after my first committee meeting with Captain Lovell, I immediately began to research his background. James Arthur “Jim” Lovell, Jr. (born

March 25, 1928) was selected as a NASA astronaut in 1962 after having served as a captain in the United States Navy.

Lovell was selected as a backup pilot for Gemini 4, which put him in a position for his first space flight three missions later as pilot of Gemini 7 with Command Pilot Frank Borman in December 1965. This flight set an endurance record of fourteen days in space. Lovell was later scheduled to be the backup Command Pilot of Gemini 10, but after the deaths of the Gemini 9 prime crew Elliot See and Charles Bassett, he replaced Thomas P. Stafford as backup commander of Gemini 9A. This positioned Lovell for his second flight

Captain James Lovell



Frank Borman





Buzz Aldrin

and first command of Gemini 12 in November 1966 with pilot Buzz Aldrin.

Lovell's two Gemini flights gave him more time in space than any other person as of 1966. However, his career was far from finished at that point. Lovell was originally chosen as the Command Module Pilot (CMP) on the backup crew for Apollo 9, planned as a high-apogee Earth orbital test of the Lunar Module (LM), along with Neil Armstrong as Commander and Buzz Aldrin as Lunar Module Pilot.

Delays in construction of the first manned LM prevented it from being ready in time to fly on Apollo 8 which was planned as a low Earth orbit test. It was decided to swap the Apollo 8 and Apollo 9 prime and backup crews in the flight schedule so that the crew trained for the low-orbit test could fly it as Apollo 9, when the LM would be ready. The original Apollo 9 medium Earth orbit test was replaced with a lunar orbital flight, now Apollo 8. Borman, Lovell and Anders were launched on December 21, 1968, becoming the first men to travel to the Moon.

As CM Pilot, Lovell served as the navigator, using the spacecraft's built-in sextant to determine its position by measuring star positions. This information was then used to calculate required mid-course corrections. The craft entered lunar orbit on Christmas Eve and made a total of ten orbits—most of them circular—at an altitude of approximately 70 miles (110 km) for a total of twenty hours. They broadcast black-and-white television pictures of the lunar surface back to Earth, and Lovell took his turn with Borman and Anders in reading a passage from the biblical account of creation in the Book of Genesis.

They began their return to Earth on Christmas Day with a rocket burn made on the Moon's far side, out of radio con-

tact with Earth. The two tensest moments of this first lunar mission were these lunar orbit insertion and trans-Earth injection burns. When contact was reestablished, Lovell was the first to announce the good news, "Please be informed, there is a Santa Claus." The crew splashed down safely on Earth on December 27.

Lovell was backup commander of Apollo 11 and was scheduled to command Apollo 14, but he and his crew swapped missions with the crew of Apollo 13, as it was felt the commander of the other crew, Alan Shepard, needed more time to train after having been grounded for a long period.

Lovell lifted off aboard Apollo 13 on April 11, 1970 with CM Pilot Jack Swigert and LM Pilot Fred Haise. He and Haise were to land on the Moon. However, an unbelievable and potentially catastrophic event occurred on April 13th. During a routine cryogenic oxygen tank stir in transit to the Moon, the electrical insulation on wiring created a spark and started a fire inside the tank. Liquid oxygen rapidly turned into a high-pressure gas, which burst the tank and caused the leak of a second oxygen tank. In just over two hours, all on-board oxygen was lost, disabling the hydrogen fuel cells that provided electrical power to the Command/Service Module "Odyssey". It was during these pressure-packed moments that the calm-sounding voice of Captain Lovell infamously reported to Ground Control, "Houston, we have a problem."

Clearly, the situation required an immediate abort of the Moon landing mission and to focus on safely returning the crew to Earth. The three astronauts and Earth-bound scientists went into emergency planning mode.

Using the LM as a "lifeboat", providing battery power, oxygen, and propulsion, Lovell and his crew re-established the free return trajectory that they had left and swung around the Moon to return home. Based on the flight controllers' calculations made on Earth, Lovell had to adjust the course two times by manually controlling the Lunar Module's thrusters and engine, using his watch for timing. Apollo 13 returned safely to Earth on April 17th.

Lovell is one of only three men to travel to the Moon twice, but unlike John Young and Eugene Cernan, he never walked on it. Remarkably, he is one of only 24 people to have flown to the Moon, the first of only three people to fly to the Moon twice, and the only one to have flown there twice without making a landing. Lovell was also the first person to fly in space four times.

Lovell accrued over 715 hours of space flight and had seen a total of 269 sunrises from space on his Gemini and Apollo flights. This was a personal record that stood until the Skylab 3 mission from July through September of 1973. It is also probable that Apollo 13's flight trajectory gives Lovell,

Haise, and Swigert the record for the farthest distance that humans have ever traveled from Earth. Lovell is a recipient of the Congressional Space Medal of Honor and the Presidential Medal of Freedom. He retired from the Navy and the space program in 1973.

After he had retired from NASA, Lovell and Jeffrey Kluger wrote a book about the Apollo 13 mission called “Lost Moon: The Perilous Voyage of Apollo 13”. This book was the basis for the Ron Howard movie Apollo 13. In the film, Lovell has a cameo appearance as the captain of the USS Iwo Jima, the naval vessel that led the operation to recover the Apollo 13 astronauts after their successful splashdown. Lovell can be seen as the naval officer shaking Hanks’ hand in the scene in which the astronauts come aboard the Iwo Jima. Filmmakers initially offered to make Lovell’s character an admiral aboard the ship. However, Lovell stated “I retired as a Captain and a Captain I will be”, so he was cast as the ship’s skipper, Captain Leland E. Kirkemo.

Lovell visits colleges and universities, where he gives speeches on his experiences as an astronaut and businessman. He strongly urges students to get involved in science and the space program, and he credits NASA in the 1960s with bringing much of the country together for a common goal. As I am writing this book in 2017, I reflect on his inspirational messages of the 1970’s and hope his goals will be achieved.

Captain Lovell and I served together on the Scientific Committee of the Health and Tennis Corporation of America in 1973. At that time, in the years before fitness centers became ubiquitous, the Health and Tennis Corporation of America was the largest health club chain center in the U.S. and probably in the world. The committee members included leading international scientists in the field of human performance. Some of the noteworthy scientists were Bruno Balke, the pioneer in using lactic acid as an indicator of fitness level; Dr. Frank Katch, a leading physiologist and nutritionist; and Dr. Thomas Cureton, one of the most well-known exercise physiologists. It was an honor for me to be able to work and share ideas with this amazing group of scientists.

While Jim and I were members of this committee, I had many discussions with him about the fitness level of astronauts for the space mission. The lack of gravity and its effect on the bone structure were significant factors for consideration at NASA. At that time, the primary goals for astronauts in space were: (1) achieving maximum fitness levels before launch, and (2) maintaining adequate fitness levels in microgravity. Another question of major concern was the length of time that astronauts could remain in microgravitational environments with no deleterious effects.

I described to Jim the Computerized Exercise Machine which I was developing in my lab in Amherst, Massachusetts

and that it was gravity independent. I also described our biomechanical motion analysis system and how it could be used to analyze astronauts in space. Jim’s response was to enumerate the many purposes that he could imagine how such a system could be used in NASA. For example, astronauts have to execute many movements in challenging gravitationally-compromised environments. One situation occurs during the thrust of takeoff, when the ability to move the arm requires tremendous strength, making it difficult to execute fine motor skills. On the other hand, in microgravity, movements are less exhausting, requiring little strength to accomplish many tasks. However, countermeasures are necessary to replace the human’s physiological need for gravity, particularly on maintenance of the structural strength and integrity of the skeletal bones. Captain Lovell explained that the ability to quantify the movements of the biomechanical analysis system and to develop an appropriate fitness regimen for astronauts was of great interest to NASA.

Captain Lovell and I continued our discussions during the years that we served together on the Scientific Advisory Board of the Chicago Health and Tennis Club. He was in-

Anders



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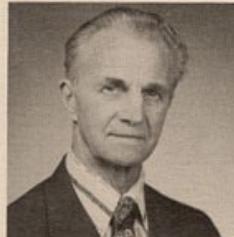


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First man to journey twice
to the moon

Members of the Scientific Committee of the Health and Tennis Corporation of America

strumental in arranging subsequent contacts between me and some of the other individuals at NASA.

The First Astronaut to visit the Research Center in Coto De Caza was Gordon Cooper.

Leroy Gordon Cooper, Jr., also known as “Gordo” Cooper, (March 6, 1927 – October 4, 2004) was an engineer and American astronaut. He graduated from high school in 1945 only to learn that the Army and Navy flying schools were not taking any new candidates. He decided to enlist in the United States Marine Corps and left for Parris Island as soon as he graduated. Since World War II ended before he could get into combat, he transferred his commission to the United States Air Force in 1949. He was placed on active duty and received flight training at Perrin Air Force Base (AFB), Texas and Williams AFB, Arizona.

In 1956, Cooper completed his Bachelor of Science degree in aerospace engineering. He was then assigned to the U.S.A.F. experimental flight test school at Edwards Air Force Base in California. After graduation, he was posted to the flight test engineering division at Edwards, where he served as a test pilot and project manager testing the F-102A and F-106B. While there, he corrected several deficiencies in the F-106 that saved the U.S. Air Force a great deal of money.

While at Edwards, Cooper was intrigued to read an announcement saying that a contract had been awarded to McDonnell Aircraft in St. Louis, Missouri to build a space capsule. Shortly after that, he was called to Washington, D.C. for a NASA briefing on Project Mercury and the part astronauts would play in it. Cooper went through the selection process with the other 109 pilots and was accepted as the youngest of the first seven American astronauts.

Each of the Mercury astronauts was assigned to a different part of the project along with other special assignments. Cooper specialized in the Redstone rocket. He developed a personal survival knife, the Model 17 “Astro” from Randall Made Knives, for astronauts to carry. He also chaired the Emergency Egress Committee which was responsible for developing emergency launch pad procedures for escape. Cooper served as capsule communicator for Alan Shepard’s first sub-orbital spaceflight in Mercury-Redstone 3 (Freedom 7) and Scott Carpenter’s flight on Mercury-Atlas 7 (Aurora 7). He was a backup pilot for Wally Schirra in Mercury-Atlas 8 (Sigma 7).

Cooper was launched into space on May 15, 1963, aboard the Mercury-Atlas 9 (Faith 7) spacecraft, the last Mercury mission. He orbited the Earth 22 times and logged more time in space than all five previous Mercury astronauts combined. He was the first American astronaut to sleep not only in orbit but on the launch pad during a countdown.

Like all Mercury flights, Faith 7 was designed for fully automatic control, which was a controversial engineering decision. In many ways, fully automatic control reduced the role of an astronaut to that of a passenger and prompted Chuck Yeager to describe Mercury astronauts as “spam in a can”.

Toward the end of the Faith 7 flight, there were mission-threatening technical problems. During the 19th orbit, the capsule had a power failure. Carbon dioxide levels began to rise and the cabin temperature jumped to over 100 degrees Fahrenheit (38° C). Cooper turned to his understanding of star patterns, took manual control of the tiny capsule and successfully estimated the correct pitch for re-entry into the atmosphere. Some precision was needed in the calculation, since if the capsule came in too steep, g-forces would be too large, and if its trajectory were too shallow, it would shoot out of the atmosphere again, back into space. Cooper drew lines on the capsule window to help him check his orientation before firing the re-entry rockets. “So I used my wrist watch for time,” he later recalled, “my eyeballs out the window for attitude. Then I fired my retrorockets at the right time and landed right on the carrier.” Cooper’s cool-headed performance and piloting skills led to a basic rethinking of design philosophy for later space missions.

Cooper was selected as backup Commander for the May 1969 Apollo 10 mission. He hoped this would place him in position as Commander of Apollo 13, according to the usual crew rotation procedure established by the Flight Crew Operations Director, Deke Slayton. However, by May 1969, when another grounded Mercury astronaut, Slayton’s assistant Alan Shepard was returned to flight status, Slayton replaced Cooper with Shepard as Commander of this crew. Loss of this command placed Cooper farther down the flight rotation, meaning he would not fly until one of the later flights, if ever.

