NASA MISSION AS-506
APOLLO 11

1969 (including Saturn V, CM-107, SM-107, LM-5)

Owners' Workshop Manual



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An insight into the hardware from the first manned mission to land on the Moon

'We are banking our whole program on a fellow not making a mistake on his first landing.'

Pete Conrad
Commander Apollo 12

Chapter 4

The Lunar Module

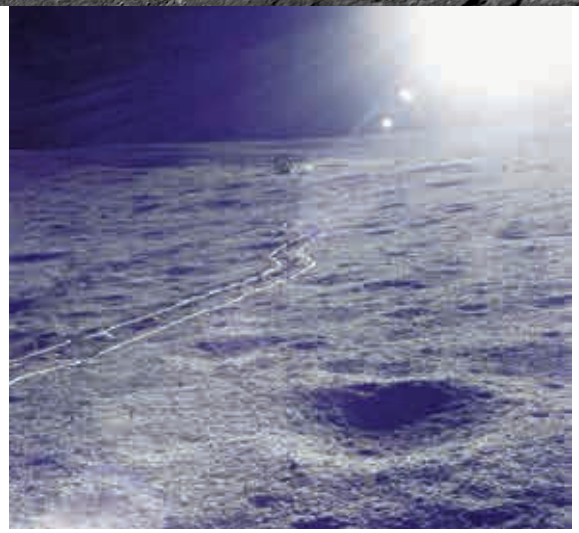
It is 22nd May 1969. Dressed in pressure suits, Tom Stafford and Gene Cernan stand shoulder to shoulder in a boxy angular spacecraft, their feet 'Velcroed' to the floor for stability. The tiny spacecraft they fly soars across the dramatic lunar mountains beneath. Its paper-thin walls, buckled by the force of a Saturn V launch a few days before, are all that is between them and the vacuum of space. Two triangular, meniscus-thin windows bulge outwards, strained by the cabin air pressure. The men charged with flying this craft's maiden mission to lunar orbit are confident that it will keep them safe. Despite its looks it is the finest flying machine Stafford has ever piloted.

Its designers, the Grumman Corporation in Bethpage, are more used to building big heavy aircraft, but the first craft built to fly exclusively in space has required a different approach. To get all the way to the Moon on a limited propellant budget they have made it so light that it is too flimsy to fly in the air and is only released from its protective shroud, inside the Saturn V, once it has reached the vacuum of space.

Now in lunar orbit, coasting along the trajectory it was made for, the stripped-down spacecraft 'buzzes' the lunar mountain tops like a nimble, responsive jet fighter. Its unique, throttleable descent engine, the first in spaceflight history, gives the pilots unprecedented control over their wingless, airless flight. And with sixteen smaller engines to orientate themselves precisely in any direction the LM is proving to be as agile as any flying machine ever built. Two small onboard computers help the astronauts to fly. They are the forerunners of the micro-computers which run our lives today.

"We is down among them Charlie", soars Gene Cernan's voice back to Houston, as the first LM to be unleashed near the Moon tips over and drops to its lowest, fastest point in lunar orbit. The fourth Lunar Module Grumman has built is now cruising the Moon's mountain tops at over 3,500mph – more than twice as fast as a Concorde's top speed. Stafford and Cernan's mission is to descend to within eight miles of the lunar surface and then return to rendezvous with John Young in the Command Module above. Success will pave the way for Neil Armstrong and Buzz Aldrin to attempt the first lunar landing in two months' time on Apollo 11. Back on Earth the Grumman engineers hold their breath.

LEFT Apollo 16 Lunar Module 'Orion' above the Moon's surface after undocking and separation. Photographed from the Command Module 'Casper' by Ken Mattingly. *(NASA)*



ABOVE The Apollo 14 Lunar Module photographed against a sun glare. A trail left by the two-wheeled Modularized Equipment Transporter (MET) leads from the LM. *(NASA)*

BELOW A scale model of an early prototype Lunar Lander is tested for stability during a simulated landing on soft material. *(NASA)*

In the beginning

Everyone who lived with, worked with or flew the Lunar Modules fell in love with them. The astronauts saw them as a safe refuge in an otherwise hostile lunar landscape. Just ten of them were eventually built to fly in space and today seven of them rest on the surface of the Moon – extra-terrestrial monuments to the ingenuity of those who built the only true spaceships ever to carry humans to another world.

