After a break of half a century, humans are returning to land on the Moon within two years, and space tourism to the threshold of space and into Earth orbit has already begun. SpaceX rockets are becoming reusable, returning intact to their launch pads to participate in further missions. What comes next ? **Humans on MARS ? Within 15 years ?**

Read on for more information from NASA, SpaceX, Virgin Galactic, Blue Origin and many other companies now working in the space industry. This report was compiled at Starfield Observatory in Queensland, Australia and uploaded on 22 October 2024.

Contents

The "elephant trunks" of gas and dust in M16 or NGC 6611, 'The Eagle Nebula' – by the James Webb Space Telescope.

After a hiatus of 50 years, NASA plans a return to the Moon

NASA's long-awaited return to the Moon came closer with the launch on 16 November 2022 of the most powerful rocket ever built to carry humans into space. The rocket blasted off from the Kennedy Space Center at 4.47 pm (AEST) from the same pad used by the last Apollo mission half a century ago. Perched on top of the 32-storey-high rocket was a new space capsule set to fly beyond the Moon and back again.

Piloted by a mannikin called **Commander Moonikin Campos**, the uncrewed flight was the inaugural test run for the ***Artemis*** program (pronounced 'Ar'-tem-iss'), NASA's project to put humans back on the Moon and eventually travel to Mars. "With the ***Artemis I*** launch, NASA is poised to begin the most significant series of exploration missions in over a generation," said Bhavya Lal, NASA's associate administrator for technology, policy, and strategy.

[The mannikin's name is a tribute to Arturo Campos, who died in 2004 aged 66. He was the electrical power subsystem manager for the *Apollo 13* lunar module in 1970. He wrote the procedures to transfer electrical power from the lunar module batteries to the command module, after an oxygen tank exploded halfway to the Moon, switching the mission from a lunar landing attempt to one of desperate survival, enabling *Apollo 13* astronauts Jim Lovell, Fred Haise and Jack Swigert to return to Earth safely. "When they called me up, I rewrote the emergency checklist on the spot," NASA quoted Campos as saying, "I had written procedures for that eventuality a year before." Campos and his colleagues in the Mission Evaluation Room and Mission Operations Control Room at the Manned Spacecraft Center (today, Johnson Space Center) in Houston were awarded the Presidential Medal of Freedom for their efforts.]

Artemis I on launch pad 39B

The six week mission not only pushed the new ***SLS Block 1*** rocket and ***Orion*** capsule to the limit – it tested a new orbit and went further than a craft capable of taking a crew to the Moon had ever been before. It also released ten small shoebox-sized satellites to scout the Moon and explore conditions for future deep-space missions. Even though the rocket and the capsule might look dated when compared with the futuristic vehicles being developed by commercial spaceflight companies such as Blue Origin, SpaceX and Virgin Galactic (*see page 37*), their missions are very different to the ***Saturn V - Apollos*** that ran on less computer power than does the smart phone of today.

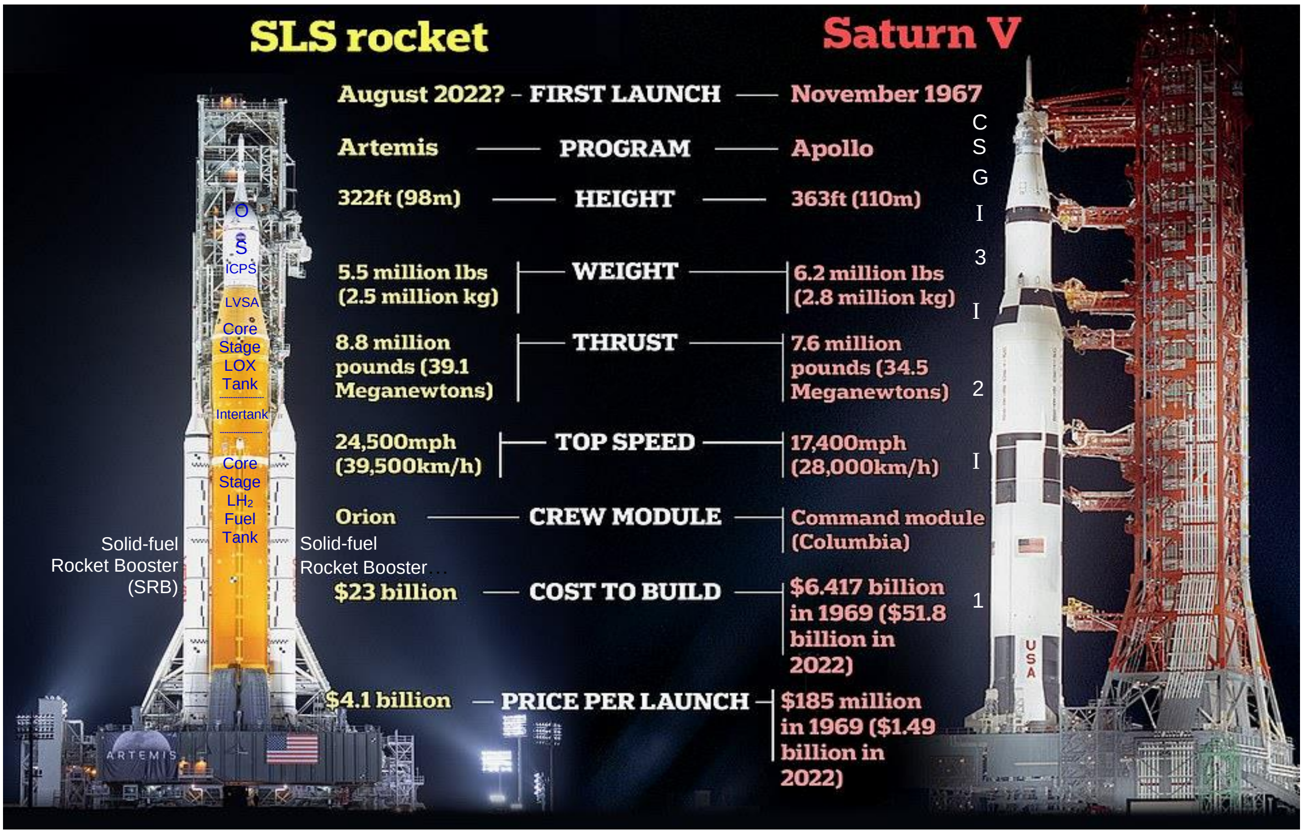
In retrospect: NASA's Project Apollo, 1961-1972:

The ***Saturn V*** rocket was split into three stages, each having fuel and oxidiser tanks with the engine(s) mounted underneath. The first (bottom) stage, S-IC (pronounced 'S-One-C'), had five *Rocketdyne* F-1 engines (burning RP-1 highly refined kerosene plus liquid oxygen oxidizer or LOX) which were open to view underneath the rocket. The supercold LOX was necessary for the fuel to burn in an airless environment. The first stage developed 7.6 million pounds or 34.5 Meganewtons of thrust at launch. The task of the first stage was to lift the massive 2965 tonne vehicle up to an altitude of 67 kilometres and a speed of 8280 kilometres per hour. Three minutes after lift-off the engines had expended their fuel and the first stage was jettisoned. It fell into the Atlantic Ocean about 560 kilometres downrange. The cylindrical interstage that had covered the engines of the second stage was then also jettisoned.

The second stage, S-II ('S-2'), had five *Rocketdyne* J-2 engines (using liquid hydrogen fuel and LOX) and was designed to place the *Saturn V - Apollo* (minus the first stage and interstage) at an altitude of 172 kilometres (close to low Earth orbit), after which it separated and fell into the Atlantic about 4200 kilometres downrange. The exhaust nozzles on each of the four outer engines on the S-IC and S-II stages could be hydraulically pivoted using gimbals to balance and control the direction of thrust, thus enabling the rocket to manoeuvre in flight to stay on course. The centre engine on each stage was fixed.

The third stage, S-IVB ('S-4-B'), had a single *Rocketdyne* J-2 engine using the same fuel as the S-II stage. It was fired twice, the first time to place itself + the Lunar Module garage + Service Module + Command Module into an orbit around the Earth for one-and-a-half orbits (Earth Orbit Insertion, EOI), and the second time to provide thrust for Trans-Lunar Injection (TLI), which came 2 hours 44 minutes after launch. The TLI burn lasted six minutes. The astronauts were now heading towards the Moon. (The '+' sign indicates that the stages and modules are temporarily docked and clamped together.)

Forty minutes after TLI, the Command + Service Modules separated from the third stage, and turned through 180 degrees to face the Lunar Module (LM) in its garage atop the third stage. Using the Service Module thrusters, the Command Module approached the top of the LM, docked with it and then extracted it from the garage. The LM + Command Module + Service Module then made a second 180 degrees turn to bring the Moon back into the astronauts' view ahead (although the LM blocked the view somewhat), and Lunar Orbit Insertion (LOI) occurred three days later. Two weightless astronauts glided into the LM and undocked from the Command Module which continued to orbit the Moon, controlled by the third astronaut. After landing on the Moon and completing their duties, the two astronauts returned to the LM's top half which then blasted off the Moon and re-docked with the Command Module. The Service Module's engine then fired, sending both Modules back to Earth. The six tonne Command Module with its human cargo was the only part of the 2965 tonne *Saturn V - Apollo* to return home. The *Saturn V* was used for nine crewed flights to the Moon and to launch the *Skylab* space station.



SLS-Orion: O = *Orion Crew Module,* S = *Service Module,* ICPS = *Interim Cryogenic Propulsion Stage or Upper Stage,* LVSA = *Launch Vehicle Stage Adapter (protects RL10 upper stage engine).*

Apollo spacecraft: C = *Command Module,* S = *Service Module,* G = *Lunar Module Garage,* I = *Interstage.*

Saturn V: 3 = *Third Stage,* I = *Interstage,* 2 = *Second Stage,* I = *Interstage,* 1 = *First Stage.*

The next step: NASA's proposed Artemis Program, 2022 > :

NASA's four key objectives for the first ***Artemis*** mission and those following are:

"First, the space agency needs to confirm that *Orion's* heat shield will be capable of withstanding atmospheric re-entry. As NASA says, 'no aerodynamic or aerothermal test facility can recreate the conditions the heat shield will experience when travelling at lunar return speeds.' The expected heat of re-entry might be as high as 3000º Celsius, half that of the Sun's photosphere.

“Second, NASA will also use ***Artemis I*** to demonstrate its operations and facilities throughout the entire mission, such as ‘NASA’s launch facilities and ground-based infrastructure, *SLS* operations, including separation events during ascent, *Orion* operations in space, and recovery procedures.’

“A third and obvious objective will be to retrieve *Orion* after splashdown. NASA will return the spacecraft to Kennedy Space Center upon the conclusion of the mission, where it will be subject to a detailed inspection. Teams will ‘gather data and test the integrity of the vehicle’ to better understand the ‘engineering uncertainties’ involved. Ground teams will also retrieve the troves of data that will have been gathered during the flight, including the data gathered by the three mannikins. Orion’s parachute system will also be retrieved and analysed. NASA’s fourth objective is to succeed with its side plans, such as certifying the capsule’s optical navigation system, deploying the ten CubeSats into lunar orbit, and gathering imagery.”

The SLS-Orion space vehicle, first flight 16 November to 11 December 2022 :

Standing 98.1 metres high and weighing 3000 tonnes, NASA’s ***Space Launch System (SLS)*** rocket develops 8.8 million pounds or 39.1 Meganewtons of thrust at launch (16% more than the *Saturn V* can manage). This, combined with a reduction in weight of 11%, enables a velocity 41% higher to be reached. The payload that the *SLS* can carry to the Moon is 5.7% heavier than *Saturn V’*s. Whereas the *Saturn V* first stage had five F1 engines, the *SLS* **Core Stage** has four RS-25D engines which have previously been flown into space on successful *Space Shuttle* missions. Sixteen of these ex-*Shuttle* engines are available, and are being used on the first four ***Artemis*** missions, after which an improved version, the RS-25E, will be used as the engines are lost into the ocean after the Core Stage separates from the Upper Stage.

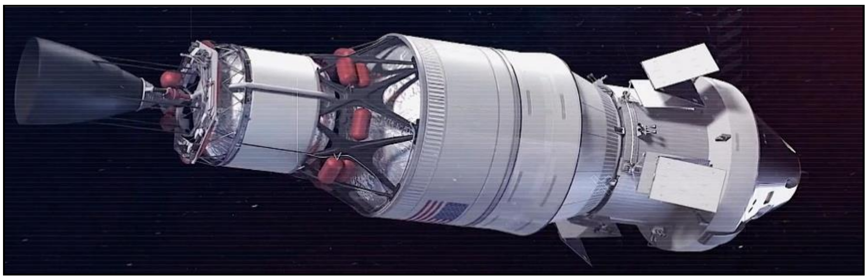
These engines burn liquid hydrogen (LH_2) plus liquid oxygen (LOX). The gases must be supercold in order to liquefy. The LOX (-147º C) allows the LH_2 fuel (-253º C) to burn without needing air. The fuel and oxidizer are carried in tanks above the engines, which are mounted on gimbals as they had been on the *Space Shuttle*, to provide thrust control for manoeuvrability. The four engines under the Core Stage provide only 25% of the vehicle’s thrust at lift-off. The remaining 75% of thrust is provided by two 54 metre high five-segment ***Solid-fuel Rocket Boosters*** (***SRB***s) mounted on each side of the Core Stage. Each SRB has a fixed engine burning 500 tonnes of solid polybutadiene acrylonitrile propellant, with very limited control once ignited. Six tonnes of this fuel are burned every second. These are stretched versions of the boosters that were used 135 times from 1981 to 2011, launching *Space Shuttles* to Earth orbit. Attached to the top of the Core Stage is the smaller-diameter ***Upper Stage***, which has a single RL10 engine mounted below tanks for LH_2 and LOX. At lift-off the engine is covered by a protective interstage called the ***Launch Vehicle Stage Adapter*** or ***LVSA*** of partial conical section. The Core Stage and the *LVSA* are sprayed with durable orange foam insulation to keep the LH_2 and LOX supercold, and resemble the *Space Shuttle’s* external tank in colour, shape and function. The solid-fuel rocket boosters, the Upper Stage and the *Orion* modules including the ***Launch Abort System*** or ***LAS*** are white, but the Crew Module may be chromed.

2 minutes 11 seconds after lift-off, the SRBs have expended their solid fuel and separate from the Core Stage, falling into the Atlantic 225 kilometres off Florida. NASA has decided to forego recovery schemes for all *SLS* components, allowing them to sink to the bottom of the ocean. This will reduce operational costs, allow heavier payloads, and permit maximum performance. At 4 minutes 10 seconds after lift-off, the ***Launch Abort System*** (***LAS***) at the top of the rocket is jettisoned as it is no longer needed. 8 minutes 20 seconds after lift-off when the rocket is 160 kilometres above the Earth, the tanks inside the Core Stage are empty, initiating ‘MECO’ (main engine cut-off). The Core Stage disengages from the Upper Stage, falling with its four engines into the sea where it is lost. The orange *LVSA* interstage covering the Upper Stage’s RL10 engine is also jettisoned at this time.

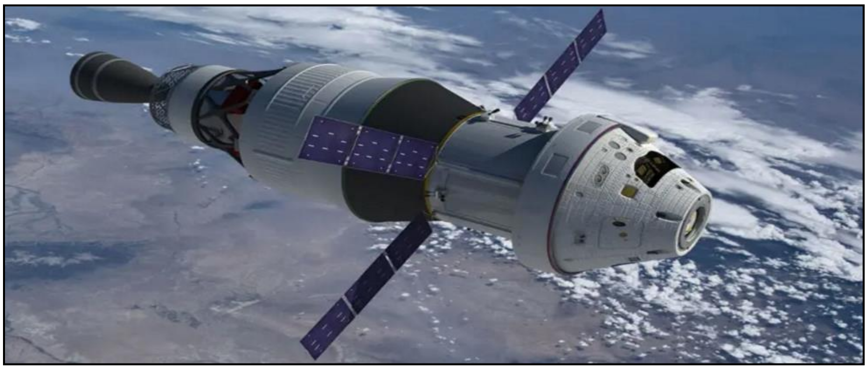
The RL10 engine in the Upper Stage, properly termed the ***Interim Cryogenic Propulsion Stage*** or ***ICPS***, then ignites and puts the spacecraft into one Earth orbit. The solar panels are deployed, after which the RL10 fires again for 20 minutes. This gives *Orion* almost enough speed for Trans-Lunar Injection (TLI) – nearly fast enough to be captured by the Moon’s gravity as it nears the Moon. The *ICPS* and *Orion* then separate – the *ICPS* releases ten small satellites (***CubeSats***) into lunar orbit, then goes into orbit around the Sun. The CubeSats are small, shoebox-sized satellites carrying experiments from international space agencies and NASA partners, including Australian universities.

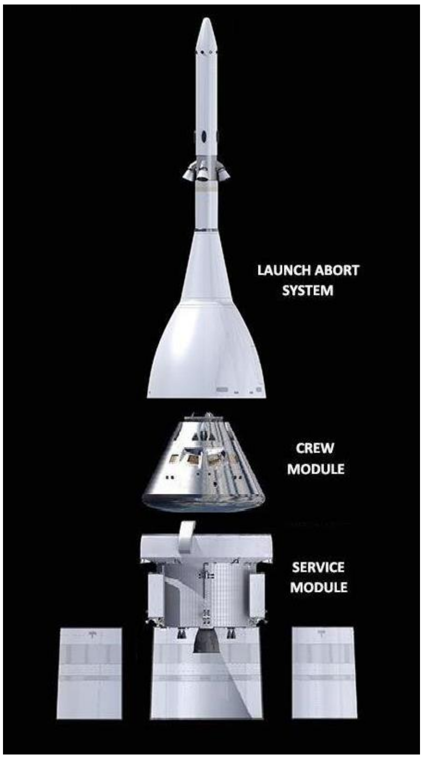
The ***Orion Multi-Purpose Crew Vehicle*** (***MPCV***) is made up of three main parts as seen in the image at below right:

1. The ***Launch Abort System*** will lift the Crew Module with its four astronauts to safety if a life-threatening situation occurs during launch. If there is no emergency, the Launch Abort System is jettisoned minutes after a successful lift-off. On the launch-pad, it completely covers the Crew Module, which is accessible by the crew via a hatch.
2. The ***Crew Module*** is a space capsule which can accommodate the crew in special seats. Built by Lockheed Martin, it is designed to keep four or six astronauts safe and healthy for long-duration missions of up to 21 days without docking. On the underside (back) of this module is the all-important heat shield that is vital for safe re-entry into the Earth's atmosphere.
3. The ***Service Module*** is built in Germany by Airbus Defence & Space for the European Space Agency. It contains solar panels and power supplies, as well as the Crew Module's life support systems. Its main engine, the ***Orbital Manoeuvring System Engine*** (***OMS-E***), has 6000 lbs of thrust. It can fire in bursts from less than a minute to 16 minutes. It gives *Orion* the impetus to achieve Trans-Lunar Injection, and is the only engine powerful enough to manage other orbital changes to keep the *MPCV* on course. There are also eight *R-4D-11* auxiliary engines in four sets of two on the back and 24 *Reaction Control System* thrusters in six sets of four on the side.



Above: From left, Upper Stage (ICPS) with RL10 engine, Service Module with solar panels beginning to unfurl, Crew Module at right.





*Left: The configuration with solar panels deployed, before Trans-Lunar Injection (TLI), after which the left-hand half of the vehicle (the **ICPS**) separates and is lost. The right-hand half (the **Orion**) heads to the Moon.*
*Right: The three sections of the **Orion** spacecraft, showing two **ICPS/Orion** interstage panels detached.*

Orion, now continuing on alone, receives its 120 volt electrical power from the Service Module. The journey to the Moon takes five days, during which time teams of technicians on Earth carefully track the capsule's performance. As the spacecraft travels towards the Moon, its speed drops to 1500 kilometres per hour, as the Earth's gravity is holding it back. On Day 5, at about 85% of the distance to the Moon (326 000 kilometres), lunar gravity overcomes the Earth's and the capsule begins to accelerate once again to about 5000 kilometres per hour. At this point, Lunar Orbit Insertion (LOI) will be the normal procedure for manned missions, in preparation for docking with the ***Gateway*** lunar space station when it is built. Once ***Gateway*** comes on-line, astronauts will be able to access a lunar lander and go down to the surface, returning after their work is complete. Then they will transfer to *Orion*, undock, and as their orbit carries them behind the Moon in another close flyby, they will fire the Service Module's engine again at the right moment, angle and power level to utilise the Moon's gravity for Trans-Earth Injection (TEI), to slingshot back towards Earth on a trajectory to re-enter the Earth's atmosphere. A mistake or failure at this point could mean that *Orion* might overshoot and head out into deep space. The journey home will also take five days. Once near Earth and just before re-entry, the Service Module is jettisoned and burns up during its own re-entry, falling as dust into the Pacific. The Crew Module is turned through 180 degrees so that its heat shield is facing the direction of travel, the crew facing backwards. The 4.8-metre-diameter shield is critical for the survival of the spacecraft and its passengers during re-entry. Moving at a speed of Mach 32 (32 times the speed of sound, or 11 kilometres per second, or 40 000 kilometres per hour, much faster than previous crewed space vehicles), the capsule encounters our planet's atmosphere. The heat shield is designed to protect the crew from the colossal furnace of re-entry, as *Orion* becomes surrounded by a bubble of hot plasma reaching temperatures of up to 2765º Celsius.

Instead of plunging through the atmosphere as *Apollo's* Command Module did, *Orion's* Crew Module breaks re-entry into two phases. First, it dips into the atmosphere and out again (as a flat stone skips across water, called a 'skip manoeuvre'), which reduces its speed to 480 kilometres per hour. Second, a series of parachutes deploys, slowing the craft to allow a gentle splashdown in the Pacific Ocean off California. The US Navy, along with teams from NASA's Exploration Ground Systems, will then recover the vehicle using helicopters, small boats and an amphibious transport dock ship.

The first three ***Artemis*** missions were planned to use the above procedures with these differences:

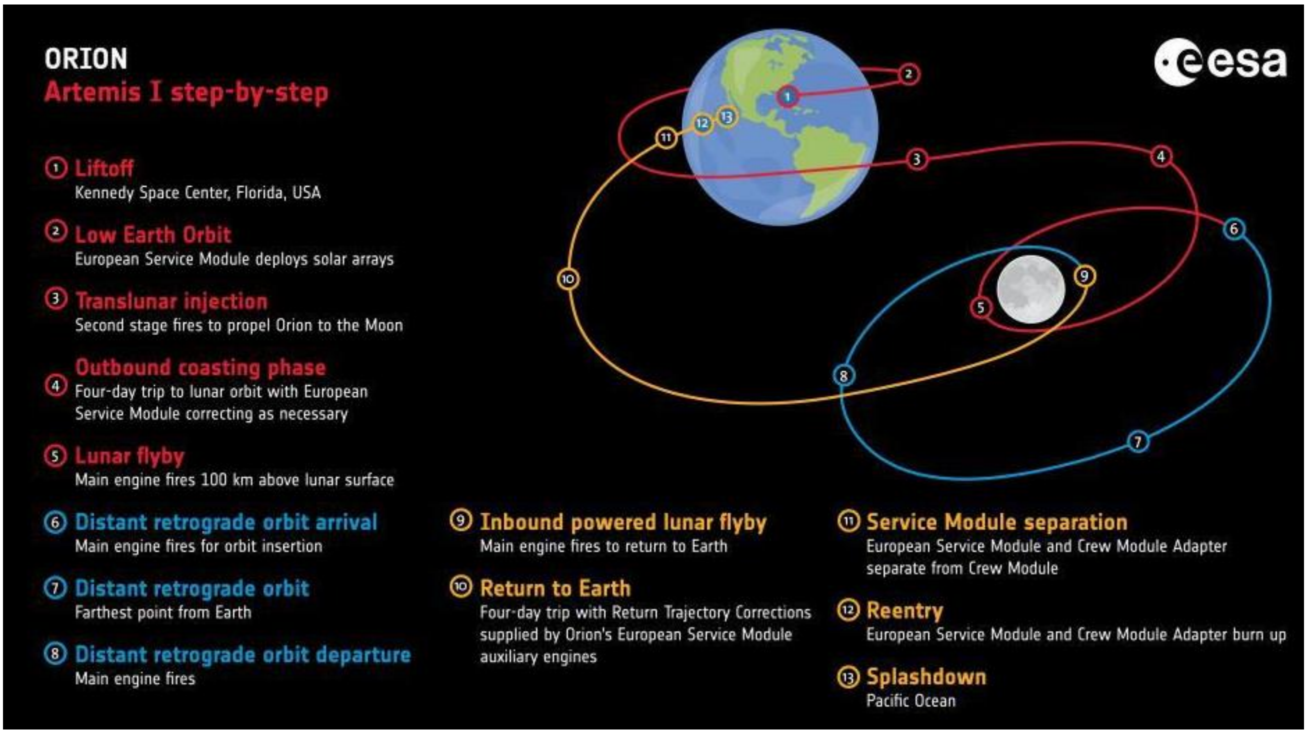
1. ***Artemis I*** had no astronauts on board, so entered a distant retrograde orbit around the Moon and stayed there for six days (half an orbit). Duration = 25½ days (Nov. 16 - Dec. 11, 2022).
2. ***Artemis II*** will have four astronauts in *Orion* and will orbit the Moon once without landing, as done by *Apollo 8*. The mission will last 10 to 21 days. To be launched by a *SLS-Block 1* in late 2025.
3. ***Artemis III*** will be launched by a *SLS Block 1* rocket in late 2026 and enter a lunar ***NRHO (Near-Rectilinear Halo Orbit)*** where two crew were originally to descend to the lunar surface in a NASA lander. They will instead transfer to a *Starship HLS*, which will descend to the Moon for several days. The crew will then transfer back to *Orion* and return to Earth (*see page 20*).