Disappointed by the reduced chances of commanding a Moon landing flight, Cooper retired from NASA and the Air Force on July 31, 1970, as a Colonel, having flown 222 hours in space.

Spending time with Cooper in California, and learning of all of the amazing things that he had accomplished in his life, evoked an even greater amazement than I had previously about NASA and the people who were involved there. Before my contacts with James Lovell and Gordon Cooper most of my heroes had been gold medal and world champion athletes. Meeting these awe-inspiring astronauts presented entirely new and exciting adventures that were previously unknown to me. Hearing the stories in personal, face-to-face renditions provided an opportunity to share, vicariously, the thrills of adventure that these amazing astronauts had per-



Gideon, astronaut Gordon Cooper, WWII pilot Bo Friedman, and tennis pro Vic Braden

formed. All of my staff was equally enthusiastic and more than ready to begin work with NASA.

Apparently, after Gordon Cooper's visit to the Coto Research Center and his familiarization with the capabilities of both the biomechanical analysis and the Computerized Exercise machine, he passed word about our technology to other people at NASA. Not long after his visit, I received a telephone call from two other famous astronauts: Dave Walker and Dr. William Thornton.

I was surprised to receive this call, because astronauts were regarded as heroes and were considered to be isolated and protected from outside interference. I was even more thrilled when they asked if they could come to our lab and discuss potential projects. Obviously, I responded that they were welcome at any time, so we set up a meeting for two weeks from then.

The first thing I did was begin research about these two individuals. Who were they and what were their areas of expertise? I felt that greater knowledge about their back-

grounds and areas of expertise would help me to tailor my presentation to address their current interests.

The first person I researched was William Thornton. Following graduation from the University of North Carolina and having completed Air Force ROTC training, Thornton served as officer-in-charge of the Instrumentation Lab at the Flight Test Air Proving Ground. He later became a consultant to Air Proving Ground Command.

As chief engineer of the electronics division of the Del Mar Engineering Labs at Los Angeles from 1956 to 1959, he also organized and directed its Avionics Division. He returned to the University of North Carolina Medical School in 1959, graduated in 1963, and completed internship training in 1964.

Dr. Thornton returned to active duty with the United States Air Force and was then assigned to the U.S.A.F. Aerospace Medical Division, Brooks Air Force Base, San Antonio, Texas, where he completed the Primary Flight Surgeon's training in 1964. It was during his two-year tour

of duty there that he became involved in space medicine research and subsequently applied for and was selected for astronaut training. Dr. Thornton developed and designed the first mass measuring devices for space, which remain in use today.

Dr. Thornton was selected as a scientist-astronaut by NASA in August 1967. He was a physician crew member on the highly successful Skylab Medical Experiments Altitude Test (SMEAT)—a 56-day simulation of a Skylab mission-enabling crewmen to collect medical experiments baseline data and evaluate equipment, operations, and procedures. Dr. Thornton was also the mission specialist on SMD III, which was a simulation of a Spacelab life sciences mission.

Dr. Thornton was a physician and a member of the astronaut support crew for the Skylab 2, 3, and 4 missions. He was also the principal investigator for Skylab experiments on mass measurement, anthropometric measurements, hemodynamics, human fluid shifts, and physical conditioning. He first documented the shift and loss of fluid changes in body posture size and shape, including an increase in height and the rapid loss of muscle strength and mass in spaceflight.

As a member of the Astronaut Office Operations Missions Development group, Dr. Thornton was responsible for developing crew procedures and techniques for deployable payloads as well as for maintenance of crew conditions in flight. He developed advanced techniques for, and made studies in, kinesiology and kinesimetry related to space operations.

During Space Shuttle operations he continued physiological investigations in the cardiovascular and musculoskeletal and neurological areas. He developed the Shuttle treadmill for in-flight exercise and several other on-board devices. His work concentrated on the space adaptation syndrome.

Dr. Thornton flew on the STS-8 Challenger (August 30 – September 5, 1983). This was the third flight for the Orbiter Challenger, and the first mission with a night launch from Kennedy Space Center, Florida, followed by a night landing at Edwards Air Force Base, California. During the flight, he made almost continuous measurements and investigations of adaptation of the human body to weightlessness, especially of the nervous system and of the space adaptation syndrome. This was a continuation of his previous work in these areas. Much of the equipment used was designed and developed by Dr. Thornton.

Subsequently, Dr. Thornton flew on STS-51B/Spacelab-3 Challenger (April 29 – May 6, 1985). The Spacelab-3 science mission was launched from Kennedy Space Center, Florida, and returned to Earth at Edwards Air Force Base, California. During the 7-day flight, Dr. Thornton was responsible for the first animal payload in manned flight and other medical investigations.

Amazingly, Dr. Thornton holds more than 35 issued patents that range from military weapons systems to the first real-time EKG computer analysis. Space-related items include the first in-flight mass measurement devices, shock and vibration isolation systems, an improved waste collection system, an improved lower body negative pressure (LBNP) apparatus, and others.

Dr. Thornton continued his work in space medicine while awaiting his next flight opportunity. He worked on problems about extending mission durations in the Space Shuttle, in the Space Station, and in space exploration, and designed the necessary exercise and other hardware to support such missions. He continued analysis and publication of results from studies of (1) neurological adaptation, (2) neuromuscular inhibition following flight, (3) osteoporosis in space and on Earth, and (4) post flight orthostasis. He completed designs for exercise and other countermeasure equipment for the Extended Duration Orbiter (EDO) and for Space Station Freedom, including improved treadmills, rowing machines, isotonic exercise devices, and a bicycle.

After my investigation of the career of Dr. Thornton, I wanted to learn more about Dave Walker. David Mathieson Walker (May 20, 1944 – April 23, 2001) was a United States Navy officer and a NASA astronaut flying aboard four Space Shuttle missions in the 1980s and 1990s.

Walker graduated from the U.S. Naval Academy and subsequently received flight training at the Naval Air Training Command at bases in Florida, Mississippi, and Texas. He was designated a Naval Aviator in December 1967 and proceeded to the Naval Air Station Miramar, near San Diego, California, where he flew F-4 Phantoms aboard the aircraft carriers USS Enterprise and USS America. David was one of 35 candidates selected by NASA in January 1978 for the new Space Shuttle program. Walker became an astronaut in August 1979.

Dr. Thornton and Dave Walker



A veteran of four spaceflights, Walker logged nearly 725 hours in space. He was the Pilot on STS-51-A Discovery (November 8–16, 1984) which was launched from and returned to land at Kennedy Space Center, Florida. During the mission, the crew deployed two satellites, Canada's Anik D-2 (Telesat H), and Hughes' LEASAT-1. In the first space salvage mission in history, the crew also retrieved the Palapa B-2 and Westar VI satellites for return to Earth.

Dave was the Commander of STS-30 Atlantis (May 4–8, 1989) which was launched from Kennedy Space Center, Florida. During the 4-day mission, the crew successfully deployed the Magellan Venus-exploration spacecraft, the first U.S. planetary science mission launched since 1978, and the first planetary probe to be deployed from the Space Shuttle. Magellan arrived at Venus in August 1990 and mapped over 95% of the surface of Venus. The crew also worked on secondary payloads involving fluid research in general, chemistry, and electrical storm studies. Following 64 orbits of the Earth, the STS-30 mission concluded with the first cross-wind landing test of the Shuttle Orbiter at Edwards Air Force Base, California.

The STS-53 Discovery (December 2–9, 1992) was launched from the Kennedy Space Center, Florida and returned to land at Edwards Air Force Base, California. During 115 Earth orbits, the five-man crew deployed a classified Department of Defense payload DOD-1 and then performed several Military-Man-in-Space and NASA experiments.

STS-69 Endeavour (September 7–18, 1995) was launched from and returned to land at Kennedy Space Center, Florida. During the mission, the crew successfully deployed and retrieved a SPARTAN satellite and the Wake Shield Facility. Also, on board were the International Extreme Ultraviolet Hitchhiker payload, numerous secondary payloads, and medical experiments.

Walker was in training to command STS-61-G, scheduled for a May 1986 launch when the Challenger disaster forced NASA to suspend all Shuttle flights. In 1989, while piloting a NASAT-38 to Washington, D.C. for ceremonies honoring the crew of STS-30, Walker came within 100 ft. (30 m) of striking a Pan Am jetliner. That encounter and other infractions of NASA flying rules caused him to be grounded from July to September 1990 and prevented him from commanding STS-44.

Dave was extremely interested in our system and perceived it as a tremendous research tool for NASA which made our visits and working together a special thrill. It was with profound sadness when we learned later, after we had completed our work with NASA, that our good friend Dave died of cancer in 2001. He was only 56 years old.

Having studied the biographical information of these two astronauts who were scheduled to visit the Coto Research Center, Ann and I planned our presentation specifically for them. When I spoke with Dr. Thornton on the phone, he had mentioned some of the ideas they hoped to explore with me. My excitement and enthusiasm to work on some of the ideas that Dr. Thornton described on the phone grew with each passing day. I was more than ready for their visit.

Finally, the day arrived when Dr. Thornton and Dave Walker met me at the research laboratory in Coto de Caza. I gave them a tour of our facility, including a detailed presentation of our biomechanical analysis methods. Ann and I demonstrated the digitizing processes and the three-dimensional results that they produced. We also demonstrated the Ariel Computerized Exercise System and showed them how the U.S. Women's volleyball team used it for training.

After we had completed our demonstration, Dr. Thornton gave me a special plaque. It recorded his take off mission from Cape Canaveral which was the first night mission to space. I was thrilled to receive this memento and it still hangs on my wall (see "Gift from astronaut Thornton" on page 413):

Following our demonstration, we all adjourned for lunch. During the meal, Dr. Thornton and Dave Walker explained the most pressing need NASA currently had. The most immediate and significant dilemma involved the joint research projects that the U.S. had with Russia. They explained that NASA and the Russian Space Authority had an agreement to share research. Each country would record space missions and then exchange the 16mm films collected during the flight. The cooperative goal was to illustrate the various functions performed in the mission capsules during the Earth orbits.

Dr. Thornton began the meeting by explaining the difficulties of maintaining human functional health in micro-gravitational environments. These health issues included muscular strength and bone density. On Earth, running, walking, and working with resistive weights are among the tasks that can provide the necessary stresses to the bones and muscles to maintain good functional health. Unfortunately, in microgravitational environments, there are negligible stresses on bones and muscles. In this environment, the body reacts to the environment with a response that "understands" that these heavy bony structures of our skeleton are unnecessary and, thus, begins to remove calcium from the bones. Were this situation to remain uncorrected, astronauts would return to Earth with devastating osteoporosis. For this reason, the Americans had devised various devices aimed at stressing the bone structure to abate the deterioration.

One of the devices the Americans had was a treadmill designed and built by Dr. Thornton. Surprising, I learned



Gift from astronaut Thornton

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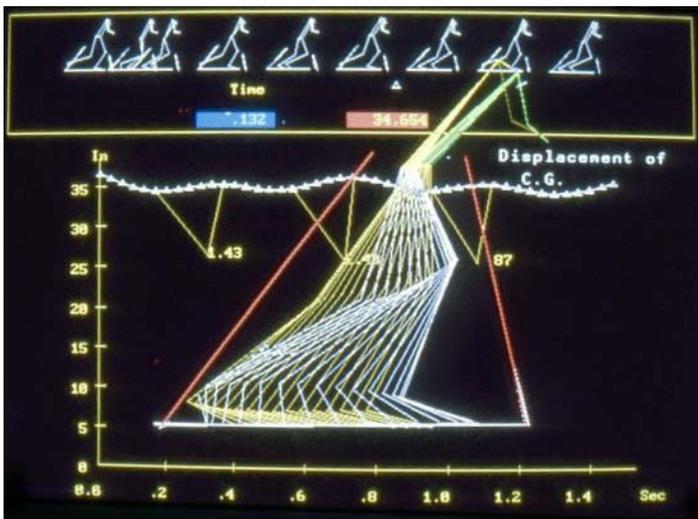
that this was the same astronaut Thornton who was standing in front of me. Dr. Thornton explained that to jog on the treadmill, the American astronauts were connected to the treadmill with bungee cords around the waist and torso. They always had to grip the handle bar with their hands to maintain an upward position. If the American astronauts did not support themselves by holding the front handle bar, they would rotate while running and lose balance. The bungee cords provided sufficient elasticity for the astronauts to have to push with great effort to “run” on the treadmill. The effort exerted to push the legs and “run” on the treadmill had been demonstrated to be effective in stressing the lower limbs and thus reducing the calcium loss in the legs. However, they had to hold the handle bars.

