FEATURE

The Law of the Stronger:
Ferenc Pavlics and the Lunar Rover

by David Clow

For the first time in 40 years, we can see them again: the Lunar Reconnaissance Orbiter photos of the Apollo landing sites show the Lunar Roving Vehicles (LRV), three bright specks on the gray lunar dust at the Marsh of Decay, the Descartes Highlands, and the Valley of Taurus-Littrow, and leading to them, distinct dark trails marked by the drivers who left them there. A million years may find them unchanged, among the longest lasting and best preserved of all human artifacts. Their journey began long before their respective launches, and that story reveals much about why it was the United States and not the Soviet Union that made tire tracks on the lunar surface.

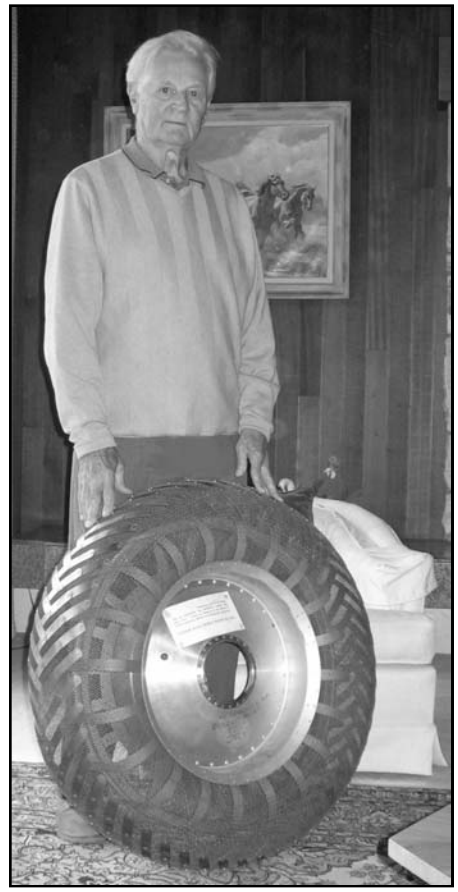
Wheels on the Moon

The fantasy of driving on the Moon preceded the fact of driving on Earth, just as H.G. Wells *Columbiad* blasted there before the Wright brothers flew at Kitty Hawk. One of the most visionary in a long succession of space fantasists was someone whose job it was to make it all real: Wernher von Braun, who collaborated with Walt Disney and the American popular press during the 1950s to show that humans would be not just walking on the Moon, but working there too, with habitations and vehicles for mining and exploration.[1] Von Braun's visions combined the fantastic with the pragmatic: driving was second nature in suburbanizing post-World War II America. Lunar vehicles made it seem all the more obvious to the viewers of Disney and the readers of *Collier's Weekly* and *Popular Science* that it was not a question of if we would live and drive on the Moon. It was only a question of when.

Nevertheless, the driving part almost never happened. The idea of the LRV was nearly sacrificed as the Apollo program evolved under time and money pressures during the 1960s. Those three extraordinary cars that we can see once again on the lunar dust speak of extraordinary events on Earth, and of remarkable people, journeys, and changes here that helped take us from here to there.

Ferenc Pavlics

The principal designer of the Lunar Roving Vehicle was Ferenc Pavlics. He still lives in the home he and his wife built overlooking the Pacific in Santa Barbara, California, during the time when the idea of a moon car stopped being fantasy. Text in italics that follows is taken from an interview by the author with Mr. Pavlics on 25 September 2010.



Ferenc Pavlics in his Santa Barbara, California home. Credit: David Clow

I was born in Balozsameggyes, a small village in the western part of Hungary, on February 3, 1928. My parents were both teachers. My mother taught me in the early grades of elementary school, and my father took my instruction over in the later grades. For high school, I commuted to the Faludi Ferenc Gymnasium in Szombathely, the closest city to our village, about 20 miles away by train. At the beginning, I was interested in chemistry, but one of my experiments at home didn't work out—it exploded and my little sister got the experiment all over her dress—so I switched to mechanical engineering. I had excellent teachers in physics and mathematics and that's what gave me the impetus to go in a technical direction. I graduated in 1946. From there I applied to the Technical University of Budapest and graduated as mechanical engineer in 1950.

Immediately I got a job as a design engineer at the Gepipari Tervezo Intezet (Machine Industry Design Institute), a fairly large government-run organization. I was designing machine tools and equipment for factories, setting up new factories and rebuilding old ones; there was plenty to do in Hungary at the time. At the same time, I was assistant professor at the Technical University of Budapest, where I was teaching machine

The LRV tire showing the woven piano wire and titanium chevron treads.
Credit: David Clow

tool design for the evening courses.

I worked for six years in Budapest. I had an apartment, and career-wise, things were going very well. One big complaint among all the technical people there, though, was that we were completely isolated from the world. There was no possibility of traveling outside the country to attend a conference or submit a paper or anything, not even as a tourist. The technical literature from the West was restricted. We could only read Russian technical literature. That was a big complaint from the technical people.

1956

"Going very well" turned upside-down for Pavlics and the rest of Hungary on 23 October 1956. It was three and a half years after the death of Josef Stalin, and in the midst of the "Nikita Khrushchev Thaw" of that year, Hungary's frustrations at the isolation and repression that came with membership in the Warsaw Pact boiled over into open demonstrations. Students from Budapest's Building Industry Technological University marched through the capital to the Hungarian parliament with demands for the immediate evacuation of the Soviet Union, withdrawal from the Warsaw Pact, a freely elected government and the dismissal of Soviet *apparatchiks*; and nothing less than a "complete reorganization of Hungary's economic life."[2] Students were detained. Gunfire broke out. The revolt spread across all Hungary with astonishing speed. In the first few days of revolution, a new government was formed; Cardinal József Mindszenty, the anti-Stalinist head of the Roman Catholic Church in Hungary, was rescued by the rebels; Moscow's troops left Budapest and retreated to the countryside; and the revolt appeared to have succeeded. Hungarians celebrated until Moscow invaded again massively with tanks and planes on 4 November. By the 10th, the Hungarian Revolution was crushed.[3]

The uprising against the communist regime started in October 1956. Students from the Technical University came up with demands and tried to broadcast them on the radio when the shooting started. I was not active in the fighting, since I was already working at the time. My participation was setting up a kind of council at the institute for continuing the management of the operations, since all the communist managers disappeared.

Under the communist system, the police kept a secret dossier on everybody. People wanted to look into what was written about them. We got into the dossiers and distributed them to everyone. I still have mine! The communists investigated my family, my relatives; my dossier said that that my parents were teachers, not proletariat, and that I was not "good material" for membership in the Communist Party.

At the beginning it appeared that the revolution succeeded. The Soviets sent their troops into the streets with tanks, but these troops had been in Hungary for years, and they were friendly with the Hungarians. When they appeared on the streets, they were greeted and welcomed. People climbed on the tanks without fear. The Soviets didn't know how to respond. Their tanks in Budapest paraded through the streets carrying Hungarian students waving flags. People didn't view this as a hostile confrontation. It didn't seem at first that the Russians were going to crack down heavily. Moscow finally saw that the troops they had in Hungary were useless for that purpose. They withdrew those troops, and to the revolutionaries it seemed like the Russians were conceding the victory.