A base on the Moon: NASA's Artemis Program, 2022 > :

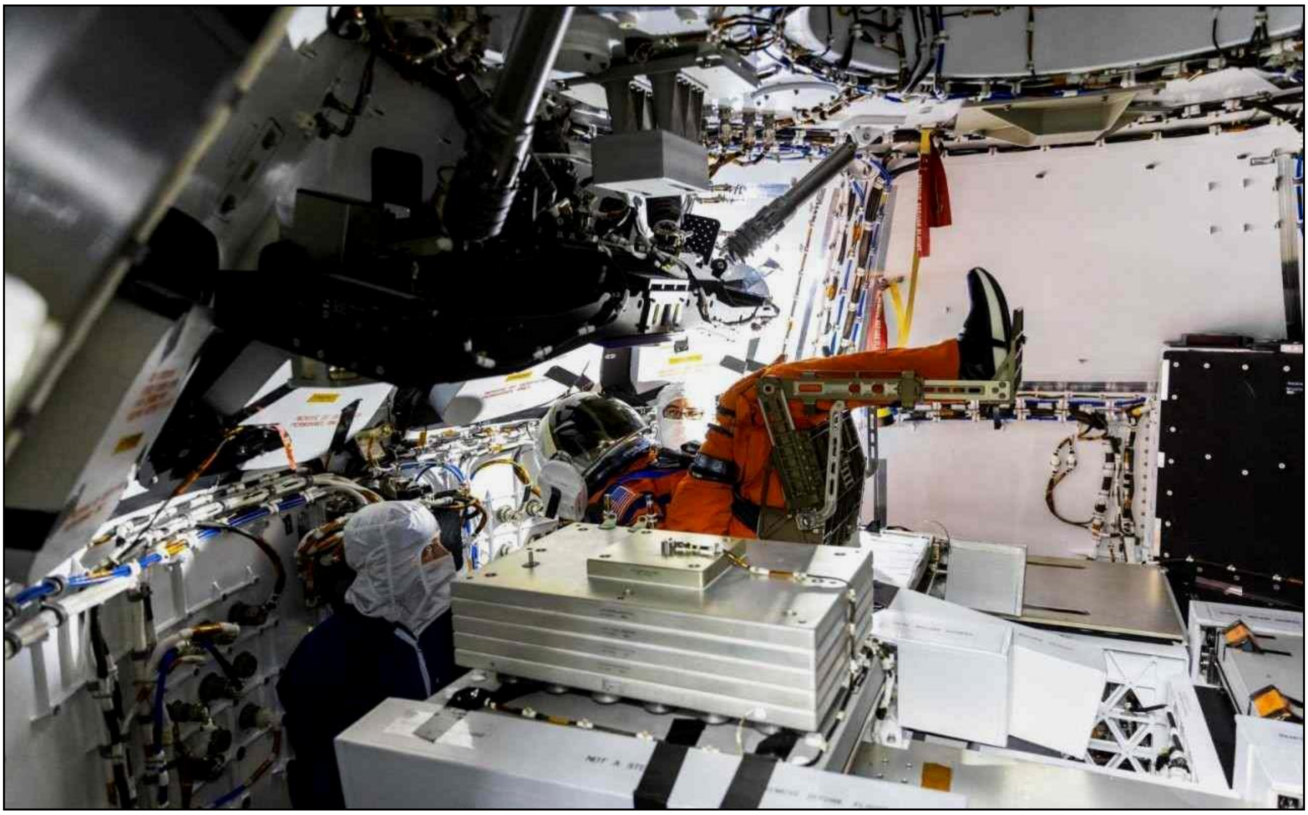
The ***Orion*** space vehicle was developed between 2005 and 2010 as part of the ***Constellation*** program organised under President George W. Bush, but the next administration, Barack Obama / Joe Biden, stopped all funding to *Constellation* in the 2011 federal budget. NASA was forced to cancel all *Constellation* missions, including development of the ***Altair***, ***Ares I*** and ***Ares V*** launch vehicles which were being designed to service the *International Space Station*. Yet NASA continued to advance work on the ***SLS*** rocket (using existing *Space Shuttle* technology) and ***Orion*** spacecraft.

On 11 December 2017, the next President, Donald J. Trump, signed *Space Policy Directive 1*, a change in national space policy that provided for a U.S.-led, integrated program with private sector partners for a human return to the Moon, followed by missions to Mars and beyond. The policy called for NASA to "lead an innovative and sustainable program of exploration with commercial and international partners, to enable human expansion across the Solar System and to bring back to Earth new knowledge and opportunities." It required that NASA co-ordinate government, private industry, and international efforts toward returning humans to the Moon, and laying the foundation of eventual human exploration of Mars. *Space Policy Directive 1* authorised a lunar-focused program to draw upon already-proposed US spacecraft programs including the ***Orion*** space capsule, the ***Lunar Gateway*** space station and ***Commercial Lunar Payload Services***, and also created entirely new programs such as the ***Human Landing System***.

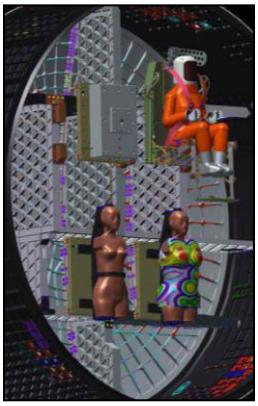
To replace the cancelled ***Aries I***, the ***Space Launch System*** (***SLS***) would serve as the primary launch vehicle for *Orion*, while commercial vehicles such as ***SpaceX****'s Dragon XL*, *Falcon Heavy* and *Super Heavy / Starship* would launch various other elements of the program. *Starship* is by far the most powerful of all these rockets, its thrust of ~17 million pounds being twice that of *Saturn V* and nearly twice that of the *SLS*. On 26 March 2019, President Trump announced that NASA's return-to-the-Moon landing goal would be accelerated by four years with a landing in 2025. NASA said on 14 May 2019 that the new program would be named ***Artemis***. (In Greek mythology, Artemis was the daughter of Zeus and twin sister of Apollo. She was a goddess of nature, and was strongly identified with Selene, goddess of the Moon.) What follows after ***Artemis III*** is still being planned.



The first attempts to launch ***Artemis I*** on 2 and 5 September 2022 were abandoned after the countdown was halted at T minus 2.7 hours due to liquid hydrogen leaking from valves in the Core Stage. The next attempt on 27 September was postponed after Category 4 *Hurricane Ian* passed directly over launch pad 39B at Kennedy Space Center at Cape Canaveral in Florida. Luckily, the rocket had been rolled back to the Vehicle Assembly Building on its mobile launcher prior to the storm. Another attempt on 14 November was postponed due to Category 1 *Hurricane Nicole*. The successful fifth attempt on 16 November was the first integrated trial of *Orion* and *SLS*. (The former had been sent into space on a trial mission in 2014, but this was the first launch for the *SLS*.) The aim was to send the US $ 20.4 billion (AU $ 30 billion) *Orion* on a 25½ day journey to the Moon and back. Its journey took place according to the procedures described on pages 4 to 6 and below.

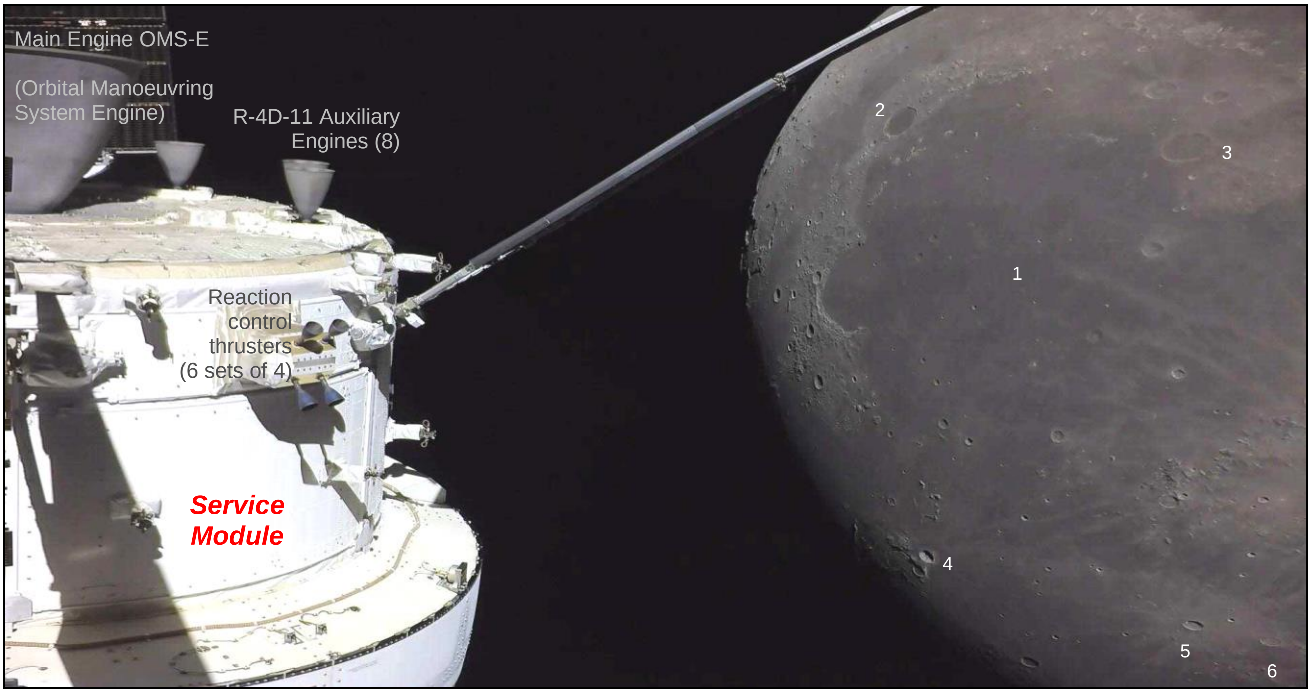


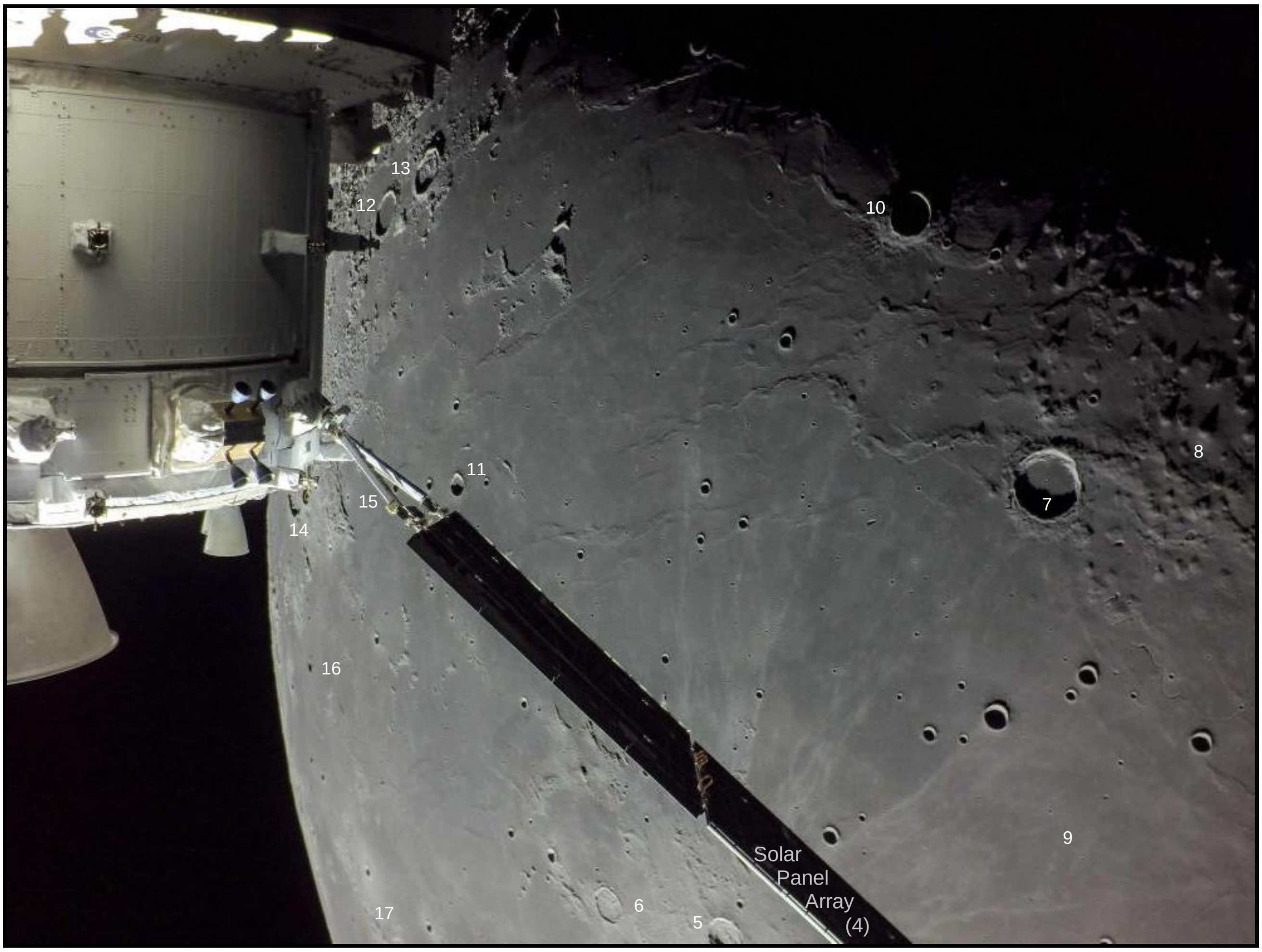
Artemis I didn't have a human crew, but it wasn't empty. The three seats installed were occupied by three mannikins: a pilot named Commander Moonikin Campos wearing a standard *Orion* spacesuit (*see images above and at right, and page 2*), and two female crew mannikins called Helga and Zohar. Together, such replica crew members can tell us what real human astronauts will have to endure during similar missions. Campos' spacesuit was fitted with sensors that measured vibrations, g-forces, and radiation throughout the 25½ -day journey. On the topic of radiation, and unlike the *International Space Station*, *Orion* travelled beyond the boundary of the Van Allen Belts (accumulations of high-energy particles positioned between the Earth and Moon) that protect life on Earth. Moonikin was also strapped to a new energy dampening system known as the Crew Impact Attenuation System.



Helga and Zohar (models of female torsos each fitted with 5600 sensors) took part in the Matroshka AstroRad Radiation Experiment (MARE) designed by the German Aerospace Centre. Zohar (lower left-hand seat) wore an AstroRad radiation vest designed by Lockheed Martin and StemRad, while Helga wore no vest and served as a control. Women are more vulnerable to the risks posed by space radiation, making necessary the mannikin experiments. In deep space, humans will be exposed to more energetic particles, including those coming from the Sun's solar flares and from outside the galaxy. This radiation is a serious concern for humans beyond low Earth orbit, so the mannikins are vital. Charlie Brown's dog Snoopy and Shaun the Sheep went along for the ride, presumably to demonstrate zero-G by floating around. An iPad was used to test Amazon's *Alexa* voice assistant.

On Day 6 of the ***Artemis I*** mission, *Orion CM-002* approached to 81 miles (130 kilometres) of the Moon. It took some monochrome images of the far side, but did not enter a low lunar orbit. Instead, the Service Module performed a critical manoeuvre called an ***outbound powered flyby burn*** for 2 minutes 40 seconds, using the Moon's gravity to slingshot it out into a deep-space orbit**.** It entered a ***distant retrograde orbit*** (***DRO***) on Day 10. Each *DRO* takes 12 days, but *Orion* only stayed for half an orbit. This tested *Orion's* navigation, propulsion and communications systems in deep space, because whenever a spacecraft cruises behind the Moon, communication with ground controllers is temporarily lost. Parked in this elongated retrograde orbit on mid-mission-Day 13, the capsule was 69 623 kilometres beyond the Moon – "55 453 kilometres farther than the previous record set during *Apollo 13* and the farthest out in space any spacecraft built for human passengers has flown," according to NASA. At this time *Orion* reached 432 386 kilometres from Earth. Although the *DRO* is very stable, it's beyond the reach of communications systems used for close-to-Earth operations such as the *International Space Station*. NASA has to communicate with the capsule using its Deep Space Network dish antennas at Goldstone (California), Tidbinbilla (Canberra) and Madrid (Spain).

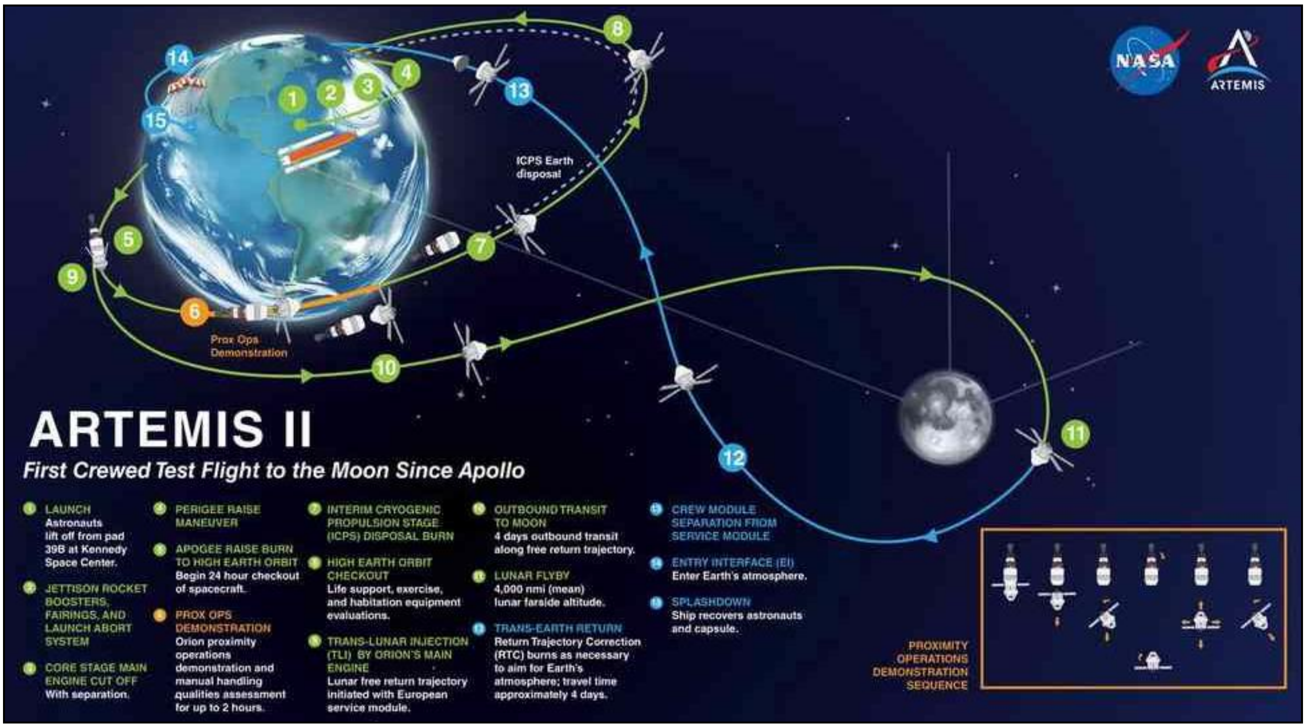




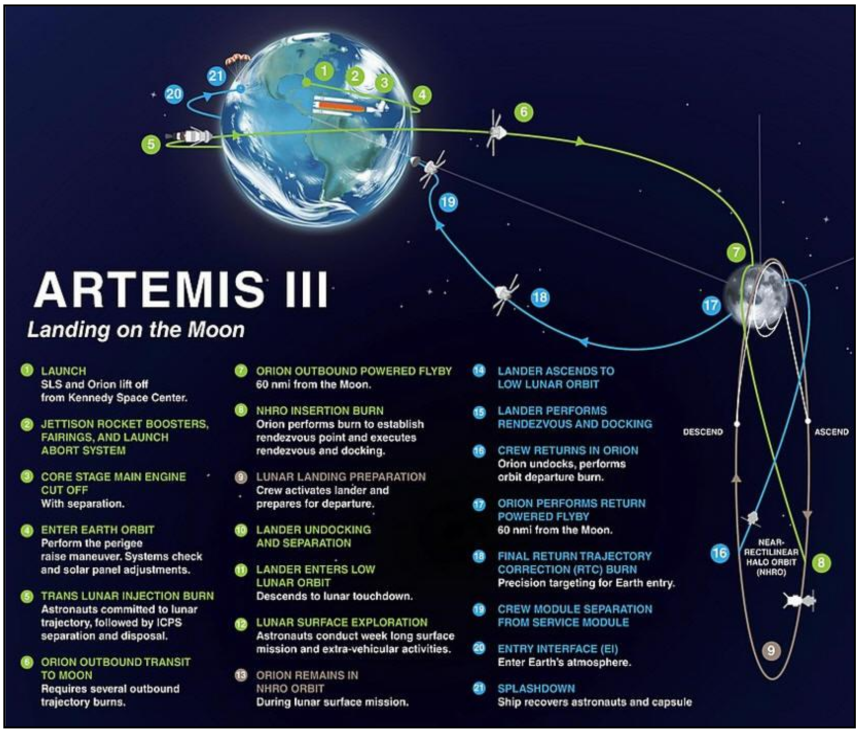
The two pictures above were taken from **Artemis I** *when near the Moon in early December 2022. The numbers identify lunar features visible from Earth, most of which also appear as images in Starfield Observatory's* **Lunar Archive***: 1 – Mare Imbrium; 2 – Plato; 3 – Archimedes; 4 – Aristarchus; 5 – Kepler; 6 – Encke; 7 – Marius; 8 – Marius Hills; 9 – Oceanus Procellarum; 10 – Reiner; 11 – Flamsteed; 12 – Billy; 13 – Hansteen; 14 – Gassendi; 15 – Letronne; 16 – Herigonius; 17 – Mons Riphaeus.*

After six days spent completing half a *DRO*, on Day 16 *Orion* performed a trajectory burn which took it out of the *DRO* and put it on course for another close approach to the Moon. For its return trip to Earth, *Orion* did a second lunar flyby on Day 20, firing its engine at the exact moment (***inbound powered flyby burn***) to use the Moon's gravity to increase its speed by 1054 kilometres per hour and put it on course for home. From Day 21, *Orion* began accelerating due to the pull of the Earth's gravity. Its speed was 39 400 kilometres per hour when it entered our atmosphere with a 'skip manoeuvre', its heat shield protecting it from temperatures reaching 2760º Celsius in a 20-minute descent. It survived re-entry intact, and splashdown by parachute occurred in the Pacific Ocean, 550 kilometres south of Los Angeles, near Guadalupe Island off Mexico's Baja California peninsula on 11 December (Day 26). The capsule was recovered by the *USS Portland* which was stationed nearby for the purpose. *Orion* had travelled a distance of 2¼ million kilometres.

This uncrewed test mission was a precursor to ***Artemis II***, which will have three or four living astronauts on board in a similar mission in late 2025. *Artemis II* will also be a precursor mission, but this time for the ultimate goal, ***Artemis III***, in which a man and woman will land on the Moon near the 21 kilometre crater Shackleton at its South Pole, which will probably occur in late 2026 or 2027 (*see pages 28-30*). The *Artemis* program is NASA's current effort to return humans to the lunar environment, but unlike *Apollo*, the missions are intended to support a sustainable and permanent presence on the Moon. To that end, NASA and its international partners are planning to build a small space station called ***Lunar Gateway***, and place it permanently in a lunar orbit called a ***Near-Rectilinear Halo Orbit (NRHO)***, period = 7 days, to support activities on and around the Moon. This orbit would bring the *Gateway* within 1500 kilometres of the lunar north pole at closest approach, and as far away as 70 000 kilometres over the lunar south pole. Eventually a lunar ***Base Camp*** will be built for stays of up to two months, initial concepts including a cabin, a lunar rover and mobile living quarters. But the real purpose of the *Artemis Program* is far more astonishing and awe-inspiring. “Our sights are not set on the Moon,” a NASA spokesman said on 5 August 2022, “our sights are clearly set on Mars.” It is hoped that technology and experience gained during the *Artemis* missions will prepare NASA and its partners for crewed voyages to the Red Planet in the late 2030s.



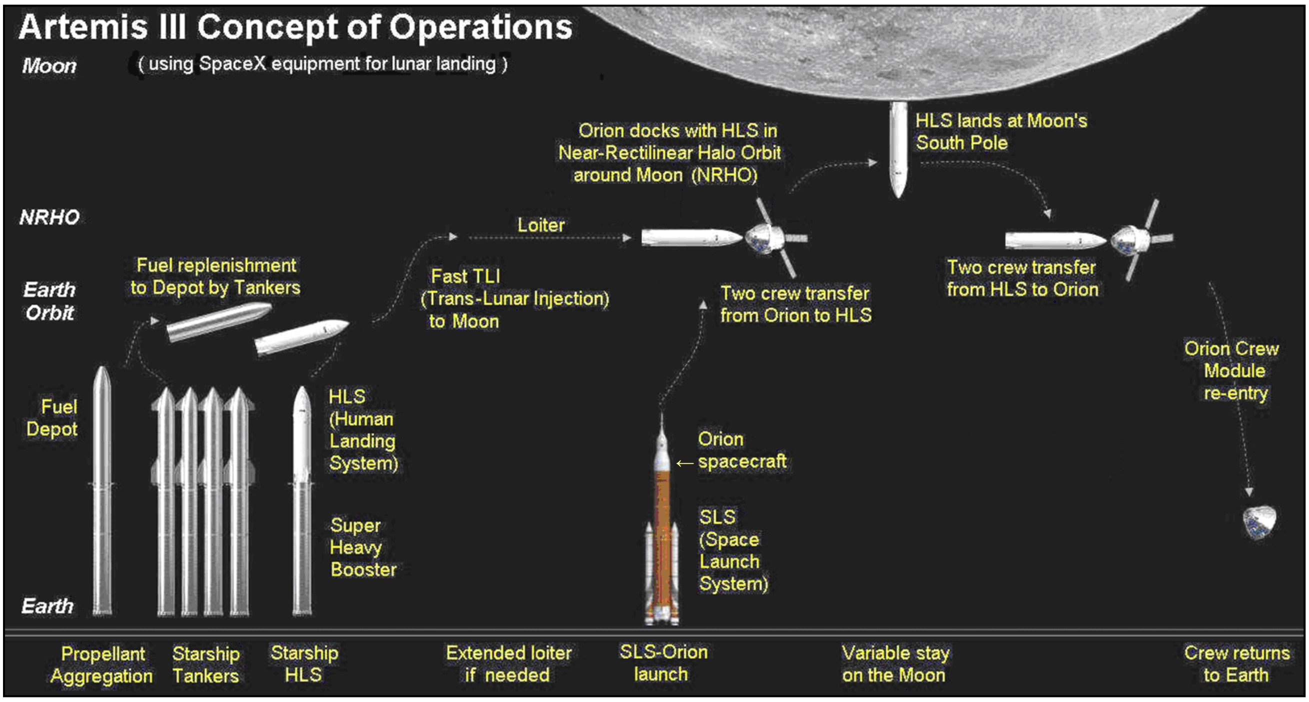
Artemis II may be the first *Orion* space capsule to carry a human crew of four, although future versions may carry six. It is planned to be launched by an *SLS Block 1* rocket in November 2025. The duration of ***Artemis II*** will be 10+ days. These astronauts will orbit the Moon once only, and will be the first people to do so in the 21st century. ***Artemis III*** is expected to land the first Americans on the Moon since the Apollo 17 astronauts landed there in the Lunar Module *Challenger* on 11 December 1972 (exactly 50 years to the day before the successful splashdown of ***Artemis I***).



NASA’s plan for ***Artemis III*** was for an *SLS-Orion* launch and then *Orion* would head for the Moon and enter the lunar NRHO. A NASA lander (*see page 28*) would undock and descend to the Moon, and, when activities were completed, it would ascend from the surface and dock with *Orion* again. The crew would transfer to *Orion* and then return to Earth. Details are shown in the diagram at left.

That plan has now been superseded, as NASA has recently contracted the private company **SpaceX** to develop the *Starship HLS* to be the lunar lander for ***Artemis III*** and ***Artemis IV*** (*see page 20*).

The revised scenario for ***Artemis III*** using SpaceX equipment for the actual lunar landing (***Starship Human Landing System*** or ***Starship HLS***) is seen in the diagram below and a description follows.



The **SpaceX** ***Alternative***

Starship is a fully reusable transportation system designed to carry both crew and cargo to Earth orbit, help humans to return to the Moon, and travel to Mars and beyond. ***Starship HLS***, or ***Starship Human Landing System***, is a variant of the *Starship* spacecraft that is being modified so that it can transfer astronauts from a lunar orbit to the surface of the Moon and back. It is being designed and built by Elon Musk's private company **SpaceX** under contract to NASA as a critical element of the *Artemis Program* to land people on the Moon in the second half of the 2020s.