The most recent films provided by the Russians showed their astronauts running on a treadmill during conditioning exercises on a Shuttle mission. Surprisingly, the Russians were able to run without holding on to the front handle bars. In fact, they did not appear to need handles at all. NASA’s difficulty was interpreting the treadmill data from this most recent mission given to them by the Russians. The question was

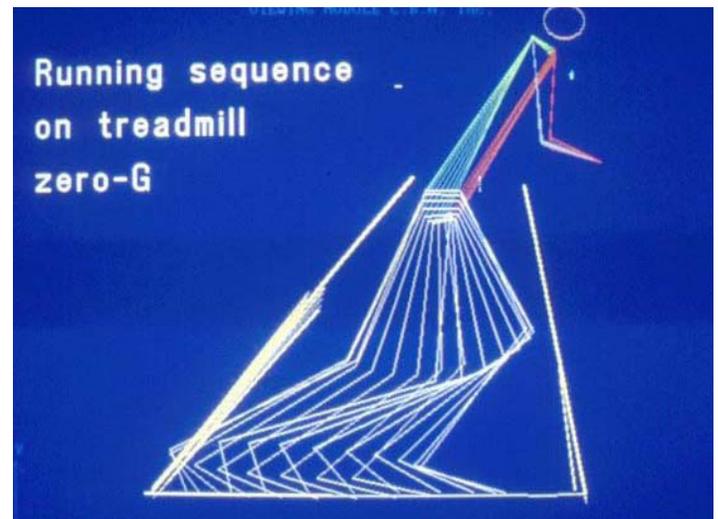
posed to us whether we could evaluate the films and explain this unique treadmill running the Russians demonstrated.

My first question was whether NASA could provide us with the films of the Russians running on the treadmill. Dr. Thornton replied in the affirmative so I explained what I thought we could analyze. Using the Ariel Performance Analysis System (APAS), we could digitize the astronaut and calculate all kinematic and kinetic parameters. I felt confident that this would provide a clue about how the Russians were able to accomplish this feat of not spinning while running. Dr. Thornton indicated that he would send us copies of all the films so that we could begin the analytic process. Thus began our first project for NASA.

In fact, our analysis was most likely the first biomechanical study of space exploration. The idea was to compare running on the ground with running in space. Comparison of running on Earth with the films of the Russians running in microgravity would allow us to determine the mechanical differences between the two environments. We hoped that the results would illuminate how the Russians had become



American



Russian

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so advanced compared to the Americans. What had they learned, and how were they able to balance their run on the treadmill in space without needing to use their hands and arms on the handles to counterbalance the gravitational spin. Dr. Thornton agreed to send us copies of the original data for the Americans and the Russian astronauts that we could analyze using our three-dimensional biomechanical system.

As soon as the film data arrived from NASA, Ann began digitizing. There were hundreds of hours of films. The bungee cords attached to the body looked very similar to those used by the U.S. but, the Russian astronauts did not hold on to the handlebar. Stick figure representations of an astronaut of each country are shown above.

Initial findings of our biomechanical analysis provided no clues concerning what the Russians were doing differently compared with the Americans. From their body angles and movements of the legs, according to our calculations in microgravity, the forces should have tilted them backward. Why and how were they able to defy the laws of physics? We struggled with these questions for weeks.

One afternoon Ann was digitizing the images on the screen. Since I was standing behind her and at an angle to the screen, I suddenly noticed a little dot moving down in the film image. Looking at it more carefully, it appeared to be a drop of sweat dropping from the face of the Russian Astronaut who was exerting great effort in his “run”. Immediately, I asked Ann to digitize this apparent sweat droplet. “Are you crazy, Gideon! You seriously want me to digitize sweat?” Ann asked. “Yes, I want to calculate the acceleration of that sweat droplet.”

This was the “eureka moment” for the NASA scientists and us! The acceleration of the drop of sweat was measured

at 9.8 meters per second per second. This meant that the sweat drop was falling at the same gravitational acceleration experienced by all objects on Earth. This gravitational acceleration rate cannot and does not occur in microgravity. The Russians had sent the NASA film purporting to be in microgravity but were collected at 1G. They were running on Earth, not on a spacecraft revolving around our planet in microgravity!

Needless to say, this finding allowed the NASA scientists to breathe a sigh of relief. They requested not to reveal this information. Their rationale was that if the Russians were less than honest with us, we should maintain silent. We could proceed with our scientific efforts and not let them know that we knew that they are being less than truthful. It also provided an opportunity for on-going dialog with the Russians and, as long as we were able to scientifically validate their data, this could serve us well in the future. To use our more modern phrase, “no harm, no foul”.

This American-Russian treadmill running study gave us significant scientifically objective standing at NASA. Not long after we had completed the Russian treadmill test, I received a call from another NASA scientist, Dr. Mike Greenisen. He was in charge of the Counter Measures Research Laboratories at NASA and wanted to meet me to discuss some potential studies for collaboration between our two groups. He would be bringing another engineer, Mr. John Probe, with him. Naturally, I agreed, and we set a date for their visit.

Several weeks later, there was a knock on the office door. Standing there were two gentlemen wearing coats and ties as though they had just stepped out of a fashion magazine. I laughed and told them to lose the coats and ties and come back looking comfortable for a day of work in a California

laboratory. They seemed stunned at this request initially, but have assured me throughout our long association that it was a fantastic beginning to a successful relationship.

Dr. Greenisen began the meeting by explaining the current perspective at NASA. When Americans reflect on the space program, two events stand out more prominently than others: the first moon landing and the Challenger disaster. On July 21, 1969, an Apollo spacecraft carried Neil Armstrong, Edwin Aldrin, and Michael Collins to the Moon. When Neil Armstrong stepped onto the Moon's surface he said, "That's one small step for man, 1 giant leap for mankind." The second event, the Challenger disaster, took the lives of seven astronauts, including the school teacher Christa McAuliffe, when the rocket boosters of the space Shuttle exploded 73 seconds after lift-off on January 28, 1986.

Neil Armstrong fixed the ultimate significance of his deed by what he said. Christa McAuliffe did the same by who she was. Armstrong, in the midst of a historical event, had the vision to say the right thing. McAuliffe, although a non-professional astronaut, had the vision to become part of the quest.

Dr. Greenisen continued that those facts were not new, but where we were in today's world was different because of those two events. He characterized NASA's position as standing before a frontier of apparently infinite proportions and challenging us to the ultimate quest. To proceed with this exploration, NASA has focused on developing the most sophisticated and rapidly expanding technologies the world has ever known. Previously, authentic heroes helped us to understand that "the right stuff" must be complemented with "the right reasons" when we undertake such a task.

With Dr. Greenisen's background in physiology and John Probe's strength in engineering, they were focused on accomplishing the "right stuff" by developing the best equipment for the tasks to be performed. One of their biggest challenges was the human physiological machine. Man, having evolved as an upright, bipedal animal, cannot consciously take the rapid onset of acceleration that would be required for long distance space travel. Additionally, the physiological adaptations of a microgravity environment were poorly understood and it was argued that long-term weightlessness resulted in the significant post-flight deleterious changes that might cause permanent debilitating results.

Dr. Greenisen and his laboratory were thus tasked with developing appropriate countermeasures to solve the situation. The objectives of his current project were to minimize the effects of deconditioning during spaceflight using individualized exercise "prescriptions" and in-flight exercise facilities, combined with extensive biomechanical analysis of movement in microgravity.



Dr. Mike Greenisen and me in the KC-135
<http://arielnet.com/ref/go/1243>

Dr. Greenisen elaborated many of the physiological, anatomical, and biomechanical needs which we had previously discussed with Dr. Thornton and Dave Walker. He described that one of the ways the human body reacts to the reduced physiological and mechanical demands of microgravity was by deconditioning of the cardiovascular, musculoskeletal, and neuromuscular systems. This human deconditioning produces a multitude of physical changes such as loss of muscle mass, decreases in bone density and body calcium. It is also responsible for decreased muscle performance, strength and endurance, orthostatic intolerance, and overall decreases in aerobic and anaerobic fitness.

Deconditioning presents operational problems during spaceflight and upon return to 1 g. Muscular and cardiovascular deconditioning contribute to decreased work capacity during physically demanding extravehicular activities (EVAs); neuromuscular and perceptual changes can precipitate alterations in magnitude estimation, or the so-called "input-offset" phenomenon; and finally, decreased vascular compliance can lead to syncopal (fainting) episodes upon re-entry and landing.

Mike explained that extravehicular activities (EVA) were the most physically demanding tasks that astronauts perform in orbit. Space Station Freedom and manned Lunar and Mars missions would greatly increase the number, frequency, and complexity of EVA's within the next 10 to 20 years.

Dr. Greenisen's task was to develop countermeasures to eliminate or reduce the severity of these problems by interrupting the body's adaptation process. Effective countermeasures would enhance mission safety, maximize mission success, and maintain crew health.



Neil Armstrong on the surface of the Moon
<http://arielnet.com/ref/go/1244>

Results from experiments on the Gemini, Apollo, and Skylab missions suggested that regular exercise was helpful in minimizing several aspects of spaceflight deconditioning. In fact, exercise was determined to be the only countermeasure that could potentially counteract the combined cardiovascular, musculoskeletal and neuromuscular effects of adaptation.

Biomechanics in space was considered fundamental to understanding the work performance capabilities of humans in space. Biomechanical projects, as conducted by NASA, had the primary goal to conduct operationally-oriented research focusing on maximizing astronaut on-orbit performance capabilities.

The laboratory focus under Dr. Greenisen's leadership was to provide biomechanical analysis in space and develop a program of exercise countermeasures to minimize the operational consequences of microgravity-induced deconditioning. Biomechanical analysis of movement in space would provide individualized exercise "prescriptions" for each crew member to optimize required tasks in a microgravity environment. The analysis would characterize the task requirements of the musculoskeletal and neuromuscular systems induced by microgravity, develop training protocols to address deconditioning in these systems, and use this information as the basis for training prescriptions.

To achieve these training protocols it was necessary to develop flight exercise hardware and associated software related to biomechanical measurement devices. He presented a list of some of the critical questions to be addressed by his laboratory:

1. What type of exercise devices such as weight training, bicycling, rowing, swimming, running, etc. are necessary to train all of the organ systems affected by deconditioning?
2. Which indices are the most reliable indicators of changes in fitness?
3. Which reliable indicators of changes in fitness best describe the changes caused by deconditioning?
4. How does training in microgravity differ from training in 1 g?
5. What are the differences between training that include impact forces and training that uses non-impact forces?
6. Can an artificial intelligence expert system be developed to aid in monitoring, controlling, and adjusting prescriptions?
7. How does in-flight exercise training affect the adaptation process?

8. Which muscle groups are critical to the performance of egress, landing, and EVA's?

An extensive software solution was required to accomplish all these and more functions. Our programmer Dr. Jeremy Wise developed these software functions.

Dr. Greenisen and John Probe then described their most immediate projects. These were related to our previous Russian treadmill project. They wanted to develop and test appropriate treadmills for use on Earth and in microgravity that would effectively and efficiently address the many physiological and anatomical needs previously discussed.

