NEW YORK CITY BAR

COMMITTEE ON AERONAUTICS NEWSLETTER

Volume 4, No. 1, March 2020

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The LM Ascent Stage: The Most Remarkable Space Vehicle Ever

Albert J. Pucciarelli[3]
apucciarelli@mdmc-law.com
Chair, General Aviation Subcommittee

As the 50th anniversary of Apollo 11 (first Moon landing – July 20, 1969) was approaching last summer, my fascination with the Apollo program was relaunched. That fascination, if not obsession, with all the hardware, genius and courage involved in that program, took off in a big way in the summer of 1968. I was 18 years old and my older cousin, Ray Cerrato, a NASA engineer, brought me to work with him one day at the Kennedy Space Center. We visited the Vehicle Assembly Building where I saw stages of the Saturn V being hoisted into place, one of which launched Apollo 8 into lunar orbit that December. Apollo 8 gave us a memorable Christmas Eve retelling of the Genesis creation story from a lunar orbit and that now iconic "Earthrise" photo. That mission was missing one major piece of equipment: the Grumman-made Lunar Module or "LM" that was not yet ready for testing in the lunar environment. An unmanned LM was flown in earth orbit in 1968. Apollo 9 and Apollo 10 conducted manned tests in early 1969 in earth orbit and then in lunar orbit, respectively. The Apollo 10 crew flew the LM below 50,000 feet from

[3] Albert J. Pucciarelli is a partner in the firm of McElroy, Deutsch, Mulvaney & Carpenter, LLP, in which he is chair of the firm's hotels and resorts and aviation practice groups. He was previously Executive Vice-President, General Counsel and Secretary of InterContinental Hotels until 1998. He is Chair of the New Jersey Bar Association Committee on Aviation Law and past-chair of the New York City Bar Association Aeronautics Law Committee (1999-2001). He is President of the Mid-Atlantic Pilots Association and the Ridgewood Arts Foundation and a Trustee of the New Jersey Aviation Hall of Fame and Museum. He is a commercial, instrument-rated pilot and aircraft owner.

the lunar surface, tantalizingly close to the Moon, but in accordance with mission plans, did not touch down. Then in July, 1969: Apollo11. We all know that the LM performed perfectly (except for two computer overload alarms during the descent to the Moon) when Neil Armstrong and Buzz Aldrin landed LM-5, named "Eagle," in the Sea of Tranquility. Just as impressive, the LM returned the two astronauts to the orbiting Command Module ("CM") named "Columbia" as Michael Collins, waiting in the CM, successfully docked the two vehicles 51 miles above the Moon.

The LM, previously referred to as "LEM" for "Lunar Excursion Module" before "Excursion" was deleted by NASA as sounding too "touristy," was designed by Grumman Aircraft, aided by several major sub-contractors. Work began in earnest in early 1963. The task was to develop a vehicle that could dock and undock multiple times with the CM, maneuver in lunar orbit, descend to and land on the lunar surface, sustain two astronauts while on the Moon, lift off from the Moon with the two astronauts and lunar rock samples and re-dock with the CM, only then to be discarded and allowed to crash into the lunar surface. That crash was intended to trigger seismic reading packages left behind at the landing site. Six LMs accomplished this ambitious mission without any significant failure, and a seventh served as a "life boat" for the Apollo 13 astronauts. On the way to the Moon, the Apollo 13 CM lost electrical power and the propulsion available to the CM from the large rocket engine of the cylindrical Service Module ("SM") that was connected behind the CM. Fortunately, the LM, with full fuel, was still attached to the CM. The three Apollo 13 astronauts moved into the LM and used its life support systems and propulsion capability to loop around the Moon and return to the earth's space environment, where they re-occupied and re-started the CM for splashdown. This role was not designed in the specs for the LM, but the LM performed it admirably.

NASA is known to require redundancy in all critical systems, never leaving the success of a mission, especially the lives of crew, dependent on one system or piece of equipment that may fail. But even with the heft of the enormous Saturn V, the payload – the CM, SM and LM with three astronauts who had to make it to the Moon and back – imposed weight demands that necessitated compromise. Look, for instance, at the tissue-thin gold Mylar covering of the descent stage of the LM. The metal portion of the skin of the LM was paper thin, yet had to sustain temperature variations of 500 degrees Fahrenheit and internal pressure in the vacuum of space so that the astronauts could rest inside without wearing bulky space suits. The interior of the LM provided a volume of living space for two astronauts that was roughly the equivalent of a typical clothes closet and there were no seats. At one point in the design phase, the exterior ladder leading down from the inhabitable cabin to the surface was going to be eliminated, but experiments showed that the astronauts could not hoist themselves back up to the entrance hatch using a rope and pulley, so the ladder, with all its weight, remained.