The mission plan calls for a ***Super Heavy Booster*** to launch a ***Starship HLS*** into ***Low Earth Orbit (LEO)***, where it will be refuelled prior to boosting itself into a lunar ***Near-Rectilinear Halo Orbit (NRHO)*** where *Gateway* will be located in the future. This refuelling requires a pre-positioned propellant depot in LEO that is kept filled with methane fuel and liquid oxygen (LOX) by multiple ***Starship*** tanker flights. Once in lunar NRHO, the ***HLS*** will rendezvous with a crewed *Orion* spacecraft launched from Earth by a NASA *SLS Block 1* rocket as used in the *Artemis I* and *II* precursor missions. After the spacecraft dock, two crew will transfer from *Orion* to the *HLS* and descend to the lunar surface for a stay of several days, which will include five or more EVAs (extra-vehicular activities or 'moonwalks'). The crew will then fire the *HLS* engines and return to the lunar NRHO where they will dock with *Orion* and rejoin the other crew member(s). The *HLS* will remain in lunar NRHO, awaiting the next visit by *Orion.* The following are details of the SpaceX spacecraft illustrated at right that NASA hopes to employ in this scenario.

Super Heavy Booster

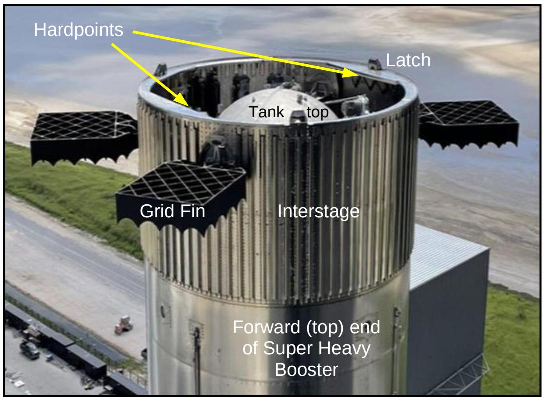
This is a first stage or booster stage, and forms the lower part of the rocket. It is made of polished stainless steel, which lessens the heat generated during landing. 70 metres tall and 9 metres wide, its base houses 33 engines in three concentric rings. The outer ring has 20 R2B2 (Raptor Boost) engines, optimised for use in launches from sea-level. These are fixed in position, the gimbal actuators having been deleted to save mass. The middle ring has 10 R2B2 engines and there is a central group of three R2B2 engines, all 13 of these having electric gimbal actuators for thrust vectoring (guidance control). Hydraulic controllers having failed in service in *Starship*'s first launch attempt, they were replaced by electric actuators for the second attempt and proved more reliable. Raptor2 is the latest in a family of rocket engines developed by SpaceX exclusively for use in *Super*

Heavy and *Starship*. These engines burn liquid oxygen and methane in a highly efficient staged combustion power cycle. The liquid oxygen must be kept just below its boiling point (-183º C) and the liquid methane likewise, at -161º C. Methane is the rocket propellant of choice, because it can be directly synthesised from carbon dioxide and water. Engines are mostly built of aluminium, steel and copper; oxidiser-side turbopumps and manifolds subject to corrosive oxygen-rich flames are made of SX500 superalloy. Raptor's main combustion chamber can withstand 300 bar (4400 psi) of pressure, the highest of all rocket engines. The Raptor's gimballing or rotation range is 15°, higher than the RS-25's 12.5°. In mass production, SpaceX aims to produce each engine for US$ 250 000.

The Raptor engines operate with an oxygen-to-methane mixture ratio of about 3.6:1. The propellants leave the pre-burners and are injected into the main combustion chambers as hot gases instead of liquid droplets. The methane and oxygen are at such high temperatures and pressures that they ignite on contact, eliminating the need for igniters in the combustion chambers. At sea level, each standard Raptor engine produces 2.3 Meganewtons (520 000 pounds) of thrust, and about 7% more when above the atmosphere. The R2V (Raptor2 Vacuum) engine, used exclusively on the *Starship* upper stage, is modified with a cooled nozzle extension which increases the thrust by another 8%. A third engine variant, the Raptor Boost, is exclusive to the *Super Heavy Booster*: this engine variant lacks gimbal actuators and has limited throttle capability, but delivers increased thrust.

According to SpaceX, the engines collectively produce 75.9 Meganewtons (17 million pounds) of thrust at full power. This is 2.2 times greater than *Saturn V*, and 1.9 times greater than the *Space Launch System* (*SLS Block 1* with two solid fuel boosters) that NASA developed for the ***Artemis*** program. The booster's tanks can hold 3600 tonnes of propellant, consisting of 2800 tonnes of liquid oxygen and 800 tonnes of liquid methane. It lasts for two minutes of flight and *Super Heavy* will reach an altitude of 65 kilometres. Then its engines are shut off, the three interstage latches are released and the rocket separates from the *Starship*, which uses its own engines to climb up to Earth orbit. The booster then uses its thrusters to turn back to Earth and ignites its engines briefly to begin its descent, during which it reaches a very high speed.

The *Super Heavy Booster* is no longer 'super heavy' when it is coming back to land, as 99% of the 3600 tonnes of propellant has been used up, and the tanks which occupy almost the full length of the rocket are nearly empty (the engines are mounted underneath the tanks). At launch it weighs upward of 3800 tonnes, but when it is landing its weight is between 160 and 200 tonnes. The booster is equipped with four massive, electrically actuated **grid fins** mounted on its top (or front when in flight or returning to land). A grid fin is a lattice of small aerodynamic surfaces within a frame of unique design, and is a flight control device used on bombs and military rockets. The four on *Super Heavy Boosters* are spaced in opposing pairs for better control.



These grid fins (*seen at right*) provide sufficient drag to help the *Super Heavy* to orient itself after the *Starship* separates and heads up towards orbit. They enable it to adjust its trajectory as it heads back to Earth and prepares to land. They are fixed in position but can make slight adjustments about the yaw and roll axes. They do not fold in as was done with the much smaller grid fins used on the *Falcon* rockets. They control the craft's aerodynamic pitch and reduce the speed during the descent.

Each fin is 4.9 metres x 2.45 metres in size, is made of welded steel and weighs 3 tonnes. SpaceX's goal of building a *Starship* that is fully reusable made the addition of grid fins on *Super Heavy* necessary. Without them, safely landing the booster would be much more difficult. Between each pair of fins is one of two 'hardpoints', used for lifting and stacking the booster and spacecraft prior to launch, and for being caught by the Tower's mechanical arms when landing. The booster's orientation can also be adjusted by cold gas thrusters using evaporated propellant in the tanks. When the booster is over the landing site it 'flips' into a vertical position. Its engines ignite in a retropropulsion landing burn, and it descends tail-first. If the *Super Heavy* is landing at its launch site, it will be captured by the mechanical arms or 'chopsticks' on the Integration Tower before it reaches the ground. The time taken between lift-off and return to touchdown is about six minutes.

Starship

Starship is a second stage or long-duration spacecraft, and forms the upper part of the rocket. Also made of polished stainless steel, it is 50 metres tall and 9 metres in diameter; it has a dry mass of less than 100 tonnes. *Starship's* payload volume is about 1000 cubic metres (35 000 cubic feet), slightly larger than the *International Space Station's* pressurised volume. It can be lengthened with a 22 metre extension. By refuelling the *Starship* in orbit using tanker spacecraft, *Starship* may be able to transport larger payloads and more astronauts to other Earth orbits, the Moon, and Mars.

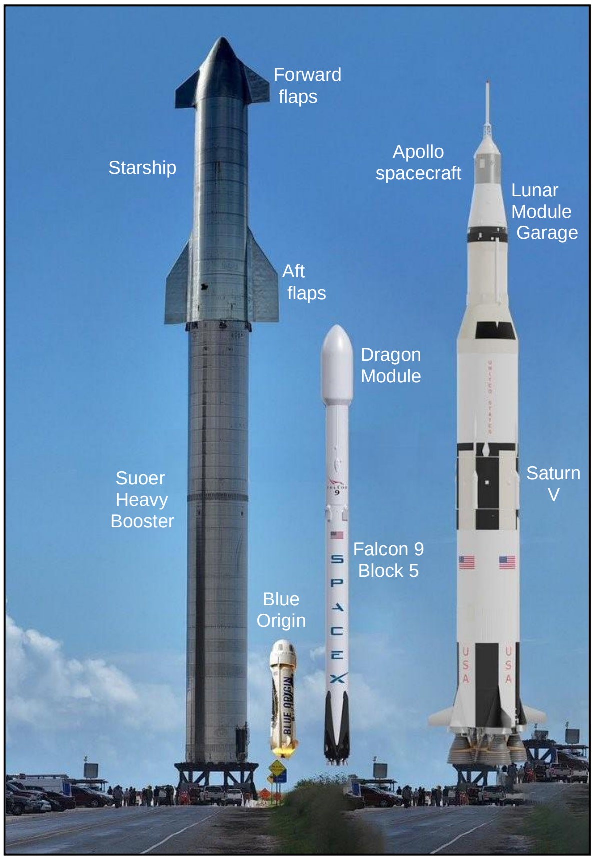
Starship has a propellant capacity of 1200 tonnes in its main tanks and header tanks. The header tanks are better insulated due to their forward position and are reserved for use when the *Starship* flips and lands following re-entry. At the aft end of the *Starship* spacecraft are six Raptor2 engines: three R2A (Sea-level) engines which are designed to operate in air after separation, and three R2V (Vacuum) engines designed for operation in space. All have gimbal mountings to control the direction of thrust. There are also 24 methane-LOX reaction thrusters mounted on the exterior for precision control, e.g. when controlling the craft's attitude while in orbit, and when landing or docking.

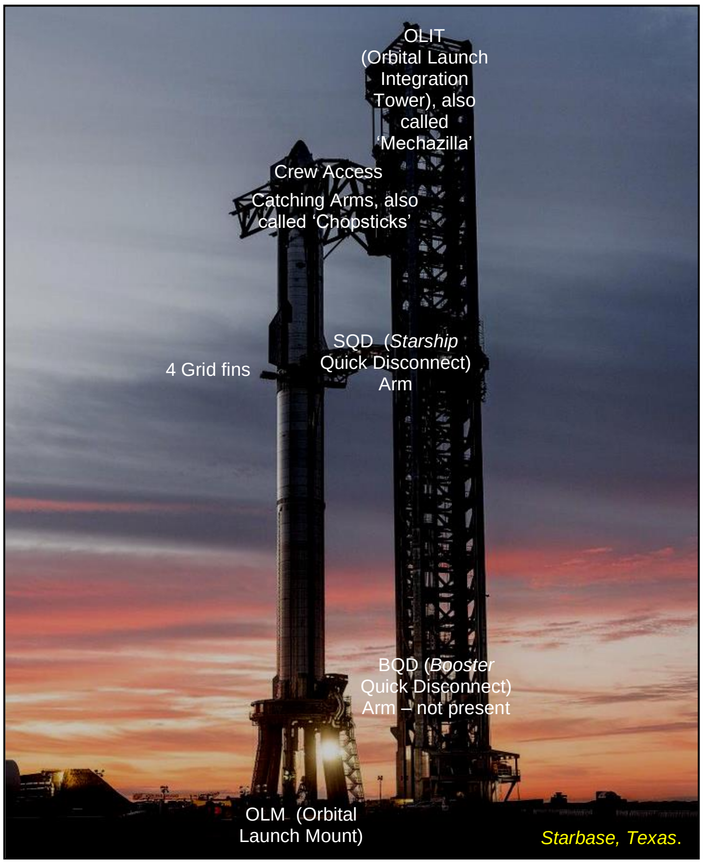
As the *Starship* is built to leave the Earth's atmosphere and return, it needs a ***Thermal Protection System*** to be able to survive the considerable heat of re-entry. It is therefore designed with one side (called the 'windward side') being completely covered by 25000 hexagonal black tiles made of silica. These are glued on as was done with the *Space Shuttles*, but those in areas subject to vibration are held on with pins. Small gaps are left between the tiles to counteract heat expansion. Re-entry is performed with the *Starship* at a slight nose-down angle with the black side facing down as a heat shield, for the tiles can withstand temperatures up to 1400º C. They are designed to be used many times without needing maintenance between flights. The other side of the *Starship*, (the 'leeward side') has no tiles and is bare stainless steel. Windows, hatches and ports are on this side. *Starships* also have two forward fins called 'flaps' and two aft flaps to allow aerodynamic control when landing on a planet with an atmosphere. Also covered on their 'windward side' with black tiles, the flaps help to dissipate energy during atmospheric re-entry. Under the forward flaps are the hardpoints which are used for lifting and catching the spacecraft via mechanical arms on the Integration Towers. The flaps' hinges are sealed with metal to avoid damage during re-entry. At an altitude of about 10 km, the *Starship's* speed has fallen below 1000 km per hour (subsonic). It descends in a horizontal attitude and then slightly nose-up in preparation for a 'flip manoeuvre' and landing (*see page 15*).

Starship Variants

Three variants of the *Starship* second stage are the 'depot', the 'tanker' and the 'cargo carrier'. The interior of the cargo carrier version can be configured according to the load, e.g. general supplies, scientific equipment and / or machinery. All variants are lifted towards Earth orbit for the first two minutes of flight atop a ***Super Heavy Booster*** first stage. For launching satellites, *Starship* will have a large cargo door which will open to release payloads and close prior to re-entry. Instead of a cleanroom, satellites will be integrated directly into *Starship's* payload bay, which necessitates purging the payload bay with temperature-controlled, ISO class 8 clean air. To deploy many *Starlink* satellites, a slot and dispenser rack will replace the cargo door. Crewed *Starship* vehicles will replace the cargo bay with a pressurised crew section and will have a life support system. For long-duration missions, such as crewed flights to Mars, SpaceX describes the interior as possibly including "private cabins, large communal areas, centralised storage, and solar storm shelters." *Starship's* life support system will recycle resources such as air and water from waste.

The most important variant is the ***Starship HLS*** or ***Human Landing System***. This is a crewed lunar lander variant of the *Starship* vehicle that is extensively modified for landing, operation, and takeoff from the lunar surface. It features modified landing legs, a body-mounted solar array, a set of thrusters mounted high up to assist with soft landing and takeoff, two airlocks, and an elevator to lower crew and cargo onto the lunar surface. *Starship HLS* will be able to land at least 100 tonnes of cargo on the Moon per flight. As it will remain in lunar orbit and never return to Earth, it is painted white and has no need of heat shield tiles nor flight control flaps. To reach high-energy targets such as geosynchronous orbit, the Moon, and Mars, *Starship* will be refuelled by docking with separately launched *Starship* propellant tankers. A *Starship* 'propellant depot' will maintain a supply of methane and oxygen in Earth orbit, and will be used by *Starship HLS* (*see diagram on page 11*).





The sizes compared – at top left, a SpaceX **Starship** *stacked on top of a* **Super Heavy Booster**. *Standing 120 metres tall and with more than twice the thrust of a* **Saturn V**, *it is the tallest and most powerful launch vehicle ever built (so far), and the first to be capable of total reusability. Next to it is the diminutive Blue Origin launch vehicle (criticised for looking 'phallic'), then the SpaceX* **Falcon 9 Block 5**, *then the* **Apollo-Saturn V**. *The four rockets in this composite image are all reproduced to the same scale.*

At top right, the ill-fated SpaceX **Starship 24** *is attached to* **Super Heavy Booster 7** *and is being prepared for launch whilst being held on its Orbital Launch Mount alongside the Integration Tower.*

Left: At 70 metres high, this SpaceX **Falcon Heavy** (**FH**) *rocket is the same height as the* **Falcon 9 Block 5** *seen above. These rockets have a core stage flanked by two Boosters, all three being almost identical and using the same engines and RP-1 liquid fuel (a highly refined form of kerosene like jet fuel, that also powered the* Saturn V*) and LOX. This one, launched from Complex 39A at the Kennedy Space Center in Florida on 15 January 2023, carried the classified USSF-67 satellite into orbit. (USSF = United States Space Force – part of the US Air Force.) Watch the video here .*

Both Boosters returned and landed simultaneously at the launch site safely after a flight of eight minutes. The core stage and second stage were not designed to fly back to base as the extra fuel needed would make this impractical, but landing them on drone ships at sea has been successful in the past and is feasible for future **FH** *missions. Abandoned oil rigs in the Gulf of Mexico may also be used.*

On 5 March 2024, a **Falcon 9 + Dragon 'Endeavour'** *spacecraft (top picture) made SpaceX's eighth trip to the International Space Station with four astronauts for a six-month stay. The* Falcon 9 *first stage shut down after 2½ minutes, released the* Dragon *module and returned to Earth, landing on a droneship in the Atlantic.*

Falcon Heavy *was the world's most powerful rocket until* NASA*'s* **Space Launch System (SLS Block 1)** *overtook it on 16 November 2022, but both were surpassed on 20 April 2023 by the* **Starship 24 + Super Heavy Booster 7** *seen at above right which lifted off and reached a height of 39 kilometres before exploding.*

Coming in for a Landing

When preparing to land, the *Starship* descends through the atmosphere, black side down and nose tilted up slightly from the horizontal. The flaps are used to slow the descent until 99% of the kinetic energy has been dissipated aerodynamically. At an altitude of about 550 metres all *Starships* fold in their four flaps and 'flip' into a vertical attitude over the landing site. When they have virtually stopped in mid-air, the three Raptor 'atmosphere' engines ignite for a 'supersonic retropropulsion for landing' burn. They descend tail first (backwards) as seen at right, shutting down one engine and then a second, landing gently on one engine, and are prepared for their next mission. If landing on the launch pad from which they took off, they are captured by the robotic arms on the Integration Tower and then lowered carefully down onto the Orbital Launch Mount to be prepared for the next flight.

Landing legs

Current *Falcon 9* boosters return to Earth and land vertically tail first on their own built-in legs, but the goal with the *Super Heavy Boosters* is for the larger rocket not to have legs at all. The *Super Heavy* landing process will use the four grid fins that are fixed at the top of its body to help control its orientation during flight. After it performs its 'flip manoeuvre', its engines will control the velocity of its final descent so that it is gently 'captured' by the arms on the Integration Tower before it actually touches the ground. Then it is lowered to the circular raised Orbital Launch Mount (*see page 14*).

The main benefit of this method, which obviously involves precision manoeuvring, is that it means SpaceX can save both cost and weight by omitting landing legs from the *Super Heavy* design. Another potential benefit is that it could allow SpaceX to ready the *Super Heavy Booster* for another mission immediately on the launch mount to which it has returned. According to Elon Musk, it could be given a new payload, refuelled, and stacked with another *Starship* upper stage in "under an hour."

The first *Starships* had six landing legs located on the inside of the skirt. For transport, launch, and flight, they were folded up 180° inwards. The legs were designed to crumple to absorb the deceleration on landing, which meant that they were not reusable. During landing, they were designed to deploy using a simple gravity system (in other words, they just fell into place using their own weight) and were locked in place, but when *SN10* came in to land, at least two legs failed to lock and swung freely back and forth during the descent. (The vehicle exploded eight minutes after touchdown.) A more robust and reliable landing system is being designed for future *Starships*.

The final leg design has not been approved at the time of writing, which is possibly one reason that the first flights were designed to end with both the booster and spacecraft performing controlled touchdowns on the surface of the sea, but neither being recovered. Future tests will include landing the booster on the launch pad and the *Starship* on a drone ship at sea, and then landing both on the launch pad, being caught by the robotic arms and then lowered into place. The number of legs (3, 4, 5, or 6) and location (outside or inside the skirt or on the body) have varied greatly between different designs (at one point, the aft body flaps also did duty as legs). It is known that the legs need to be self-levelling, which is a requirement in order to land on uneven surfaces as on the Moon and Mars.

CTRL+Click on these video links that show the SpaceX rockets to date:

Falcon 9 launches Starlink 53 and first stage landing on drone ship *Falcon Heavy lands all three Boosters for the first time* *Starship SN10 takes off, climbs to 10 km altitude, then lands* (explosion not shown)

The Starbase Facility

Starbase is a spaceport, production, manufacturing and development facility for *Starship* rockets, located at Boca Chica Beach, Texas. It is owned by SpaceX, an American aerospace manufacturer. It is 200 kilometres south of Corpus Christi and 4.5 kilometres north of the Mexican border, close to where the Rio Grande flows into a delta and then into the Gulf of Mexico. It is the most southerly point in the continental United States. The nearest city is Matamoros / Brownsville, a conurbation of 520 000 people which straddles the border river and is 35 kilometres from Starbase. The surrounding area is a wildlife refuge. The rockets are manufactured and assembled at Starbase by over 1800 employees, and then stored vertically in a 'Rocket Garden'. A level road capable of handling heavy loads heads 2.5 kilometres east-north-east from Starbase to the launch site, which is less than 500 metres from the undeveloped beach, and is 280 kilometres closer to the Equator than the Kennedy

Space Center in Florida. When needed, the rockets are transported vertically to the launch site which is where the propellants are stored in huge tanks. Five *Starships* will be produced in 2023.

Test flights from Starbase:

Prior to the first launch of the *Starship* + *Super Heavy Booster* on 20 April 2023, the SpaceX team completed multiple sub-orbital test flights from Starbase (to an altitude of only 10 kilometres and return) of the *Starship's* upper stage flying by itself, successfully demonstrating an unprecedented approach to controlled flight. These test flights helped validate the vehicle's design, proving that the *Starship* can fly through the subsonic phase of re-entry before re-lighting its engines and flipping itself to a vertical configuration for landing safely. None of these test flights had any crew on board.

The first *Starships* to attempt safe landings after a suborbital flight suffered a high attrition rate due to various malfunctions, often resulting in total loss of the vehicle. The SpaceX technicians were able to learn from each of seven extremely violent explosions (as with *SN10*), and proceeded to improve the vehicle at each iteration, until the *Starship SN15* was able to fly to an altitude of 10 kilometres and then return safely to its launch site on 5 May 2021. As the first *Starship* to fly, land and be recovered intact, it now has an honoured place in the 'Rocket Garden' at Starbase.

In addition to the testing of *Starship's* upper stage, numerous tests have been conducted of the *Super Heavy Booster*, which included increasingly complex clamped-down launch mount ignitions that culminated in a full-duration 31 Raptor engine test – the largest number of simultaneous rocket engine ignitions up to that time. The team has also constructed the world's tallest rocket 'launch and catch' tower. At 146 metres tall, the Integration Tower is the highest of its kind in the world. It is designed to support vehicle integration ('full stacking' of the first stage *Super Heavy Booster* with the *Starship*), the launch, and then the capture of the *Super Heavy Booster* and/or *Starship*.

The first test flight of Super Heavy Booster + Starship, together known as 'Starship':

The SpaceX ***Starship* orbital test flight** (officially the ***Starship* Flight Test**) was the first flight of the *Starship* launch vehicle from Starbase. The main aim of the test was to see how well the two stages operated together. With a test such as this, success is measured by how much can be learnt to inform and improve the probability of success in the future as SpaceX rapidly advances the development of *Starship*. This two-stage rocket configuration is known by SpaceX as 'the Full Stack' or '*Starship*' for short. It can lift a payload of 150 tonnes if the *Super Heavy Booster* is to be reused, possibly up to 250 tonnes if the booster is to be expendable. Like all previous *Starship* launches, there were no crew members on board, and of course the boosters cannot carry crew.

The flight vehicles – *Super Heavy Booster 7* and *Starship 24* – were stacked on the Orbital Launch Mount on 6 April 2023, and on 15 April the Federal Aviation Administration (FAA) gave flight approval, which ensured that the rocket's flight path was clear of other traffic. For the first flight of the combined *Starship* + *Super Heavy Booster* on 20 April 2023, no vertical landing of either stage was planned. Just prior to lift-off, three of the 33 Raptor engines in the booster indicated "non-nominal functions" and were shut down. At T+85 seconds the hydraulic power units providing thrust-vectoring control failed, possibly due to damage by chunks of concrete as big as cannon balls blasted up from the Orbital Launch Mount's base (made of heat-resistant concrete called *Fondag*), which had a huge hole blown in it by the force of the engines. Unfortunately, a massive water-cooled steel base had not been installed in time for this launch. Much damage was caused to infrastructure, with sheds and fuel tanks dented, and rubble scattered over 385 acres. Large pieces of concrete splashed into the ocean half a kilometre away, and fragments fell on the town of Port Isabel 6.5 km to the north, where windows were smashed, possibly by the arrival of shock and pressure waves. As the rocket gained speed (reaching 2150 km per hour) and altitude (39 km), five more engines died. It became unstable, turning, tumbling and falling. Four minutes into the flight, the FTS (*Flight Termination System*) failed, preventing a safe separation of the stages. Technicians aborted the mission in what they called a "rapid unscheduled disassembly" (RUD, tech-speak for "catastrophic explosion"). The debris fell 29 km into the sea. *Video of Starship 24's failed flight and damage caused.*

Details of the second flight, also unsuccessful :

The SpaceX team learned a lot from the failure described above. The Orbital Launch Mount (OLM) and associated structures were rebuilt and strengthened to include the water-cooled steel base and a water deluge system. 57 FAA safety concerns were complied with, and the next test flight of an integrated *Super Heavy 9* + *Starship 25* rocket took place on 18 November 2023. This was what was planned (red text) and what actually happened (black text):

T - 1 hour 39 minutes: Booster propellant loading (LOX and Liquid Methane) begins;
T - 1 hour 22 minutes: *Starship* fuel loading (Liquid Methane) begins;
T - 1 hour 17 minutes: *Starship* LOX loading begins;
T - 16 minutes 40 seconds: Booster engine chill begins;
T - 40 seconds: Fluid interfaces with engines begin their ventdown sequence;
T - 10 seconds: Water deluge starts;
T - 08 seconds: Booster ignition sequence starts, all 33 Raptor engines nominal;
T + 4 seconds: Clamps release, actual lift-off, booster engines at full power;
T + 10 seconds: Rocket clears the Orbital Launch Integration Tower (OLIT);
T + 68 seconds: MaxQ (Maximum aerodynamic pressure and stress on rocket, speed of sound surpassed);
T + 2 minutes 39 seconds: MECO (Main Engine Cut-off) at an altitude of 65 km – 30 booster Raptors shut down, 3 central Raptors to drop to 50%, but don't;
T + 2 minutes 44 seconds: Six *Starship* engines begin ignition, go to full power;
T + 2 minutes 49 seconds: *Super Heavy* booster latches release, complete *Starship* separation;
T + 2 minutes 50 seconds: *Starship* pulls ahead of booster, climbs at full power towards orbit, Booster begins flip manoeuvre using two centre engines (one fails) . and re-ignites its other engines for a boostback burn to descend nose-first to the waters of the Gulf of Mexico 32 km off-shore;
T + 2 minutes 57 seconds: Four booster engines fail, gimbal control fails and direction of thrust becomes very erratic; the booster begins to gyrate and is unstable;
T + 3 minutes 21 seconds: The booster rocket violently explodes and debris falls into the ocean.

T + 4 minutes 06 seconds: Booster boostback burn shutdown;
T + 7 minutes 32 seconds: Booster becomes transonic (decelerates below speed of sound – 1062 km per hour at 11 km altitude);
T + 7 minutes 40 seconds: Booster landing burn startup:
T + 8 minutes 03 seconds: Booster water impact in Gulf of Mexico.