We were all rejoicing. We organized the new government and started out like a free country. That lasted only 10 days. Then the Russians sent in fresh new troops, and then they just shot the city to pieces. Twenty thousand people died. Kids, little children…machine-gunned in the streets. One of my brothers was studying to be a priest. During the revolution, he distributed leaflets against the communist regime. He also participated in freeing Cardinal Mindszenty from prison. After the revolution was broken, he was put in jail, where he spent two years. It was obvious after that the revolution was broken that it was advisable for me to leave, and in November I decided to escape.

"We Might Have Crossed Paths"

Years later and under different circumstances, Ferenc Pavlics and David R. Scott would meet. Figuratively, they nearly did as Hungary was overwhelmed.

Having graduated fifth in his class of 1954 at West Point, Scott could pick his service. He chose the Air Force because he wanted to fly jets. He was stationed at the 32nd Fighter Day Squadron at Soesterberg Air Base (RNAF), in The Netherlands, during the revolution. "Soviet tanks rolled into Budapest in October 1956," he said, "and we suited up for war. We really thought the U.S. would defend the Hungarian freedom fighters, since here was a group of people finally trying to break out of

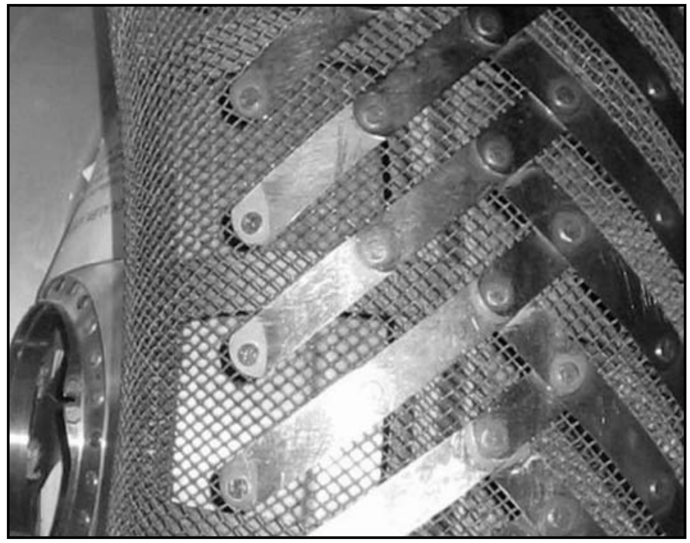
Communism," Scott later wrote. "There they were down on the streets, fighting. We thought the U.S. would support them the way the U.S. had been saying it would. But it did not."[4] Scott's units were on high alert: "The whole squadron could be airborne and in combat within an hour." The most likely area of engagement was over Czechoslovakia, so Scott was armed with Czech maps and currency, and carrying a Beretta pistol and "every bullet we could get our hands on," that he, like his squadron mates, had bought himself, because they weren't issued side arms. "We were ready to go," he remembers, "but the big boys called it off." Reminded of Pavlics' escape on the ground, Scott said, "We might have crossed paths."[5]

Pavlics' path was far below Scott's, and no less dangerous.

I was lucky; I'd grown up in the western part of the country, 20 miles from the Austrian border, and my parents still lived there. One of my sisters lived in a village just three miles from Austria. Her husband was a doctor. I left Budapest with my wife. We took a train to about 30 miles from the border. You needed a special permit to enter that border zone, so we got off the train at night, and we walked through the countryside avoiding villages. We finally approached my sister's village.

My brother-in-law knew the people in the village, and knew that the butcher sent out meat every other day to the Soviet border patrol. He arranged it that for one of these deliveries my wife and I got on this butcher's horse-drawn cart along with a Hungarian soldier, a friend of the butcher, and the soldier took us to the Austrian border and showed us how to get across.

It was three miles' ride to get there, and on the way there were patrols and checkpoints that stopped the carriage and required papers. I had my brother–in-law's documents, and my wife had my sister's papers. I was to tell them that I'm a doctor going to the village to treat someone, and my wife is going to assist me. At this checkpoint a Soviet officer was training a new group of soldiers, showing them how to properly check the documents for the correct stamps and dates and so on. He was so focused on our documents that he didn't even look at me. There was a photo of my brother-in-law on the papers, and it would have been plain that I wasn't that person in the photo, but the officer didn't check. They let my wife and me go through to the village.



A close-up of the tire exterior.
Credit: David Clow

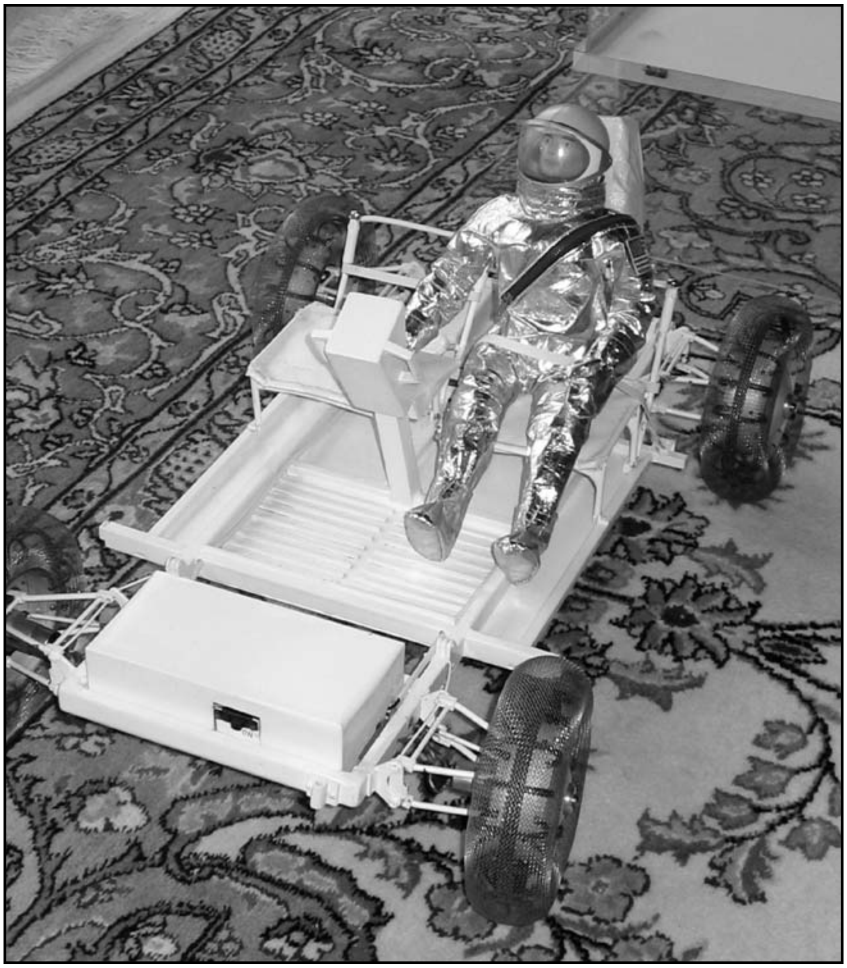
We went to a house on the border at the edge of a cleared and demined no-man's land. The Hungarian soldier told us when the sentries with dogs would come. We could see the lights of the Austrian village in the distance. There was a 10-minute opening to cross. It was raining, muddy, dark; I was carrying a briefcase with some papers. We had nothing else. I gave all my Hungarian money to the soldier, and we started across.

On the Austrian side, the villagers were prepared for refugees. They converted a school to a temporary collection center. The police met us there and debriefed us. My wife and I spent the night there. The next morning they bused us all to a larger camp where we spent about three months. We applied for visas. I spoke German and applied for a West German visa. Someone came out to interview people and offered me a job in Bremerhaven on the Baltic Sea. They told us they'd take care of the paperwork. We waited and waited, and there was no way to follow up, so we needed a Plan B. We went to Vienna and lined up at the American Embassy for two days. It took us two days to get in! The line went around the entire block.