The biggest compromise of all in the LM design was the decision to have only one propulsion system to lift the ascent stage back into lunar orbit to re-unite with the CM. That task required a distance of about

50 miles above the lunar surface and a speed of about 3,800 mph so that the LM could dock with the orbiting CM/SM combination to return the astronauts back to earth. A hard decision was taken because of the weight constraints: there would be only one rocket engine in the LM ascent stage. It would have to ignite and provide a stable source of 3,500 pounds of thrust for up to 550 seconds (nine-plus minutes) to accomplish the task. The engine on the ascent stage of the LM could not fail or the astronauts would be stranded on the Moon. In addition to the human tragedy, the criticism of NASA for not having a back-up plan – and there was none – would be devastating.

The engine developed for the task was a fixed-thrust hypergolic (means the two fuels ignite on contact) rocket engine developed by Bell Aerosystems. It used Aerozine 50 fuel, and N_2O_4 oxidizer. Rocketdyne provided the injector system. The main advantages of hypergolic propellants are that they can be stored as liquids at room temperature and that engines which are powered by them are easy to ignite reliably and repeatedly. The two fuels were stored in pressure in tanks in the ascent stage. Hypergolic propellants are difficult to handle due to their extreme toxicity and corrosiveness, but the lack of an ignition system was seen as an advantage in that the ignition and lift-off would not be dependent upon an ignition system that might fail. Spontaneous ignition, though harder to control – i.e., shut down and restart – was surely a more reliable source of ignition than the available alternatives.

There is no doubt that all the while they walked the Moon, the two astronauts were excited at having successfully landed there. They exited the LM, and in two of the six missions, unfolded and drove a "Lunar Rover" stored in the descent stage. Even so, thoughts of the rocket ignition that would have to be successful lest the Moon become their final resting place must have always been present. When the moment to depart came, the firing of the ascent stage engine was televised live back to earth, either from the interior of the ascent stage, or in the case of Apollo 15, 16 and 17, from remote cameras on the surface that were aimed at the ascent vehicle and followed it upwards after ignition. The countdowns and liftoffs of the ascent stages of Apollo 15, 16 and 17 are available on YouTube. The calm of the astronauts as the countdown proceeded is truly remarkable. Even after all the intervening years, the viewer experiences relief at the ignition. The sudden upward movement and the lack of visible flame (due to the zero-atmosphere condition) have been cited by "the Moon-landing-was-fake" conspiracy proponents.

Six successful ignitions from the lunar surface returning twelve astronauts to the CM for the journey home is one more tribute to the engineers who designed this "cannot fail" ascent-stage engine. In addition, the LM ascent stage had several small thruster engines that made possible its maneuvers during the landing and ascent phases to assure a stable touchdown and a successful docking with the CM. It is interesting to note that the small 180-pound engine in the Apollo 11 ascent stage fired for 434.9 seconds, leaving residual fuel of 75.1 seconds in case re-ignition had been required to improve its position vis-à-vis the CM when docking in lunar orbit.

On October 30, 1972, NASA published a comprehensive report on the development, design and performance of the LM ascent stage engine. It is the APOLLO EXPERIENCE REPORT - ASCENT PROPULSION SYSTEM I, Manned Spacecraft Center, Houston, Texas 77058 by Clarence E. Humphries and Reuben E. Taylor. It can be found at:
https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19730010173.pdf