T + 7 minutes 02 seconds: *Starship* continues to climb towards orbit as photographed by Earth-based cameras but communication with the spacecraft suddenly and inexplicably ceases. At T + 8 minutes 5 seconds, fluctuations in the flame plume behind the *Starship* indicate that explosions are occurring around the engines due to fuel leaks and at T + 8 minutes 15 seconds it begins to tumble. As there was no possibility of it completing its mission, either SpaceX decided to abort, or the automated FTS (*Flight Termination System*) took matters into its own hands, for the *Starship* is believed to suffered a "rapid unscheduled disassembly" or RUD soon after the 9 minutes 7 seconds mark. The nose-cone appears to have broken off in one piece and burned up in the atmosphere.

T + 9 minutes 20 seconds: SECO (*Starship* Engine Cut-off) – spacecraft enters temporary trans-atmospheric Earth orbit (250 km x 50 km);
T + 1 hour 17 min. 21 secs: *Starship* entry interface, decay from orbit begins, engines not used;
T + 1 hour 28 min. 43 secs: *Starship* becomes transonic (slower than the speed of sound);
T + 1 hour 30 min. 00 secs: *Starship* water impact in Pacific Ocean near Kauai, north of Hawaii.

After a successful lift-off with all 33 Raptor engines working, the booster and spacecraft separated successfully 172 seconds into the flight. The booster flipped as required and began to descend, but suddenly exploded (another RUD), possibly due to overheating caused by the "hot staging" method of separation used by Russian *Soyuz* rockets that had been trialled. Meanwhile, the *Starship's* six engines had ignited and it continued to ascend towards orbit. It was expected to reach SECO (*Starship* Engine Cut-off), at about 9.3 minutes into the flight, having attained a speed of 24 124 km/hour and an altitude of about 180 km. In order to reach the desired trans-atmospheric Earth orbit, the spacecraft would need to reach an apogee (maximum height) of 250 km. At 8 minutes, before the *Starship* could reach orbit, communication with it was lost and the flight was aborted.

This second flight was more successful than the first: the orbital launch mount and pad suffered little damage, except that the *Starship* Quick Disconnect Arm needed some repairs. All Booster Raptor engines worked perfectly until just after separation; second stage separation and ignition went as planned, and the Booster's flip manoeuvre was a success as far as it went. The third flight took place on Thursday, 14 March 2024 using the *Super Heavy Booster 10* + *Starship 28*, in which the trajectory was shortened so that the *Starship 28* would land softly in the Indian Ocean, south of the island of Timor, instead of near Hawaii. Neither the *Booster* nor *Starship 28* would be recovered.

The launch was flawless with all 33 Raptor engines working as one, and the hot-stage separation of the *Booster* from the *Starship* went according to plan as follows: at T + 2 minutes 44 seconds thirty of the *Booster's* engines shut down, leaving only the central group of three providing thrust. The altitude was 71 kilometres and the speed was 5670 kilometres per hour. The six Raptor engines on the *Starship* (three R2As surrounding the central three R2Vs) then ignited. Two seconds later the three latches released and separation occurred. The *Booster* ignited its middle ring of ten Raptors which enabled it to perform its flip manoeuvre away from the *Starship*. Heading down tail first, it performed a 'boost back burn' to reduce speed. At T + 6 minutes, the *Booster* had descended to an altitude of 53 kilometres, and its speed had fallen to 3642 km per hour. Meanwhile, the *Starship*, heading towards Earth orbit, had reached a speed of 12 650 km per hour.

By T + 6 minutes 40 seconds, the *Booster* was having trouble with its engines – only one was still working. The *Booster* was now at an altitude of 7 kilometres, falling at 2524 kilometres per hour, and needed to have 13 engines operational for the 'landing burn' to slow it down for a soft landing in the sea. Video feed from the rocket's on-board cameras showed the grid fins waving around desperately, trying to stabilise the rocket, but without success. Something drastic had gone wrong with the engines, the fuel supply or the control system. At T + 6 minutes 58 seconds, communication and video from the *Booster* were suddenly lost at an altitude of 0 kilometres – presumably it crashed into the Gulf of Mexico at 1114 km per hour. Meanwhile, *Starship 28* continued to accelerate up towards Earth orbit – it was now at an altitude of 144 kilometres and a speed of 17 538 km per hour.

At T + 8 minutes 20 seconds the three sea-level engines on *Starship* were closed down, but the three Vacuum engines remained on full power. 15 seconds later, those engines were shut down too. The spacecraft had now reached an altitude of 150 kilometres and a speed of 26 485 km per hour, fast enough to enter Earth orbit if that had been one of the goals of the test flight. *Starship*, now unpowered, continued to climb, but its speed slowly dropped. At T + 9 minutes 16 seconds, *Starship* slowly swung around so that it was flying tail first. At T + 10 minutes, its altitude was 162 kilometres and its speed was 26 434 km per hour. At T + 25 minutes, *Starship* reached its apogee (highest point in its flight) of 234 kilometres, at a speed of 26 114 km per hour. From now on, the spacecraft would descend, its altitude decreasing but its speed increasing. Two tests were conducted in which the *Starship* successfully opened and closed its payload door. It also transferred fuel from one tank to another as an experimental first step towards the eventual refuelling of one *Starship* by another, which will be vital for long-range missions. An attempt to re-ignite the Raptor Vacuum engines in space was deferred for a future flight.

At T + 44 minutes, at an altitude of 120 kilometres and a speed of 26 640 km per hour, the *Starship* began to re-enter the Earth's atmosphere, and faint smoke was seen. Within two minutes, black tiles and fragments of tiles were seen flying off the spacecraft (as seen in video images transmitted to Starbase via *Starlink* satellites) and an aft flap was seen to glow with plasma from friction with the air. At T + 47 minutes flames became visible and the images received began to break up. At T + 48 minutes 44 seconds the video signal failed at an altitude of 75 kilometres and a speed of 26 628 km per hour. The last data were received at T + 49 minutes 31 seconds from an altitude of 67 kilometres and a speed of 26 053 km per hour. It seems that the spacecraft did not survive the early stages of re-entry, and suffered a RUD as did *Starships 24* and *25.* The boostback burn, the flipping into a vertical attitude and the landing burn did not occur. By that time the *Starship* would have been over the Indian Ocean, south of Timor, so no debris has been salvaged. This third flight was relatively successful in that the *Starship* flew in space for 38 minutes – halfway around the Earth.

The launch of the fourth test flight held on Thursday, 6 June 2024 was normal as was the separation of the two stages. The *Super Heavy Booster 11* completed its flip manoeuvre and boostback burn and returned to the splashdown zone where it performed a landing burn and soft splashdown in the Gulf of Mexico after a flight of 7 minutes 24 seconds. Meanwhile, *Starship 29's* second stage Raptor engines powered the vehicle to the edge of space and it coasted above the Atlantic and Indian Oceans to re-entry, during which the flaps suffered some heat ablation and damage. It performed the first flip manoeuvre and landing burn attempted from space, and had a soft splashdown in the Indian Ocean 66 minutes after launch. The successful fifth flight (October 13, 2024) went further in that the booster returned to Starbase and was flawlessly captured by Mechazilla's 'chopsticks'.

Left: Starship 24 atop Super Heavy Booster 7 alongside the Integration Tower at the Boca Chica launch site. A spare booster is alongside. The lights in the middle distance are the Starbase facility. On the horizon are the distant lights of the US city of Brownsville.

A typical profile for a successful Super Heavy Booster + Starship mission in the future:

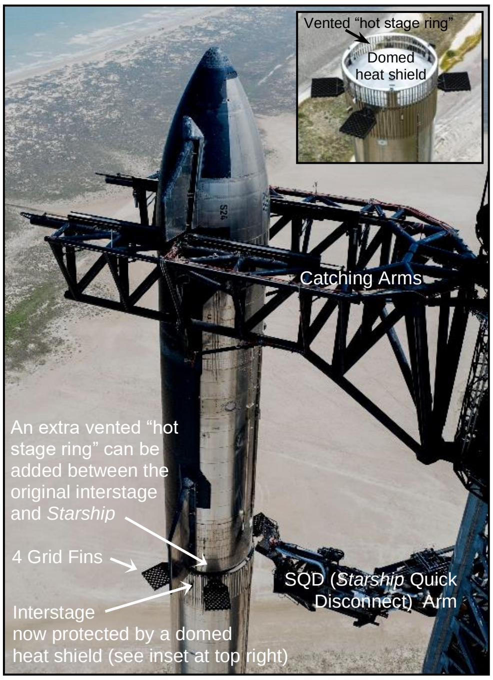
The payload will be loaded into *Starship* at the Starbase facility and then rolled out to the launch pad. After *Super Heavy* and *Starship* are stacked and latched together on the Orbital Launch Mount by lifting from their 'hardpoints' by the Catching Arms on the adjacent Integration Tower, they will be loaded with propellant via the Quick Disconnect Arms. Roughly four hundred truck deliveries of fuel and LOX are needed for one launch, although some commodities will be provided on-site via an air separation unit.

Then the pair of robotic mechanical Catching Arms (known by the technicians as 'Chopsticks') will disengage and open wide, the Quick Disconnect Arms will detach, all 33 engines of *Super Heavy* will ignite, and the rocket will lift off. After 2 minutes 52 seconds, at an altitude of 65 kilometres, *Super Heavy* shuts off 30 engines and releases the interstage latches. *Starship's* engines have already ignited moments before and the rocket stages separate. Using its three central engines at reduced power, the booster then turns around ('flips') and heads down, using its four grid fins to regulate its falling speed and attitude. As the booster arrives at the launch site via a controlled descent and then another 'flip' similar to the *Falcon 9's* first stage to bring it into a vertical attitude, the 'Catching Arms' open wide to capture the incoming rocket descending backwards. After six minutes of flight, only about 20 tonnes of propellant remain inside the booster's fuel tanks. Meanwhile, the *Starship* accelerates to orbital velocity. Once in orbit, the spacecraft can be refuelled by one or more tanker *Starships*, so that it can continue its mission.

To land on bodies without an atmosphere such as the Moon, *Starship* will turn on its engines and thrusters to slow down, manoeuvring into a vertical position before landing. To land on bodies with an atmosphere such as Earth and Mars, *Starship* will slow down by entering the atmosphere nose first, the side with the black silica heat-shield tiles leading. When the speed is sufficiently reduced, the spacecraft will perform a 'belly-flop manoeuvre', by diving down through the atmosphere body-first at a 60° angle to the ground. The half of its body that is protected by black tiles will face in the direction of its descent, and the speed of its fall will be controlled by the four flaps.

As it reaches about 550 metres from the ground, the Raptor engines will fire, using propellant from the header tanks located at the precise nose, causing the spacecraft to flip to a vertical orientation. At this stage, the Raptor engines' gimballing, throttle, and reaction control system's firing will help to precisely manoeuvre the *Starship*. A pseudo-spectral optimal control algorithm by the German Aero-space Centre predicts that the landing flip will tilt the craft up to 20° from the ground's perpendicular line, and the angle will decrease to zero on touchdown. On Earth, future *Starships* are envisioned to land next to an Integration Tower on their launch pad, and be captured by the mechanical catching arms, like the booster. If *Starship's* rocket stages land on an *ASDS* (*Autonomous Spaceport Drone Ship*), a hydraulic lift will then move them to a transporter barge. They will be taken to a port and returned to their base by road. The recovered *Super Heavy* and *Starship* will either be positioned on the launch mount for another launch, or refurbished at a SpaceX facility.

Starship's reusability is expected to reduce launch costs, expanding space access to more payloads and entities. CEO Elon Musk has stated that a *Starship* orbital launch will eventually cost $1 million (or $10 per kilogram). Eurospace's director of research Pierre Lionnet, however, stated that *Starship's* launch price will likely be higher because of the rocket's development cost. A *Starship* may be able to launch three times per day and make obsolete the company's *Falcon 9* and *Falcon Heavy* rockets. Such a launch program will be necessary for *Starship's* profitability. One way for *Starship* to meet demand would be organise 'ride-share' missions that carry many satellites at once.



Right: These are the two robotic arms (called 'Catching Arms' or 'chopsticks') that capture the booster or the Starship at their 'hardpoints' as required. They open wide to receive the rocket, and close to hold it rigidly. Below, above the Interstage, can be seen the Quick Disconnect Arm attached to the rear end of the Starship, and three of four grid fins attached to the top of the booster. The coast of the Gulf of Mexico is at the upper left-hand corner.

SpaceX *trialled a number of changes to the second Starship vehicle (*Starship 25 + Booster 9*). Perhaps the most prominent of these changes was a switch to a* Soyuz-type *"hot staging" strategy, in which the upper stage ignited its engines before it had fully separated from the first-stage booster. That switch required modifications to the upper end of* Booster 9*, including the installation of a domed heat shield and a vented "hot stage ring" to protect it from the blast of* Starship 25's *engines when ignited.*

NASA purchases access to SpaceX*'s re-usability technology for future Moon landings*

In 2022 SpaceX launched 61 orbital missions, nearly doubling its previous single-year record of 31, which was set in 2021. This was close to the Chinese total of 62, and three times as many as other US companies combined (including NASA). 34 of these launches were primarily devoted to building the *Starlink* mega-constellation of internet satellites, which by October 2024 had placed in orbit more than 6371 operational satellites serving 48 countries. The other 27 missions served a variety of customers, including NASA. On average, SpaceX launched every six days from one of its three sites, with 92% of missions completed with flight-proven first stage rocket boosters. *Falcon 9* now holds the world record for the most launches of a single vehicle type in a single year. The record is shared with the erstwhile Soviet Union, which successfully launched 61 R-7 rockets in 1980.

SpaceX is now the leading global launch provider, with a net worth of US $ 150 billion. It has achieved an enviable record of having its *Falcon* rockets safely return to their launch pads to be used for future missions, something that NASA has not yet been able to accomplish. As there are many innovative procedures involved in this, on 16 April 2021 NASA signed a sole-source agreement with SpaceX to share this re-usable technology, which drew protests from competing companies Blue Origin (with their *ILV – Integrated Lander Vehicle)* and Dynetics with their *ALPACA* (*Autonomous Logistics Platform for All-Moon Cargo Access*). NASA required SpaceX to develop, produce, and demonstrate the capability and reliability of the *Starship Human Landing System (HLS)*.

In this agreement, NASA decided to send the ***Artermis III*** astronauts to the Moon, not in its own proposed lunar lander (shelved for the time being, at least until ***Artermis V***) but in an improved SpaceX *Starship HLS.* SpaceX can do the job for about one tenth the cost of using normal NASA contractors. They have awarded SpaceX a US$ 2.89 billion contract to perform one demonstration flight prior to the use of their system on the ***Artemis III*** mission. The demonstration will involve putting an uncrewed *Starship HLS* in a Near-Rectilinear Halo Orbit (NRHO) around the Moon, sending it down to land on the lunar surface, and then returning to the lunar NRHO, all being controlled robotically. If this demonstration is successful, SpaceX is to have the *Starship HLS* ready to land on the Moon as ***Artemis III*** in late 2027. To facilitate these missions, in late 2021 NASA and SpaceX announced their plans to jointly construct Launch Complex 49 at Florida's Kennedy Space Center. The following is the proposed mission profile for ***Artemis III***, which is now postponed to early 2027, due to delays caused by problems with *Starship* control and the new type of spacesuits.

As with all ***Artemis*** missions, the ***Orion*** spacecraft with four NASA crew will be lifted into orbit by an *SLS* rocket. (***Artemis I*** to ***III*** will use the *SLS Block 1*; all following missions up to ***Artemis VIII*** will use the *SLS Block 1B*, which has an expanded upper stage with a cargo hold. From ***Artemis IX*** on, the *SLS Block 2* rocket will be used.) ***Orion*** will transfer to the Moon and enter a ***Near-Rectilinear Halo Orbit (NRHO)***, where later on the ***Lunar Gateway*** space station will be located. The *Starship HLS for **Artemis III*** will be launched into low Earth orbit (LEO) using a SpaceX *Heavy Booster*, with a SpaceX crew. *Starship* tankers will refuel it before Trans-Lunar Injection. It will then head to the

Moon where it will enter the same lunar NRHO as *Orion*. The aim is that the two spacecraft should rendezvous and dock with each other. Two of *Orion's* NASA crew will transfer to the *HLS*, which will descend to the Moon's South Pole where they will stay for a week (*see diagram on page 11*).

In contrast to other proposed designs that use multiple stages, the entire *HLS* spacecraft will land on the Moon and will then launch from the Moon as a single-stage-to-orbit (SSTO) vehicle. Like other *Starship* variants, *Starship HLS* has three Raptor R2V (Vacuum) engines mounted in its tail as its primary propulsion system. However, when it is within tens of metres from the lunar surface during descent and ascent, it will use 24 high-power methane-LOX reaction-control thrusters located high up instead of the Raptors, to avoid raising a plume of dust or blasting a hazardous crater under the vehicle. A solar array located on the nose below the docking port will provide electrical power.

Some equipment (such as an unpressurised rover for use during excursions) will have been pre-positioned at the landing site prior to the astronauts' arrival. After they have completed their lunar activities (which will take about a week), *Starship HLS* will lift-off from the Moon and return to lunar NRHO to rendezvous with *Orion*. The two NASA crew will then transfer back to *Orion* and depart for Earth. The mission will take 30 days. Although not yet confirmed, the *Starship HLS* could be refuelled in orbit by a *Starship* tanker to ferry more crews and cargo to the Moon's surface.

NASA and SpaceX teams are working together to ensure the company's design meets all of the mission and safety requirements. Later, the *Starship HLS* will be required to demonstrate its ability to dock with ***Gateway***, a small space station that will orbit the Moon to support both lunar and deep-space exploration. This is necessary so that *Starship HLS* can deliver the supplies, equipment and science payloads that are needed for extensive surface exploration of the Moon's South Polar area.

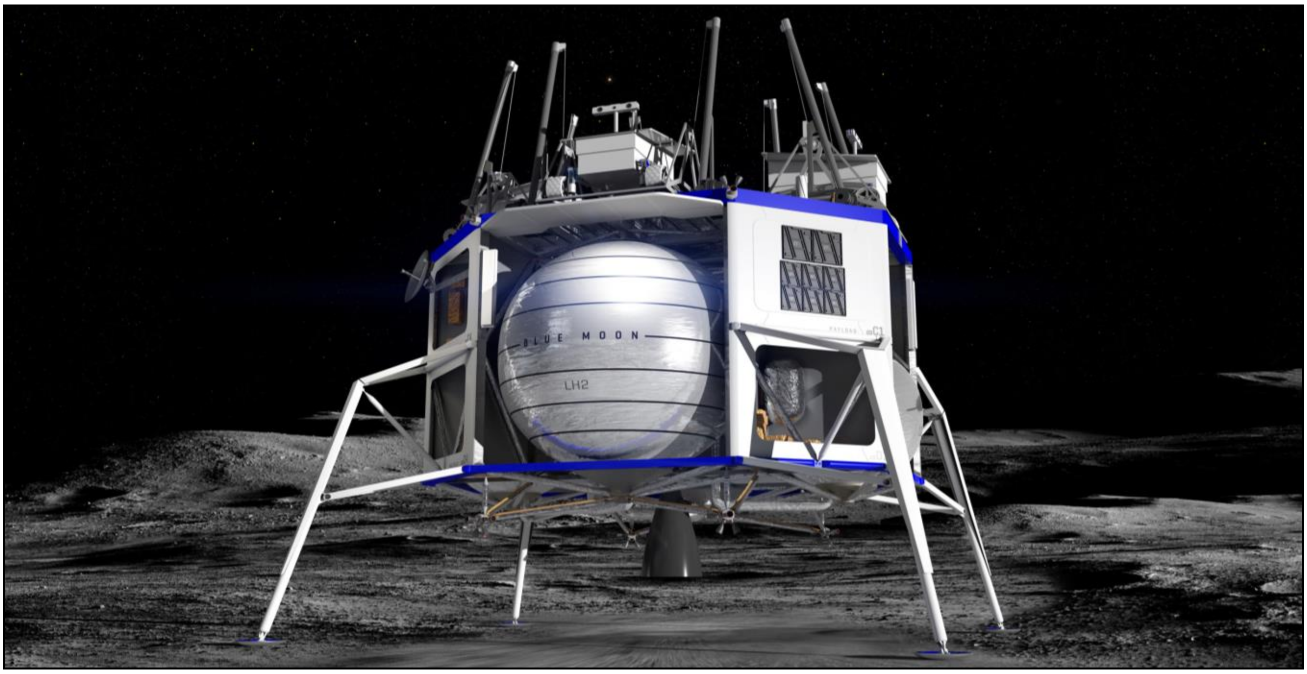
There are no details as yet as to how the SpaceX crew will get back to Earth, as the *Starship HLS* is not designed for re-entry into the Earth's atmosphere. It is possible that this early *HLS* may be provided on its 'windward side' (*see page 13*) with similar silica heat-resistant black tiles to those used on ordinary *Starships*, to enable it to return to Earth. It would also need four flaps to provide aerodynamic control, but the current plan is for the *HLS* to be disposed of by sending it into an orbit around the Sun. The SpaceX crew would therefore need to hitch a ride on *Orion* to get back home. SpaceX has said, "Our *Starship* spacecraft and *Super Heavy* rocket represent an integrated and fully reusable launch, propellant delivery, rendezvous, and planetary lander system with robust capabilities and safety features uniquely designed to deliver these essential building blocks. We are honoured to be a part of NASA's ***Artemis Program***, to help return humanity to the Moon and usher in a new era of human space exploration."

NASA has since modified the contract, requiring SpaceX to further develop the *Starship HLS*, paying SpaceX an extra US$ 1.35 billion to manage a second landing demonstration prior to NASA's ***Artemis IV*** mission and then to provide a *Starship HLS* for that mission too. The contract with SpaceX is only for the two demonstrations (trials), plus the ***Artemis III*** and ***Artemis IV*** lunar landing excursions from NRHO, after which it will expire. None of the missions described below is locked in.

NASA hoped the next Moon mission, ***Artemis IV***, would occur in 2027, but as each *SLS* launch costs $4.1 billion, it has now been deferred to September 2028. (A SpaceX launch with a reusable ***Falcon Heavy*** rocket costs on average just $1 million.) For this mission, the first two modules of the ***Lunar Gateway***, the ***Power and Propulsion Element (PPE)*** and the ***Habitation and Logistics Outpost (HALO)***, will be joined together on Earth and delivered to the lunar NRHO as a unit by a ***Falcon Heavy*** rocket in 2026. It will take about a year for these modules to spiral out into a stable NRHO orbit. When this orbit has been established, the NASA crew will board their *SLR Block 1 + Orion* space vehicle and travel up to the NRHO. When they arrive, *Orion* will dock with a small 'docking node' and the two NASA crew members (a man and a woman) will transfer from their *Orion* spacecraft into the part-built *Gateway*. Soon, a refuelled SpaceX *Starship HLS* will arrive and dock with the *Gateway* modules. The two NASA crew will transfer into the *Starship HLS* and descend to the Moon's south polar area near Shackleton crater. This will be the second human landing in the 21st century. (Originally planned for ***Artemis V***, it was brought forward a year.) After a week conducting scientific activities on the Moon, they will re-enter the *Starship HLS* and ascend to the NRHO. There they will dock with the *Gateway*, where the two NASA crew will transfer back to *Orion*. Leaving *Gateway* and the *Starship HLS* docked, *Orion* will perform a close lunar flyby (60 nautical miles or 110 kilometres above the surface) and return to Earth. This mission will also take 30 days.

NASA is conducting competitive procurement processes for other *Human Landing Systems* for use in ***Artemis*** missions to the Moon, and on 19 May 2023, they announced that Amazon founder Jeff Bezos' **Blue Origin** company had been awarded a $3.4 billion contract to build a spacecraft to fly astronauts to and from the Moon's surface in 2026. Not surprisingly, this came just a month to the day after the catastrophic loss of SpaceX's *Starship 24* (*see page 16*). This is a breakthrough for Blue Origin as two years earlier it lost to SpaceX in the first round of contracts (*see page 20*). Blue Origin plans to build its 52-feet (16-metre) tall ***Blue Moon*** lander in partnership with Lockheed Martin, Boeing, software firm Draper and robotics firm Astrobotic. NASA chose Blue Origin over a rival bid led by the defence contractor Dynetics that also involved Northrop Grumman Corporation.

NASA's decision to award Blue Origin a contract will give it a second option for sending astronauts to the Moon under its *Artemis* program, the other option being the SpaceX *Starship HLS* described above. NASA Administrator Bill Nelson said when announcing the contract, "We want more competition, we want two landers, and that's better. It means that you have reliability, you have backups." The contract complies with NASA's policy in recent years to help fund development of spacecraft by private companies, then pay to use their craft in missions, rather than spending the huge amounts required to develop their own fleet of space vehicles. Blue Origin, founded in 2000, is investing substantially more than the $3.4 billion contract figure to develop their spacecraft, and the company, not NASA, will pay for any cost overruns. Jeff Bezos said, "We are honoured to be on this journey with NASA to land astronauts on the Moon – this time to stay."

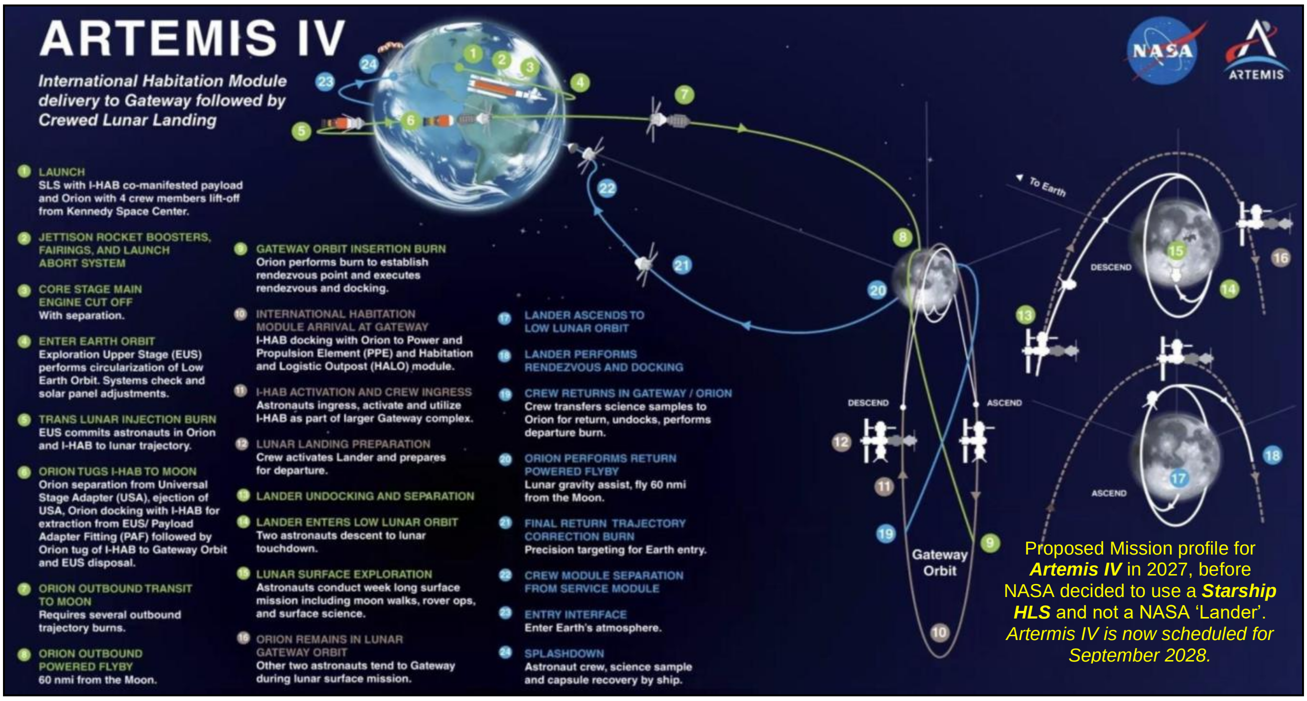


The four-legged *Blue Moon* lander can carry up to four crew and its upper deck is designed to carry different types of cargo. According to Blue Origin, its liquid hydrogen-powered rocket engine generates 10 000 pounds of thrust. Fully loaded with fuel, the lander weighs about 33 000 pounds (16.5 tonnes) and has a payload capacity of up to 14000 pounds or 6.5 metric tonnes. The spidery-looking spacecraft resembles a bigger version of the iconic Apollo lunar modules that landed twelve NASA astronauts on the Moon in the late 1960s and early 1970s. Its four landing pads, though, are noticeably smaller, as the lunar surface is firmer than was expected when the Apollo lunar modules were designed. The ***Blue Moon*** lander will likely ride on top of Blue Origin's ***New Glenn*** rocket, a 313-feet-tall (95 metres) booster that is still in development. The first stage will have seven BE-4 engines which are larger and slightly more powerful than the Raptor 2s of SpaceX. The second stage will have two smaller BE-3U engines. The rocket will be equipped with radio and laser-based communications gear, as well as a LiDAR system that will use laser beams to scan the lunar surface and guide the craft to its landing site. In addition to landing humans and cargo on the Moon, the lander will be able to deploy small Moon-orbiting satellites during its descent to the lunar surface. Blue Origin hasn't revealed any specific launch dates for *Blue Moon* (a mock-up is shown above), but its hydrogen-powered BE-7 rocket engine had a series of hot-firing tests in 2023. The first *New Glenn* rocket, expected to be reusable like *Starship*, is due for launch in mid-2024.