After the revolution collapsed, we had expected the West, especially the United States, to help us. On the radio, Radio Free Europe, Voice of America, they were telling us to hang on, help was coming, and of course, nothing happened. At the same time there was the Suez Canal situation, and Eisenhower had bigger problems, so we were kind of abandoned. But the West did donate and help—they took in 200,000 people, private citizens, government agencies, and private agencies providing food and clothing. We were shown good care and people were very nice. Every place the refugee trains stopped, people were there with food, drink. We were heroes at the time for daring to rise up against the communist regime.

Finally, we got into the American embassy. We filled out the application, and they told us to go back to the camp and wait. It turned out that we heard on the same day that we were admitted by both the Germans and the Americans; so, big decision about where to go. I told my wife, I have a job offer in Germany. I don't speak a word of English, and I don't have anybody in America; logically the decision is Germany. My wife said, "I don't want to stay in Europe. I've had enough of wars and revolution. Let's get out of here." We compromised. Since the American ship that would take us to the United States left from Bremerhaven, where the job offer was, I said, let's take the train to Bremerhaven as though we're going to America. If we like Bremerhaven then we'll stay there; if we don't like it, we'll go to the U.S. That was in mid-February.

The day the train arrived in Bremerhaven, it was lousy, overcast, cold, rainy; an ugly industrial city. We



Ferenc Pavlics' original 1/6 scale Lunar Roving Vehicle model which he drove across the floor of Dr. Wernher von Braun's Huntsville Office.

Credit: David Clow

agreed, we'll take the ship and take our chances in the U.S.

We finally boarded USAT General Nelson M. Walker, a big recommissioned World War II troop carrier built to transport 4,000 people. They separated men and women. Bunks were stacked in fours. We spent a couple of days in Bremerhaven and then left. They fed us the standard Navy rations, and after months of eating in the refugee camps, it was fantastic. Heaven! People went for seconds. The people in charge had to announce they'd issue meal tickets because they were running out of food.

The voyage was two weeks long in the North Atlantic. Seasickness was terrible all over the ship. In the meantime, aboard ship, they started processing us. They were assessing who people were in terms of skills and education, but also probing about your background. It wasn't easy—were you a communist? Are you a spy? It was a fairly extensive set of interviews. But I landed in the United States with a Social Security card; essentially I had legal status here and was ready to work. We disembarked in New York and were taken to Camp Kilmer, a reactivated military base in New Jersey. Thirty-eight thousand people were admitted there. They modified the barracks to give people a little privacy, and so we started our lives in the U.S. there. They wanted anyone who could to move through as quickly as possible to make room for the next ones—get a job, go to relatives, make room. I was extremely lucky in this respect.

Camp Kilmer, Detroit, and GM

Pavlics' luck wasn't his alone.

The Lunar Rovers never got call signs the way the Command Module and the Lunar Modules did, *Falcon*, *Orion*, and *Challenger*; each a name reflecting the traditions of the military and the spirit of exploration. The rovers' names might have been *Fortuna* or *Serendipity*, reflecting the coincidences that wove together in the lives of people, such as Ferenc Pavlics, to make them possible. The next timely break happened in Camp Kilmer.

Mieczyslaw Gregory Bekker's personal history was not greatly unlike that of Ferenc Pavlics. Bekker was born in 1905, in Strzyzów, near Hrubieszow, Poland, and graduated from Warsaw Technical University in 1929. He worked for the Polish Ministry of Military Affairs, doing pioneering research off-road traction for tracked vehicles. The German invasion of Poland caused the retreat of his group to Romania and then, in 1939, to France, where in 1942 the government of Canada offered him a chance to move to Ottawa. After 13 years in the Canadian army, he retired and in 1956 moved to the United States. Bekker's book, *Theory of Land Locomotion: The Mechanics of Vehicle Mobility*, published in 1956, was a forerunner of engineering in off-road vehicles that would help lead in the development of their ultimate expressions.[6] In 1956, Mieczyslaw Bekker was hunting for talent.

Right around that time, Dr. Bekker, my future boss, was given the task of setting up a research laboratory to investigate soil-vehicle relationships for General Motors. GM wanted government work, research and development for off-road vehicles, tanks, agricultural machinery, and the military. They set up the GM Defense Research Laboratory and Dr. Bekker's section was to investigate off-road vehicle mobility. He could not find American engineers for this. He heard on the radio that refugees were arriving at Camp Kilmer, including engineers. He was Polish himself and knew the quality of the training in eastern Europe. The U.S. National Academy of Sciences was calling on industry to try and give jobs to refugees, and so Dr. Bekker came to the camp. Less than a week after my wife and I arrived, Bekker *interviewed five Hungarian engineers and hired all five of us.*

We accepted, of course, and Bekker told us to come to Detroit. At the refugee camp, I was given a train ticket and five bucks. They took me to the train station in New York, and—now you're on your own! I didn't speak a word of English. I'd started learning on the ship, just looking at the dictionary, but it was nothing really. My wife stayed in the camp, where she'd be safe until I got settled and got my first paycheck. I went alone to Detroit. I had no relatives in the United States who could sponsor me. My official sponsor was an organization in the Catholic Church, working through the parishes in Detroit. A Polish couple from that organization met me with my name on a sign. The Hungarians had taken care of many Polish refugees when German invaded Poland, and so they were happy to give something back. They took me in. We talked in mime and sign language because we didn't speak each other's languages. I stayed with them for a good month or so. They took me to work, picked me up, fed me. I finally got my first paycheck and I could rent a little place and I brought my wife in and started life in Detroit.

In this new facility, the Land Locomotion Laboratory, we Hungarians were in the majority. One of us spoke reasonably good English and my boss, Dr. Bekker, spoke German and he and I communicated that way. I was working as a draftsman at the beginning, designing test equipment for the laboratory. We took English for Foreign Students classes in Detroit at Wayne State University and picked up enough English—it's amazing how much you can pick up in three months if you must. Then we could communicate and I got working as an engineer doing testing and designing test equipment and so on. My wife and I spent three and a half years in Detroit. My two sons were born there.

In 1960, GM decided that the Defense Research Laboratories would be moved to Santa Barbara because one of the departments was supporting the U.S. Navy and investigating acoustic detection of submarines, and they needed access to deep water. Santa Barbara offers deep-sea access in the Santa Barbara Channel and south off the Channel Islands. In those days, GM was rich and happy and fat and very generous. They even sent me and my wife out for one week; they put us up in the best hotel in Santa Barbara to let us decide if we'd accept the transfer. It took us five minutes.

So we moved here and set up the new Land Locomotion Laboratory and continued our mobility research. We expanded the lab to 1,200 people here in Goleta, California.

Santa Barbara

The whole world was exploring. In 1960, two aquanauts dove 10,916 meters down in the Mariana Trench in the *Trieste*, the first humans to reach the reach the lowest spot on Earth.[7] The *USS Triton* accomplished the first submerged circumnavigation of the globe.[8] President Dwight Eisenhower formally dedicated the Marshall Space Flight Center in Huntsville, Alabama, as Richard M. Nixon and John F. Kennedy campaigned to become his successor.[9] NASA had selected its first group of men to fly in space and was rigorously testing boosters and spacecraft in preparation for launch to be first, guessing that the Soviet Union was doing precisely the same things. The Cold War was at its coldest: a MiG-15 downed an Air Force Stratofortress over the Barents Sea with four Air Force officers killed and two imprisoned. In Moscow, U-2 pilot Francis Gary Powers was sentenced to 10 years in prison for espionage. Communists seized Cuba.