There were two projects related to treadmill running. One project involved developing and testing the actual treadmill hardware focusing on the vertical impact forces. The second study was to compare the performance of four astronauts running on that specific treadmill in both microgravity and Earth, or 1G, gravity. These were technologically complex studies. I quickly learned that NASA studied and researched each and every apparent facet of spaceflight down to minuscule detail. They were committed to performing excellent research but, more importantly, to flying humans into space and returning them safely to Earth.

As part of this study, a rigid body dynamic model of the astronaut and the treadmill system had been evaluated. I have presented them here to give better insight into the measured forces. The idea was to incorporate the force platform, the interface plate, and the treadmill to better describe the differences in 1 g and zero-g experiments.

The forces existing between the force plate and interface plate are considered to be applied at a known point on the force plate (point 0) as shown in the free body diagram on page 419. The force plate was initialized without the subject.

John Probe and I on the KC-135



Dr. Moore, the astronaut's medical physician, Bob Wainwright, Dr. Jeremy Wise, Dr. Ann Penny and I, were assigned the workspace on the Space Shuttle.

If no forces or moments were exerted by the hands, it would be possible to use these equations to calculate the reaction forces at the foot (or feet) of the subject. Since there are typically forces at the hands, it would be necessary to add instrumentation to resolve the actual foot contact forces fully.

Following the design and mechanical calculations needed for the treadmill device, the next step was to test the system. This would require evaluation on Earth at 1 g as well as in the simulated microgravity, or zero-g, in the KC-135 experimental aircraft. These two steps were required before including the device on a Shuttle mission.

The project had two purposes. One was to measure and evaluate the vertical impact forces in both 1 g and zero-g environments using the force plate. The second was incorporating the use of the force plate and/or bungee instrumentation to determine if a subject's 1 g weight could be replicated in zero-g by adjusting the bungees to elicit the proper load. The magnitude of the impact loads generated in 1 g on the Shuttle treadmill for the given walking, jogging and running velocities (1 g, 1.5 g, and 1.726 g respectively) were not observed in the zero-g environment. However, for the higher zero-g jogging and running velocities (3.5 mph and 5.0 mph) greater than 1 g loads were seen (1.2 g and 1.5 g). Thus, the issue becomes "How much impact is enough?"

As a part of the system, it was necessary to incorporate a data collection instrument. NASA designated our biomechanics analysis system to serve as the data collection device. Using this system, data was acquired from all data input channels at a rate of 250 samples/channel/second. A rugged hardware cabinet had to be obtained to encase this system and the other associated electronics equipment before they could fly on the KC-135 aircraft. A KC-135 floor to cabinet interface plate, a back plate, and cabinet insertion plates had to be designed and created for mounting the equipment inside the hardware cabinet. The cabinet backplate and the hardware insertion plate, as well as the assembled hardware cabinet system, are depicted on page 421.

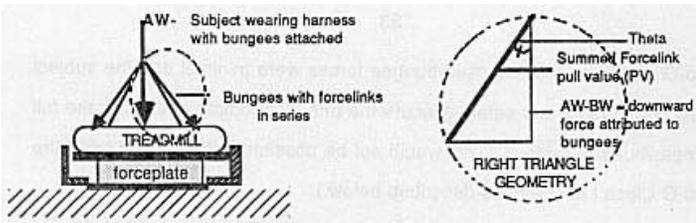
In a seemingly unrelated step, we had to formalize our relationship within an appropriate legal format in order for the scientists and engineers to work with us at NASA. Our company signed the legal documents necessary to formalize this relationship and we were then able to continue work with NASA.

It was now necessary to develop and fabricate the instruments and hardware necessary to quantify the vertical impact forces F_z imparted to the Space Shuttle passive treadmill during human locomotion in a three dimensional zero-grav-



Jeremy Wise at the Space Station & Dr. Moore, Bob Wainwright and Dr. Ann Penny running the system
<http://arielnet.com/ref/go/1245>





Free Body Diagram of force plate on KC-135

ity environment. The Shuttle treadmill was instrumented using a force plate (Kistler) to measure vertical impact forces. The current passive treadmill system employed a harness/bungee device as a means to restrain an astronaut in zero G. Force links (Kistler) were employed to measure the bungee cord loading. The hardware was designed so that it would meet crash loading requirements for experiments flying in the Reduced Gravity Aircraft (KC-135). The impact force and bungee cord data were to be collected and analyzed using a biomechanics performance analysis system.

To verify that the instruments and hardware were functional, they had to be tested in the Anthropometry and Biomechanics Laboratory (ABL) at the Johnson Space Center. The KC-135 reduced gravity aircraft was used to determine if

Free Body Diagram of treadmill without subject

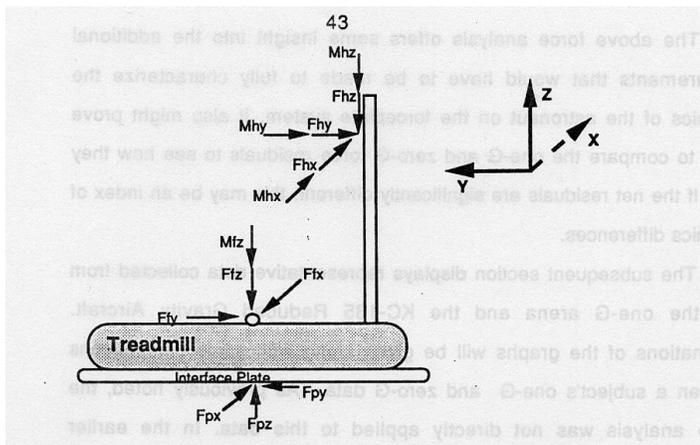


Figure 17: Free Body Diagram without Subject

The following force equations show the forces along the x, y and z axes (Note- { } denotes one-G only):

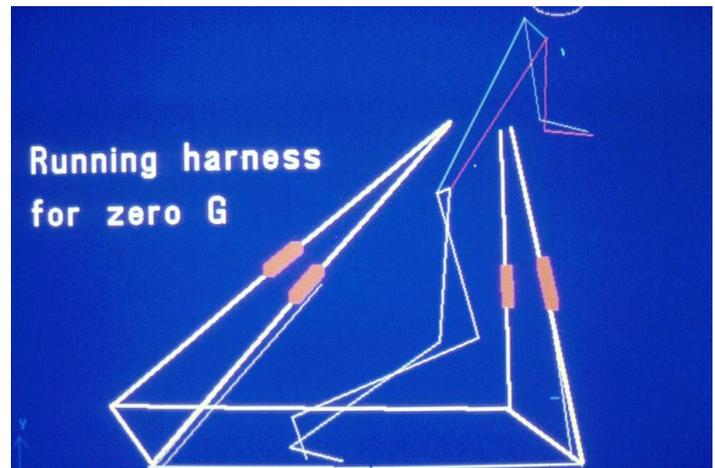
$$F_x = F_{fx} + F_{hx} \quad F_y = F_{fy} + F_{hy} \quad F_z = F_{fz} + F_{hz} + \{mg\}$$

The moments about point O in the x, y and z directions are as follows:

$$M_{xO} = (d_z F_{hy}) + (d_y F_{hz}) + M_{hx}$$

$$M_{yO} = (d_x F_{hz}) + M_{hy}$$

$$M_{zO} = (d_x F_{hy}) + M_{hz}$$



One digitized frame on the treadmill with bungee cords

<http://arielnet.com/ref/go/1247>

the system could operate successfully in a three-dimensional zero-gravity environment. This study would be the first time that I would be among the NASA scientists collecting data on the KC-135.

Before I would be able to test this hardware on the KC-135, I would need to be qualified for this flight experience. All participants must be thoroughly trained for space flight which consists of “decompression” testing; performance under low oxygen environment; an awareness test simulating the microgravity environment, and additional medical tests. The evaluation sequence involved 3 days of test performances and written work. There were eight astronaut candidates in the group as well as some other research scientists that train to fly in the KC-135.

Free Body Diagram of treadmill with subject

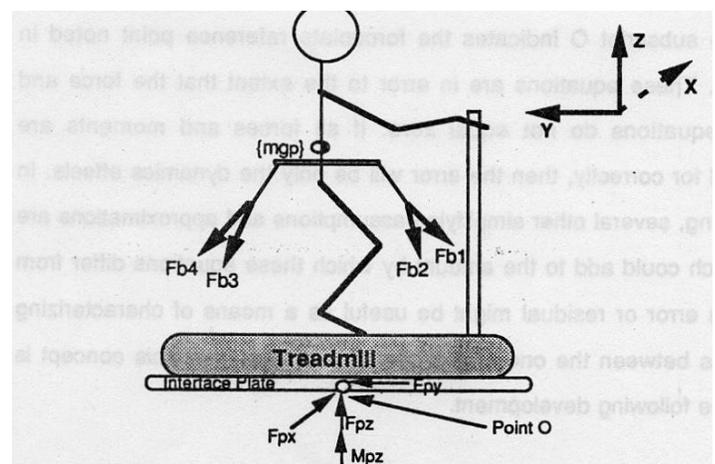


Figure 15: Free Body Diagram with Subject



Dr. Ann Penny at the Space Station
<http://arielnet.com/ref/go/4028>

I was pleased and proud when they informed me that I had successfully passed all of the required tests to qualify for participation aboard the KC-135 experimental aircraft. NASA issued a certificate which indicated that I was officially qualified for the initial testing of being an astronaut. Although I was not actually planning to become an astronaut, receiving this certificate was nonetheless an exhilarating moment. Despite the passage of time, I am still very proud of this achievement which qualified me to participate in additional tests for NASA aboard the KC-135.

The NASA Reduced Gravity Program began in 1959 and the KC-135 was the perfect aircraft for this astronaut training. The Boeing four-engine turbojet Stratotanker was originally designed for aircraft in-flight refueling and later as a 707 for commercial flights. Further modified to meet NASA's needs, the KC-135 is used to understand the role of gravity in humans and hardware in space. The KC-135 aircraft has provided NASA with an opportunity to simulate a "space-like" environment. A reduced-gravity aircraft is a type of fixed-wing aircraft that provides a brief near-weightless environ-

ment for training astronauts, conducting research and even making gravity-free movie shots. Versions of such airplanes, officially nicknamed "Weightless Wonders", have been operated by the NASA Reduced Gravity Research Program. The unofficial nickname "Vomit Comet" became popular among those who experienced their operation.

The aircraft gives its occupants the sensation of weightlessness by following an (approximately parabolic) elliptic flight path about the center of the Earth. While following this path, the aircraft, and its payload are in free fall at certain points of its flight path (see page 422). The aircraft is used in this way to demonstrate to astronauts what it is like to orbit the Earth. During this "free fall" time the aircraft does not exert any ground reaction force on its contents, causing the sensation of weightlessness.

Initially, the aircraft climbs with a pitch angle of 45 degrees using engine thrust and elevator controls. The sensation of weightlessness is achieved by reducing thrust and lowering the nose to maintain a neutral, or "straight and level" config-



Treadmill in Zero Gravity
<http://arielnet.com/ref/go/1248>



The APAS System on the KC-135
<http://arielnet.com/ref/go/1249>

uration (0-degree angle of attack), in other words, a zero-lift angle of attack. The “weightlessness” condition begins while ascending, continues as the aircraft travels up-and-over the hump, and only stop when the craft reaches a declined angle of 30 degrees. At this point, the craft is pointed downward, traveling at a high speed, and must begin to pull back into the nose-up attitude to repeat the maneuver. The forces are then roughly twice that of gravity on the way down, at the bottom, and up again. The forces last until the aircraft is again half-

way up its upward trajectory and the pilot again initiates the zero-g flight path.

