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MOON SHOT

How a Grumman engineer helped rescue the Lunar Module and land men on the Moon
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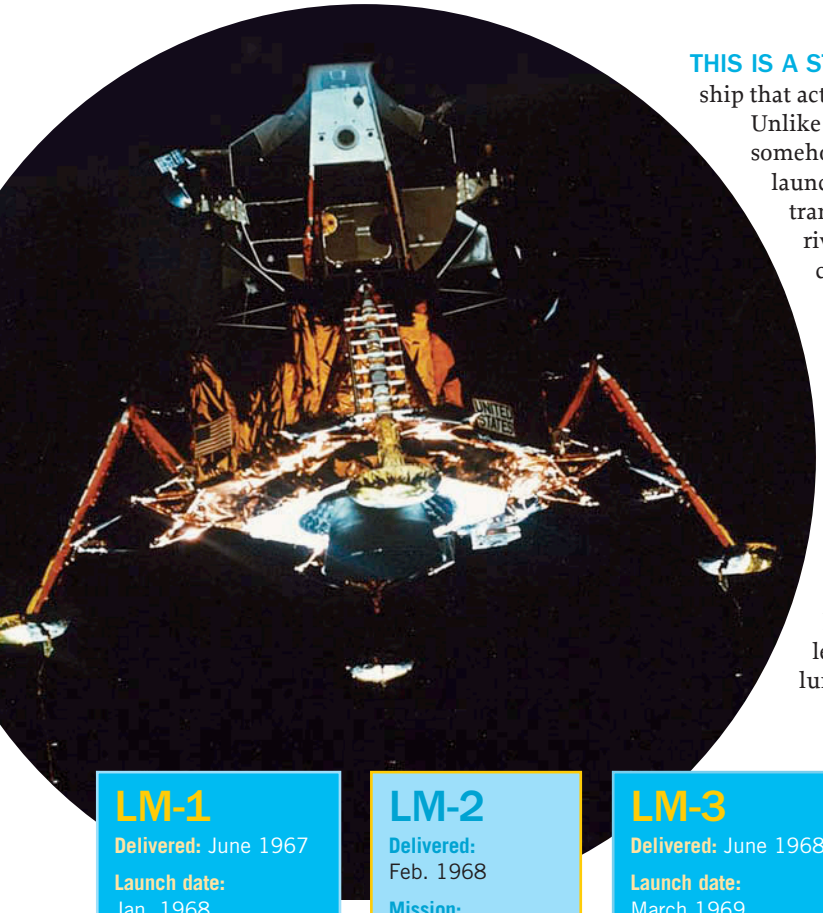
A renewed bid last week to explore the atomic-level secrets of the universe recalls another technological milestone nearly 40 years ago: the Apollo moon landings

Lunar Lessons

By George Leopold



THIS IS A STORY ABOUT A MAN who helped build a spaceship that actually went somewhere.

Unlike today's Space Shuttle missions—exhilarating yet somehow almost humdrum—NASA's Apollo program, launched under President Kennedy in 1961, sought to transport Americans to the Moon amid the intense rivalry of the Cold War. Sam Avati helped oversee construction of a critical piece of that program—the most ungainly but reliable manned spacecraft ever, the Apollo Moon lander, aka the Lunar Module (LM).

Avati, 76, worked for 35 years at Grumman Aircraft Engineering (now a unit of Northrop Grumman, Bethpage, N.Y.), prime contractor for the LM. Talk about good timing: A coal miner's son from the hills of western Pennsylvania, Avati got his engineering education in the Air Force in the early 1950s. He spent part of his Air Force hitch in Florida, never imagining he'd return a decade later to troubleshoot problems that threatened the success of the first lunar module.