The Moon was an obvious Cold War prize, and "As soon as human beings have established a foothold on the Moon," wrote longtime pioneer Hermann Oberth, "and this even is not as far in the future as some still prefer to believe—they will need a vehicle in order to make a systematic exploration of the Moon." Oberth's book, *The Moon Car*, repeated this message in 1959, no doubt with the Soviet Union and American paying equal attention. "Of course they could walk," he wrote, "and in the beginning it will not be necessary to make long trips. But when the immediate neighborhood of the first base has been explored, the time will come to proceed to more distant objects."[10] With space a new military front, von Braun's plans for an ambitious American presence on the lunar surface seemed not fantastic, but credible, and moreover, necessary. Investigation into speculative lunar vehicles accelerated even before it was confirmed just what sort of surface those vehicles would ride on, or even in. GM Defense Research Laboratories (GMDRL) was just one among many private entities investigating lunar vehicles. Companies such as Grumman, Northrop, and Boeing, already involved in lunar spacecraft design, created speculative designs on lunar surface vehicles of all manner—one-person, two-person, long traverse, short-hop, rolling RV-sized habitations that could carry multiple crew and operate autonomously for weeks at a time, and even a rocket-belt idea (this never made it as a flight item, but it did end up flying Sean Connery in *Thunderball*.)[11] Not surprisingly, General Motors, one of the most powerful companies in history as the space race gained momentum, wanted in. Surface transportation, after all, was GM's *métier.* Such companies also recognized the financial opportunity in creating such a high profile, prestigious vehicle: Oberth himself speculated that the "Moon car" might cost as much as $100,000.[12]

In fact, a great deal more money than that was already on the table: while millions of visitors experienced the results of the von Braun/Disney collaboration, and around the time when Soviet Premier Nikita Khrushchev was denied permission to visit Disneyland himself due to security concerns, von Braun was secretly briefing the U.S. Army on its own Tomorrowland: *Project Horizon*, a 1959 proposal for nothing less than "a manned military outpost on the Moon." Said the classified report, "The lunar outpost is required to develop and protect potential United States interests on the Moon; to develop techniques in Moon-based surveillance of the earth and space, in communications relay, and in operations on the surface of the Moon; to serve as a base for exploration of the Moon, for further exploration into space and for military operations on the Moon if required; and to support scientific investigations on the Moon."[13] The ambition was mind boggling, and more prosaic, it was budget boggling. The deadline of 1966 to open the base, and its planned expansion in 1967 required a projected launch schedule of more than 200 Saturn I and II boosters, not to mention a new launch complex on the equator, outside the United States (the colossal Vehicle Assembly Building was originally conceived to support six simultaneous stackings of Apollo launch vehicles.[14]) The cost was projected in billions of dollars, and if the price seemed daunting, the argument for it was framed in brutally non-negotiable cold war terms. The Horizon report quoted Oswald Spengler. "An abstract idea of justice pervades the minds and writings of all whose spirit is noble and strong and whose blood is weak, pervades all religions and all philosophies but the fact-world of history knows only the success which turns the law of the stronger into the law of all. Over ideals it marches without pity, and if ever a man or a people renounces its power of the moment in order to remain righteous then, certainly, his or its theoretical fame is assured in the second world of thought and truth, but assured also is the coming of a moment in which it will succumb to another life-power that has better understood realities." In 1959, much of the world knew too well that the Soviet Union understood realities. The vision for Horizon naturally included a variety of surface vehicles.[15]

At GMDRL, Mieczyslaw Bekker was head of the Mobility Research Laboratory. Chief of Lunar and Planetary Programs was Samuel Romano. No wonder General Motors felt this was worth pursuing. Even a scaled down Project Horizon would require massive spending and development on lunar vehicles.

Developing Rovers

Our first considerations were about the nature of the lunar surface, and in the early stages of vehicle development during the early 1960s, we didn't know much about it. Radar telemetry from unmanned probes suggested a deep, soft surface of dust covering the Moon. The chief proponent of that theory was Dr. Thomas Gold of Cornell. He theorized that something landing on the surface might actually sink into it like an object landing on powdery snow. So the early speculative designs for surface navigating lunar vehicles included big fat tires that would not sink, and even an Archimedean screw that would borrow through a deep layer of dust.

Our GM lab started looking at all kinds of concepts that might be applicable to the lunar surface. Then we finally started getting in touch with NASA. Our first contact was with JPL. They were interested in putting a rover on the Surveyor unmanned probes, the same spacecraft that would actually land and test the nature of the surface for bearing strength. GM got a contract with JPL to develop a Surveyor roving vehicle, a six foot long, solar powered, six-wheeled articulated vehicle with three axles connected by flexible springs which allowed pitch freedom as well as roll freedom.[16] *To put it on Surveyor we'd kind of bend it up into an S shape and hang it on the side of Surveyor; we were able to package it so it would fit. It was lightweight, and the wheels were maybe fifteen inches or so in diameter.* [In May 1963, GMDRL published Bekker and Pavlics' paper, "Lunar Roving Vehicle Concept: A Case Study" describing this vehicle. It was the first appearance of the signature woven-wire wheels that would later provide traction for the crewed Lunar Rovers.[17]]

We went as far as submitting proposals, and under contract to JPL we built a working engineering model that we tested and eventually delivered to JPL where they continued testing. It became obvious that they were out of time and money so that a rover never got aboard Surveyor. They were on a very accelerated schedule. Eventually they canceled the program in 1965, but they played with the model at JPL for a very long time, testing it, and they loved it. It had excellent mobility because of its frame flexibility. It could climb a vertical obstacle twice the diameter of the wheel. The normal 4 x 4 can climb something maybe about one-third the diameter of the wheel. It had excellent off-road mobility, and this was how the Mars Rover concept was born.

JPL tested our six-wheel flexible frame vehicle and liked its mobility, but found it impractical to split the payload into three separate compartments between the axles, with flexible connection between them. One of the JPL guys, Don Bickler, invented the "rocker bogie suspension" that allowed the pitch/roll movement for all six wheels and permitted one common payload compartment. This concept was used for the Mars Pathfinder/Sojourner *and then for the Mars Exploration Rovers* Spirit *and* Opportunity. *It will also be used for the* MSL *as well—a big vehicle!*

NASA had big plans for vehicles in the mid 1960s. They came up with the concept of a mobile laboratory, MOLAB, providing pressurized shirtsleeve environment for two astronauts for long-range two-week surface explorations. We worked with them on that concept under contract for several iterations. We designed and built a full-size mobility test article with five-foot diameter wheels. We also built a cabin type vehicle which was tested in the field in Arizona for geological experiments and sample collection.

The problem, though, was that it would have required a separate Saturn V launch vehicle to land these big monsters there, and they pretty soon realized that they couldn't afford it. They gave up on the big version and tried a reduced-scale version of it called the Local Scientific Survey Module, and it was a smaller size, but even that was not affordable. There were designs for one-man, two-man, four-wheel, six-wheel, items that looked like lunar go-karts and all of them were still on the drawing boards. But time was short, and finally NASA gave up on the idea of vehicles.