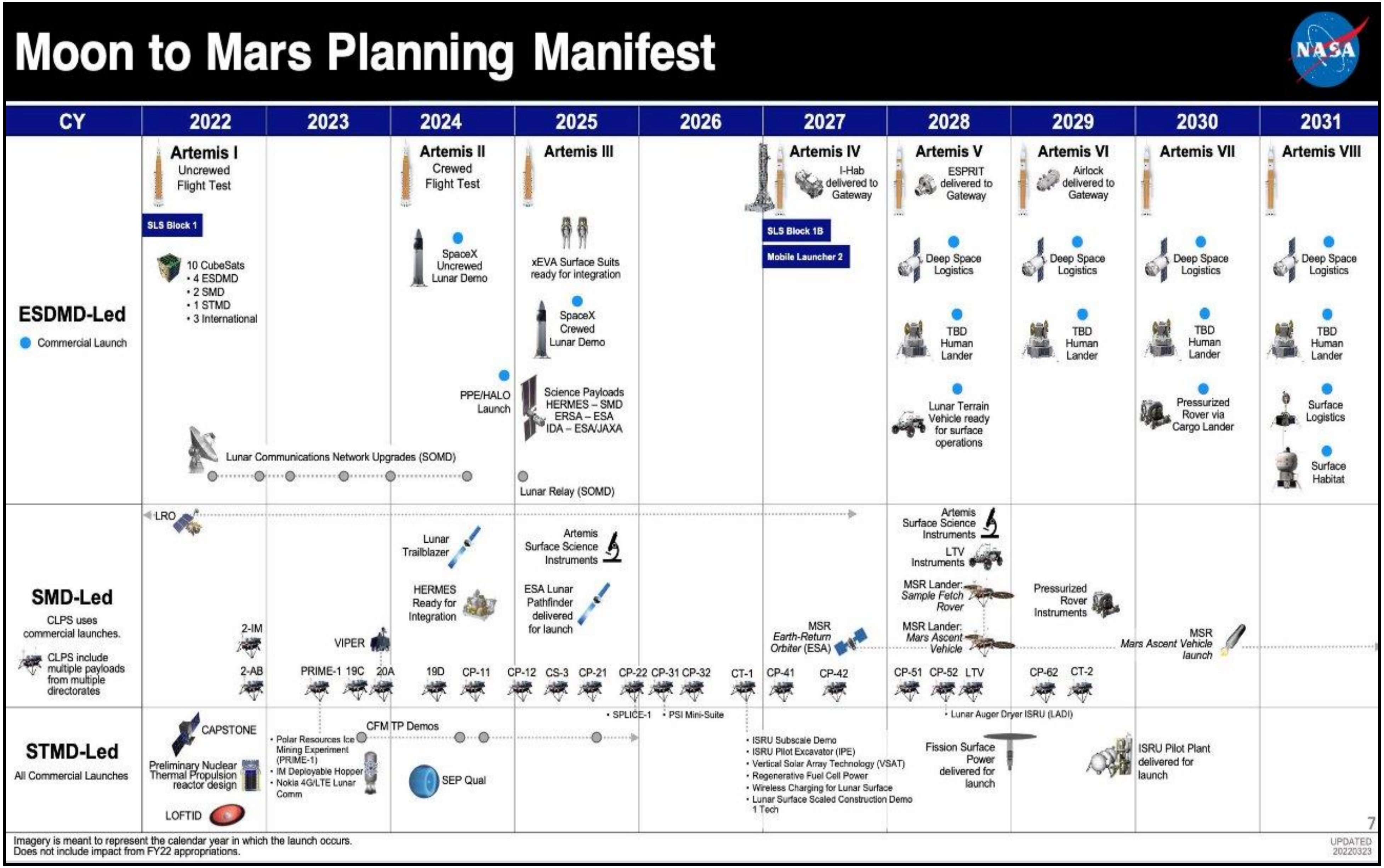
SpaceX and Blue Origin have at least six other competitors vying to win these contracts. Once initial capabilities are tested and established – the ***Orion*** spacecraft, ***SLS Block 1B***, ***Starship HLS***, ***New Glenn Blue Moon***, and then ***Lunar Gateway*** – NASA will award more contracts and slowly build up its lunar architecture. First, once ***Gateway*** is operational, it will be used as a rendezvous for which-ever human landing system is chosen. Second, commercial cargo landers will begin delivering heavier equipment to the Moon's South Polar Base, such as an unpressurised *Lunar Transportation Vehicle*. When these are in place and regular commercial landing services are established, the ***Gateway*** will double as a refuelling point, for itself or for reusable human landers. During this phase, the ***Gateway*** will continue to add more science, resource, communications and research capabilities.

Meanwhile, on the lunar surface, a pressurised rover will possibly be delivered to the south pole site as well as the first permanent surface habitat. Both of these would allow for extended stays and the extraction of resources. After everything is in place, NASA hopes to use *Gateway* and the ***Artemis Base Camp*** for various simulations for missions to Mars. This could include a mock Mars mission, travelling to the *Gateway* for a stay of about six months, then land on the lunar surface for a period of time, then return to the *Gateway* for another six months, and then return to Earth. This would simulate an expedition to Mars. During all of this time, communications would incorporate variable time delays to replicate the delays experienced by a crew in a Mars mission.

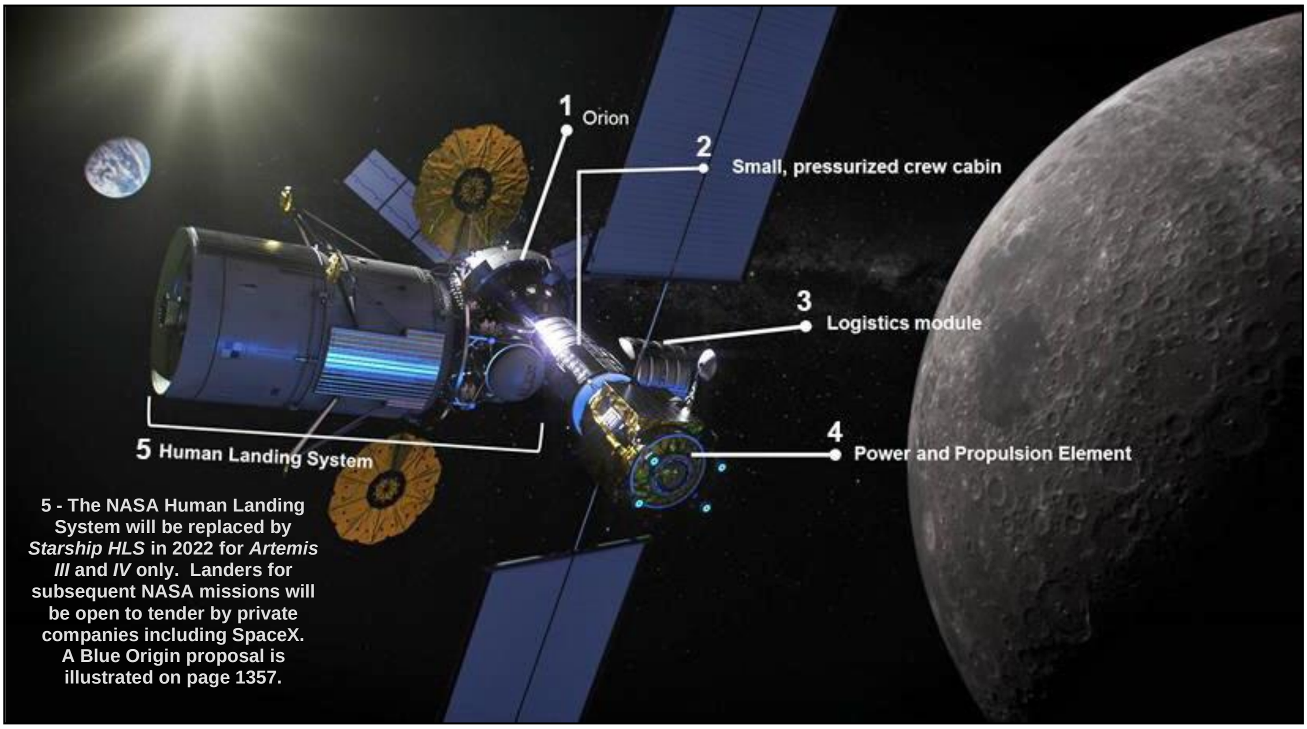
NASA would prefer to continue with the procedures used for ***Artemis IV*** for later ***Artemis*** missions (NASA *SLS+Orion* to *Gateway*, *Starship HLS* for the lunar excursion and return to *Gateway*, and *Orion* to return to Earth), but there is a growing opinion that the non-reusable NASA *SLS* is old and wasteful space shuttle technology of 45 years ago, and the reusable SpaceX rockets and *Starship HLS* are the way of the future, especially when one considers their suitability for a mission to Mars. NASA plans to use the *SLS Block 1* rocket up to and including ***Artemis VIII*** in 2031, and then use *SLS Block 2* up to ***Artemis XI*** in 2034, the missions being limited to once every two years, but the rapid progress by SpaceX in rocket technology may convince NASA to put aside the *SLS-Orion* part of the ***Artemis*** program either temporarily or permanently, and send its astronauts from the Earth to the lunar NRHO aboard a standard SpaceX *Starship*. When *Gateway* is available, a *Starship HLS* could be docked permanently there in lunar NRHO, until required for the next transfer of passengers to the Moon's South Polar Base, while its previous passengers returned to Earth via the normal *Starship* which had brought them up to NRHO. If *Gateway* was not yet available, then a *Starship HLS* would need to be modified to carry out a complete mission from the Earth to the Moon. To return safely, it would need to be able to withstand re-entry into the Earth's atmosphere through the fitting of flaps and black silica tiles, something that SpaceX could easily do as the technology is already present on standard *Starships*. Alternatively, *Blue Moon* could be viable. Such scenarios may be found necessary by NASA through budgetary constraints applied by the US Government.



Proposed Mission profile for ***Artemis IV*** in 2027, before NASA decided to use a ***Starship HLS*** and not a NASA 'Lander'. *Artemis IV is now scheduled for September 2028.*



*Original timeline for an extension of the **Artemis** program to include preparations for a mission to Mars. As of 2024 **Artemis II** through **IV** are deferred for a year.*



Meanwhile, planning and development is on-going for construction of ***Gateway***. This will be a mini-space station in lunar orbit, that will serve as a solar-powered communication hub, science laboratory, short-term habitation module, and holding area for rovers and other robots. Canada, Europe and Japan will contribute some of the eight modules, and *Gateway* will be built up module by module as the *International Space Station* was. Three proposals are on page 27, the final one being the latest version. It is hoped that the first two modules will be assembled and joined prior to the ***Artemis IV*** mission, and delivered to the lunar NRHO by 2027, and the ***I-HAB*** soon after.

At one end of *Gateway* will be a multi-purpose module where *Orion*, *Starship HLS* and other spacecraft can dock to enable transfer of crew and supplies. It is hoped that most of the modules will be in use by ***Artemis VI*** in 2029 (*see below*), and that the lunar base will be started by ***Artemis VII*** in 2030, to service more landings near the Moon's South Pole in the following decade.

Some planned modules for Gateway – Nos. 1 and 2 will be the first

1: The ***Power and Propulsion Element*** *(PPE)* was developed as a robotic, high performance solar-electric spacecraft that would retrieve a multi-tonne boulder from an asteroid and bring it to lunar orbit for study. When that experiment was cancelled, the solar-electric propulsion was re-purposed for the *Gateway*. The *PPE* will allow access to the entire lunar surface and act as a 'space tug' for visiting craft. It will also serve as the command and communications centre of the *Gateway*. The *PPE* is intended to have a mass of 8 to 9 tonnes and the capability of generating 50 kilowatts of solar-electric power for its ion thrusters, which can be supplemented by chemical propulsion. Maxar was awarded a firm fixed-price contract of US$ 375 million to build the *PPE*.

2: The ***Habitation and Logistics Outpost*** *(HALO)*, also called the *Minimal Habitation Module (MHM)*, will be built by Northrop Grumman Innovation Systems (NGIS). The *HALO* is based directly on a *Cygnus Cargo* resupply module, to the outside of which radial docking ports, body mounted radiators (BMRs), batteries and communications antennae will be added. The *HALO* will be a scaled-down habitation module, yet it will feature a functional pressurised volume providing sufficient command, control and data handling capabilities, energy storage and power distribution, thermal control, communications and tracking capabilities, two axial and up to two radial docking ports, stowage volume, environmental control and life support systems to augment the *Orion* spacecraft and support a crew of four for at least 30 days. On 9 July 2021, Northrop Grumman Innovation Systems was awarded a contract by NASA for US$ 935 million to design and build the *HALO*, and to integrate it with the *PPE* being built by Maxar.

3: The ***European System Providing Refueling, Infrastructure and Telecommunications (ESPRIT)*** service module will provide additional xenon and hydrazine capacity, additional communications equipment, and an airlock for science packages. It will have a mass of approximately 4 tonnes, and a length of 3.91 metres. The European Space Agency (ESA) has awarded two parallel design studies, one mostly led by Airbus and one led by Thales Alenia Space. The construction of the module was approved in November 2019, and in October 2020 Thales Alenia Space announced that they had been selected by *ESA* to build the *ESPRIT* module.

The *ESPRIT* module will consist of two parts. The first part, called the *Halo Lunar Communication System (HLCS)* will provide the communications for the mini-station *Gateway*. It will launch pre-attached to the *HALO* module, for which Thales has separately been awarded a contract by NASA to construct its hull and micrometeoroid protection. The second part, called the *ESPRIT Refueling Module (ERM)*, will contain the pressurised fuel tanks, docking ports and a small windowed habitation corridor, and will launch in 2027.

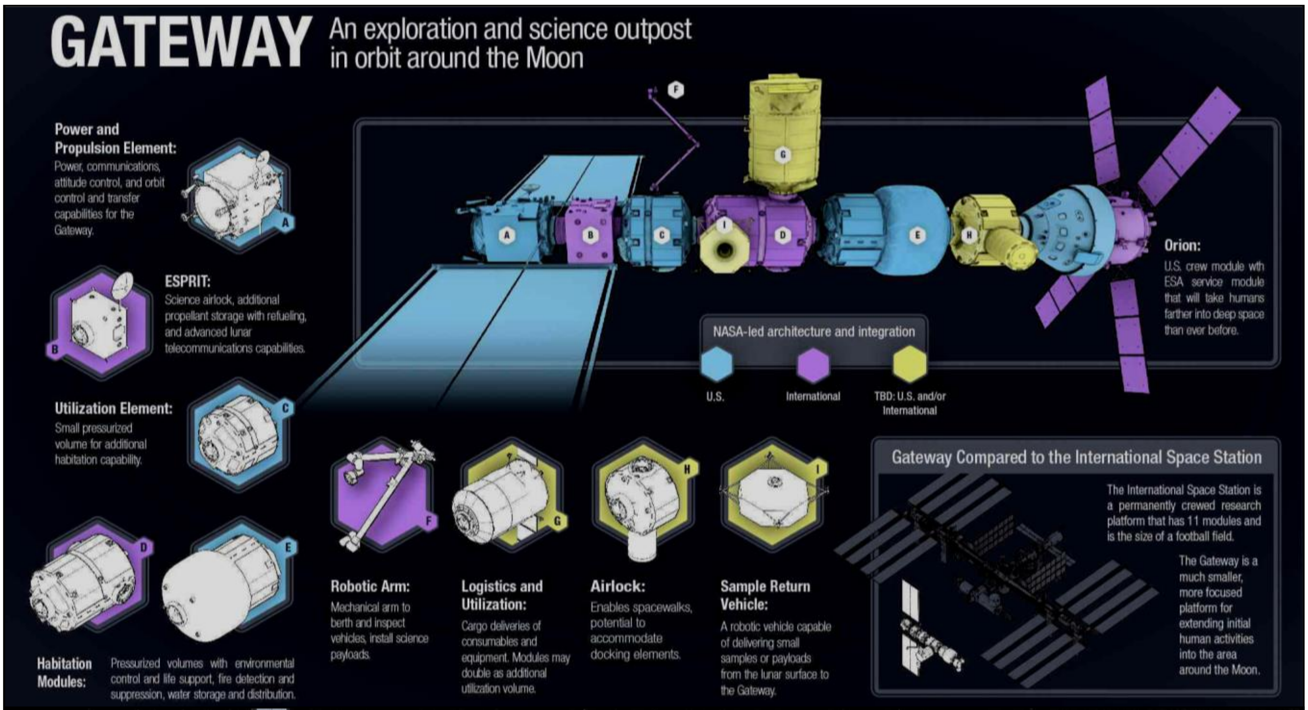
4: The ***International Habitation Module (I-HAB)*** will be an additional habitation module built by ESA in collaboration with the Japan Aerospace Exploration Agency (JAXA). Together with the *HALO* module, they will provide a combined 125 cubic metres of habitable volume to the station. On 14 October 2020, Thales Alenia Space announced that they had been selected by ESA to build the *I-HAB* module. The module will also feature contributions from the other station partners, including a life support system from JAXA, avionics and software from NASA and robotics from the Canadian Space Agency (CSA). The module is slated to launch in 2027-2028 on the *Artemis IV* mission as a co-manifested payload on the *SLS-Orion* spacecraft.

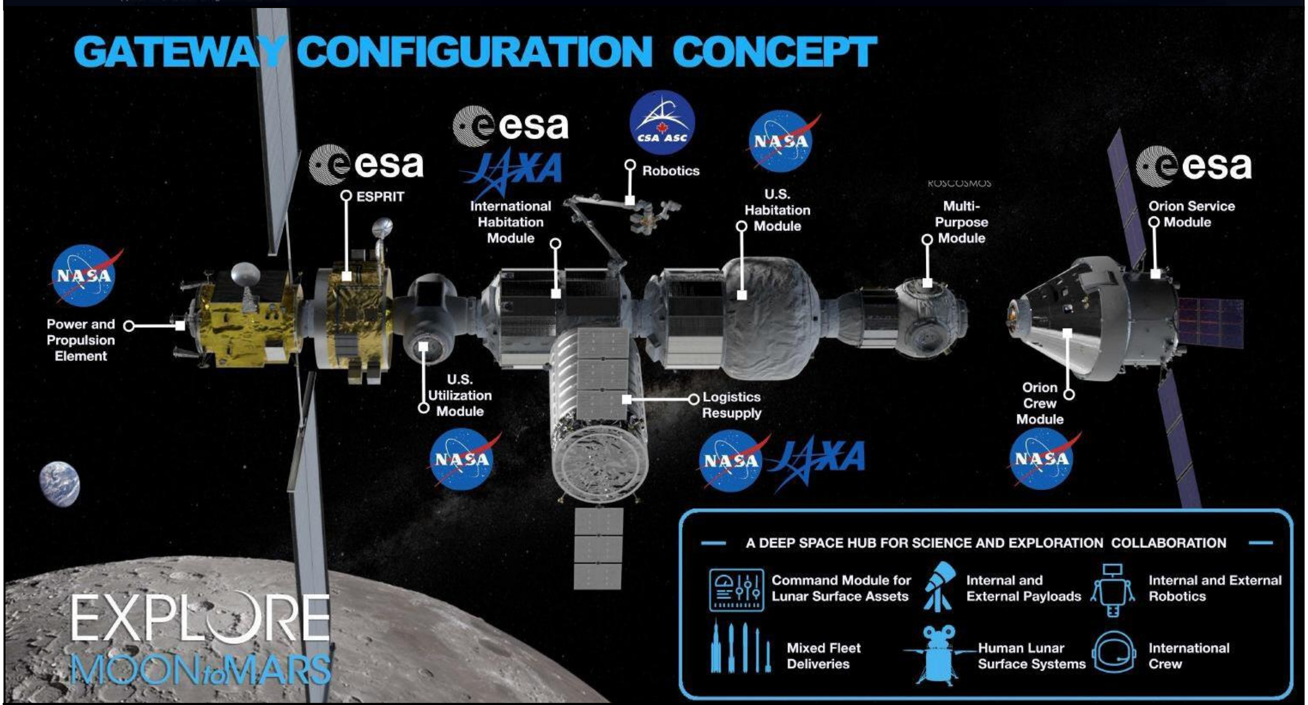
The concept for the *Gateway* is still evolving, and the following modules will be included:

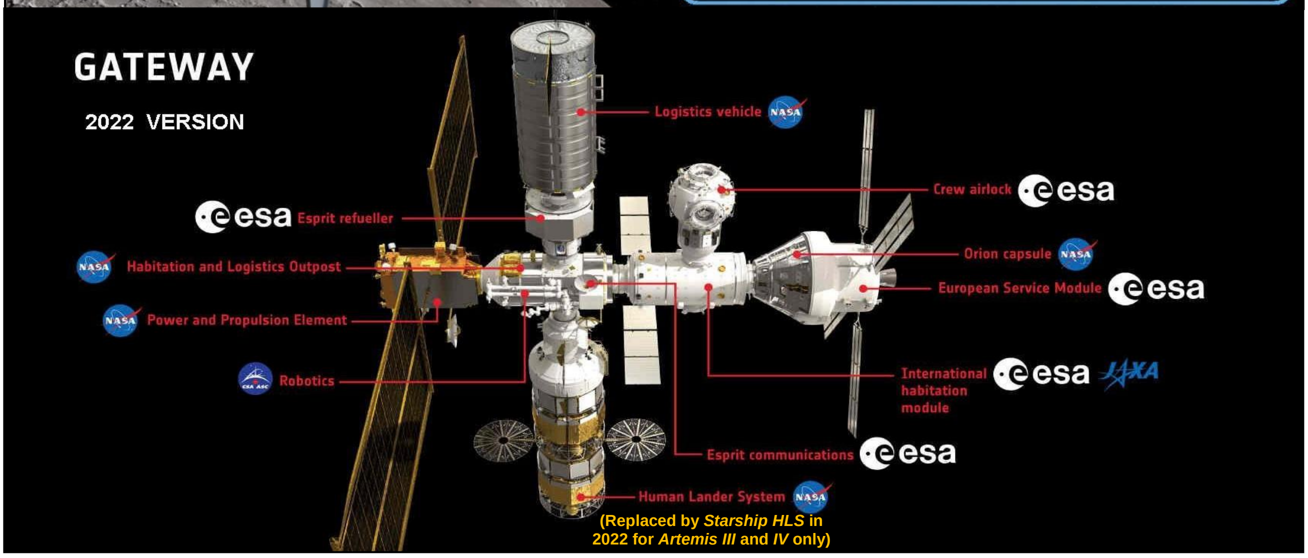
- The ***Gateway Logistics Modules*** will be used to refuel, resupply and provide logistics on board the mini-space station. The first logistics module sent to the *Gateway* will also arrive with a robotic arm (*see below*).
- The ***Gateway Airlock Module*** will be used for performing extravehicular activities outside the mini-space station and will have a docking port for the *Orion* crew module and other proposed Deep Space Transport vehicles (*see below*).
- The ***Canadarm3***, a robotic 8.5 metre-long remote manipulator arm, is similar to the *Space Shuttle's Canadarm* and the *International Space Station's Canadarm2*. The arm will be the contribution of the Canadian Space Agency (CSA) to this international endeavour. CSA contracted MDA (formerly MacDonald, Dettwiler and Associates) to build the arm. MDA previously built the *Canadarm2*, while its former subsidiary, Spar Aerospace, built the *Canadarm*.

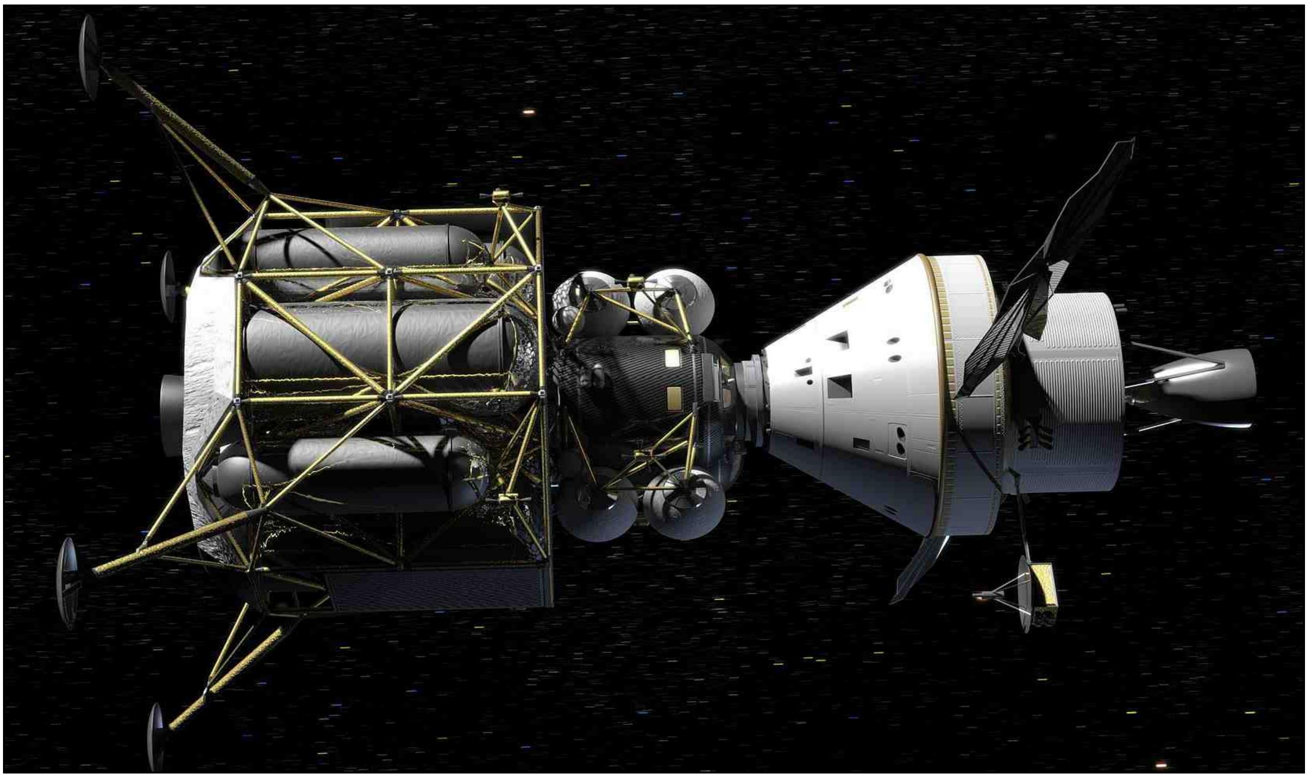
Crewed flights to *Gateway* are expected to use the *SLS-Orion*, while other missions may be carried out by commercial launch providers. NASA has announced that SpaceX with its future spacecraft *Dragon XL* will be the first commercial partner to deliver supplies to the *Gateway*. The first two modules (*PPE* and *HALO + HLCS*) will be launched on a *Falcon Heavy* rocket in November 2024.