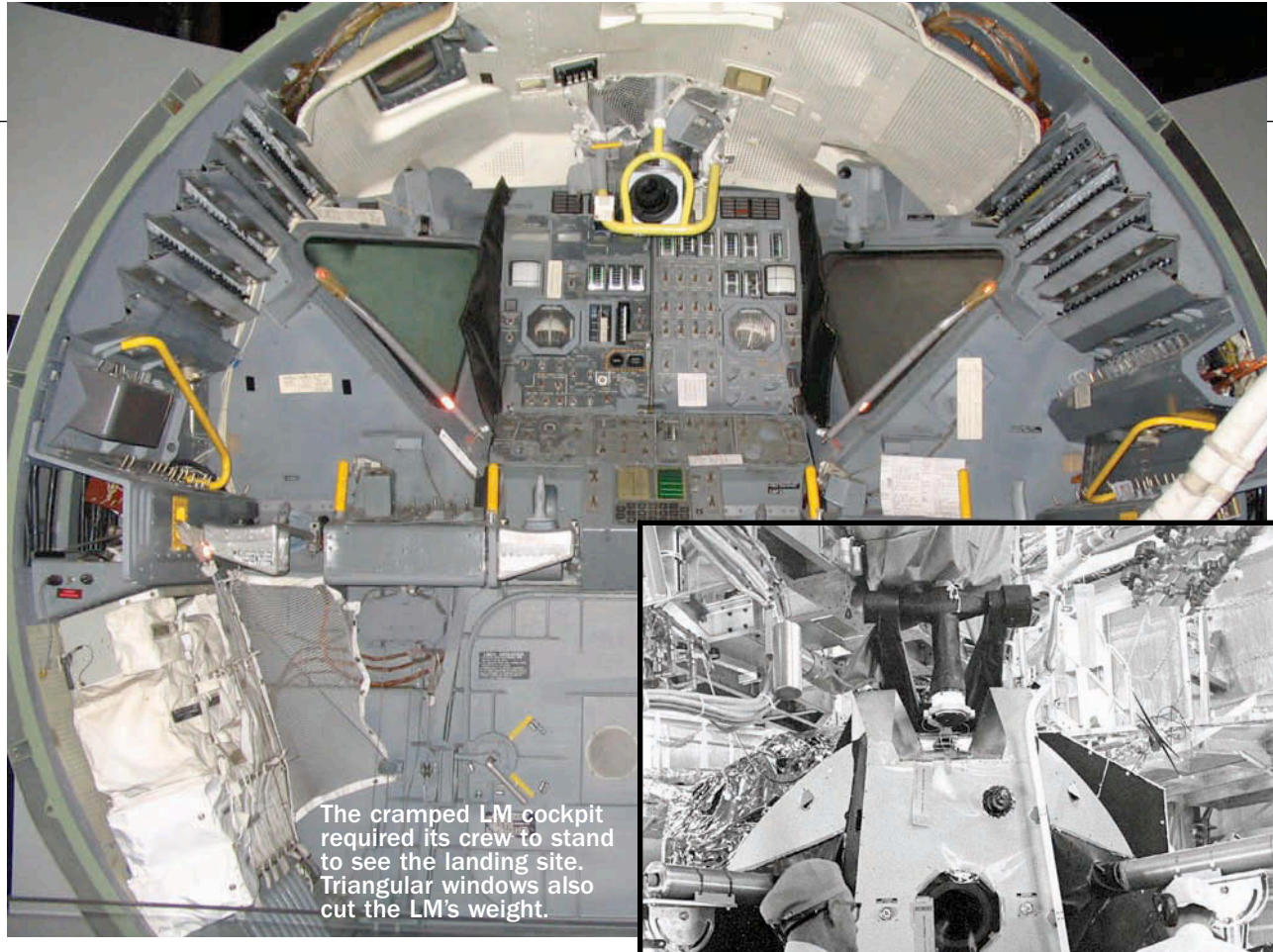
LM-1
Delivered: June 1967
Launch date: Jan. 1968
Mission: Unmanned Earth orbit flight aboard Apollo 5