The irony was that all the Disneyesque visions that had helped to move Apollo forward in the public imagination were now, in the matter of vehicles, the same ideas that were holding it back in fact. The rest of the Apollo hardware had been subject from the early days to considerations of weight and cost. Pounds and dollars: those pitiless taskmasters required the mission planners to drop dual Saturn launches, and to change the mode from direct ascent and Earth orbit rendezvous to lunar orbit rendezvous. Likewise, it made the hardware designers pare the LM down from a Chesley Bonestell dream machine to a flying pup tent. Meanwhile, all the fantastic lunar surface vehicles in the public and classified visions had still somehow never climbed onto the scales, and as Gemini missions marched ahead, as Surveyor scratched the Moon's sand and tested its bearing capabilities, as the Apollo landing sites were finalized and the crews were being trained, as North American planned and fabricated CM-012 …when reality was being measured in terms of grams and ever-tighter dollars, the lunar surface vehicle designers were still imagining in terms of tons, and eventually they had to concede the obvious. There would be no two-week surface expeditions, no separate Saturn cargo launches to place machines up there, no two-mission rendezvous on the surface of astronauts and equipment after the manner of *Apollo XII* and *Surveyor III*. The need was bare-bones simple: onboard a single Saturn launch along with everything else needed for a mission, a vehicle that would be stripped to the minimum, used flawlessly but only once, and abandoned. By 1967, when there were no realistic proposals on the table and the clock was ticking down to President John Kennedy's deadline, NASA said it couldn't be done. But the idea was just too good to leave behind.

The Folding Car

The scientific community was pushing hard. They really wanted a vehicle. Heck, the landing sites are always the flattest and safest places, and even if we can drop the LM on a dime, all the interesting places we want to go to are far away. We want to go to slopes and crater rims and rilles, and using a rover is the only way to do that.

This is 1967, 1968—it's really late in the program to create a new vehicle that could be ready and North American already has to redesign the Command Module after the fire. The LM is behind schedule too. So NASA's path is set. It was 1968 or so when they canceled MOLAB, and it looked like it was all done for vehicles. Then, independent research-and-development money provided by GM was used in our study—even if NASA did not want to pursue this, we still did. We did a study of how to create a vehicle to all the required specs and fit it either inside or attached to the outside of the existing LM. We went to NASA headquarters, Sam Romano and myself, and talked with the brass and asked, can you identify what space might be available on the LM? We were also in contact with Grumman. They said, well, this small corner could be made available. Whatever was in there could be repositioned and the space freed up—we could use that much for whatever GM came up with. They we came home and started figuring it out.

The space was inside the descent stage to the right of the ladder. It was "a triangular bay 60 inches high, 70 inches wide at the base, and 36 inches deep"[18] just more than 30 cubic feet,[19] and the shape of it narrowed from the broad end to a point like a tall, wide slice of layer cake. "Figuring it out," as Pavlics put it, meant visualizing a way "to store a Jeep size vehicle carrying a payload of 1,200 pounds into a space not larger than the back of a station wagon."[20] Pavlics saw the solution before anyone else did. The problem was communicating the possibility of vehicular origami. The solution he figured out changed the Apollo program: a Rover built to traverse an office carpet.

I came up with this idea of folding the vehicle, but nobody could really visualize it. That's why I built a little 1/6 scale model and with that, people could see it. Some of the pieces that needed machining we did in the shop at GM, but I made most of it and assembled it here at home.

I cheated! I bought some stainless steel mesh off the shelf and cut it to the right size, rolled it into a cylinder and then knitted the ends into a torus shape. The 1/6 scale was perfect for the passenger, an astronaut G.I. Joe with a silver Mercury-type space suit that I borrowed from my son. My wife and I made an Apollo backpack. She helped to sew the folding seats. The instrument panel and the steering joystick, the wire wheels with the titanium bumpers, the folding seats, the way the front and rear sections folded up and the wheels tucked in; it was all accurate, all to scale. And it was radio-controlled, so you could unfold it, sit G. I. Joe in the seat, and drive it on the floor.

GM knew I was doing it, but NASA was out of the loop. We were trying to sell the idea: look NASA, it's possible to do this! We went to NASA headquarters, to Houston, and to Huntsville, and gave presentations demonstrating the model. We made a scale model of the space in which it had to fold, and showed how it worked.

In Huntsville, we pitched the engineering group. One of them, Len Bradford, said, "Hey, we need to show this to von Braun."

He led the way to von Braun's office, and he opened von Braun's door. Instead of going in, I put the model rover on the floor. Von Braun was on the phone, and the model drove in over his rug. He hung up and said, "What the heck is this?" Sam Romano and I and this engineer followed in and we gave him the presentation of how it worked, how it folded. Von Braun was a remarkable man, and this was exciting to him right away. The week after, he called in Sonny Morea, and Morea became the program manager to develop the LRV. NASA issued another Request for Proposals. GM bid against Bendix for the job; it was pro forma really, because our folding and packaging design couldn't be duplicated. We got the contract, and we and Sonny Morea had just 17 months to deliver the rover.

Specifications and Pressure

Folding the LRV solved one big problem. The additional unprecedented challenges that followed included creating a vehicle that could:

- Operate in 1/6 G and in a vacuum with temperatures between ±250 degrees Fahrenheit;
- Permit ease of use by drivers wearing bulky protective suits;
- Cross obstacles one foot high and more than two feet deep;
- Work without a transmission and gears, using instead four motors, one for each wheel, and operate if three of the four motors were out;
- Permit the operators to venture miles from, and out of sight of, the Lunar

Module while still being able to return to it in the minimal time, that is, not by retracing their path but by the most direct route;

• Communicate via television and radio (voice and telemetry) with Houston in real time for the performance of both astronauts and the LRV, plus in support of the scientific objectives at each location visited;

• Protect itself from temperature extremes and dust, and dissipate its own heat;

• Weigh only about 450 pounds in 1 G, about 75 in 1/6 G, and carry more than twice its weight;

• Climb grades as steep as 25 degrees, and remain stationary when parked on a grade of 45 degrees;

• Turn in a radius equal to its own length;

• Provide real-time feedback on its condition to the operators and to Mission Control; isolate faults in its batteries and take corrective action;

• Deploy safely in 1/6 G from the bay on the LM Descent Stage and be operable within 15 minutes or so; and

• Deliver maximized freedom of movement for the greatest possible scientific exploration of every site.[21]

It also had to do something no spacecraft to date had done: operate without ever having been tested under actual working conditions. The accelerated timeline was:

• May 1968: GMDRL becomes AC-Electronics Defense Research Laboratories.

• June 1968: AC-E Defense Research Laboratory proposes packaging a disposable vehicle on the LM that can meet all the requirements and stay under weight constraints.

• 23 May 1969: NASA commits to the LRV.

• June 1969: Saviero Morea is put in charge of the Lunar Roving Vehicle Project Office at Marshall Space Flight Center in Huntsville.

• 11 July 1969: Morea's office issues the RFP to 29 companies to build the LRV. They schedule a preliminary design review in 10 weeks, and a critical design review in 22 weeks with contract approval.

• 11 July-28 October 1969: Morea's office and team of engineers evaluate proposals from Grumman Aerospace, Chrysler Space Div., Bendix Corp, and the Boeing Co. It comes down to Bendix and Boeing with Boeing picked on 28 October.

• 28 October 1969: MSFC announces Boeing as the winner and AC-E DRL as the prime subcontractor. Boeing has 10 weeks to finalize the details of eight systems on it.

• 18-19 January 1970: All-hands preliminary design review at Marshall with 120 NASA, Boeing, and other personnel and John Young, Gerald Carr, and Charles Duke.