In May 2020, NASA decided it was time to set some rules to govern activities on the Moon. They called these rules the "***Artemis Accords***", and asked other nations and commercial interests to sign on as partners. Eight countries agreed: Australia, Canada, Italy, Japan, Luxembourg, United Arab Emirates, United Kingdom and the United States of America. China did not sign, as it aims to build a permanent base near the lunar South Pole with Russia. Although Russia is NASA's most important partner in space exploration (the two are largely responsible for the *International Space Station* and American astronauts have been travelling to and from the *ISS* on Russian *Soyuz* spacecraft since the *Space Shuttle* program ended in 2011), it also refused to sign and withdrew from the *Artemis Program* altogether for political reasons, claiming that it was "too dominated by the US". This meant that plans for Russia to build and supply the ***Gateway Airlock Module*** had to be scrapped. As the airlock needs to be compatible with other modules being built by Thales Alenia Space for the European Space Agency (ESA), the ESA has selected Thales Alenia Space to build the airlock as well. By October 2024, 45 countries have signed up to be partners of the *Artemis Accords.*

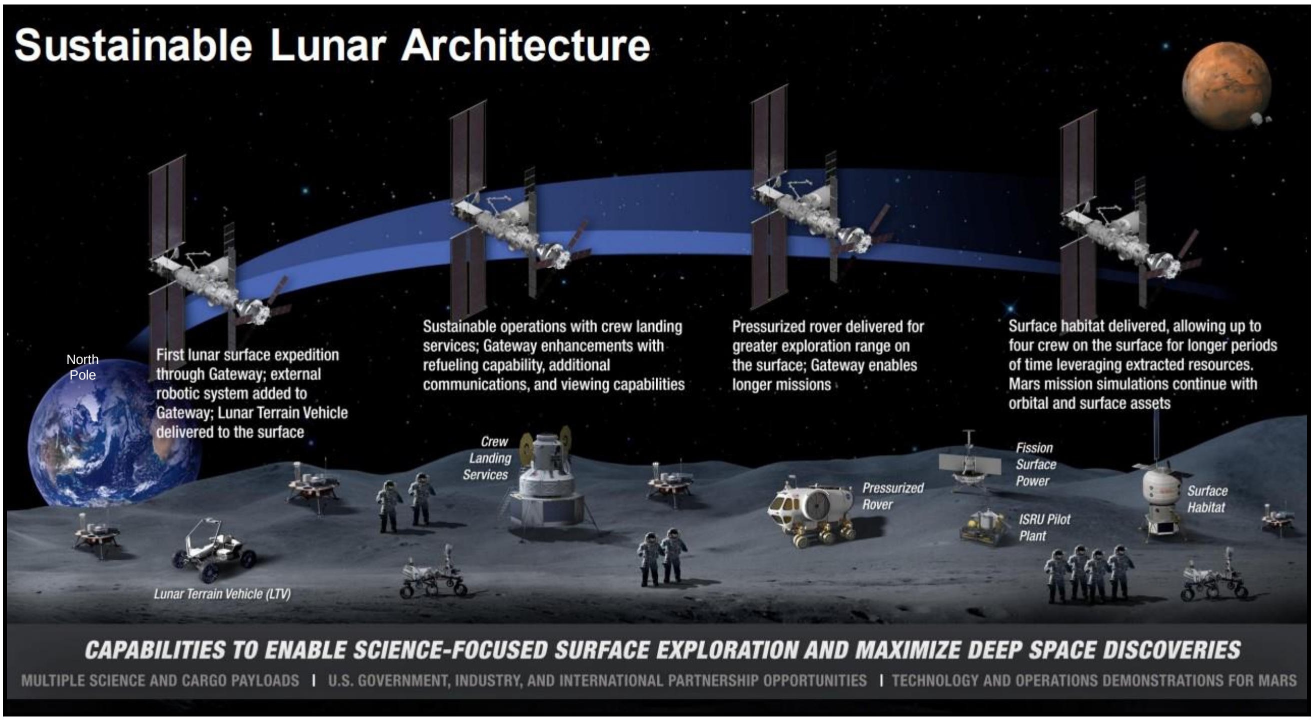

GATEWAY An exploration and science outpost in orbit around the Moon
Power and Propulsion Element: Power, communications, attitude control, and orbit control and transfer capabilities for the Gateway.
ESPRIT: Science airlock, additional propellant storage with refueling, and advanced lunar telecommunications capabilities.
Utilization Element: Small pressurized volume for additional habitation capability.
Habitation Modules: Pressurized volumes with environmental control and life support, fire detection and suppression, water storage and distribution.
Robotic Arm: Mechanical arm to berth and inspect vehicles, install science payloads.
Logistics and Utilization: Cargo deliveries of consumables and equipment. Modules may double as additional utilization volume.
Airlock: Enables spacewalks, potential to accommodate docking elements.
Sample Return Vehicle: A robotic vehicle capable of delivering small samples or payloads from the lunar surface to the Gateway.
Orion: U.S. crew module with ESA service module that will take humans farther into deep space than ever before.
NASA-led architecture and integration
U.S.
International
TBD: U.S. and/or International
Gateway Compared to the International Space Station
The International Space Station is a permanently crewed research platform that has 11 modules and is the size of a football field.
The Gateway is a much smaller, more focused platform for extending initial human activities into the area around the Moon.


GATEWAY CONFIGURATION CONCEPT
esa
ESPRIT
esa
JAXA
International Habitation Module
CSA ASC
Robotics
NASA
U.S. Habitation Module
ROSCOSMOS
Multi-Purpose Module
esa
Orion Service Module
NASA
Power and Propulsion Element
U.S. Utilization Module
NASA
Logistics Resupply
NASA JAXA
Orion Crew Module
NASA
EXPLORE MOON to MARS
A DEEP SPACE HUB FOR SCIENCE AND EXPLORATION COLLABORATION
Command Module for Lunar Surface Assets
Internal and External Payloads
Internal and External Robotics
Mixed Fleet Deliveries
Human Lunar Surface Systems
International Crew

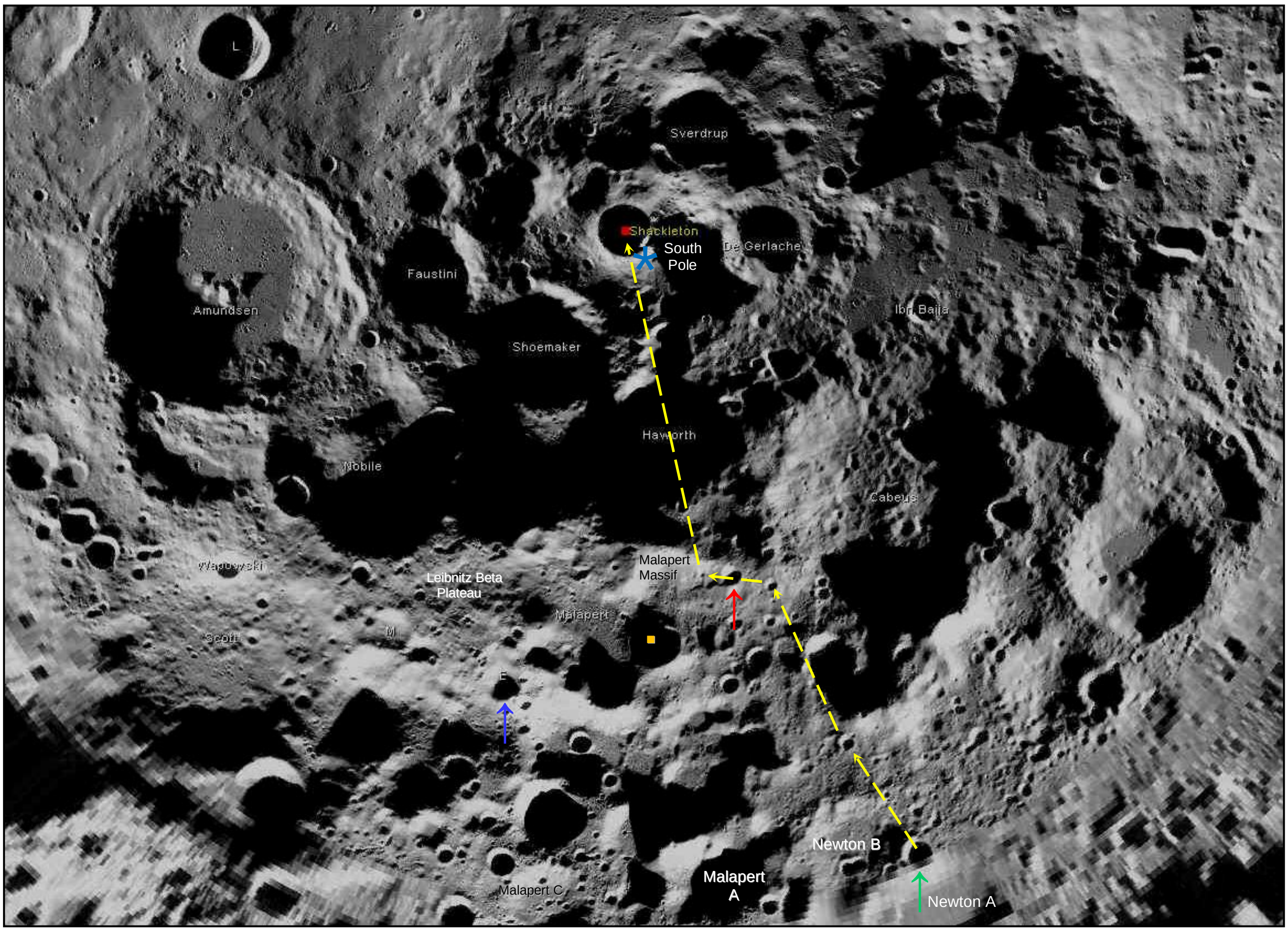

GATEWAY
2022 VERSION
Logistics vehicle NASA
esa Esprit refueller
Crew airlock esa
NASA Habitation and Logistics Outpost
Orion capsule NASA
European Service Module esa
NASA Power and Propulsion Element
CSA ASC Robotics
International habitation module esa JAXA
Esprit communications esa
Human Lander System NASA
(Replaced by *Starship HLS* in 2022 for *Artemis III* and *IV* only)



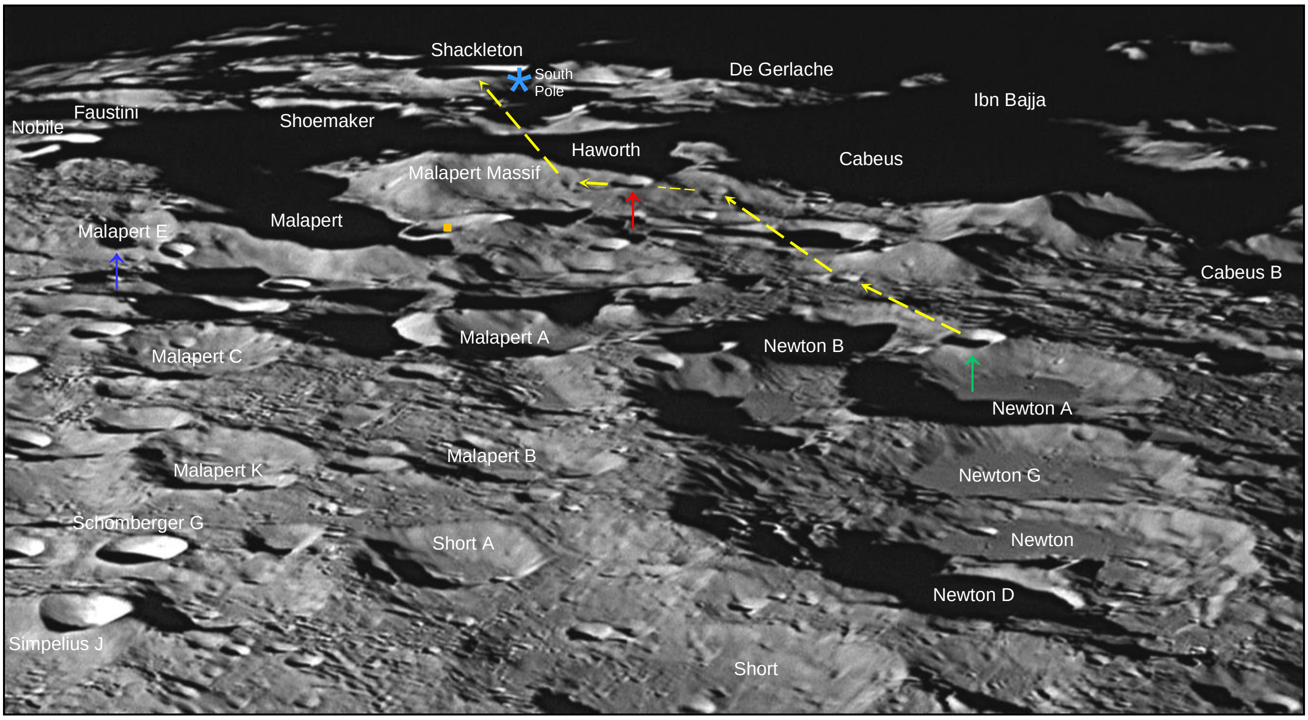
The ***Human Landing System (HLS)*** is a critical component of NASA's *Artemis* mission, as it will transport crew from lunar orbit (the *Gateway* or an *Orion* spacecraft) to the Moon's surface, act as a lunar habitat, and then transport the crew back to lunar orbit. The SpaceX ***Starship HLS*** will be used for *Artemis III and IV.* In the meantime various companies will compete for contracts to build future landers. Above is an artist's idea of a possible configuration, with a typical version of a Lunar Lander at left + Orion Crew and Service Modules at right (*see pages 20-24*).



Above is a possible progression for the *Artemis Project.* It predates the decision to utilise the *Starship HLS* instead of a NASA lunar lander for the first missions. Note numerous robots collecting samples, a pressurised Roving Vehicle, and a Large-Scale Cargo Lander for supplying scientific equipment to the manned Lunar Base. The site for the base will be near Shackleton Crater at the South Pole, although the erroneous orientation of Earth in the background suggests a site at the North Pole.



The Moon's South Polar area from above, with the north-west rim of the crater Shackleton marking the pole. Crater Shoemaker is nearby. The larger craters Amundsen and Scott are near the left margin. – Lunar Orbiter.



The view from Starfield Observatory at 10:25 pm on 4 May 2020. Three craters found in both images above and on pages 31, 34-38 and 40 are indicated by colour-coded arrows thus: "↑ ↑ ↑". If telescopic observers wish to locate the Moon's South Pole, they will need to choose a time when the libration and phase are favourable. First locate the 12 km crater on the southern (far) rim of Newton A (green arrow). Follow the yellow arrows to Malapert Massif, then head 75 km south across Haworth to 21 km Shackleton. A blue asterisk marks the pole.

As NASA prepares to send astronauts back to the Moon under *Artemis*, the agency has identified thirteen candidate landing regions near the lunar South Pole. Each region contains multiple potential landing sites for *Artemis III*, which will be the first of the *Artemis* missions to bring crew to the lunar surface, including the first woman to set foot on the Moon.

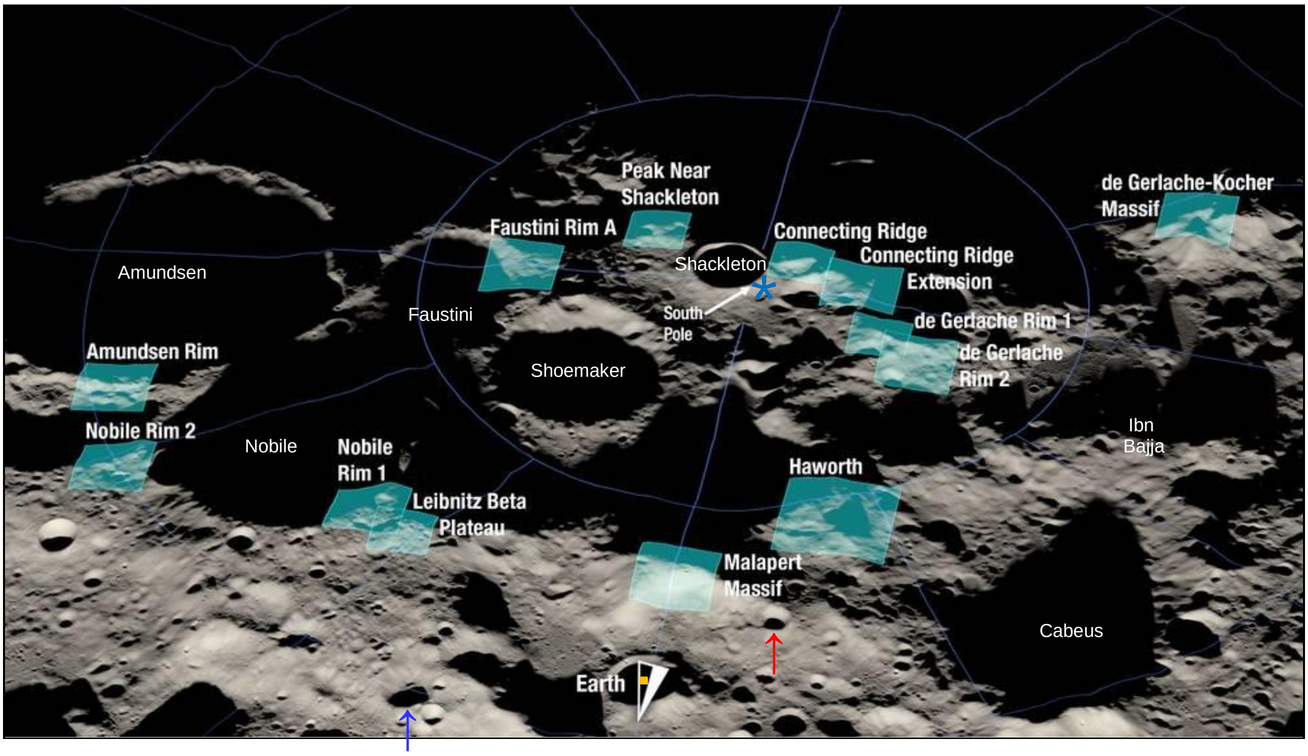
“Selecting these regions means we are one giant leap closer to returning humans to the Moon for the first time since Apollo,” said Mark Kirasich, deputy associate administrator for the Artemis Campaign Development Division at NASA Headquarters in Washington. “When we do, it will be unlike any mission that’s come before as astronauts venture into dark areas previously unexplored by humans and lay the groundwork for future long-term stays.”

NASA identified the following candidate regions for an *Artemis III* lunar landing:

Faustini Rim A	Peak near Shackleton	Connecting Ridge	Connecting Ridge Extension
Amundsen Rim	de Gerlache Rim 1	de Gerlache Rim 2	de Gerlache-Kocher Massif
Malapert Massif	Nobile Rim 1	Nobile Rim 2	Haworth	Leibnitz Beta Plateau

All of these regions are located within six degrees of latitude of the lunar South Pole and, collectively, contain diverse geologic features. Together, the regions provide landing options for all potential *Artemis III* launch opportunities. Specific landing sites are tightly coupled to the timing of the launch window, so multiple regions ensure flexibility to launch throughout the year.

To select the regions, an agency-wide team of scientists and engineers assessed the area near the lunar South Pole using data from NASA’s [Lunar Reconnaissance Orbiter]() and decades of lunar science findings and publications. In addition to considering launch window availability, the team evaluated regions based on their ability to accommodate a safe landing, using criteria including terrain slope, ease of communications with Earth, and lighting conditions. The latter are very important as many crater interiors and valleys near the lunar poles are in perpetual darkness. To determine accessibility, the team also considered the combined capabilities of the *Space Launch System* rocket, the *Orion* spacecraft, and the SpaceX-provided [Starship Human Landing System]().

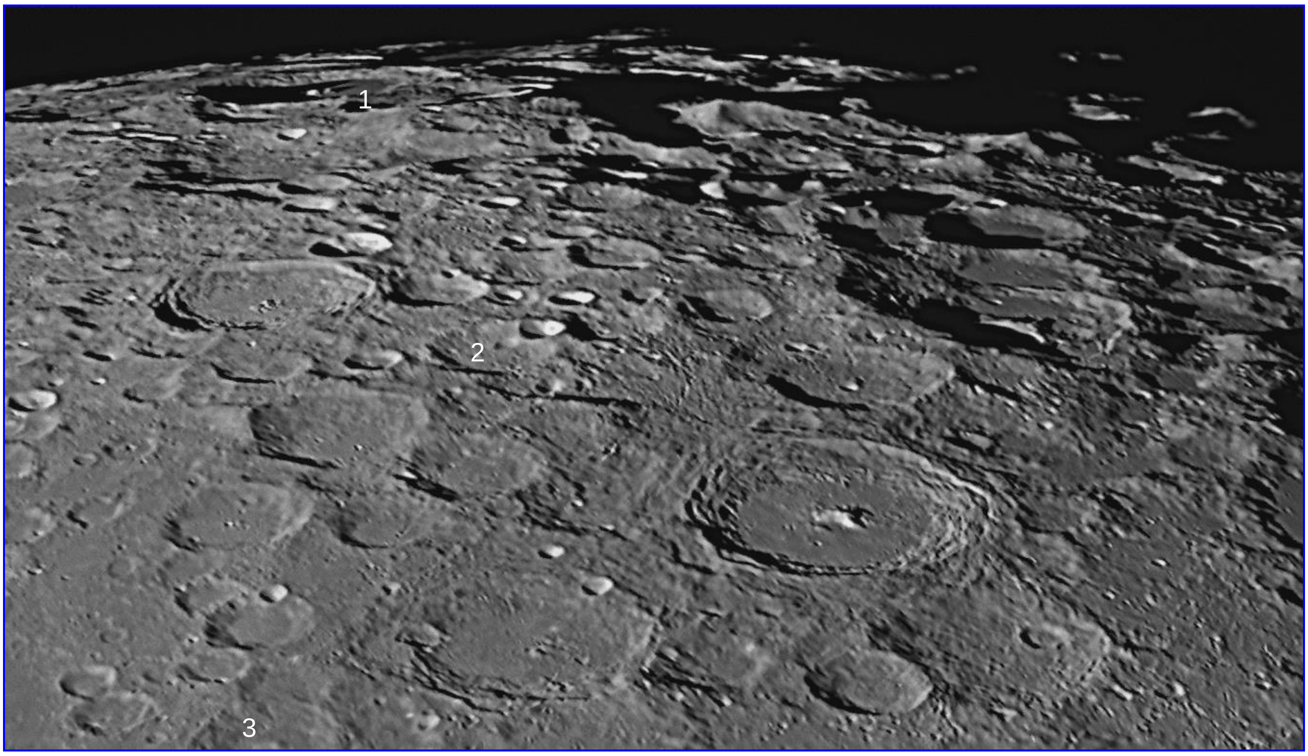


These are the thirteen candidate landing regions for Artemis III. *Each region averages approximately 20 x 20 kilometres. A landing site is a location within these regions with an approximate radius of 100 metres. A small orange square marks an anonymous 23 km crater that appears in this image, two on the previous page and some others following, to assist the reader in orientation.* – Lunar Reconnaissance Orbiter.

Observer's Guide to the Artemis landing sites near the Moon's South Pole

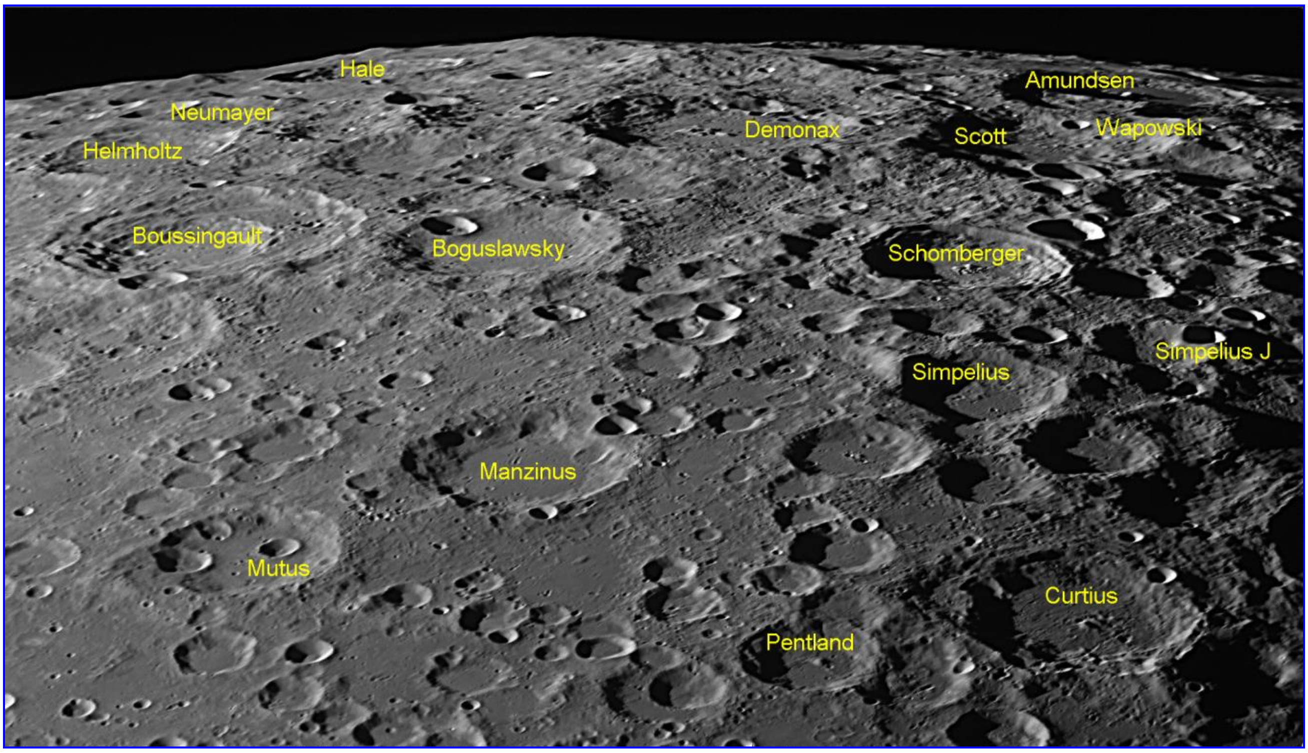
The first four images give a wide angle of view, and will allow observers to become familiar with the area near the Moon's South Pole. On this page, the medium-sized craters marked 1, 2 and 3 in white are the same craters in both images. The images were taken at Starfield Observatory on the evenings of May 4, 2020 and May 20, 2021.