LM-2
Delivered: Feb. 1968
Mission: On display at National Air & Space Museum, Washington

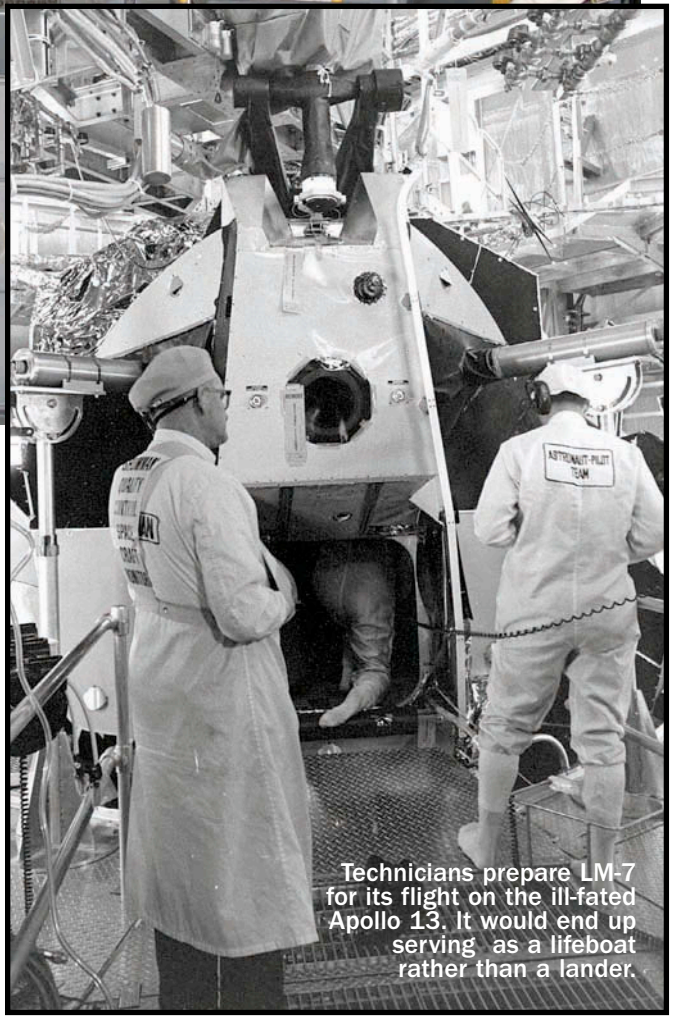
LM-3
Delivered: June 1968
Launch date: March 1969
Mission: First manned flight in Earth orbit aboard Apollo 9

LM-4
Delivered: Oct. 1968
Launch date: May 1969
Mission: First lunar orbit and landing approach aboard Apollo 10

LM-5
Delivered: Jan. 1969
Launch date: July 1969
Mission: First lunar landing, at the Sea of Tranquility aboard Apollo 11



The cramped LM cockpit required its crew to stand to see the landing site. Triangular windows also cut the LM's weight.



Technicians prepare LM-7 for its flight on the ill-fated Apollo 13. It would end up serving as a lifeboat rather than a lander.

In 1955, Avati applied for a job at Grumman headquarters during a visit to Long Island to attend a wedding, and subsequently spent his entire career at the aerospace company, building airplanes, fighter jets and the Moon lander. Along the way he married and raised three children with his wife of 51 years, Joanne.

By the time he retired from Grumman, Sam had risen through the ranks from LM manufacturing manager at the Kennedy Space Center to deputy general manager for product development.

Career takeoff

Avati bent a lot of metal during the height of the Cold War, including work on the F-14 fighter built by Grumman for the U.S. Navy. But it was the Moon lander that defined his career, perfected his skills as a resourceful, dogged manufacturing engineer and taught him how to help manage one of the highest-profile engineering projects in the history of human exploration.