The KC-135 aircraft is used to train astronauts in zero-g maneuvers since they are given about 25 seconds of “weightlessness” out of the 65 seconds that each repetition of the parabolic pattern of flight provides. The typical session for KC-135 flight tests is 2 to 3 hours in length consisting of 40 to 60 parabolic cycles. Unfortunately, during weightlessness, even the most seasoned astronaut may experience the stom-

Flight Certificate



My systems on the KC-135 before flight
<http://arielnet.com/ref/go/1250>

PASSENGER	
Physiological Training	
NASA - LYNDON B. JOHNSON SPACE CENTER	
<i>This is to certify that the following person has met the requirements for the Physiological Training Program as prescribed by the National Aeronautics and Space Administration.</i>	
NAME	
ARIEL, Gideon	
ISSUING OFFICIAL  CHARLES K. LA PINTA, MD.	DATE OF EXP. 31 Aug 1992
JSC FORM 124C (REV OCT 76)	NASA-JSC





KC-135

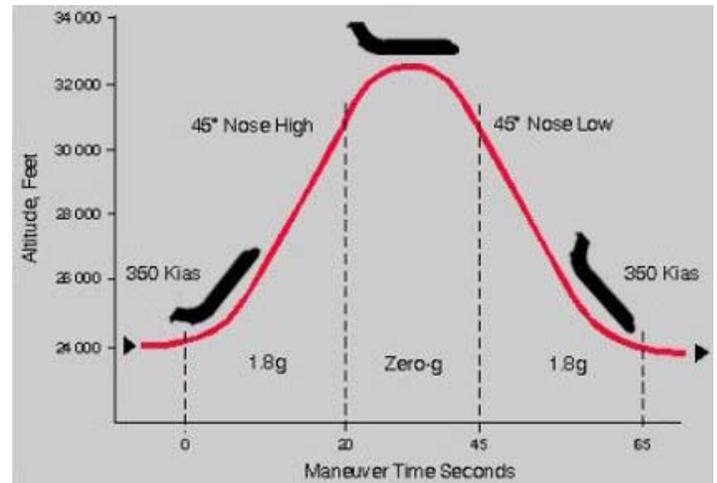
ach-turning effects. In about two-thirds of cases, this motion produces nausea due to airsickness, especially in novices, giving the plane its nickname. The astronauts seem to take it in stride without discussing who was or was not sick. For them, they realize that this experience is all part of a day's work.

The initial study we prepared was designed for human subjects running on the instrumented force plate treadmill. The objective was to compare the performance of subjects (astronauts) running on a treadmill in a zero-gravity environment (space) to the same subjects running in the normal gravitational environment of Earth. A photo of one of the astronaut subjects preparing for a KC-135 treadmill run sequence is presented on the right.

Some of the instrumentation for the force plate and the treadmill can be seen taped to the floor in the foreground of the picture. The young man in the foreground is Mr. John Probe, who was one of the NASA engineers with whom we worked closely. While he worked at NASA, John flew more than 30 flights on the KC-135 and never had to use an airsickness bag! On a personal level, John is a wonderful person as well as a friend and colleague for many years.

To collect EMG and force platform data on the KC-135, we had to prepare all of the equipment in the aircraft so that none of it floated away. We discovered that one of the most important contributions to scientific experimentation under such conditions is... duct tape!

Another important NASA person we worked with was Dr. Tom Moore who was focused on the medical needs of the astronauts. He worked closely with all of us to design the appropriate tests so that the medical staff could evaluate astronaut performance on Earth as well as in microgravity. Dr. Moore is shown on page 418 during a land-based test of the



Aircraft flight path

treadmill, bungee cord apparatus, and the force plate. Also shown is a close colleague of mine, Mr. Robert Wainwright, who worked with us on several projects.

Mr. John Probe was the leader for the research for both the force plate and treadmill data collection. John had flown many missions which enabled him to anticipate when we had to begin data collection and for how long during each data collection segment. These testing segments had to be carefully timed within the parabolic flight segments so that the astronauts would run during the period that was deemed “zero G” or “weightless”. It was critical that we start and stop the running sequences on time and John was attentive and precise so that every collection cycle was perfect.

My participation had begun days before, when Mike Greenisen, John, and I had prepared the sequences in their biomechanics laboratory. We had discussed and planned for what data would answer the biomechanical questions that NASA had asked. John, Mike Greenisen, and I determined, before the flight, exactly which parameters were deemed the most necessary and appropriate. Mike was not going to fly with us so we needed to make all of our decisions, prepare the equipment, and secure the instrumentation in the aircraft ahead of time.

Despite my many years of air travel and my training for the KC-135 flight, it was an experience that can only be understood by actually flying on one of these missions. I accompanied Mr. John Probe on two KC-135 treadmill running data collection flights. However, the first flight was the most interesting, exciting, and memorable experience, to say the least. At the beginning of the flight, all of the scientists and engineers sat in normal airline seats with the seat belt fastened. At that point, a naive participant—which included me—has no realistic understanding of what is to come.



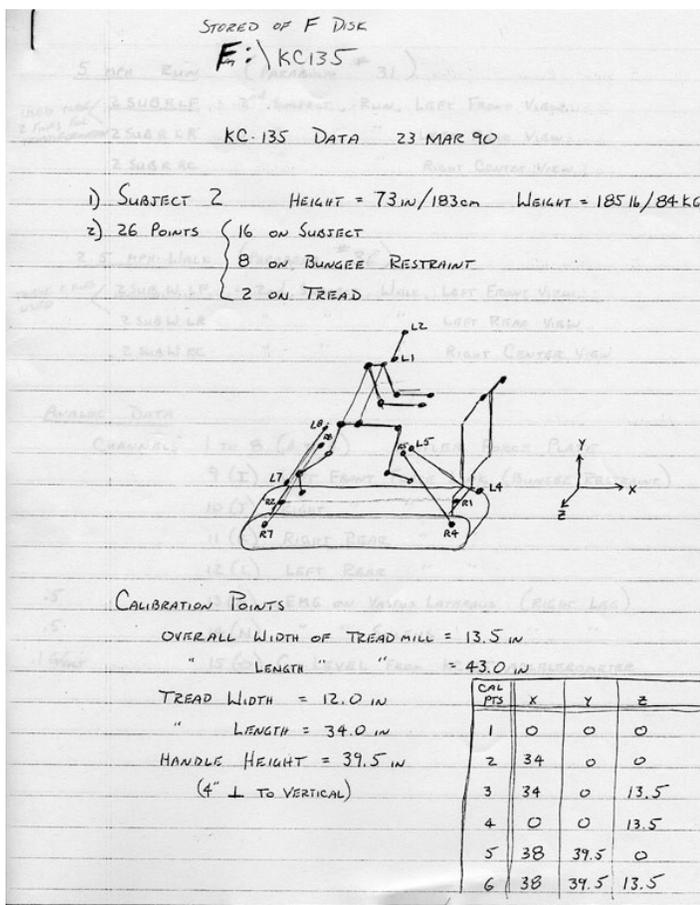
Astronaut preparing to run on instrumented treadmill aboard KC-135

<http://arielnet.com/ref/go/1251>

On the day of the test flight, John and I sat in airline seats that appeared normal. We buckled ourselves into them as though on any routine flight. However, I soon discovered that the normalcy and routine airline passenger experience did not last very long on the KC-135.

Once we were airborne, John and I worked in harmony to coordinate the equipment and the astronaut running on the treadmill. Between sessions, we had to save all of the data and prepare for the next cycle. The astronauts were connected to the bungee cords, ran as hard as they could during the short moments of “weightlessness”, and John and I quickly fell into a routine. We had to trigger the force plate before and after the simulated “weightless” condition. We had to

store the data into the computer with appropriate information so that when retrieved in the lab we would know to whom it belonged. We had to synchronize the cameras and the force plate data for each trial. This is just a short list of some of the details which we had to attend to on each parabola. There was one other situation unique to data collection on this aircraft, remember the name? Yes, indeed, there were some participants that had to use the vomit bags which frequently triggered sympathetic responses in others. It was quite unusual for me to be in a laboratory environment and have to dodge vomit bags or other particulates floating in the air. This entire mission was quite an experience to say the least.



Data Collection Form

Once the KC-135 had executed all of the parabolic sessions, we were once again seated and buckled in as though we had morphed back into normal airline passengers. After we had landed, Mike Greenisen met us and helped John and I remove the treadmill, computers, cameras, and force plates. We returned all of the equipment to the lab so that we could begin data analysis in the morning.

The flight and data collection aboard this experimental aircraft was very intense but stimulating. There are no words to describe the sensation of "weightlessness" or the scientific drama associated with working on this research flight. There is a special thrill of Olympic competition but the exhilaration of simulated "space" flight is indescribable.

I am proud to have been awarded another certificate. This honorary membership is to the "Society of Interplanetary Free Floaters" and was awarded by the Zero G Test Director. The certificate is shown on page 425.

After the flight on the KC-135, John Probe and I processed the data we had collected. When we digitized the motion from the supplied film, we produced many stick figures to illustrate the results.

Following the completion of the treadmill studies at NASA's land-based center and aboard the KC-135 flights, we were able to establish the appropriate procedures for future space exploration about fitness for the astronauts. We determined the timing and extent of training to provide astronauts with sufficient stress on the bones and other bodily systems. These stressors are essential for space exploration since the body's adaptation to microgravity would adversely impact their healthy return to Earth. These projects were designed for and were successful in determining what human beings were able to do to counteract microgravitational effects.

Needless to say, there are many factors to evaluate for humans to successfully fly into space and return safely and healthy. Following our involvement with the treadmill studies, we were asked to help assess various movements required by astronauts. Some of the issues that NASA needed to address included:

1. Focus studies to examine the functions of upper extremities during space flight.
2. Examine the use of power tools to enhance performance and reduce fatigue of the crew members.
3. Compare the use of a robotic hand to EVA crew interaction.
4. Use of the prediction of work and tools required performing a given task.
5. Comparison of perceived target accuracy and spatial orientation to actual target accuracy and spatial orientation.
6. Comparison of gross tasks to fine motor control.
7. Quantify performance of metabolism, muscles, forces, etc.
8. Evaluation of muscle, EMG, etc. of crew members.
9. The investigation into the use of a robot glove as an extension of the space suit.

As part of our on-going relationship with NASA, we provided them with our Ariel Computerized Analysis System. Kinematics, the study of motion exclusive of the influences of mass and force, was one of the primary methods used for the analysis of human biomechanical systems as well as other types of mechanical systems.

The Anthropometry and Biomechanics Laboratory (ABL) in the Crew Interface Analysis section of the Man-Systems Division was tasked to perform both human body kinematics as well as mechanical system kinematics using the Ariel Performance Analysis System (APAS). The APAS supported both analysis of analog signals (e.g. force plate data collection) as well as digitization and analysis of video data. There were several evaluations proposed to address

methodological issues concerning the accuracy of the kinematic data collection and analysis used in the ABL.

A study was conducted by Robert P. Wilmington, a NASA engineer, to evaluate the accuracy of the Ariel Performance Analysis system for use by NASA in studying astronaut motions. The study describes a series of evaluations performed to gain quantitative data pertaining to the position and constant angular velocity movements under several operating conditions. Two-dimensional as well as three-dimensional data collection and analysis were completed in a controlled laboratory environment using typical hardware setups. In addition, an evaluation was performed to evaluate the impact on accuracy due to a single-axis camera offset.