• 16-17 June 1970: Final certified design review at Marshall. The design is considered complete and production of the vehicles could proceed.[22, 23]

• 26 July 1971: *Apollo 15* lifts off.

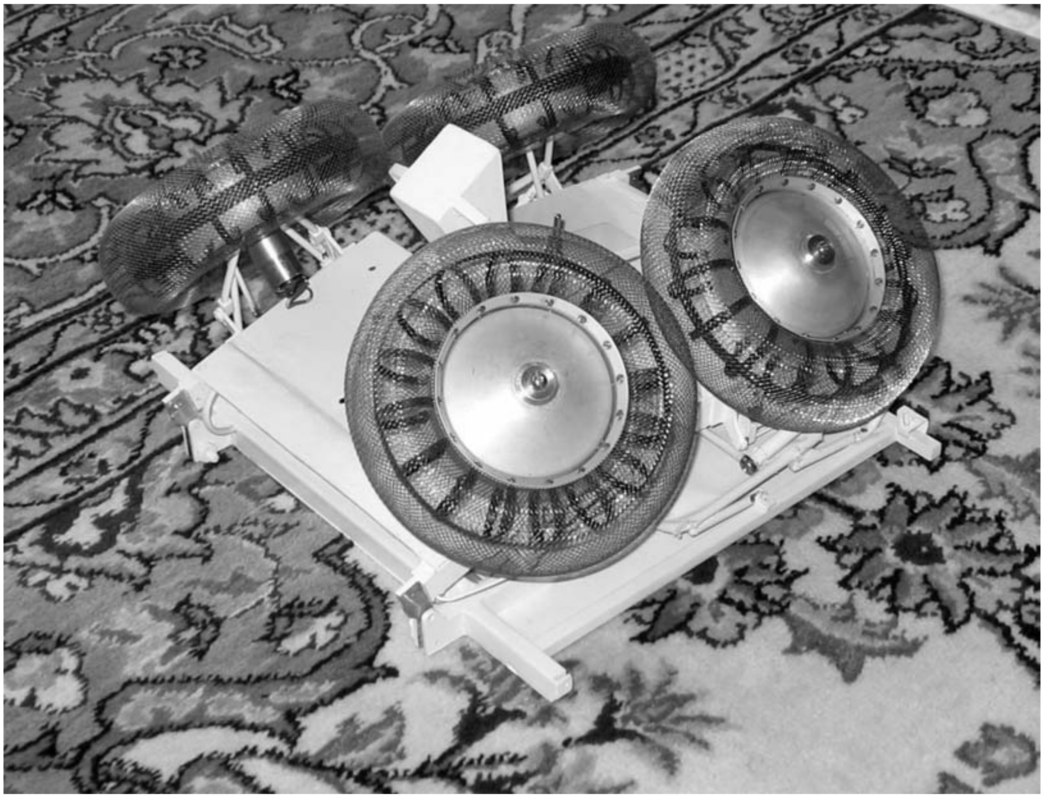
It was to be a spacecraft every bit as much as were the CM, the LM, and the EVA suits. Morea's office specified as absolute the requirement that requirement that "no single point failure shall abort the mission and no second failure endanger the crew,"[24] so regardless of the deceptive simplicity of it, and the casual sense of familiarity its design and the nicknames like "Moon buggy" invited, the LRV was subject to the same inviolable standards as all the rest of the Apollo hardware. Unlike the rest, it was never tested in space before the lives of humans in space depended on it. Its first Apollo EVA, more than two kilometers out in the Apennines past Rhysling and Elbow, then looping back along the gaping Rima Hadley on the way back with Dave Scott and Jim Irwin depending on it, would be its shakedown cruise.

When we got the contract, we had less than 18 months to design, test, and deliver the first rover to NASA according to specifications for manned spaceflight. GM needed a partner for vacuum testing and conditions testing. We didn't have those capabilities. GM didn't have any background in space, after all. Boeing in Seattle did. We had partnered on MOLAB with Boeing and agreed on delineating duties. Boeing would handle the power system, navigation, communication, and integration with the LM, and GM would do the vehicle itself including the chassis, wheels, suspension, steering, electric drive, controls, and displays. We had some testing capability at GM but the qualification testing had to be done by Boeing. They had someone on site with us to ensure close communications. Both NASA and Boeing had a permanent presence here, in fact.

That 18 months was rush, rush, rush—a nonlinear schedule of simultaneous systems development and testing in parallel. Fortunately, we had plenty of knowledge to leverage and lots of the hardware had been developed, so we weren't starting from scratch. Also, we assigned parallel teams where each major subsystem had one engineer in charge—steering, traction, and so on—and they were responsible for not just the design but carrying it all through testing and redesign and so on until delivery. In critical areas like electric drive, we had parallel and simultaneous development of alternatives, one with a DC drive and one with an AC drive, with the subcontractors. We knew we'd pick one, and we would commit to the best when the time came. That's how we cut development time.

We did experience test failures, and weight was a serious constraint. Every morning, my first meeting was a weight analysis meeting, with the engineers contending over every gram.

This was a highly compressed schedule. Nothing in Apollo had been started and stopped like this. It was day and night, weekends; our families hardly saw us. Nobody died, but some people got sick. But the great thing was, the people were so enthusiastic. You didn't have to prompt people, or ask "Can you stay an extra hour today?" Everyone volunteered and worked together, 400 people from Santa Barbara working on this in a very enthusiastic team effort.



NASA was following it very closely. I don't think at the beginning they believed it. The top Apollo people seemed very dubious…Mueller, Low…Rocco Petrone seemed skeptical. This little outfit in Santa Barbara, no space experience; but the crew was testing the land version and training on how to be field geologists. The press was expectant. NASA knew they'd go without it to Hadley if they had to, but to have gone to that site without it… they'd never have found the Genesis Rock, never have gone to the edge of Hadley Rille.

We made the deadline. It was delivered two weeks before the launch. I was sitting in Houston at liftoff. I was there as part of the two-man support team from GM. They gave us an office off the MOCR so in case something happened, we'd be there. We were watching the deployment. The setup all went perfectly. Then Dave Scott goes to the checkout procedure and calls back, "Hey, the front steering is not working." They rushed out to us to come up with a procedure for what to do. The only thing I could think if was to exercise the joystick. The potentiometer was made with conductive plastic that provided positioning input to the steering; the joystick operated that potentiometer that signaled the steering to go to that position. We used conductive plastic instead of metal because metal to metal in a vacuum under pressure and cold sticks and cold-welds; it cannot move. We'd found in some testing at very cold temperatures that sometimes the contact was lost in the vacuum chamber. That was my thought immediately. I told Joe Allen, the CapCom, about it. He was the only guy who was allowed to communicate with Dave Scott. By then, however, they had decided to proceed with the rear wheel steering only. The rover was fully controllable with one steering system operating, and they completed the first EVA as planned without any problem. The next day the front steering worked fine. The mechanism warmed up in the sunlight. Dave was joking and called back to Joe Allen that "I bet you guys from Huntsville came up ~~an~~ fixed it," and given the track record of the team, that wasn't impossible.