This image shows the moonscape south of latitude -65º to the Pole, and between longitude 80º East (left) and 8º East (right).

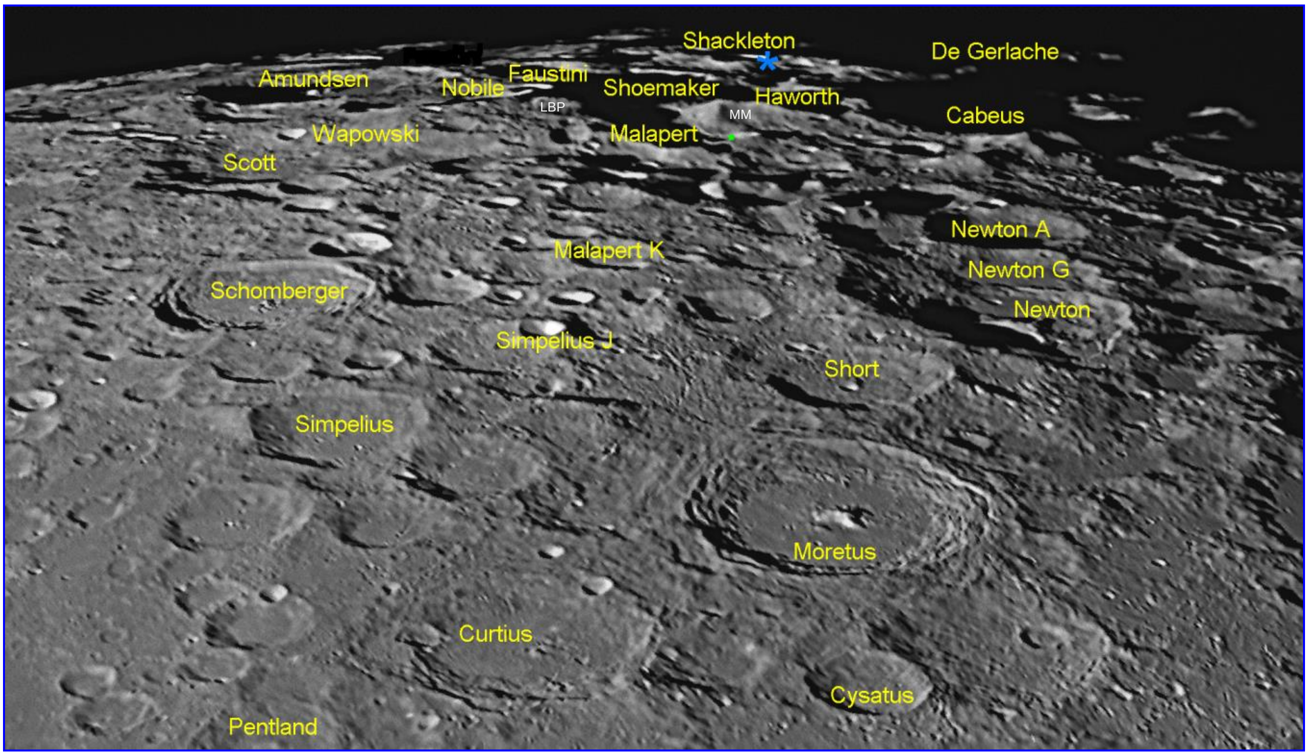


This image adjoins the one above, and covers the region south of latitude -65º to the Pole, and between longitude 43º East (left) and 32º West (right).

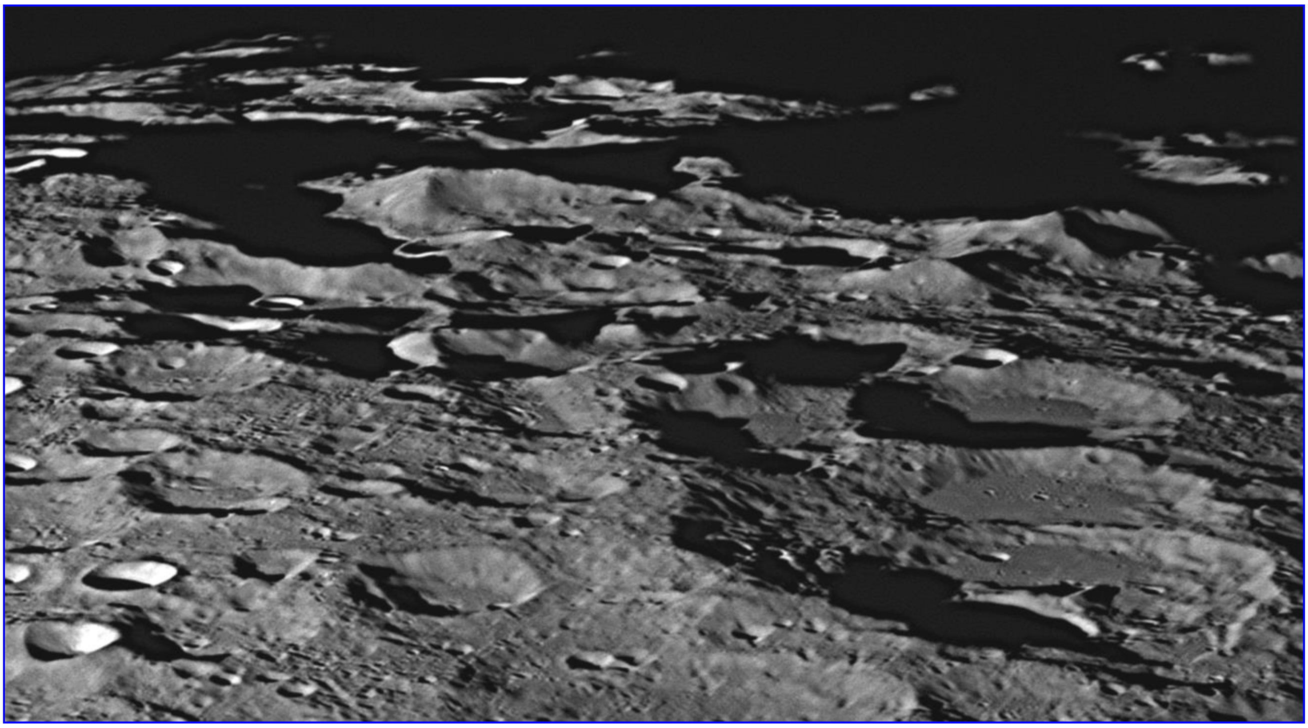
The two images on this page are identical to the two on the previous page, except that large craters are identified with their official names, many of which were selected by Giovanni Riccioli and Francesco Grimaldi when they created their selenograph (or map of the Moon) in 1651. A number of craters not charted at that time (as they were not noticed by astronomers using seventeenth century telescopes) were detected as instrumentation improved in modern times, and therefore have been given modern names such as Hale, Amundsen, Scott, Shackleton and Shoemaker.

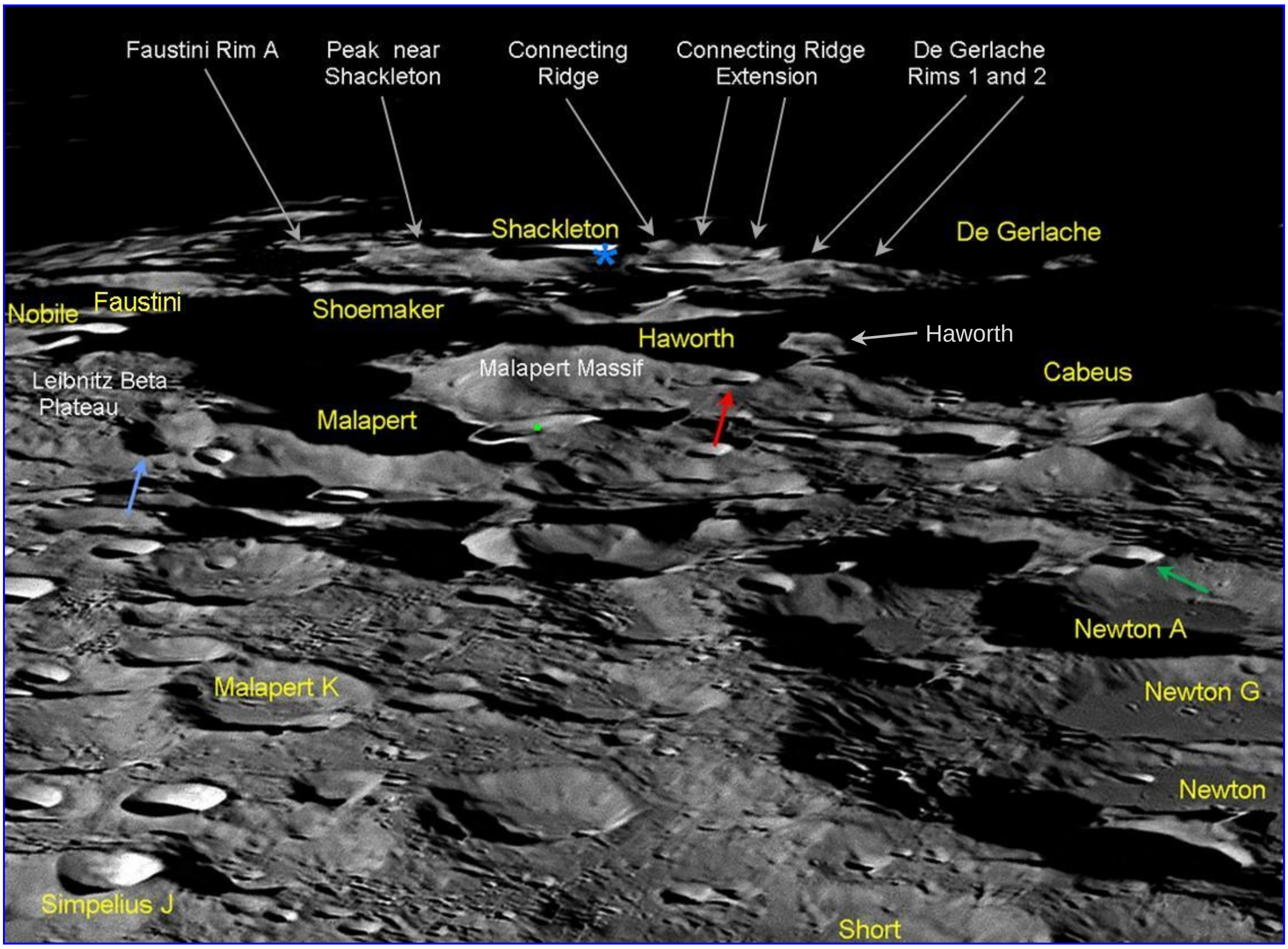


The above image was taken at Starfield Observatory on May 20, 2021.
The one below was taken on May 4, 2020.



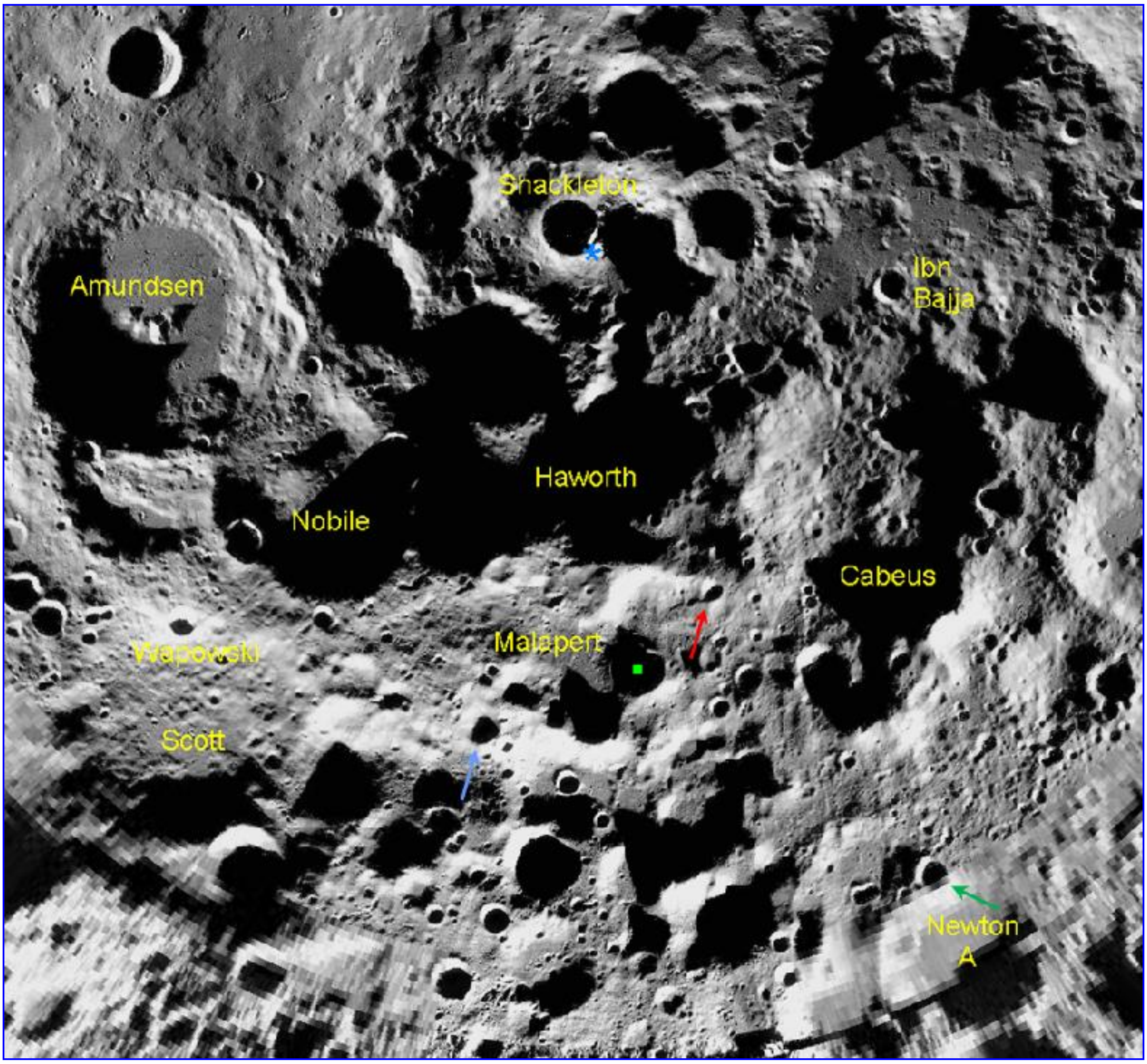
The nearest crater to the pole is 21-kilometre Shackleton. The actual South Pole is on that crater's north-west rim, and is marked with a blue asterisk. 'MM' is the Malapert Massif, 'LBP' is the Leibnitz Beta Plateau.



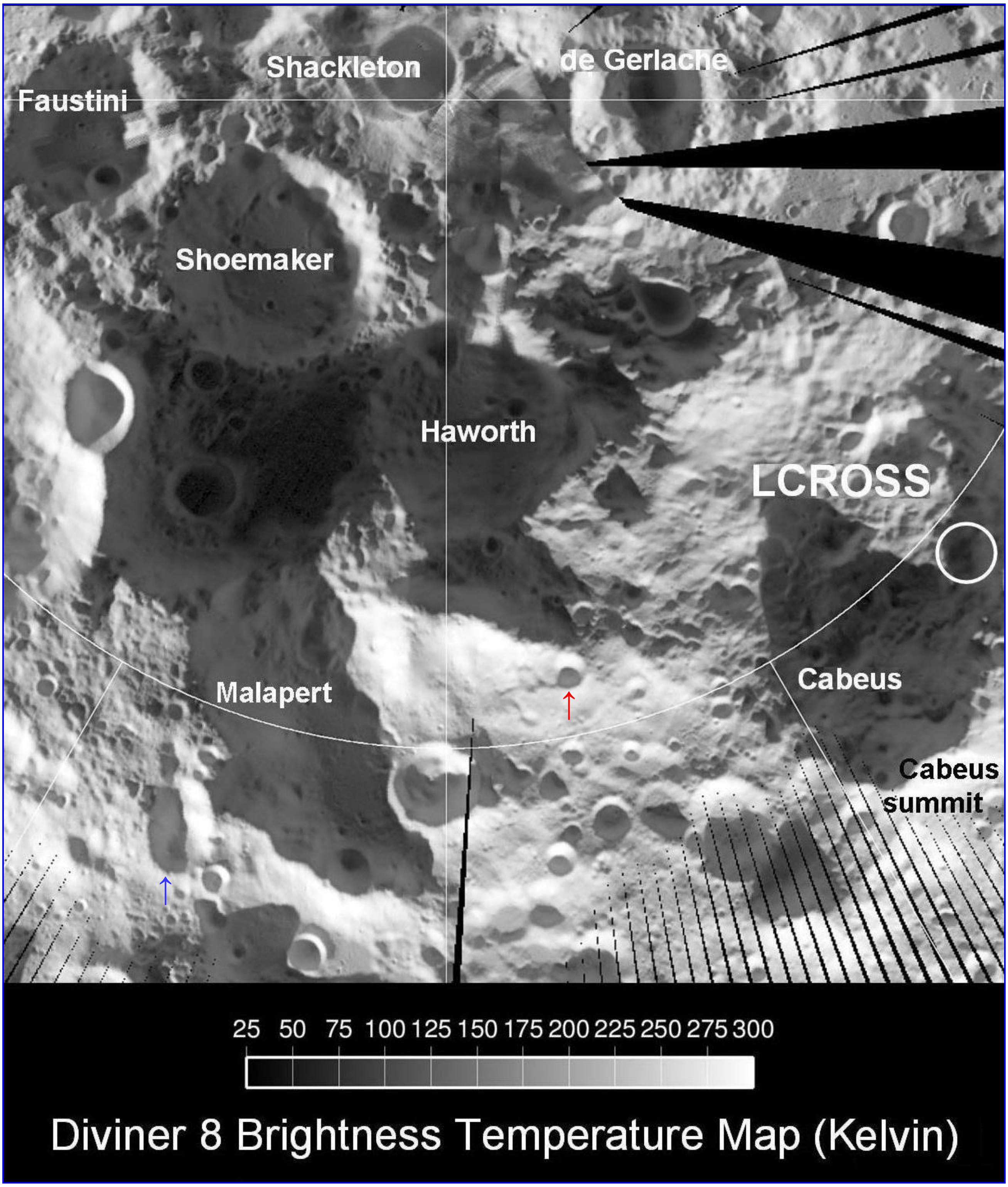


These are nine of the thirteen candidate landing regions near the lunar South Pole. The red ones in the list below are off the image:

Faustini Rim A	Peak near Shackleton	Connecting Ridge	Connecting Ridge Extension
Amundsen Rim	de Gerlache Rim 1	de Gerlache Rim 2	de Gerlache-Kocher Massif
Malapert Massif	Nobile Rim 1	Nobile Rim 2	Haworth	Leibnitz Beta Plateau

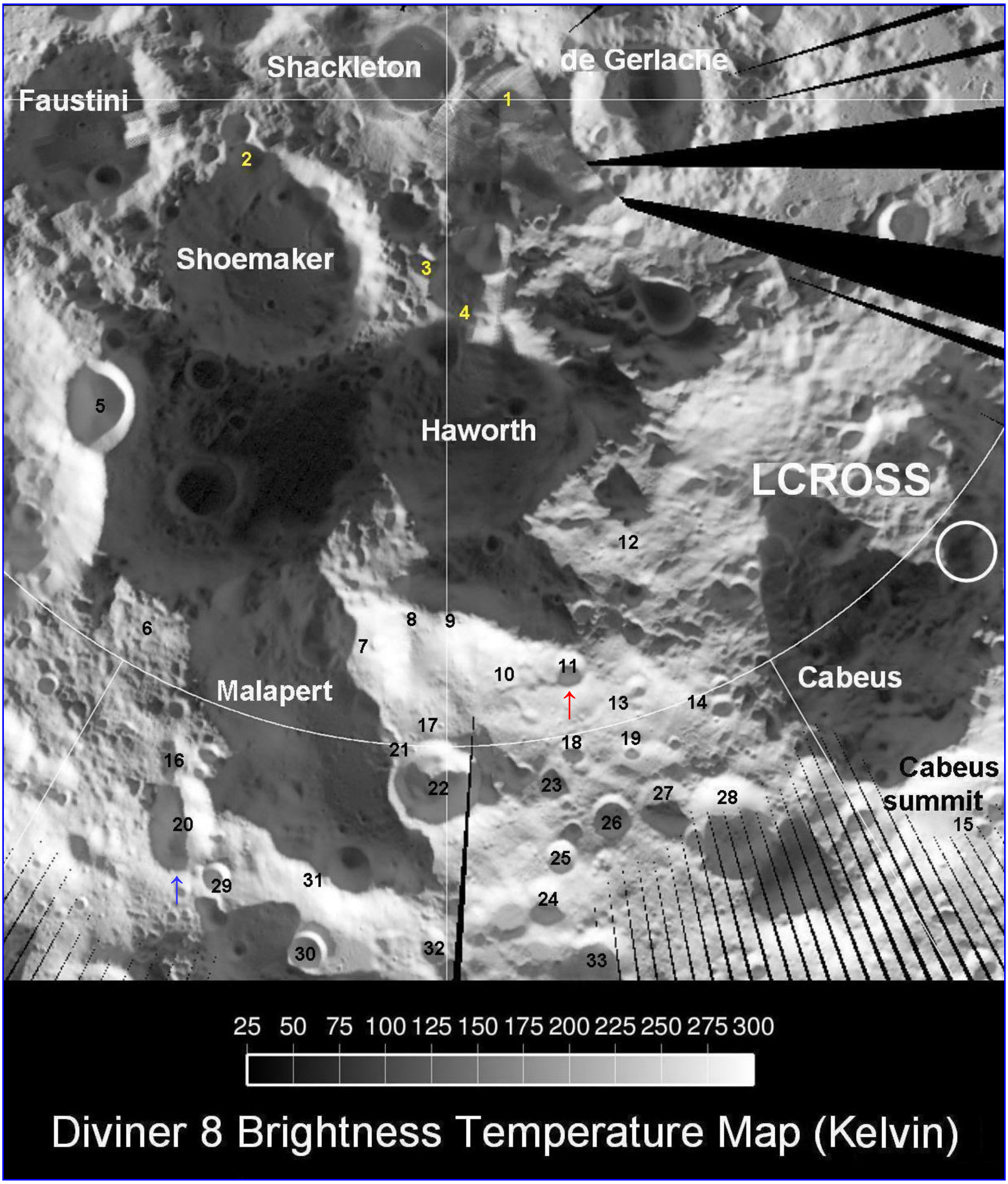


Lunar Reconnaissance Orbiter photograph of the south polar area, vertical view.

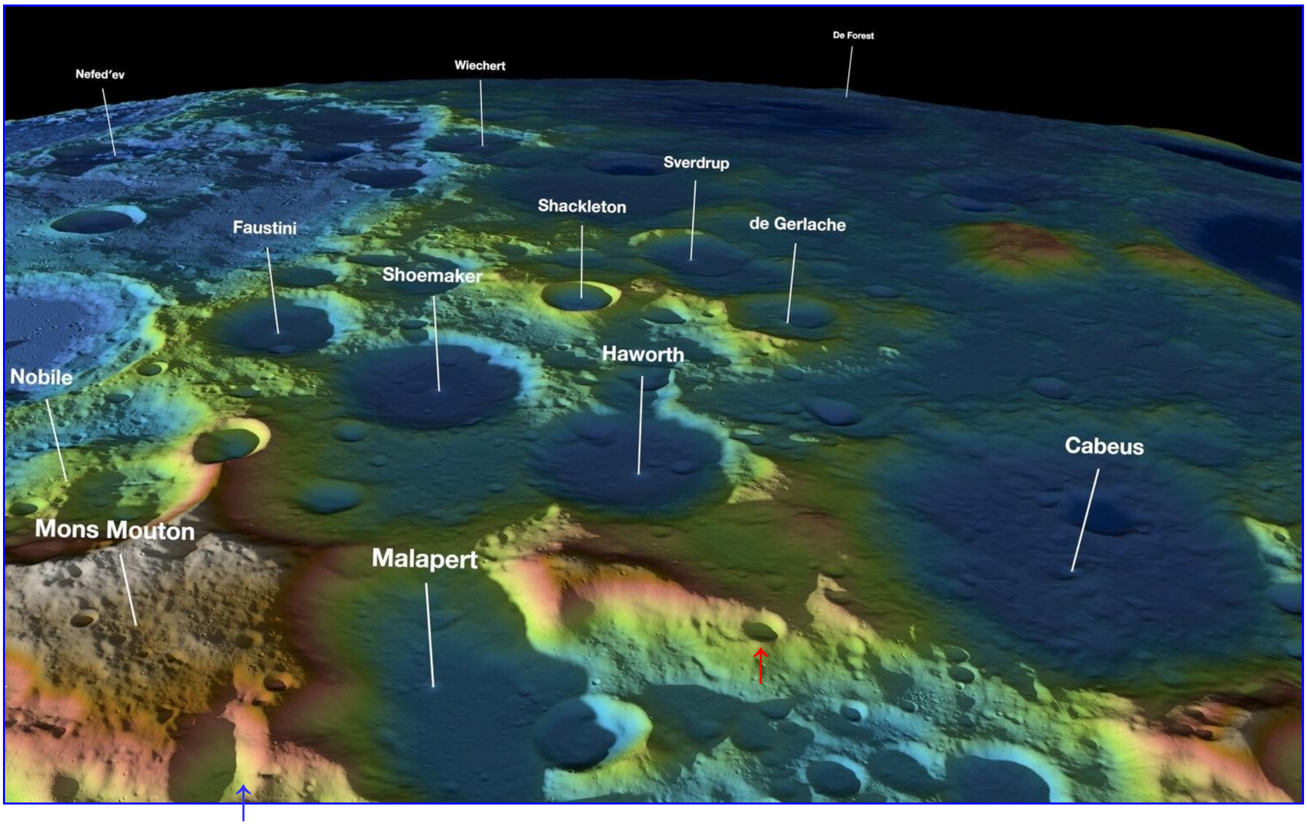


Lunar CRater Observation and Sensing Satellite (LCROSS) temperature image of the south polar area, vertical view. Launched on June 18, 2009, it was to collect data from the impact and debris plume resulting from the launch vehicle's spent Centaur *upper stage striking the crater Cabeus on the Moon (180 kilometres north-west of the South Pole) on October 9, 2009. The data was gathered by a small "Shepherding Space-craft" which followed the* Centaur *down and flew through the debris plume.*

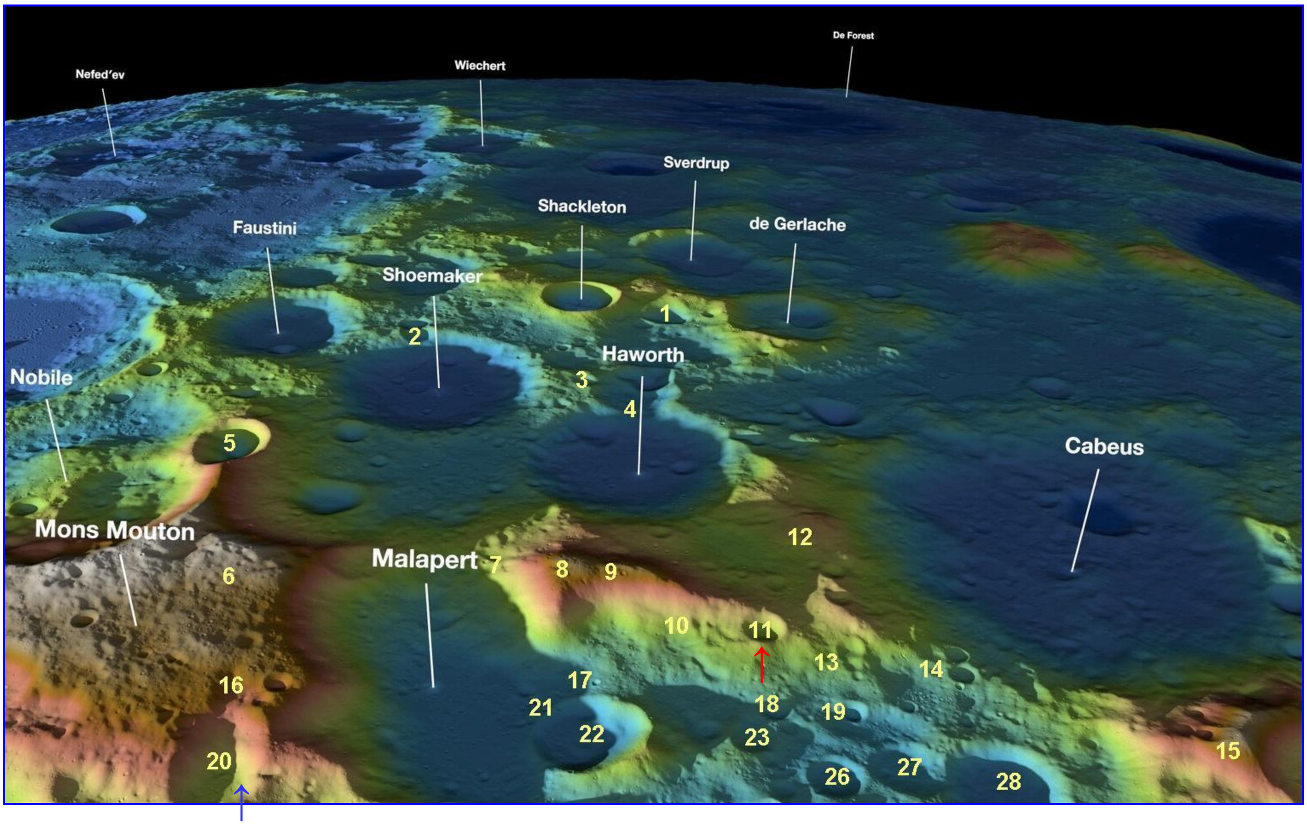
The impact, which created a 27 metre crater and excavated more than 350 tonnes of lunar material, confirmed that water was detected in the blast. This was anticipated, as research indicated that water molecules would not be found elsewhere on the Moon, as the high temperatures on the surface during the lunar day would cause any water molecules to evaporate and be lost into space. The only place where water might be found would be in the floors of deep craters at the poles which would be frozen in perpetual darkness. This fact convinced NASA to go ahead with establishing a lunar base in the nearby south polar area, for the presence of water was a prerequisite for making hydrogen.