LM-6

Delivered: March 1969

Launch date: Nov. 1969

Mission: Second lunar landing, at the Ocean of Storms aboard Apollo 12

LM-7

Delivered: June 1969

Launch date: April 1970

Mission: Explosion aboard Apollo 13 en route to the moon transforms lander into a lifeboat that returns crew safely back to Earth

LM-8

Delivered: Nov. 1969

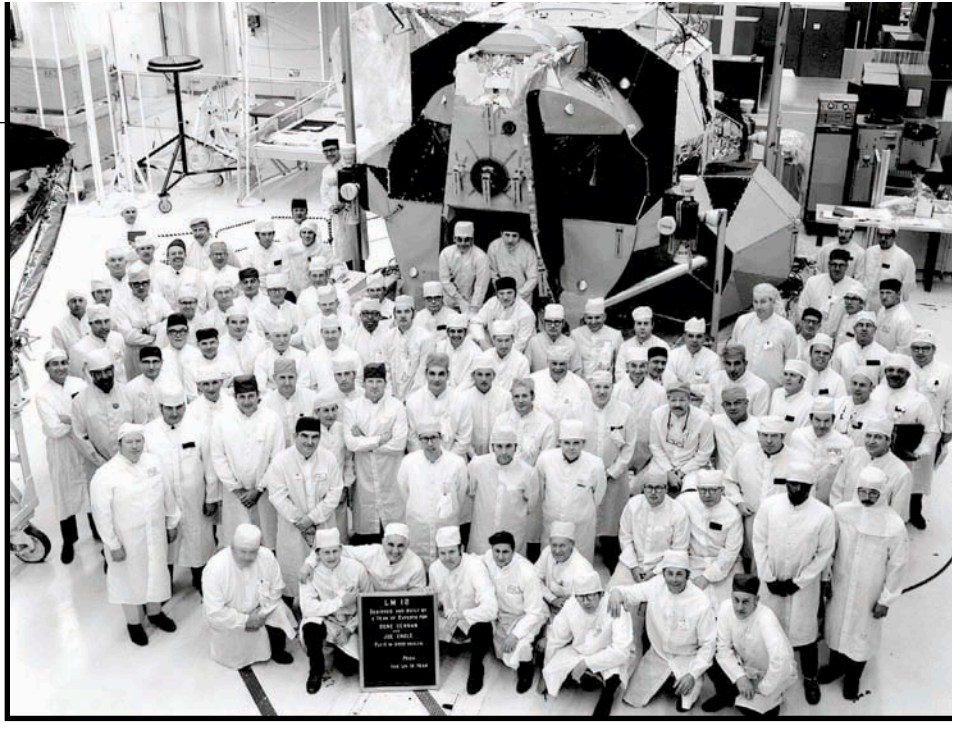
Launch date: Jan. 1971

Mission: Third lunar landing, at Fra Mauro Formation aboard Apollo 14

LM-9

Delivered: June 1970

Mission: Last "H" series lander, on display at Kennedy Space Center



Grumman workers gather around the ascent stage of LM-12, the last LM to land on the moon, in December 1972

There were plenty of 3 a.m. phone calls from Cape Canaveral to deal with along the way—and bureacracy and egos. One of the moon walkers was especially hard on LM instrumentation and controls. "He was a real pain in the ass," Avati recalled, quickly adding that the mentality of that test pilot, the mythic *"right stuff,"* was precisely what was needed to land the LM on the Moon.

Fast forward to Sunday, July 20, 1969, as Avati and his Grumman colleagues held their collective breath upon hearing Houston's mission control tell Apollo 11 Commander Neil Armstrong, "30 seconds of fuel remaining" ("Land that thing!" Avati remembers thinking). Finally, humankind, a U.S. government bent on beating the Soviets to the moon, Grumman and its manufacturing team led by Samuel C. Avati, the coal miner's son, met President John F. Kennedy's deadline to land humans on the moon by the decade's end.