The LRV's Effects

To say the LRV saved the Apollo program may be overreaching, but then again its value can hardly be overstated given the limitations of the first three landings. The EVAs of *11, 12,* and *14*, all covered ground relatively close to the LM, which was tantalizing and frustrating to the scientists. Alan Shepard and Edgar Mitchell on *14* used a Modularized Equipment Transporter (MET), a hand-pulled rickshaw-type equipment cart with tools, cameras, films, sample bags, a work table, and the Lunar Portable Magnetometer. Empty it weighed 26 pounds; full, 140 in 1 G.[25] Those limitations helped make for cumbersome progress over rough terrain, fatigue, and limited utility, as the EVA to Cone Crater showed. After the near-disaster on *13*, said Dave Scott, "the program was in serious trouble. It was behind schedule, over budget, and not satisfying its basic requirements. By June 1970, two months after the near-loss of the *Apollo 13* crew, termination of the program was being seriously considered."[26] Under pressure, with the budget cut, with the public losing interest and the scientific community demanding better results, NASA leaped ahead to the "J" missions, voyages into more dangerous and interesting territory, with advanced equipment and the use of the LM as a base camp from which long traverses could be made, instead of as the sole determinant of the range of exploration. With these began the true science of lunar exploration, and the process of learning how the Moon was formed.

"For our mission on *Apollo 15*, (as well as *16* and *17*)," Scott continues, "the shift to a 'J' mission and the inclusion of the LRV meant that we could cover seven times the distance covered on 'H' missions. We would travel almost four times the distance from the LM, we would be able to carry many more tools, and we could collect and return twice the amount of surface rocks and soil. Further, because of the mobility of the LRV, we would be able to explore three different geological areas at our landing site, from a rille, to large craters, to the mountains; a true boon to the scientific exploration and comprehensive understanding of the Moon."[27] The "J "missions, said historians Charles Murray and Catherine Cox, were "magical"—"through them, planetary science was transformed."[28]

Flight director Gene Kranz notes that the camera on the LRV wasn't there to dazzle the networks. Its primary function was to permit Houston to "see what the astronauts saw, close up and in real time."[29] He called the LRV "a miracle of engineering" and "the gold prospector's burro."[30] There were additional and sometimes overlooked benefits. First was the time it gave the Moonwalkers to rest. Work on the surface was strenuous, and those few minutes driving from station to station extended their productive time by hours. Second, and just as important, it gave them a few moments' respite from the relentless pace to reflect. "We didn't do that very much," said Harrison Schmitt, "except when we were sitting in the Rover, driving from place to place. Then we had a chance to at least look straight ahead and see what was there. That really was the only opportunity at the time."[31] Jim Irwin enjoyed it because "The Rover made us feel more at home, like we were on earth where we could just get into our car and drive around wherever we wanted to go."[32]

The LRVs each performed three traverses, and even taking into account the first day's steering problem, all of the traverses were accomplished without failure. The ratio of net weight to gross weight ended up being about 1:3.5, meaning it weighed less than 80 pounds on the Moon, and carried almost 275 pounds of astronauts, tools, and samples.[33] Ferenc Pavlics' own evaluation of the LRV's performance on the lunar surface reads like this:[34]

Performance parameter	Planned	Actual
Total traverse (miles)	60	58
Samples collected (lb)	260	515
Maximum speed (MPH)	9	11
Maximum slope (degrees)	15	15
Wheel sinkage (inches)	1.0	0.2-2.0
Average wheel slip (%)	2.3	2.1
Energy usage (whr/mi)	190	150

Asked about the surprising difference between planned and actual samples collected, Pavlics smiled and said, "Jack Schmitt was really carried away."

Today and Tomorrow

Toward the end of the program, we submitted a proposal to NASA to make the rover remote-controllable from Earth and to continue the program after the astronauts returned as a remote-controlled operation. We worked it all out, but people started getting blasé about the whole project and money was short. So they just cut it out.

The television signals lasted for more than a day after *Challenger*'s ascent stage lifted off.

Forty years later, they remain where they were parked. Dave Scott left a Bible on the seat of LRV-001. Gene Cernan wrote his daughter's initials in the sand beside LRV-003. They remain the ultimate off-roaders, and they are the only spacecraft from Apollo that might be operable again. Ferenc Pavlics speculates that the hot days and cold nights on the surface have damaged the electronics, but feels sure that with replacements and a charge to the batteries, the LRVs would rove once more. NASA got offers on them, even *in situ*. Cagon Motors, Inc., of Pomona, California, offered $100. A Hawthorn, California, party tendered 10 times that. NASA was flummoxed. The agency bounced the bids from headquarters around to the various centers until the hopeful collectors gave up.[35]

"It was my most exciting program," Pavlics says. "Personally, for me to watch them deploy it." On the wall of his home office are a fading photo of LRV-001, a license plate from human's first wheels on the Moon, and a signed note of thanks from Dave Scott, Jim Irwin, and Al Worden. Beside them hangs the *Order of Merit (Medium Cross)* of the Republic of Hungary. PuliSpace, a team from his homeland, is among the competitors for the Google Lunar X PRIZE, a $30 million international contest challenging privately funded teams to safely land a robot on the surface of the Moon, travel 500 meters, and send images and data back to Earth. Pavlics consults for the team to make sure that if their vehicle makes it to the Moon, the 500 meters are assured.

Keeping the spirit alive is a challenge, particularly when institutional memory fades and a surprising amount of hard-won knowledge must be recaptured. During Apollo, Pavlics recalls, he and his colleagues had to document every detail of the work fastidiously. *When it was time to deliver the documentation, it was not just the drawings and plans but all the test reports and specifications and analysis and traceability of every goddamned screw in the machine—and the documentation had to be delivered at the same time as the machine. The documentation filled a truck and outweighed the rover. Then when it was all over, we asked NASA what to do with the documentation. They told us to scrap it.*

Decades later, when too briefly there was renewed interest in lunar surface transportation as part of the Constellation program, Pavlics was contacted by NASA, asking if he happened to have any materials that might help them understand the unique woven-wire tires that worked so well before. National Public Radio covered the lapse, saying, "The Rovers are still on the Moon, and so are their tires, and that posed a problem for NASA scientists trying to recreate those tires for a new lunar rover. No one at NASA could find instructions for building them."

Dr. VIVAKE ASNANI (head, research team, NASA Glenn Research Facility): We wanted to understand its basic utility for what vehicles can we use these tires directly. And if not, how can we apply the technology and modify it versus going back and reinventing the wheel.

NPR: But that's exactly what Asnani and his team would have had to do if original Apollo scientists followed orders to pitch all the spare Moon tires. Eighty-year-old Ferenc Pavlics emigrated from Hungary in 1956 and now lives in Santa Barbara, California. Pavlics invented the Lunar Rover and its unique tires while working for GM's defense research labs in the late 1960s.

Mr. FERENC PAVLICS (inventor, Lunar Rover): When we asked NASA what to do with the residual equipment which was left over from testing and manufacturing, they told us, destroy it.

NPR: Still, NASA's Vivake Asnani had a hunch that Pavlics would be the person best able to help recreate the original Moon tire. He was right.

Mr. PAVLICS: I have a kind of a walk-in closet and stored it there over the years.

NPR: It turns out Ferenc Pavlics stored a Moon tire in his house for nearly 40 years. Pavlics brought his tire to Akron where he tutored engineers at Goodyear on the finer points of its manufacture.

Mr. PAVLICS: It is not a simple thing to build here, because there are many tricks to it and it's not that mass-produced type of a thing. It is more of an art needed to build it.

NPR: The 14-gauge wire found in almost any piano. NASA's Vivake Asnani shows how the open woven mesh design made Moon travel practical.

Dr. ASNANI: Well, it's one of the most amazing things about the structure. If you push on it, it completely envelops whatever you're placing on top of the tire. So, right now, my fist is being pushed into the tire and it's sinking in. At the same time, it can carry the full load of the vehicle.