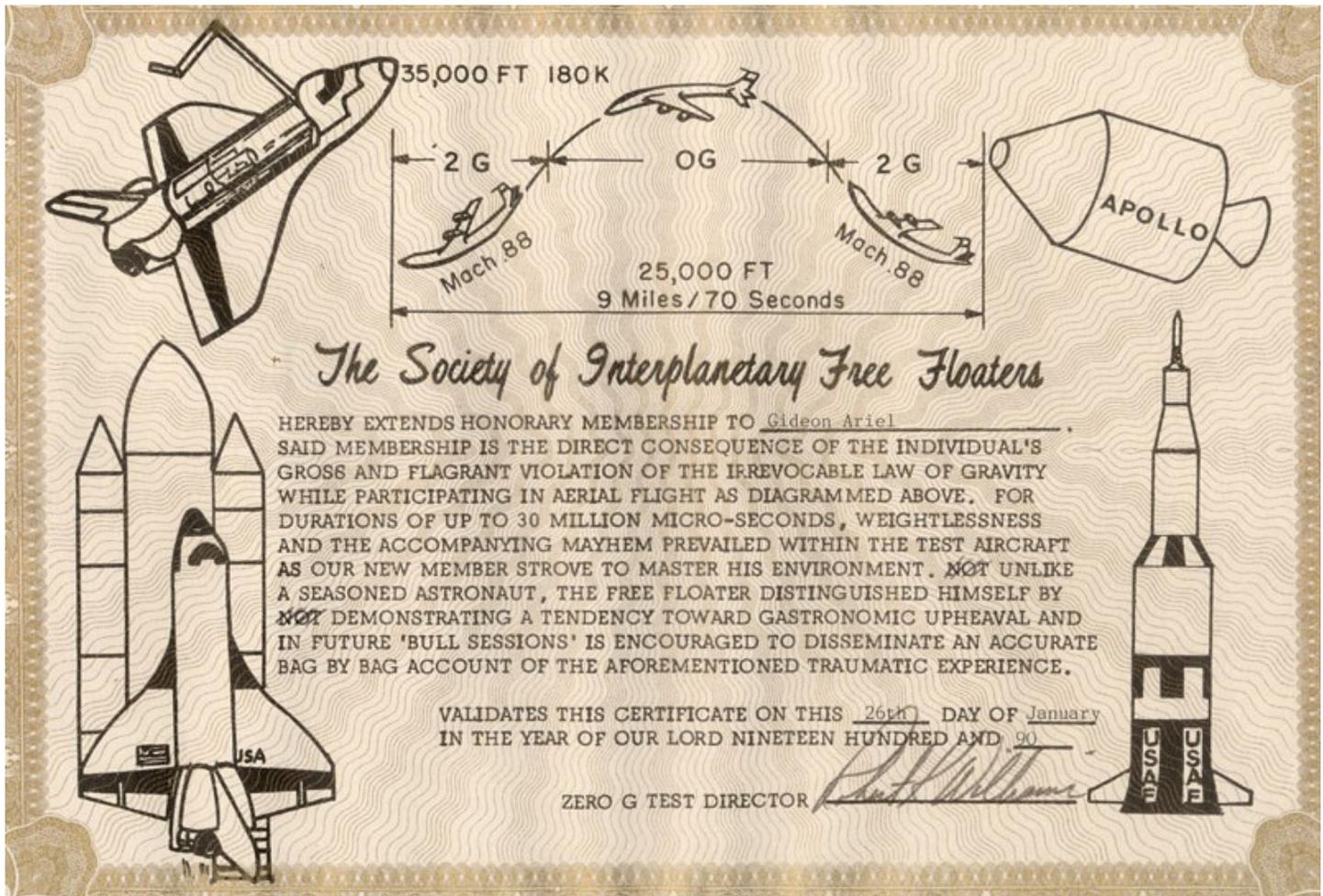
The specific results from this series of evaluations and their impacts on the methodology issues of kinematic data collection and analysis were presented in detail in Mr. Wilmington's paper. The accuracy levels observed in these evaluations were also presented. His analysis concluded that

the Ariel Performance Analysis System was able to identify and produce measurable movements accurately.

One of the first studies that NASA performed after this determination of the accuracy of the APAS by Mr. Wilmington was related to Landing and Normal Egress. The focus of the study was on functions related to reentry to Earth. The ability of astronauts to exit, or egress, the Shuttle, particularly during emergency conditions, may be reduced following physiological adaptations in space. This concern is based on anecdotal information. The tasks inherent to egress must be systematically documented to identify the critical issues for subsequent study. This investigation had immediate application to crew member safety for mission success and completion. The results would also provide information discerning critical issues facing the Exercise Countermeasures Project for the development of appropriate countermeasure protocols and hardware.

The specific purpose of this initial investigation was to document the performance of physical tasks (logical se-

Certificate upon completion of the flight on the KC-135



NASA Contractor Report 185689

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Task analysis of landing and normal egress

quence of events from video recordings) for astronauts to accomplish during Shuttle landing and normal egress. The activities required to accomplish events and the timing of event sequences would be documented by kinematic analysis.

Data about astronaut performance on tasks for Shuttle entry, landing and normal egress, would be video recorded before and after missions. Subsequent investigations would focus on emergency egress and exercise countermeasure development.

This study required video recording astronaut performance during entry landing and normal walk-out egress of the Shuttle in two phases:

1. Preflight during simulated entry and landing and normal egress in a simulator.
2. Post flight during actual entry and landing and normal walk-out egress.

A total of eight assigned astronauts were requested to participate in the investigation.

After training in the Shuttle simulator, crew members would be video recorded while performing simulated tasks specific to their flight requirements. These recordings would be during flight tasks associated with the entry, landing and normal egress. Shuttle egress would be video recorded during seat exit, orbiter exit, and walking a distance of 10 meters from the orbiter. The first four steps at ground level would be on force plates to determine force patterns for gait analysis.

After Shuttle missions, crew members would be video recorded while performing actual flight tasks associated with the entry, landing and normal egress, identical to Phase 1.

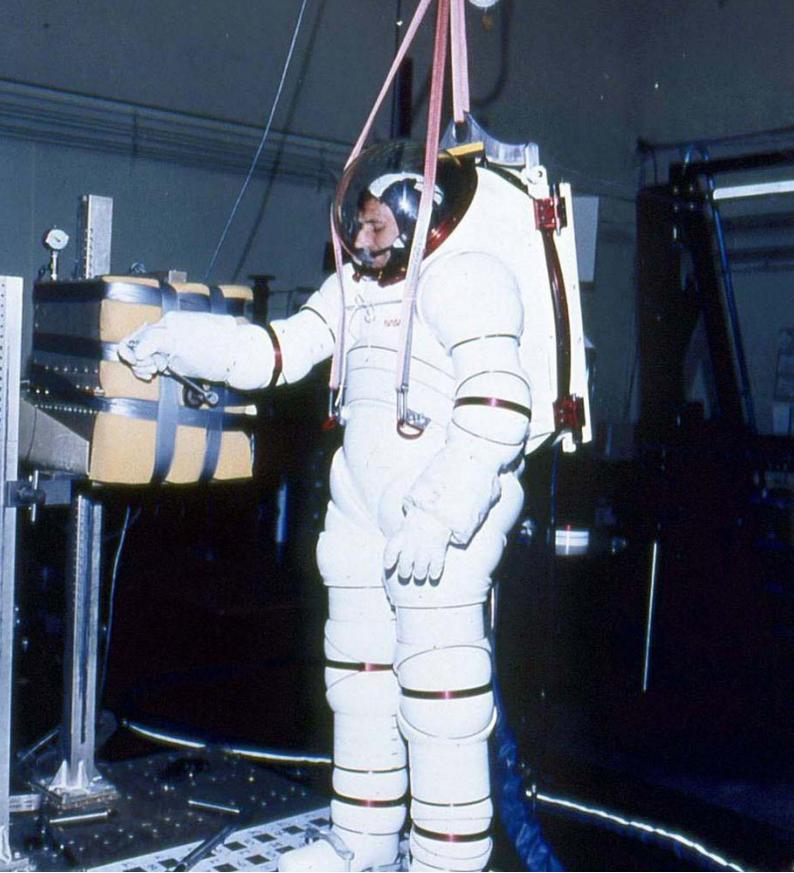
This study required using the astronauts preflight during egress training, post-flight during landing, (out of seat egress), and during normal exit from the Shuttle to ground level. A total of ten astronauts were tested in addition to five pilots and five mission specialists or Payload Specialists. The test subjects were selected so that comparisons could be made on post-mission, out of the seat, and walk-out egress performance. Video cameras and force plate instrumentation were placed appropriately to record the simulated tasks associated with landing and egress during normal training in the Full Fuselage Training (FFT) and the Crew Compartment Trainer (CCT). After egress training and during the practice of simulated egress, crew members were video recorded as they performed the actual tasks that were specific to their flight duties. Normal, walk-out of the orbiter, egress was also video recorded for a distance of 10 meters from the orbiter; however, specifying that the first three to four steps on the level ground be done on the force plate for force patterning and gait analysis.

During landing, video cameras in the orbiter recorded task procedures in upper and mid decks and for out-of-seat egress. Additional video cameras also recorded normal walk-out egress from the orbiter (down the stairs) to a distance of 10 meters with the first three to four steps placed on the force plate at ground level.

This study was the first of several to scientifically quantify the forces, movement patterns, the center of gravity, limb acceleration, and force velocities of motion during landing and egress tasks. This initial investigation of normal egress would be expanded in the future to evaluate ground-based emergency egress of volunteer subjects.

One of the tasks performed during this evaluation project required a full-suited astronaut to turn a handle from top to bottom and reverse. The photo on page 428 shows this simulation.

Another evaluation of the APAS system was related to lens distortion errors. Since our analysis system was video-based, the engineers needed to determine precisely the accuracy of our measurements. Since one of the errors inher-



Underwater testing using APAS to quantify the designated movements

crogravity. With this type of strength and functional performance testing, better training on Earth and in space could be prepared.

Extravehicular activity (EVA) in space requires the most physically demanding task that astronaut perform on-orbit. Therefore, it was necessary to develop exercise programs as well as an exercise device to countermeasure these effects.

Dr. Greenisen prioritized the following biomechanical research objectives for immediate research projects:

- The design of a flight dynamometer
- Task analysis and efficiency of IVA and EVA
- Biomechanical countermeasures of zero-g effects

The biomechanical analysis needed to integrate high-speed videography, EMG, and force plates. Also, a computer-controlled dynamometer was programmed to provide specific exercise prescriptions for the astronauts to maximize their muscular strength and endurance to perform the require tasks. NASA used the term “dynamometer” to identify what we had previously called the “Computerized Exercise Machine.”

The initial focus for the NASA personnel in the astronaut training center at the Johnson Space Center in Houston, Texas, was to test before and after spaceflight. They needed to have quantifiable data for each astronaut. This allowed the doctors and physiological specialists to evaluate each per-

son in detail regarding their specific strength and endurance status. When they returned from their time in microgravity, they were immediately retested to evaluate their condition. Then they would be prescribed training sessions to recover their strength and fitness losses due to the absence of gravitational effects on their bodies.

The Ariel Computerized Exercise System machines were essential in this evaluation process. It was the only system that could determine their strength at each point in the movement, determine if there had been any change in their force and/or movement velocity output, and record their data for other considerations. It was imperative that the individuals train on the system after spaceflight and be evaluated on their recovery levels for strength and endurance in addition to determining the length of time needed to return to pre-flight fitness levels.

The next step for us was to develop a computerized exercise system, or dynamometer in NASA parlance, that could be used on the KC-135 flight simulator aircraft. Initially, we would design an interim dynamometer similar to our ex-

Specific task evaluation



isting Computerized Exercise Machine. This interim unit would be the “Resistive Exercise Device” (RED). Before flight use, we would have to modify the frame and arm/leg mechanisms. We worked closely with Mr. John Probe to create a system that could be bolted to the floor of the aircraft as well as appropriate restraint devices for the person exercising. My friend and colleague, Mr. Bob Wainwright, was extremely helpful in working with me on this venture. Mr. Wainwright had purchased one of my first computerized exercise machines several years before this time and he and I had spent many hours modifying equipment for specific uses. Of course, neither one of us had previous experience in microgravity, so this was new and exciting work. The areas in contact with the human body had to be sufficiently well-padded so that there would be no bruising during the forceful exertions with each exercise.

I also flew my main programmer, Dr. Jeremy Wise, to Houston so he could see for himself the hardware arrangement and to discuss the specific software requirements for testing and working in microgravitational situations. Dr. Wise is a nuclear physicist, so the math and engineering requirements were quite straightforward for him.