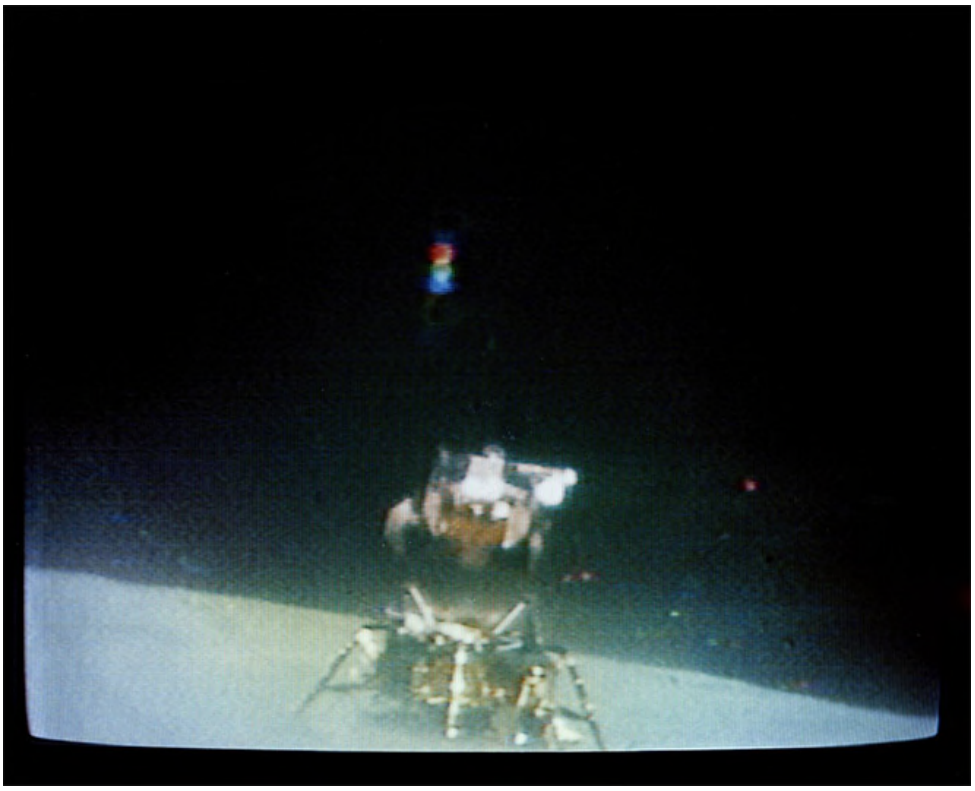
Have a look at the attached photos of the LM, CM and SM. The CM and SM have obvious aerodynamic designs that were required for their performance atop the Saturn V during lift-off and, in the case of the CM, for its re-entry into the atmosphere with its heat shield forward. But the amazing LM, especially its ascent stage, has no aerodynamic accommodation at all and derives its shape purely from its interior components, each covered by a thin metallic skin capable of withstanding temperatures on the lunar surface ranging from 248 degrees Fahrenheit above zero to 238 degrees Fahrenheit below zero, while providing a safe and reasonably comfortable, albeit cramped, living quarters for two astronauts (three, in the case of Apollo 13). The ascent engine is tucked in the interior, under a cover just behind where the astronauts stood, in an alcove that also provided storage for their bulky spacesuits and back packs. The fuel tanks occupy the asymmetric bulging compartments on each side of the LM cabin area. Over fifty years ago, the awkward-looking LM exceeded all reasonable expectations for flawless performance. It is the product of both genius and daring. It is a tribute to the human ability to imagine and then make it happen.

The following photos can be found at https://www.nasa.gov/specials/apollo50th/photos.html

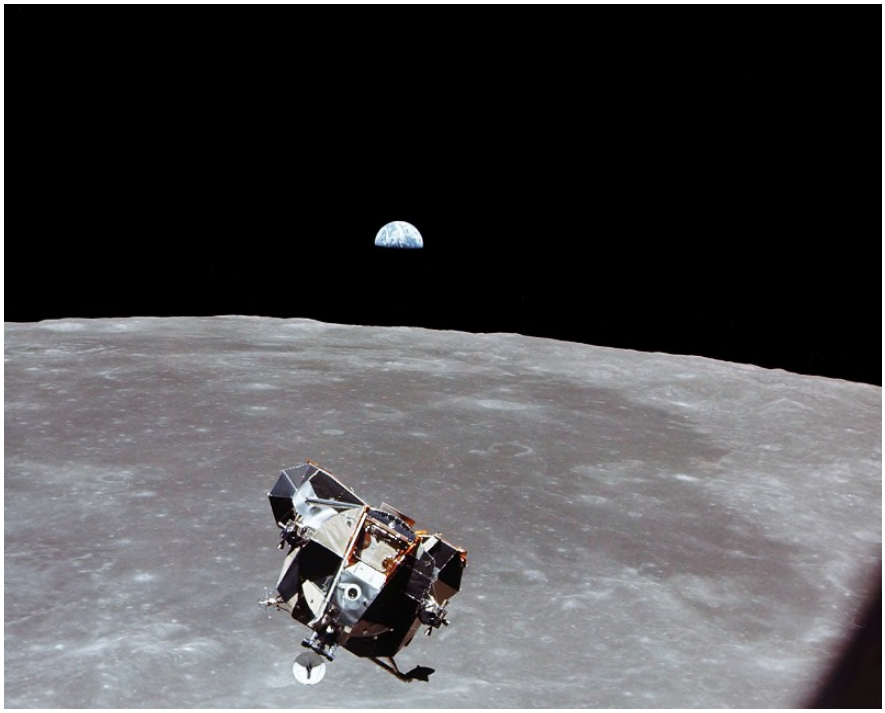
Apollo 11 lifts off on July 16, 1969; CM (covered in a protective shield under the Escape Rocket Tower) and SM atop Saturn V.

Buzz Aldrin descends the Ladder of the Apollo 11 LM on July 20, 1969.

Apollo 16 Ascent Stage Liftoff from the Moon on April 24, 1972.



Apollo 11 LM Ascent Stage approaches CM for Docking above Lunar Surface on July 21, 1969.



Apollo 10 CM and SM in Lunar Orbit on May 22, 1969.