NPR: The wire mesh also allows fine lunar dust to sift into the wheel providing traction.

Dr. ASNANI: There isn't too much complexity to the final tire design. It's quite elegant.

NPR: Asnani admits that the spare closet space of an elderly Apollo scientist isn't the best way to archive specialized designs.

Dr. ASNANI: Obviously, we shouldn't be relying on people's memories, but in this case, that's the way it was.[36]

When they picked up the thread for Constellation and wanted to adapt the LRV wheels for it, they wanted at first to build 12 duplicate wheels of the old LRV. But they didn't have an original one. They started in Huntsville and looked all over Houston, Glenn Research Center in Cleveland, JPL; and finally they came to Santa Barbara and set up a meeting with those of us who are still around. They wanted to learn from us about our experience, and they asked if we had any drawings or hardware. I had a set of drawings of the wheels and this tire. They borrowed my wheel and I gave them drawings to use to build their test wheels. At the end of the test program, they canceled Constellation. But they did have a joint meeting about documentation, so this doesn't happen again that they scrap everything.

Since Constellation is canceled, there is no prospect for the knowledge being applied soon. Someday, though. "Maybe my great-grandchildren can visit the landing sites as tourists and kick the tires," Pavlics smiles. The LRV tire sits today beside his desk as he gives this interview.

Replica rovers are on display at the National Museum of Naval Aviation in Pensacola, Florida, and Kansas Cosmosphere and Space Center in Hutchinson, Kansas. Fittingly, one can be seen at EPCOT Center at Disney World in Florida. Test rovers that actually served during development and validation can be seen at Seattle's Museum of Flight, the Davidson Saturn V Center at the Marshall Space Flight Center in Huntsville, the National Air and Space Museum, the Johnson Space Center, and the Kennedy Space Center Visitors Complex.

Like the tire, the 1/6 scale model remains with Ferenc Pavlics at home, kept in a Plexiglas box. He brings it out like a proud parent and sets the box down on the floor. His son's astronaut G.I. Joe still sits in the driver's seat. There's something ceremonial about the way he unlatches the side of the box to make a ramp, and then, taking the same radio control he used to propel it into Wernher von Braun's office and from there to the Moon, he drives the model rover out and onto the rug.

Conclusion

This traverse began at the Austrian border in 1956. This leg of it, we hope, is not the last.

The late Guenter Wendt, beloved and obeyed as the formidable Pad Leader for missions from Mercury through Apollo, spoke of "the unbroken chain" that led to the Moon. The links customarily documented by historians are hardware, procedures, contracts, tests, meetings, reviews, and truckloads of documentation on every goddamned screw in the machine; which is simply to say that dedicated people were the links because none of these outcomes happened by themselves.

The personal commitments, competitive fastidiousness, the rivalries and *esprit de corps;* we begin to appreciate these after the dust has settled on the Moon and on Earth. The engineering speaks for itself. It is harder to weigh the links of luck. A border guard's momentary neglect to check a photo against a face, the weather in Bremerhaven one day, a wife's insistence that "I've had enough of wars and revolution"; these chance fortuities are forged into the chain between Earth and the Moon as surely as is any technology or process. This all began when children were trained to duck and cover, when the eventual driver of the first rover was flying an F-86 over Europe looking for MIGs to battle, and when a lunar base might easily have sheltered the last vestige of human life.

Those countless decisions by tired people to stay the extra hour; those myriad personal origins, life stories, backgrounds, and accents converging in a single effort under a single flag; the will to dig deep and relish the freedom to give one's best; those were what kept the links together, the heat that forged the chain. The law of the stronger prevailed, but strength in the end was not mere might. It was openness, liberty to innovate, and competitive entrepreneurship that drew on the best of committed, gifted people from all over the world. What the Soviet Union sacrificed in losing talent, such as Ferenc Pavlics, cost it the race to the Moon.

"Maybe my great-grandchildren can visit the landing sites as tourists and kick the tires," Pavlics smiles. Maybe so. Maybe they will look at the tracks in the lunar regolith and talk about sentries with dogs and refugee camps, marvel that Navy rations could ever have been called heaven, and looking back on Earth, remember that we came in peace not just for all humankind, but with it.

About the Author

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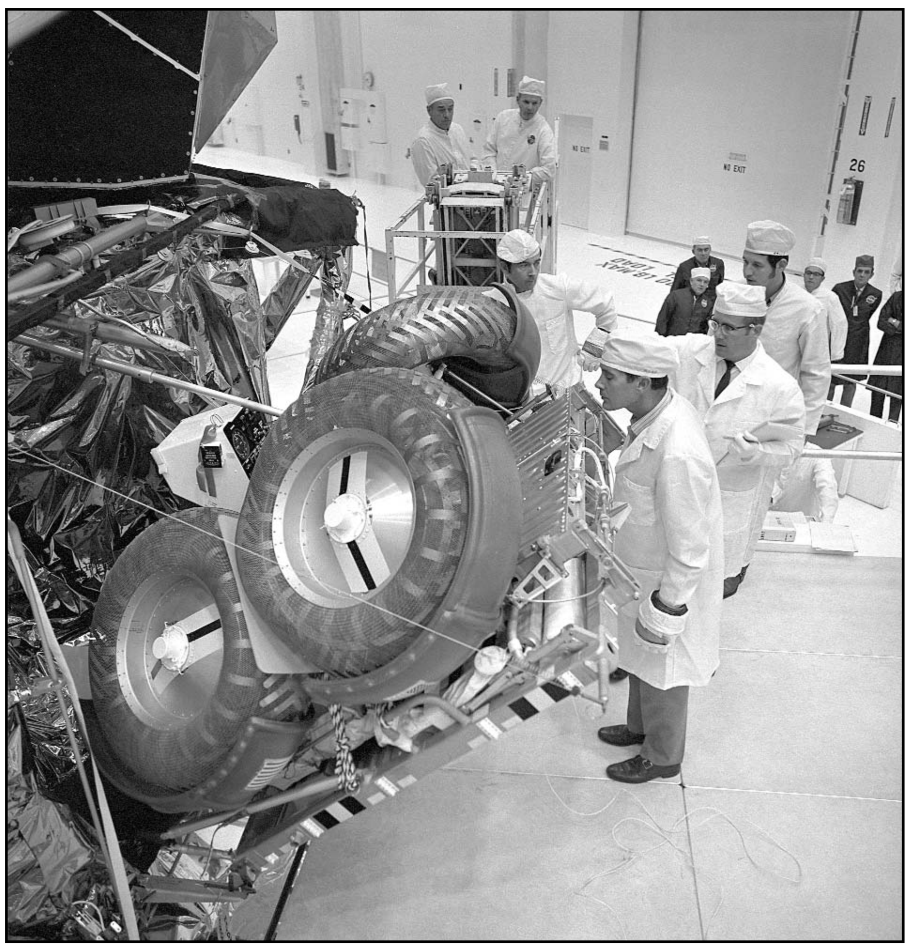

Apollo 16 Commander, John Young, center; and Lunar Module Pilot Charles Duke, foreground, inspect the Lunar Roving Vehicle they will use for transportation on the Moon during a Deployment Test in the Manned Spacecraft Operations Building at the Kennedy Space Center (12 November 1971). The Rover is stored in the Descent Stage of the Lunar Module for the trip to the Lunar surface. This inspection came during a review of Apollo Lunar Surface Experiments at the Spaceport. Credit: NASA