Some of the requirements for the in-flight zero-g exercise dynamometer were as follows:

1. Flexibility to perform exercises and diagnostics in isotonic, isokinetic, isometric, accommodating velocity at variable loads as well as accommodate resistance at variable speeds or any combination of these exercise controlled modes.
2. Ability to perform exercises and diagnostics from a pre-programmed sequence of tests and exercises stored on disk. The NASA investigator could prescribe the testing and rehabilitation programs from a library of specialized programs or create specific protocol tailored for each individual astronaut.
3. Provide user-friendly, menu-driven software modules which can be easily learned and are simple to operate.
4. Allow data transfer to other commercial or custom software applications for graphing, data report formats, statistical analysis, etc.
5. Enable external analog data acquisition which can be correlated with acquired force curves such as EMG data and load cells.
6. All dynamometer functions can be controlled or monitored either from the keyboard, hard disk storage, or a remote location, via telephone modem and satellites.
7. The ability to simulate real task activities for comparison of strength and endurance in 1 and zero g.



The regular commercial Computerized Exercise System (CES)

8. All exercise program variables, such as intensity, frequency, duration, sets, workload, percent fatigue, can be controlled and changed from the control keyboard or by the remote modem.
9. The software is an artificial intelligence expert system that monitors, controls and adjusts prescriptions according to the measured output of the exercise.

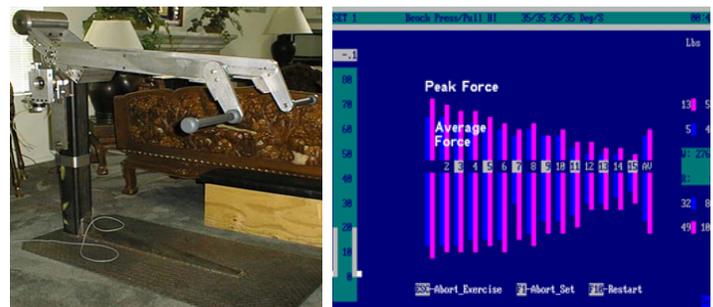
Our Ariel Computerized Exercise System (see page 429) fulfilled all of these requirements.

At this time, a modified version, which NASA referred to as the “Resistive Exercise Device” (RED) was the next step for KC-135 testing. This modified Ariel Machine had to be smaller in size and with modified arm units for it to be functional on the experimental aircraft.

In addition, suitable methods for bracketing and stabilizing the computers and screens on board had to be created. Some photos illustrating this modified RED during one of the KC-135 test sequences are shown below:



*Original prototype and sample screen
for the RED presented to NASA, 1989*
<http://arielnet.com/ref/go/1253>



This newly developed RED and its successful performance by the astronauts on the KC-135 were perfect. The unit performed flawlessly, each of the individuals who utilized the machine was able to do so without difficulty, and the computer functioned and stored all of the data perfectly.

Dr. Greenisen was on the landing strip when we returned from the flight and was thrilled to hear the positive responses on all levels of consideration. We memorialized the event with a photo of Dr. Greenisen and me in front of the RED on the KC-135 (see page 415).

Shortly after we returned to Earth, Dr. Greenisen sent us a letter of appreciation for our efforts in delivering the RED. A copy of this letter is shown on the right:

After completing our activities on the Shuttle with the RED, I traveled to the Johnson Space Center (JSC) with an Israeli colleague of mine, Moshe Lahave. Moshe had served in the Israeli air force as a pilot. One of his missions involved a dangerous and challenging flight to the Iraqi nuclear plant located in Baghdad. His task was to fly over the plant, photograph it, and safely return to Israel. The mission began after months of preliminary practice takeoffs and flights near Amman, the capital of Jordan. Jordan was one of the two countries that had signed a peace treaty with Israel, the other one being Egypt. However, the Jordanians were not going to be asked for help in this adventure because of mission security and to avoid placing Jordan in a difficult diplomatic position.

Moshe took off from his airbase around midnight and quickly altered his flight pattern to fly near a Lufthansa passenger 747 jet which had left Amman a short time after Moshe had gained the correct altitude. Unbeknownst to the pilot, crew, or passengers, Moshe flew his jet closely behind and below the Lufthansa aircraft. He flew without navigational or warning lights and maintained radio silence. He



Thank you letter from Dr. Mike Greenisen

needed to fly close enough to the passenger jet so that he appeared to be part of the same signal observed by ground radar trackers. It was essential to the mission that he not be detected but, fortunately, Moshe was highly skilled pilot.

He flew this highly irregular flight plan, accompanying his passenger jet "host", all the way to Baghdad. When he reached Baghdad, he had to increase his altitude to the maximum capacity of his aircraft. Then, he had to turn his engines off, so that he could take the photographs necessary for the mission. The engines had to be turned off to reduce



NASA personnel exercising on the RED aboard the KC-135

<http://arielnet.com/ref/go/1254>



as much vibration as could be achieved so that the camera would acquire the pictures in sharp focus. The year was 1981 and the camera he had to use was much less sophisticated than a recent smart-phone. The camera lens had a one-meter diameter and was extremely heavy.

After taking all of the necessary photographs, his task was to return safely to his air force base in Israel. This was, by no means, as easy feat. By that time, he had been detected by radar and, under normal flight plans, he would have to fly through defensive ballistic fire from the ground as well as attacks by fighter jets. However, Moshe's plane had been stripped of all its guns or protective gear had been replaced with the large camera and extra fuel. These changes to his aircraft meant that he had to use other piloting skills to return to base.

With the distance he needed to cover to his target and return home safely would require all of his piloting skills and tremendous luck. Moshe again changed his flight altitude and flew as close to the ground as could be achieved without actually hitting anything. He had to fly below radar detection, in broad daylight, as well as outrun and out maneuver the Iraqi fighter jets. If everything went as planned, Moshe would probably be flying on fumes when he returned to base. Fortunately, Moshe was one of Israel's best pilots and was able to execute the return flight successfully. The camera had functioned perfectly, as well, and the data proved extremely useful in the days that followed. After the Israelis successfully destroyed the Iraqi Osirak nuclear plant on June 7, 1981, Saddam Hussein did not rebuild it to the relief of many.

Another example of Moshe's superb flying skills was on one of his flights in an F-4 fighter jet. As he was returning to his base following a mission, a missile knocked off one of the wings on his F-4 fighter jet. For most pilots, losing a wing means crashing the plane while hoping that the parachute correctly deploys before the plane's impact. Moshe, however, immediately shut off all of the automatic equipment. Using his hands and feet to guide the critically compromised aircraft as well as manipulating the power thrusts and manual

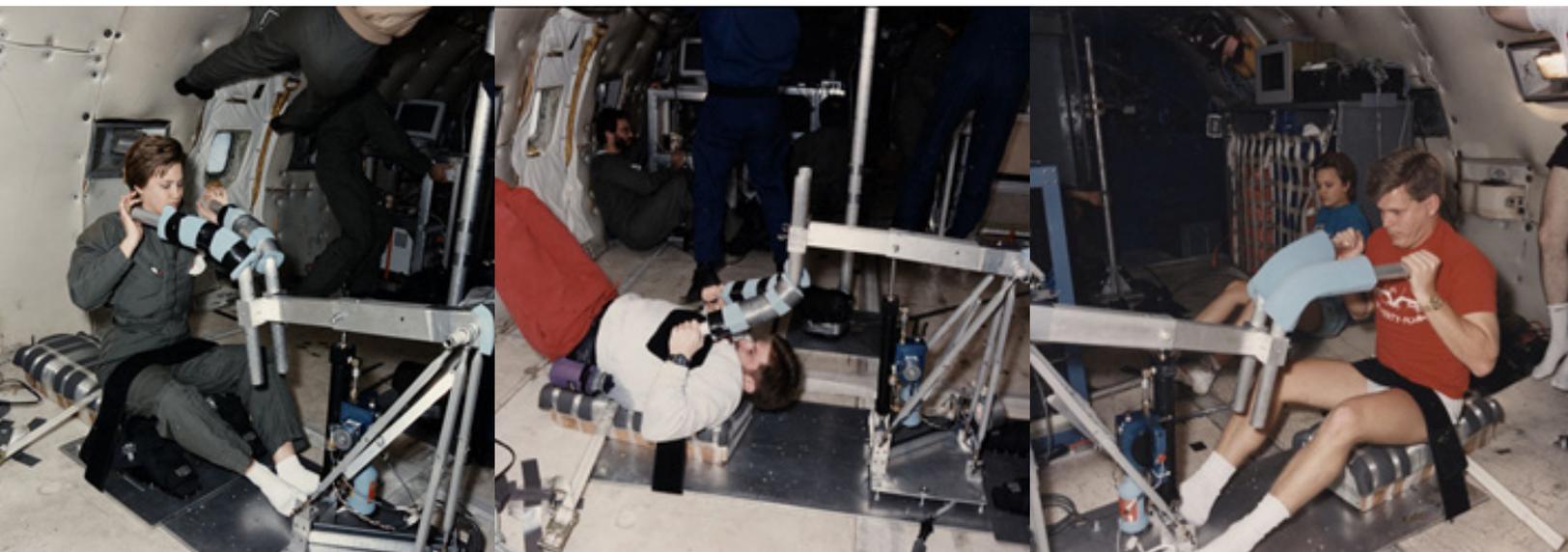
guidance mechanisms, he was able to land the plane with one wing. As of this book's publication, I am aware of only one other pilot, with the U.S. Navy, who has successfully flown an F-4 safely back to base after losing a wing.

For years, Moshe had nagged me to take him to NASA to see the technologies there. However, there was a policy in NASA regarding non-American visitors. I discussed the matter with my friend Mike Greenisen and he told me to bring Moshe. Mike told me that when we arrived at the entrance and were asked identification, Moshe should keep his mouth closed. Mike would provide documentation for us which would be sufficient, as long as Moshe remained mute as his pronounced Israeli accent would be immediately detected.

Mike met us at the entrance and began the tour of the facilities on the way to the biomechanics lab. But, ever the inquisitive Israeli, Moshe wandered off and into a secure area. His visitor's badge was not coded for this area so all of the horns began hooting and the warning lights began flashing. Once again, Mike Greenisen had to clear up the security mess. He warned Moshe that he would personally usher him out of the building if he moved one step out of line or away from Mike's side.

One of the reasons for Mike Greenisen's interest in having Moshe visit the JSC was the subject matter of Moshe's Master's thesis. His thesis was investigating the multiple g-forces affecting jet fighter pilots during aerial combat flight. His experimental study had been to test Israeli pilots on the Ariel Computerized Exercise Machine. Each pilot executed a series of sit-ups. During each upward motion, four isometric contractions were elicited for 5-second durations. The system could be programmed to perform combined isotonic and isometric tasks during each segment of the movement. Moshe was able to store all of the individual data for each pilot during the six-week training sessions. The exercise sessions were conducted every other day for six weeks.

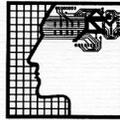
The study results revealed increased abdominal strength throughout the range of movement. More importantly, how-





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Ms. Barbara J. Perkins
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Johnson Space Center
Mail Code BD 3
Houston, Tx. 77058

October 25, 1989

Re: Unsolicited Proposal For Using The Ariel Dynamics Inc.,
Exercise and Analysis Dynamometer and Software System As An
In/Flight, 0-G, Exercise Dynamometer System.

Ariel Dynamics Team For This Project:

Gideon Ariel, Ph.D. - Company Chief Executive Officer, Inventor and
Founder.
Jeremy Wise, Ph.D. - Chief Programmer and Executive Officer of
Software Systems Development.
Robert W. Wainwright, P.T. - Clinical Applications Director for
Medical and Sports Related Fields.

INTRODUCTION

This document is an unsolicited proposal to present the case for the use of the Ariel Computerized Exercise System [hereafter, for the purpose of this document, referred to as CES] dynamometer for consideration as an in-flight dynamometer system, for future 0-G orbitor and space station missions.

ever, was the transfer of this increased strength to flight performance. Each pilot was able to contract his abdominal muscles repeatedly resulting in greater g-force tolerance levels. The ability to contract and release the muscles of the torso enabled the pilots to maintain adequate blood pressure and blood flow to the brain. With the increased blood flow and pressure, the oxygen levels in the brain were increased. Without the ability to keep sufficient oxygen in the brain, pilots faint. During combat, pilots must be able to turn, twist, and dive their aircraft frequently at high gravitation forces. Maintaining appropriate oxygen levels in the brain allows pilots to achieve enhanced flying skills that can mean the difference in life or death. This increased abdominal muscular strength allowed improved combat skills and, thus, improved success in battle and survivability.