Progress on the Lunar Module, following Kennedy's challenge, was initially held up by NASA's indecision over how to reach the Moon. When Lunar Orbit Rendezvous was finally approved as the way to go the hunt was on for a company to build a dedicated Lunar Lander spacecraft to compliment the Command Module mother ship which was already being built by North American Aviation.

The favourite company to build the new spacecraft was Martin Marietta. But among the half dozen or so competitors in the autumn of 1962 was also a small aircraft company on Long Island called Grumman. It had already spent almost two years studying the idea of a dedicated lightweight lunar landing craft. No one had ever really considered the practicalities of designing such a thing and not everyone at the Grumman Corporation thought that the company should attempt something it had no experience of building. Grumman was best known for its heavy, well-built WWII fighter planes, designed to land on aircraft carriers. But a lot of Grumman's managers were excited about the chance of playing a part in Apollo so they applied what they had learnt over the last two years to a bid for the contract.

Grumman decided LOR meant that the landing craft would need two stages, each with its own engine. A lower descent stage incorporating the landing gear would carry the vehicle down to the Moon's surface, and then a smaller upper ascent stage would lift off, leaving the bulky descent stage behind, to carry the cabin and the crew back to lunar orbit and a rendezvous with the Command Module. This weight-saving idea would prove a crucial factor in winning the contract.

Grumman's winning design had five legs – giving more stability than four and greater safety than three. The cabin boasted two docking hatches, swivelling barstool-type seating in front of the controls and a glass cockpit which looked more like a helicopter than a spacecraft. Once on the lunar surface, the astronauts would climb out of a side hatch and down a knotted rope to go exploring.

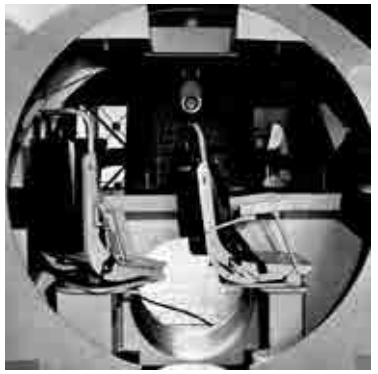
The Lunar Module contract was not signed until January 1963, two years after work on the Command Module had begun. It was going to







LEFT Artist's concept of how the Grumman LM might eventually look on the surface of the moon at lift off – as the ascent stage separates from the descent stage. *(NASA)*



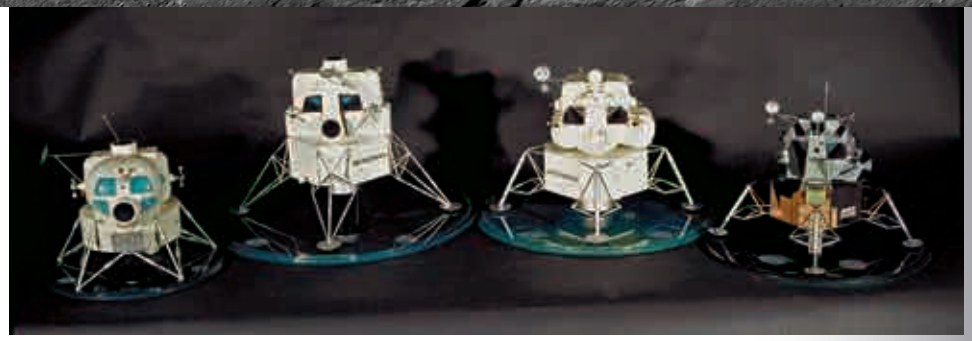
LEFT The original seating design for the LM cabin. *(Grumman/NASA)*