Nothing since has topped the exploits of the Apollo engineers. And it was Grumman's LM team that safely transported the Apollo astronauts those last few miles to the lunar surface and back to their mothership, having built each of the 14 LMs, the only spacecraft ever designed to travel to another world, by hand.

The simpler the better

Simplicity was the byword for LM designers and Avati's manufacturing team. LM Chief Engineer Thomas Kelly, considered the "father of the LM" (and one of Avati's bosses at Grumman), wrote in his 2001 book "Moon Lander": "Our proposed design already had gone a long way toward simplicity. It was helium pressure-fed (no pumps); hypergolic (no igniters); ablatively cooled (no intricate liquid-cooling passages); and operated at a single fixed level of thrust (simple controls). Minimizing the amount of plumbing, components and joints was also a virtue in [the ascent propulsion system] because it reduced the chance of leakage, which, due to the small margins on the amount of propellant required to achieve lunar orbit from the moon's surface, could be disastrous."

The lander Kelly had imagined and designed, the one built by Avati's team, had done nothing less than take two human beings to the cratered surface of the moon and, in the words of President Kennedy, "return[ed] them safely to the Earth" by re-linking to the Apollo command module in lunar orbit.

In six landings, 12 astronauts explored the Sea of Tranquility, the Ocean of Storms, the lunar highlands and a snake-like scar called Hadley Rille. These explorers, including a professional geologist, gathered evidence strongly indicating that the Moon was once part of the Earth, and that a satellite orbiting the Earth at a distance of about 240,000 miles plays a vital role in stabilizing the Earth's rotation and orbit around the sun while also controlling ocean tides—all prerequisites for life on Earth.

The Moon walkers sent back pictures of a starkly beautiful place no one had ever seen. Humans have not returned to the Moon since 1972.

Avati and his colleagues took to heart Kennedy's words, delivered in the slain president's 1961 address to a joint session of Congress setting the deadline for a U.S. manned landing on the moon by the end of the decade: "No single space project in this period will be more impressive to mankind, or more important to the long-range exploration of space, and none will be so difficult or expensive to accomplish."

The LM was the very antithesis of the rocket that carried it.

LM-10

Delivered: Nov. 1970

Launch date: July 1971

Mission: First "J" series "extended stay" vehicle lands near Hadley Rille aboard Apollo 15; carries first Lunar Rover

LM-11

Delivered: May 1971

Launch date: April 1972

Mission: Fifth lunar landing, at Descartes Highlands aboard Apollo 16

LM-12

Delivered: June 1971

Launch date: Dec. 1972

Mission: Final lunar landing, at Taurus-Littrow Highlands aboard Apollo 17

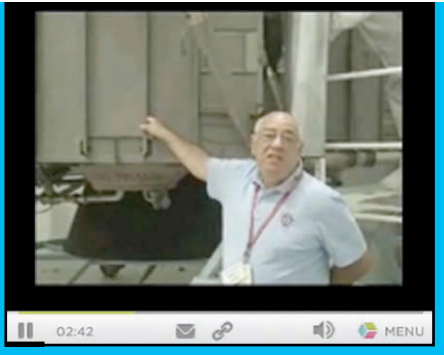
LM-13

Was to have flown on cancelled Apollo 18; on display at the Cradle of Aviation Museum, Garden City, N.Y.

LM-14

On display at the Franklin Institute, Philadelphia

SOURCES: Northrop Grumman, NASA, Kennedy Space Center



VIDEO http://link.brightcove.com/services/player/bcpid1758282323

Take a tour of the Grumman clean room.

The Saturn V, itself one of the great engineering feats in human history, stood some 36 stories tall (Astronaut Michael Collins called it "the most colossal pile of machinery ever assembled"). Launch controllers had to dump millions of gallons of water on the Saturn V launchpad just to dampen the thunderous roar of its five F1 engines. Every time the Saturn V carried men, it worked almost flawlessly—even after being struck by lightning during the Apollo 12 launch.