Mike Greenisen's interest in Moshe's thesis was the similarity of air force fighter pilots and astronaut skill requirements during Shuttle lift-off and re-entry. The increased gravitational forces were quite high during these segments so that task requirements and control device placements were critical for mission safety. Any factor that would impact the physical abilities of the Shuttle astronauts was of special interest to NASA.

Moshe and I spent the rest of the day working with Mike Greenisen and his assistants on setting up an experimen-

The order of discussion shall include:

- I. HISTORY OF DEVELOPMENT
- II. SYSTEM OVERVIEW
- III. CONSIDERATIONS FOR THE ARIEL CES AS A FLIGHT QUALIFIED DYNAMOMETER
- IV. RATIONAL FOR USING THE CES AS AN INTEGRAL PART OF ASTRONAUT SELECTION, TRAINING AND FLIGHT ACTIVITIES
- V. OPERATING SYSTEM [a comparison of the CES to the NASA document, "Request For Quotation For A Prototype Dynamometer."
- VI. DISCUSSION OF ESTIMATED COST

I. HISTORY OF DEVELOPMENT

Ariel Dynamics Inc. was incorporated on in 1971 as CBA Inc., for the purpose of developing and marketing the Ariel Dynamics Computerized Exercise Systems [CES]. Product development was begun in 1968, at the University of Mass., Amherst, using the University mainframe computer as an interface to a universal type weight stack machine. The first commercial version was completed in 1976. The first machines were based on Data General mini computers. The instrument was used for individual evaluation of elite olympic and professional atheletes, many associated with the United States Olympic Committee, of which Dr. Ariel was chairman of the Biomechanics Committee.

With the advent of the low cost microprocessors, in the late 1970's, the product was redesigned and introduced to the marketplace at a much lower cost, in 1980. Since that time, the Ariel CES is being utilized by physicians, physical therapists, hospitals, researchers, government agencies, product development companies, military organizations, universities, cardiac rehabilitation centers, medical schools and olympic organizations throughout the world. The information collected and reported by the Ariel [CES] is widely accepted by insurance companies, the medical community and the legal community when disability analysis is an issue in legal cases.

The company is entering its 20th year of business with the current patented software and hardware design. Although the evolution of the software and hardware has undergone many improvements and revisions,
p. 2

tal program for the astronauts. Since NASA had the Ariel Exercise System, they could conduct experiments on Earth, as well as use the RED on the KC-135. Despite setting off all of the alarm bells at NASA, Moshe ended the day in a more favorable position with Mike.

Our next task was to work with NASA to modify our Ariel Computerized Exercise System for the Space Station. This would be the actual "dynamometer" which was the previously designated name and goal of a space-based exercise unit. The goal of this proposal was to develop a computerized, feedback-controlled, portable, battery-powered, hydraulic dynamometer that can be used in normal, reduced-g, and zero-g environments. The proposed device would provide a closed-loop feedback system to measure and control various muscular strength parameters. The innovativeness of this device includes (1) the ability to measure muscular strength without the limitations imposed by traditional weight-related devices; (2) computerization of the feedback control feature, allowing adjustment of the device to the individual rather than the individual accommodating the device, (3) customization of the diagnostic and exercise protocols with data storage capabilities; (4) low-voltage, (5) portability, and (6) compactness. The relevance of the proposed equipment

for NASA was in its ability to evaluate astronaut strength and endurance levels as well as to design and follow appropriate exercise protocols in all gravitational environments. Data could be stored for later evaluation and for use in conjunction with other medical or physiological assessments in the continual effort to identify and counter the deconditioning caused by microgravitational conditions.

Our proposal to Mike Greenisen and his technical staff at NASA was to develop equipment intended for use as an effective countermeasure tool as well as addressing several of the operational restrictions imposed by spaceflight. Utilization of a hydraulic mechanism would provide a means for adequately creating resistance thus overcoming the ineffectiveness of weight-based equipment in zero-g. The apparatus would be compact, portable, and powered by low-voltage DC batteries that eliminated the need for power necessary for the Shuttle itself. These attributes were deemed necessary for easy and safe use in the restricted confines of the Shuttle or on the Space Station.

Computerization of the apparatus would provide several important innovations:

1. Activities performed would be programmable for "individualized" diagnostic routines and exercise protocols with results stored for subsequent evaluations.
2. The feedback control afforded by rapid computerized assessment and adjustment would ensure that the equipment would adjust to the performance levels of the astronaut rather than the reverse. An individualized adjustment would assure that size and/or gender would be irrelevant for successful operation.
3. Activities would be designed bi-directionally since resistance could be provided in both directions of bar movement.
4. Graphic displays and audio cues would provide information to the individual with such items as current strength level, repetition number, and bar location. The sound cues could be modulated in proportion to the exerted force to inform the individual about his or her performance response without the need to see the computer monitor. This would simplify operation as well as provide biofeedback. One of the most important features of the proposed device concerned its functionality under all gravitational fields. Thus, medical and physiological researchers could design and test models on earth with the ability to recreate and evaluate the same models under reduced-g conditions.

The first thing we needed to do was to select a portable, battery-powered computer that had the capability of inter-

facing with a controller board used for analog to digital signal processing and dynamometer control. Additional attention would focus on disk storage capacity, secondary storage mediums, and visual display characteristics.

The second thing was to select a controller board used for analog to digital signal processing and dynamometer control that would interface with the selected computer.

Thirdly, we needed to develop software on the computer tailored specifically for Earth and microgravitational activities. This software would be similar to the programs that had been tested on the previously designed RED model.

The software considerations were not trivial with several problems that had to be overcome:

1. The power requirements of the computer, the controller board, and the transducers needed to be more efficient and with the greater capacities. The power supply would have to be independent and could not be taken from the Shuttle power supply.
2. Rapid computer processing required innovative programming code to afford smooth response for real-time feedback control.
3. The flat panel monochrome displays characteristics associated with portable, built-in single monitor computers presented a unique challenge concerning the speed and aesthetic qualities for the interactive visual medium.

This was an ambitious design goal which would require frame materials to have maximum strength-to-weight ratios and the structure had to be engineered with attention directed towards compactness, storage size, and both ease and versatility of operation.

Existing transducers available commercially would be utilized for the proposed exercise machine project. The function of these input devices is to supply information to the computer about the location of the bar or handle against which the individual exerts force as well as the amount of that force. This information must be provided rapidly enough for the computer to process the input signal and respond with an adjustment, if needed, to the hydraulic valve assembly so that the internal response adjustments are undetectable by the individual using the device. A characteristic essential to the proposed equipment was that the individual who was exerting force perceived only a smooth operation and was insulated from any detection of hardware and/or functional adjustments. The continual exchange of data between input sensors and the regulation of the hydraulic system was one of the most crucial segments of the software programs.

We were able to use the hydraulic valve, pack, and cylinder assembly that was currently integrated with our existing, commercially available stepper motor. A stepper motor was



Moshe Lahav

attached to a hydraulic valve assembly which opened and closed an orifice regulating the flow of hydraulic fluid, thus controlling the amount of force needed to push or pull the piston within the cylinder. Our plan was to design a smaller and lighter hydraulic valve, pack, and cylinder assembly for the future Shuttle missions.

Further consideration was to identify a flight-qualified fluid which would be more appropriate for microgravitational locations. Consideration of alternative resistive mechanisms had been abandoned because of the limitations imposed in zero-g conditions. Weight-based devices would have no value under reduced-g or zero-g conditions. Pneumatic resistance was rejected because of the pressure requirements, the problems associated with the compressibility of gases, the difficulties associated with accuracy and calibration of measurements, and the need for pressurized cylinders. Hydraulic mechanisms are less affected by gravitational forces, can be regulated by low voltage, battery powered devices, can operate in both up and down stroke directions, and can function passively. Consideration of an "active" hydraulic system, which would provide conditions in which the individual would have to resist forces generated by the dynamometer, were rejected for the following reasons: (1) user safety, (2) decision against employing any motorized devices within zero-g workspaces for environmental safety considerations, and (3) more than sufficient and adequate results are obtainable with "passive" mechanisms.

The software would provide computer interaction with the individual operator and was planned to function automatically by presenting a menu of options when the dynamometer system was activated. The menu included four options: (1) diagnostics, (2) controlled velocity, (3) controlled resistance, and (4) controlled work. For all cases, the motion

would be regulated in both directions, that is, when the bar moved up and down. Each of these four options will be briefly described in the following paragraphs.

Selection of the diagnostics option would allow several parameters about that person to be evaluated and stored if desired. The diagnostic parameters included the range of motion, the maximum force, and the maximum speed that the individual could move the bar for the specific activity selected. The maximum force and maximum speed data would be determined at each discrete point in the range of movement as well as the average across the entire range. The diagnostic data could be used solely as isolated pre- and post-test measurements. However, the data could also be stored within the person's profile so that subsequent actions and tests performed on the exercise machine could be customized to adjust to that specific individual's characteristics.

The controlled velocity option would permit the individual to control the speed of bar movement. The pattern of the velocity would be determined by the person using the equipment and these choices of velocity patterns included: (1) isokinetic, which provided a constant speed throughout the range of motion; (2) variable speed, in which the speed at the beginning of the motion and the speed at the end of the stroke are different with the computer regulating a smooth transition between the two values; and (3) programmed speed, which allowed the user to specify a unique velocity pattern throughout the range of movement. For each of the choices, determination of the initial and final velocities will be at the discretion of the individual through an interactive menu. The number of repetitions to be performed could also be indicated by the person. It would be possible to designate different patterns of velocity for each direction of bar movement.

The controlled resistance option would enable the person to control the resistance or amount of force required to move the bar. The alternatives include: (1) isotonic, which provided a constant amount of force for the individual to overcome in order to move the bar; (2) variable resistance, in which the force at the beginning of the motion and the force at the end of the movement are different with the computer regulating a smooth transition between the two values; (3) programmed resistance, which permitted the individual to specify a unique force pattern throughout the range of movement. An interactive menu enabled the person to indicate the precise initial and final values, the number of repetitions to be used, and each direction of bar motion will be independently programmed for each of the three choices.

The controlled work option allowed the individual to determine the amount of work, in newton meters or joules, to be performed rather than the number of repetitions. Also, the person was able to choose either velocity or resistance as the method for controlling the bar movement. As with the previous options, bi-directional control was also possible.

Needless to say, our chief programmer, Dr. Jeremy Wise, was well known to Mike and his NASA staff. Jeremy had worked previously with them on several software modifications so that our systems functioned in the manner required by NASA. He would be an integral part of the new dynamometer and its software needs.

Among those software needs was the accuracy of measurement. This was an essential factor since data had to be collected in one- and zero-gravitational fields. This function

was deemed as one of the most important considerations in the software development. Calibration of the proposed exercise device would be possible under dynamic conditions and was a unique feature that the computerization and the feedback system were allowed. Calibration would be performed using weights with known values and would be executed on Earth before any reduced gravitational environmental activities. The calibration procedure allowed the operator to place known weights at the start position and, when released; force data would be sampled until the end position was reached. The calibration procedure was performed in both up and down directions. This type of calibration is unique in that the accuracy of the device can be ascertained throughout the range of motion.

We continued to work with Mike Greenisen and his NASA staff over the years with the on-going dynamometer development as well as other projects. I was both fun and challenging work to be involved with these various projects at NASA. Mike Greenisen and his able staff of engineers were wonderful colleagues to work with and share ideas. It was a unique environment of immersion on the exciting frontiers of space exploration and the need to develop tools so that humans could successfully and safely explore horizons beyond the Earth.

We continued to work with NASA over the years. In addition to the work with Mike Greenisen, we also moved to a new laboratory in our beautiful Coto Valley. This exciting development will be covered in the next chapter.