FAR LEFT A very early prototype model of the Lunar Lander – with much bigger windows, a round side hatch, five legs and no ladder. *(Grumman/NASA)*

LEFT A latter-stage mock-up of the Grumman LM – with its smaller triangular windows, four legs and a porch and ladder. Note that it still has a round hatch which was eventually changed to a more square shape. *(Grumman/NASA)*



ABOVE Evolution of the shape of the Grumman Lunar Module – from a five-legged design with a round hatch and large windows, to a four-legged design with smaller windows and a square hatch. *(Grumman/NASA)*

BELOW Scale model of an intermediate design for Grumman LM configuration descent and ascent stages. *(Grumman/NASA)*



take a lot of catching up if Grumman was to deliver the new craft in time for the first Apollo flights set for 1967.

Back to the drawing board

Grumman soon began to realise that its winning design was still far from being suitable for the job of landing on the Moon. Winning the contract had merely been an entrance exam it had passed to take part in the business of defining the actual requirements of a lunar lander.

For the first few months of 1963 Grumman led a study with NASA, North American Aviation (builders of the Command Module) and the Massachusetts Institute of Technology (which was working on the Apollo navigation system) to come up with a concept for a real moon landing flight set for May 1968. The 'reference mission' they came up with would involve landing two men on the lunar surface, carrying 250 pounds of equipment, keeping them alive for 48 hours, and returning them to the CSM in orbit with 100 pounds of rock samples.

Every detail they could imagine, from trajectories to propellant budgets, was calculated and published in a bulky three-volume document which specified the exact requirements for the Apollo lander. To reach the surface, in a controlled descent, the LM would need a new kind of throttle-controlled rocket engine. And the life-support systems would need to be as reliable and efficient as those of the Command Module, but at a fraction of the weight.

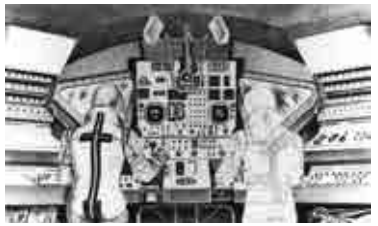
Unlike every other flying machine Grumman had created, this one would never be test-flown on Earth before being sent on a mission. The engineering would have to be so perfect that flight testing would not be necessary. Such unique and stringent demands would prove to be a huge burden on those who tried to build the LM, but it would ultimately also make them better aircraft builders.

Weight watching

As with every piece of Apollo hardware, keeping weight down was crucial as ever and from the very start Grumman was under instructions to lose anything that was superfluous. The first casualty of this weight cull was one of the five legs. The circular chassis configuration was swapped for a square stronger cross structure with one leg at each corner. The knock-on effect of these structural changes was that six propellant tanks from the original design now became four, with an engine in the middle. This also reduced the piping needed, which brought the weight down further.

Space inside the prototype LM cabin was also being rethought. Grumman quickly began to realise that there was simply not enough room in the original design for the crew's pressure suits, their bulky life-support backpacks, helmets, boots, gloves, and somewhere to stow the rock samples the astronauts would collect. The designers could not make the cabin any bigger because of the weight limits, so more space was created by losing the seating. The astronauts would stand up for the 15-minute landing, anchored to the floor with waist harnesses and foot holds. Their legs would act as shock absorbers on landing and lift-off. Fold-down armrests would also be added so they could steady themselves at the controls during flight. This redesign also allowed for smaller, triangular downward-tilted windows placed at head height. A third, small, rectangular window was built into the roof of the LM to give the commander a view of the Command Module during approach and docking.