Sitting near the top of the three-stage stack of the Saturn V rocket were the command module and, just below it, the LM. Like Avati, many Grumman engineers were more concerned about the hazards of launch—severe vibrations and G forces—than the actual descent to the Moon's surface. Once en route, the three astronauts aboard the command module would dock with and extract the LM from its third-stage cocoon, fire up its life support and guidance systems, then extend and lock the four legs on its descent stage. After exploring the Moon's surface, two of the astronauts would use that lower stage as a launchpad, rendezvousing and redocking with the command module pilot in lunar orbit. (The third astronaut remained with the command module throughout the lunar mission.) Then the LM's ascent stage would be jettisoned, sometimes being programmed to crash into the lunar surface to calibrate seismometers left on the surface by Moon walkers.

It appears from the historical record that most of the Apollo astronauts—many of whom participated in the LM design process, suggesting, for instance, a square hatch instead of a round hatch—liked the lander design for its relative simplicity and aircraft-like instrumentation. Along with the descent and ascent stage engines, the LM had 16 reaction control rockets mounted in clusters of four along the four sides of the ascent stage. Navigation was basically the same as in an aircraft.

In the 2007 documentary "In the Shadow of the Moon," Apollo 15 commander David Scott described the process: "The lunar module had been very difficult to design and develop. It was way behind schedule because, again, it was building a flying machine to land on the Moon, and nobody had ever done that before. However, it did come online well, it performed like a charm because the engineers and the test conductors and the people who put it together had done the right job on the ground. Again, the teamwork. So the spacecraft flew like it was supposed to fly."

Gaining perspective

The Apollo program cost an estimated $25.4 billion, or about $135 billion when adjusted for inflation, a massive expenditure of resources devoted largely to the political purpose of beating the Soviets to the Moon while gaining international prestige for America (the real purpose of Apollo, many scholars agree). For all that money, it was the Moon walkers—a group of supremely

TWO GENERATIONS OF PERFECTIONISTS

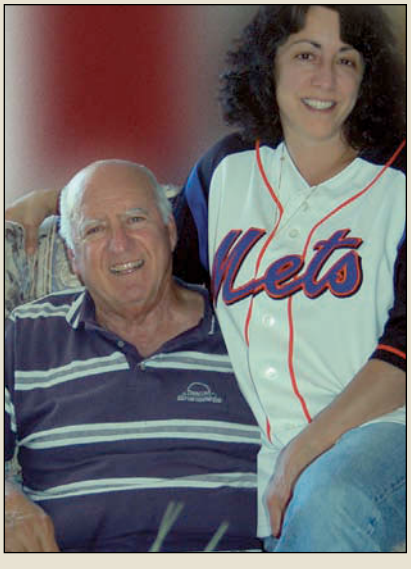
LIKE FATHER, LIKE DAUGHTER. Listening to Sam Avati's daughter, Debee Rommel, talk about rolling out a new publishing system or a Web site redesign for *EE Times* sounds a lot like accounts I've read of how the lunar module was conceived, designed and built.

The Cold War-driven NASA, not today's bloated bureaucracy, insisted that LM builder Grumman Aircraft Engineering Corp. meet every deadline, test every bolt, document every design and every design change, simulate every conceivable landing and take-off scenario—and do it all within budget with a 1969 deadline staring its engineers in the face.

Grumman didn't make every deadline, but the LM worked every time.

Matter-of-factly but with obvious pride Debee says, "My dad built the LM."

The lessons Sam Avati learned while helping to build the LM were passed on to his oldest daughter (the first of twins), the no-nonsense art director of *EE Times* publisher TechInsights. Debee, who worked as a graphics intern at Grumman for three summers while attending college, insists on perfection, brooks no slackers, and ensures that every publishing system—online and print—is tested before it is rolled out.