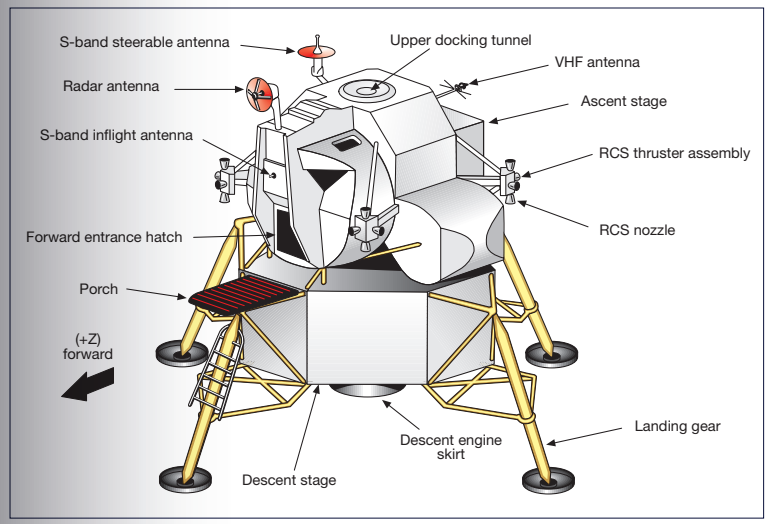
Early studies on the knotted rope access idea to enter and exit the LM on the Moon quickly revealed how impractical it was. Even with a winch system an astronaut in a pressure suit and life-support backpack struggled to haul himself back up to the hatch and so a ladder was added to one of the legs instead. A small flat 'porch' was also added just outside the hatch to bridge the gap to the ladder.



LEFT Artist's concept of the LM interior layout with the two astronauts standing at the main control panel and looking out of the triangular windows at head height. *(Grumman/NASA)*

By the beginning of 1964, three years after Kennedy's challenge was announced, Grumman was still changing the design of the lunar lander to accommodate new ideas. These constant changes begin to push back the spacecraft's construction schedule and NASA set a deadline in late 1965, after which no more changes would be allowed.

The final design which emerged was not the prettiest machine in the world, resembling a giant other-worldly insect. But, shaped by the environment it would dwell in, Grumman's lunar module was perfectly tuned to the mission it would be called upon to perform.



LEFT The final Grumman LM configuration descent and ascent stages. *(Matthew Marke)*

To the 400,000

"We would like to give special thanks to all those Americans who built the spacecraft; who did the construction, design, the tests, and put their hearts and all their abilities into those craft. To those people tonight, we give a special thank you, and to all the other people that are listening and watching tonight, God bless you. Good night from Apollo 11."

Neil Armstrong,
Dedication transmitted on the 23rd July 1969, on the way home from the Moon.

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Conversion factors

Note: *All distance and velocity figures quoted in the text of this book are given in Imperial units, as would have been the case at the time of the Apollo missions.*

Distance

feet	0.3048	metres
metres	3.281	feet
kilometres	0.6214	statute miles
statute miles	1.609	kilometres
nautical miles	1.852	kilometres
kilometres	0.54	nautical miles
nautical miles	1.1508	statute miles
statute miles	0.86898	nautical miles

Velocity

feet/sec	0.3048	metres/sec
metres/sec	3.281	feet/sec
metres/sec	2.237	statute mph
statute mph	0.447	meters/sec
feet/sec	0.6818	statute mph
statute mph	1.4667	feet/sec
feet/sec	0.5925	nautical mph
nautical mph	1.6878	feet/sec
statute mph	1.609	kph
kph	0.6214	statute mph
nautical mph	1.852	kph
kph	0.54	nautical mph
statute miles/sec	1.609	km/sec
km/sec	0.6214	statute miles/sec

Volume (capacity)

US gallons	3.785	litres
litres	0.2642	US gallons
US gallons	0.833	Imperial gallons
Imperial gallons	1.201	US gallons
cubic feet	0.02832	cubic metres

Mass

pounds	0.4536	kilograms
kilograms	2.205	pounds

Pressure

pounds/sq inch	70.31	grams/sq cm
grams/sq cm	0.0142	pounds/sq inch

Propellant weights

RP-1 (kerosene)	Approx 6.7 pounds per gallon
Liquid oxygen	Approx 9.5 pounds per gallon
Liquid hydrogen	Approx 0.56 pounds per gallon

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