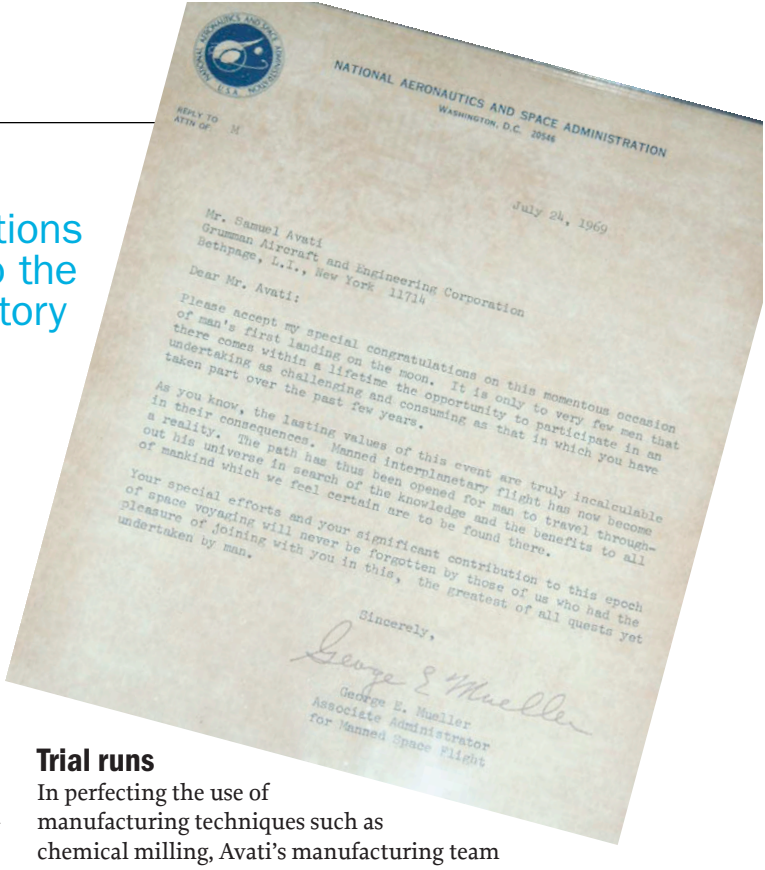
Among Debee's Herculean efforts each week are designing and producing our magazine and sister publication *Embedded Systems Design*. She's usually the one who turns out the office lights each night.

Debee's dad helped land 12 humans on the moon. His daughter makes sure the pages you are now reading are perfect, week after week.

Guys like Sam Avati made America the technological envy of the world. In her own way, Debee Rommel is continuing that tradition.

—G.L.

One of Sam Avati's citations acknowledging his contributions to the greatest adventure in human history



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: M

July 24, 1969

Mr. Samuel Avati
Grumman Aircraft and Engineering Corporation
Bethpage, L.I., New York 11714

Dear Mr. Avati:

Please accept my special congratulations on this momentous occasion of man's first landing on the moon. It is only to very few men that there comes within a lifetime the opportunity to participate in an undertaking as challenging and consuming as that in which you have taken part over the past few years.

As you know, the lasting values of this event are truly incalculable in their consequences. Manned interplanetary flight has now become a reality. The path has thus been opened for man to travel throughout his universe in search of the knowledge and the benefits to all of mankind which we feel certain are to be found there.

Your special efforts and your significant contribution to this epoch of space voyaging will never be forgotten by those of us who had the pleasure of joining with you in this, the greatest of all quests yet undertaken by man.

Sincerely,

George E. Mueller

George E. Mueller
Associate Administrator
for Manned Space Flight

confident, highly motivated test pilots and aviators—who first realized that the most important legacy of Apollo was its refocusing attention on the fragile blue ball—the Earth—suspended in the void. At least one Moon walker said he cried when he looked at the Earth from the lunar surface. All NASA's training never prepared the astronauts for that sight.

Little did Sam Avati and the estimated 9,000 Grumman workers who helped build the LM know their labors would give us a completely new perspective on humanity's home.

Avati was rising through the ranks at Grumman as the LM moved from design to construction, eventually becoming manager for spacecraft assembly and test at Plant 5, the building where the LMs were assembled. Kelly in "Moon Lander" described the Apollo project as the "biggest engineering job in history." Once the thrill of winning the LM contract wore off, Grumman engineers and Avati's manufacturing staff set out to invent something that had to be developed and built for a mission never before attempted. According to Kelly, who died in 2002, the program quickly encountered a mountain of technical and manufacturing problems ranging from weight gain (25,000 to 32,000 pounds as features were added), corrosion, leaking propellants and faulty batteries to the inevitable schedule slips.

The first LM delivered to the Kennedy Space Center (KSC), in June 1967, was described by NASA officials, according to Kelly, as "a piece of junk that leaked like a sieve." With the LM far from airworthy for its first scheduled test flight in Earth orbit, NASA brass changed Apollo 8's mission to a sensational lunar orbit on Christmas Eve in 1968 that upstaged the Soviets.

After that, Avati's boss and future Grumman president George Skurla told Avati to hurry down to Cape Canaveral. "We're in trouble down here, and we need you," Avati recalled Skurla, then director of operations at KCS, saying. Avati was reluctant to pull his children out of school, but agreed to move his family to Florida for six months.

"At KSC, no one was talking to each other" about solving manufacturing and test problems, Avati said. "I knew the [LM] inside and out. It was just a matter of getting the right people to do the job."

Grumman engineers initially did not understand that manufacturing processes like chemical milling of the LM's aluminum alloy skin, often to thicknesses of 0.0004-inch, made the vehicle prone to stress corrosion, especially in Florida's humidity. That was the main source of leaks, which Skurla, Avati and the manufacturing and test crew discovered and sealed.

With manufacturing processes refined, Grumman began cranking out landers throughout the latter part of the 1960s. Each had a designation, LM-1 though LM14 (see time line). The last three LMs to land on the moon were reconfigured as "extended duration" versions that carried heavier payloads, including the lunar rover. "After LM-3, [manufacturing] felt like it was routine," Avati said.

Trial runs

In perfecting the use of manufacturing techniques such as chemical milling, Avati's manufacturing team helped cut the LM's weight, barely getting the craft under its allowed capacity in the Saturn V stack. The LM crew cabin was built with aluminum alloy the thickness of three sheets of kitchen foil, Kelly wrote. The cabin, propellant tanks, the reaction control and environmental control systems suffered no mission-threatening leaks on any of the LM's two orbital test flights, six moon landings and one infamous rescue mission, Apollo 13.

In the movie "Apollo 13," Bill Paxton, portraying LM pilot Fred Haise, watches the LM lifeboat float away prior to reentry. "She sure was a good ship," he says.

Haise could not be reached to confirm the film's account, but Avati and several other former Grumman employees recalled that Haise was perhaps the most knowledgable of the Apollo astronauts when it came to LM systems.

Avati took the manufacturing knowhow he'd gained building the LM to other programs. Weight-saving techniques and avionics designs perfected during the LM program were later applied to the manufacture of the F-14 fighter. From a technical management standpoint, the biggest lesson Avati learned was keeping the lines of communication open at all times. "You have to interface with people," Avati said in August from his home in Hicksville, N.Y. "You have to make sure everyone is on the same page."

When George Skurla pressed Sam Avati to come to Florida in 1967 to help rescue the LM and, indeed, Grumman's engineering reputation, Avati rolled up his sleeves, talked to the testers and workers in the KSC clean room, worked his old military friends and suppliers near Cape Canaveral to get what he needed, and helped put the LM program—and the moon race—back on track.

Avati and his team were of course just some of hundreds of thousands of government contractors devoted to the Apollo program. But it's clear the organizing principles underpinning Apollo worked. It's also clear those same principles, applied to other monumental challenges, could work again. ■