Lunar Crater Observation and Sensing Satellite (LCROSS) temperature image of the south polar area, vertical view. The brightness of an area indicates its temperature. 33 lunar craters and craterlets are marked with numbers. See page 39 for identification and descriptions of these features.



Lunar Reconnaissance Orbiter: LRO Camera. This natural-colour global mosaic is based on the 'Hapke normalised' mosaic from LRO's wide-angle camera. The data has been gamma corrected, white balanced, and range adjusted to more closely match human vision. Horizontal view. with 28 lunar craters and craterlets marked. See page 39 for identification and descriptions of these features.



Lunar Reconnaissance Orbiter: LRO Camera. This is a horizontal view, with 28 lunar craters and craterlets marked with numbers. See page 39 for identification and descriptions of these features.

Key to Numerals in images on pages 37, 38 and 40.

1: 13 km crater between Shackleton and De Gerlache, impinging on the connecting ridge between those two craters.

2: Two conjoined 8 km craterlets on the south-eastern rim of the 52 km crater Shoemaker.

3: 7 km craterlet 35 km due north of Shackleton.

4: 50 km long valley leading south from the 51 km crater Haworth towards crater #1 in this list.

5: One of two 21 km craters sitting squarely on opposite sides of the rim of the 79 km crater Nobile - this is the one nearer to the South Pole.

6: The Leibnitz Beta Plateau - a proposed lunar landing site.

7: A meteor strike on the eastern slope of the Malapert Massif has left a downhill scar with a craterlet at its lower end. The Malapert Massif is another proposed landing site.

8: The eastern summit of the Malapert Massif.

9: A one-kilometre craterlet near the western summit of the Malapert Massif.

10: A small group of craterlets in the north-western foothills of the Malapert Massif.

11: A 7 km craterlet at the western end of the Malapert Massif.

12: An elevated part of the rim between the Haworth crater and 98 km Cabeus crater.

13: A group of three contiguous craterlets 10 km west of #11 in this list. They are aligned almost north-south, the largest being furthest south.

14: Two conjoined craterlets sitting on the north-north-western rim of Cabeus crater. The one nearer the South Pole is slightly smaller than the other.

15: The highest point on the north-western rim of Cabeus crater.

16: A 7 x 10 km badly eroded crater adjoining the eastern rim of 70 km irregular Malapert crater.

17: A one-kilometre craterlet just outside the southern rim of crater #22 in this list.

18: A 6 km craterlet 13 km north of #11 in this list.

19: A 5 km craterlet 9 kilometres west of #18 in this list. The four craterlets #11, 13, 18 and 19 form a useful squarish shape to the west of the Malapert Massif.

20: This is an elliptical crater about 22 km long in its major axis. It is called Malapert E and is adjacent to #16 in this list.

21: This is a one-kilometre craterlet just inside the south-eastern rim of crater #22 following.

22: This 23 km crater is due north of the Malapert Massif and is a good guide to nearby features.

23: This 8 km craterlet is 14 km west of #22 and abuts on #18 to the south-west.

24 to 28: This is a curved line of five craters in roughly increasing order of size, #28 being the largest.

29: This 8 km craterlet adjoins the north-west rim of #20.

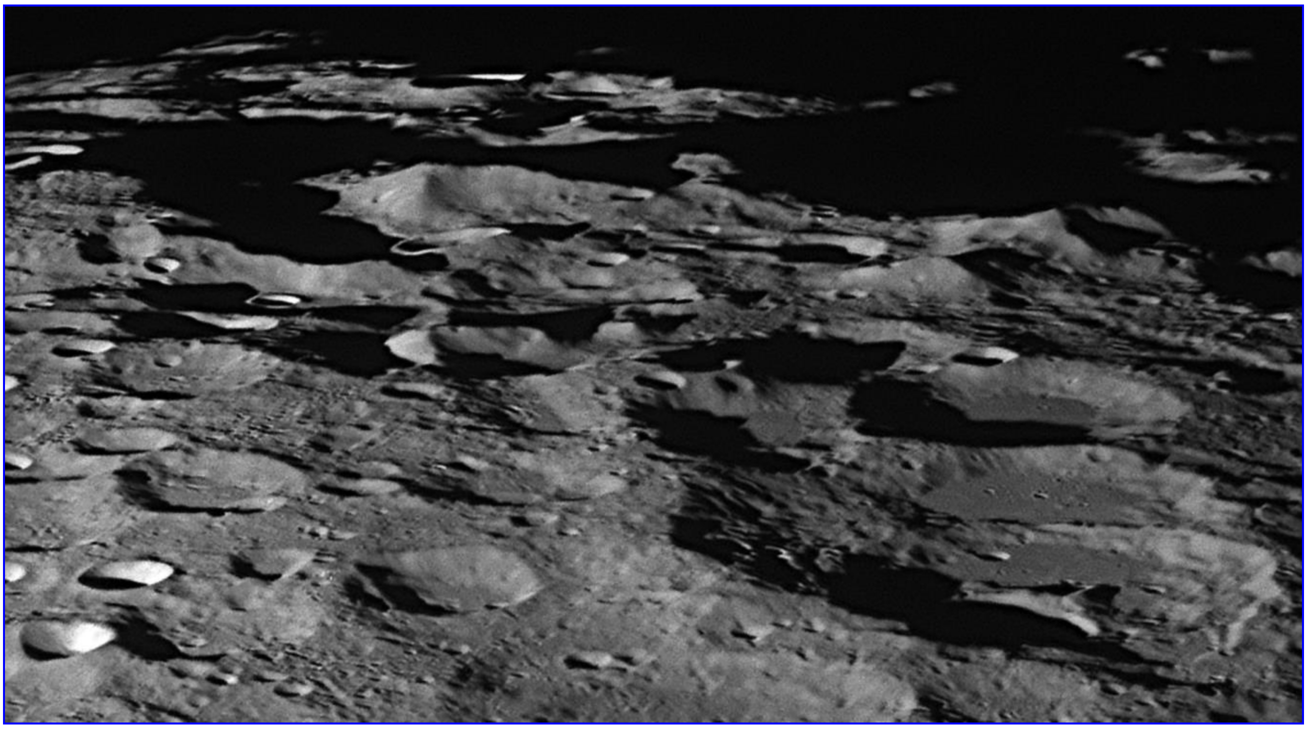
30: This 10 km crater lies in a valley, separated from the 70 km irregular crater Malapert by a ridge running south-east to north-west, which is part of Malapert's northern rim.

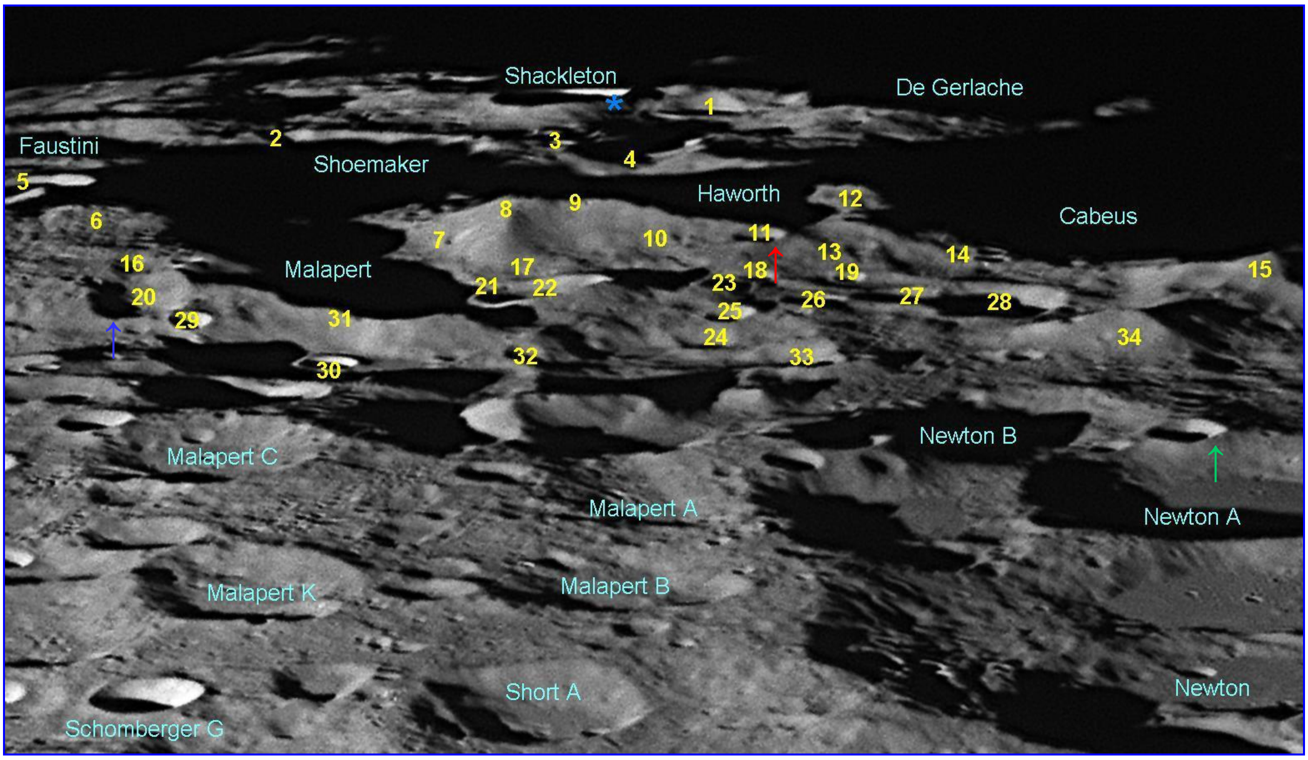
31: This one-kilometre craterlet sits squarely on the skyline of the ridge referred to in #30. It is 13 km south of #30.

32: This is a 5 x 7 km craterlet 29 km north of #22.

33: This 16 km crater appears as a continuation of the curved line of craters from #28 to #24.

34: This craterlet was formed when the impactor struck the northern slope of a mountain.





The width of the field of view (left margin to right margin) at the foreground of this image (Short A crater) is about 185 km.

The width of the field of view (left margin to right margin) in the background of the image (Shackleton crater) is about 195 km. The difference in size between the foreground and background is tiny, as there is very little difference in the distance from the observer on Earth to Short A (361 200 kilometres), and to Shackleton (361 600 kilometres) on that particular date (May 4, 2020), only about 400 kilometres difference.

34 lunar craters and craterlets are marked with numbers. See page 39 for identification and descriptions of these features.

NASA's Collaborations for Commercial Space Capabilities

NASA has for decades wished to support a robust 'low Earth orbit economy' that will boost education and job growth in science and engineering, and will spur economic growth through the creation of new space markets. Private space industry companies were rapidly being established in the new century, and NASA felt that everyone would benefit if they all co-operated and learned from each other. With this in mind, they set up a new division called ***Collaborations for Commercial Space Capabilities (CCSC)*** in early 2014 to co-ordinate the work of those companies with NASA. Initially, the aim was to develop new types of space technology including commercial rockets, spacecraft and spacesuits, and private companies were asked to offer suggestions.

The first invitation for companies to submit proposals for Collaborations for Commercial Space Capabilities (CCSC-1) was issued in March 2014 and resulted in selection in December 2014 of four non-reimbursable Space Act Agreements that were associated with the development of commercial launch vehicles, spacecraft, and space suits:

- **Northrop Grumman** said it would develop its *Mission Extension Vehicle (MEV)* to reliably and safely rendezvous and dock with a client satellite running low on fuel, taking over its attitude and orbit maintenance. Two of these MEVs have been successfuly fielded for commercial missions. Its *Antares 230* rocket would be adapted to take cargo to the *International Space Station*. As the *Antares 230* uses Russian engines, a new *Antares 330* series will be developed.
- **Final Frontier Design** would improve its space suit designs for high altitude and space flight, and after acquisition by Paragon Space Development Corporation is supporting NASA's Extravehicular Activity Services (xEVAS) Contract.
- **SpaceX** would develop its *Starship* fully reusable transportation system designed to carry both crew and cargo to Earth orbit, the Moon, Mars, and beyond. *Starship* is currently undergoing flight tests.
- **United Launch Alliance** would perfect its new *Vulcan Centaur* launch vehicle that will replace its *Atlas* and *Delta* systems, and provide higher performance and greater affordability. *Vulcan Centaur's* initial flight is planned for late 2023.

NASA has for many years supported a continuous U.S. human presence in low Earth orbit with astronauts living and working aboard the *International Space Station*. In 2019, NASA adopted a strategy to help achieve the agency's goal of a low-Earth orbit marketplace where NASA is one of many customers, and the private sector leads the way. This strategy will allow NASA to focus on its *Artemis* missions to the Moon ahead of human missions to Mars while continuing to use low-Earth orbit as a training and proving ground for deep space exploration.

After observing the remarkable progress shown by private companies in recent years, in 2023 NASA released CCSC-2 which invited these companies to submit further proposals which could be advantageous to NASA. On the strength of their applications, **Blue Origin LLC** (Kent, Washington), **Northrop Grumman Systems Corporation** (Dulles, Virginia), **Sierra Space Corporation** (Broom-field, Colorado), **Space Exploration Technologies Corporation** (also called **SpaceX**, Hawthorne, California), **Special Aerospace Services** (Boulder, Colorado), **ThinkOrbital Inc**. (Lafayette, Colorado), and **Vast Space LLC** (Long Beach, California) were confirmed as members of the group.

NASA selected the projects below based on an evaluation of their relevance to achieving the agency's goals and its ability to provide the requested resources, as well as the feasibility of the company's business and technical approach. Each company bears the cost of its participation.

"It is good to see companies invest their own capital toward innovative commercial space capabilities, and we've seen how these types of partnerships benefit both the private sector and NASA," said Phil McAlister, director of commercial spaceflight at NASA Headquarters in Washington, D.C. "The companies can leverage NASA's vast knowledge and experience, and the agency can be a customer for the capabilities included in the agreements in the future. Ultimately, these agreements will foster more competition for services and more providers for innovative space capabilities."

Current Projects:

Blue Origin is working with NASA to develop integrated commercial space transportation capability that ensures safe, affordable, and high-frequency US access to orbit for crew and other missions.

Northrop Grumman is collaborating with NASA on the company's 'Persistent Platform' to provide autonomous and robotic capabilities for science research in low Earth orbit. As the final *Antares 230* rocket flew on 1 August 2023, they will use SpaceX rockets until the *Antares 330* comes on-line.

Sierra Space is collaborating with NASA for the development of the company's commercial low Earth orbit ecosystem, including next-generation space transportation, in-space infrastructure, and expandable and tailorable space facilities providing a human presence in low Earth orbit.

SpaceX is collaborating with NASA on an integrated low Earth orbit architecture to provide a growing portfolio of technology with near-term *Dragon* evolution and concurrent *Starship* development. This architecture includes *Starship* as a transportation and low Earth orbit destination element supported by *Super Heavy*, *Dragon* and *Starlink*, and constituent capabilities including crew and cargo transportation, communications, and operational and ground support. When the *International Space Station* reaches its operational end around 2030, it may be replaced by a modified *Starship*.

Special Aerospace Services is collaborating with NASA on an in-space servicing technology, propulsion, and robotic technology called the 'Autonomous Manoeuvering Unit (AMU)' and the 'Astronaut Assist-AMU' for mobility applications intended for safer assembly of commercial low Earth orbit destinations, servicing, retrieval, and inspection of in-space systems.

ThinkOrbital is collaborating with NASA on the development of 'ThinkPlatforms' and 'CONTESA (Construction Technologies for Space Applications)'. ThinkPlatforms are self-assembling, single-launch, large-scale orbital platforms that facilitate a wide array of applications in low Earth orbit, including in-space research, manufacturing, and astronaut missions. CONTESA features welding, cutting, inspection and additive manufacturing technologies, and large-scale in-space fabrication.

Vast is collaborating with NASA on technologies and operations required for its microgravity and artificial gravity stations. This includes the 'Haven-1' commercial destination, which will provide a microgravity environment for crew, research, and in-space manufacturing, and the first crewed mission, called *Vast-1*, to the platform. Development activities for larger space station modules will also take place under the Space Act Agreement.

NASA's support for a robust low Earth orbit economy is intended to boost education and job growth in science and engineering, and to spur economic growth through the creation of new space markets. In 2019, NASA adopted a strategy to help achieve the agency's goal of a low Earth orbit marketplace where NASA is one of many customers and the private sector leads the way. This strategy will enable NASA to continue using low Earth orbit to foster scientific discovery and technology development that both improve life on Earth and advance human exploration into deep space. For manned spacecraft visiting the Moon and other planets, the US Defense Advanced Research Projects Agency (DARPA) has asked the **Lockheed Martin Corporation** to develop a nuclear-powered spacecraft under a project called *Demonstration Rocket for Agile Cislunar Operations (DRACO)*. This project is expected to lead to a rapid advancement in propulsion technology. For more information about these initiatives, visit https://www.nasa.gov/leo-economy

Space Tourism

Independently of these collaborations, the space tourism company **Virgin Galactic** launched its first commercial flight to the threshold of space on 29 June 2023. This flight was jointly paid for by the Italian Air Force and the National Research Council of Italy. Virgin Galactic's spaceflight system is to use a mothership which looks like a regular jet plane except that it has two widely-spaced fuselages attached to its long wing. The fuselages are identical, with a pilot's cockpit up front and a tailplane at the rear. The one used for the first commercial spaceflight (*Galactic 01*) was called ***VMS Eve*** (*VMS = Virgin MotherShip*). Attached to the centre of the wing between the two fuselages was the ***SpaceShipTwo*** spaceplane called ***VSS Unity*** (*VSS = Virgin SpaceShip*). This is a small rocket-powered plane that has a cabin for two pilots and six passengers. It is superficially similar to the two cabins ahead of the mothership's wings so that when loaded, the mothership looks like a plane with

VMS Eve with VSS Unity attached in the centre, on the morning of 29 June 2023, prior to its successful flight.

one wing, three cabins, two fuselages, two tailplanes and four jet engines. The RM2 rocket engine in *Unity* only has enough fuel to reach an altitude of 100 kilometres. The spaceplane has two stubby wings, each of which has a hinged boom running aft which carries an inclined tailplane with a rudder and two stabilisers. The booms are normally horizontal but prior to re-entry, both can be pivoted up from the wing trunnion bearings by 60º or more to increase drag, reduce speed and minimise heating from friction. This is called 'feathering' the wings and allows *Unity* to act as a spacecraft. The whole underside of the spaceplane has black heatproof tiles to protect it from the heat of re-entry. On descending to an altitude of about 23000 metres, both booms are brought down to horizontal to increase lift, for the spaceplane then has to act as a glider when preparing to land. Like the earlier but much larger *Space Shuttles*, the spaceplane is now without power. It glides to the Spaceport runway and touches down nose-up on its two wheels, and then the nose skid.

This was *VSS Unity's* sixth flight to suborbital space, although there were also some early experimental flights. This was the first commercial flight, being hired by the Italian government. It began on the morning of 29 June from Spaceport America in the New Mexico desert. The mothership took off and climbed to an altitude of 15 000 metres and a speed of 550 kilometres per hour. At that point the *VSS Unity* was released, and dropped away to fly by itself, while the mothership returned to Spaceport America.

The underside of VMS Eve with VSS Unity in flight; release of VSS Unity; VMS Eve lands without VSS Unity.

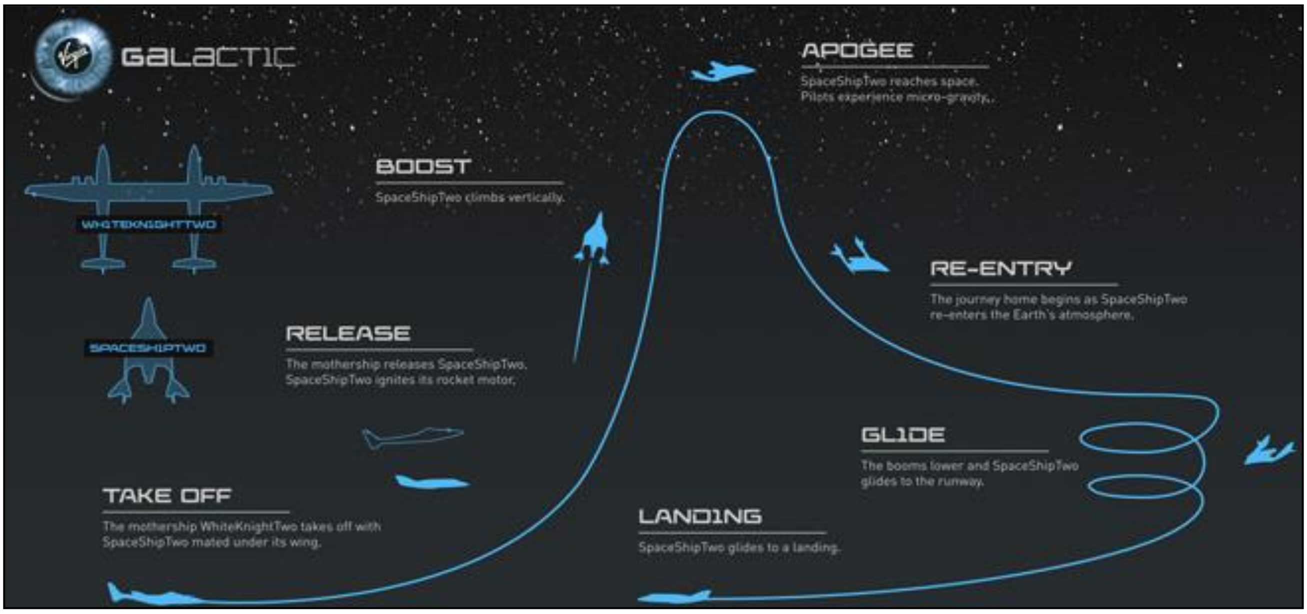
The spaceplane then ignited its rocket motor, and accelerated to Mach 1 (the speed of sound). It turned upwards and climbed vertically, continuing to accelerate to a maximum speed of Mach 2.88 (3550 km/hour). At an altitude of 85 kilometres, 2 minutes 38 seconds after release from *VMS Eve*, the rocket motor was shut down and the two pilots, astronaut instructor and three Italian scientist/passengers enjoyed a few minutes of weightless conditions, and seeing the curve of the Earth against the blackness of space. In that short time, over 13 science experiments were conducted (a mix of autonomous and guided tasks), that studied fluid dynamics and sustainable materials for medical applications. The

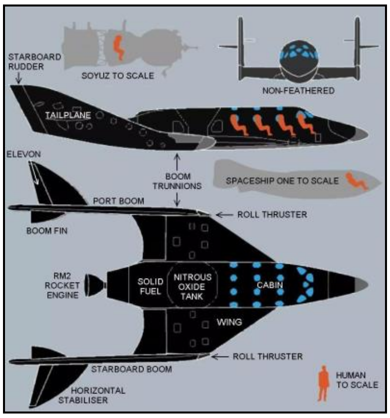
two booms and tailplanes were feathered by 60º for re-entry, and the crew experienced forces up to 6G as the craft decelerated. When the altitude had been reduced to 22.9 kilometres, the booms were returned to the horizontal configuration and the craft became a glider. After a flight of 90 minutes, the spaceplane landed back at Spaceport America. The flight was a complete success.

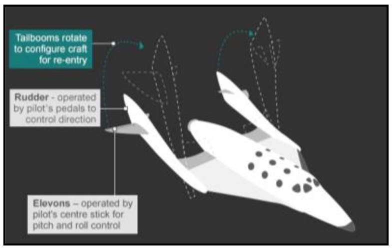
'Feathering' the wings: *Attached to the end of each wing is a boom running aft, carrying an inclined tailplane with a rudder and two electric servo horizontal stabilisers – a large one outboard with an elevon, and a smaller one inboard. The tailplanes are inclined to enable nose-up landing. When flying attached to the mothership, or when under rocket power or gliding, the booms are in their horizontal positions. Thus the stabilisers and elevons are also horizontal, providing lift and no drag. The pilot manages the rudders with pedals to control direction, and manages the elevons with his centre stick for pitch and roll control.*

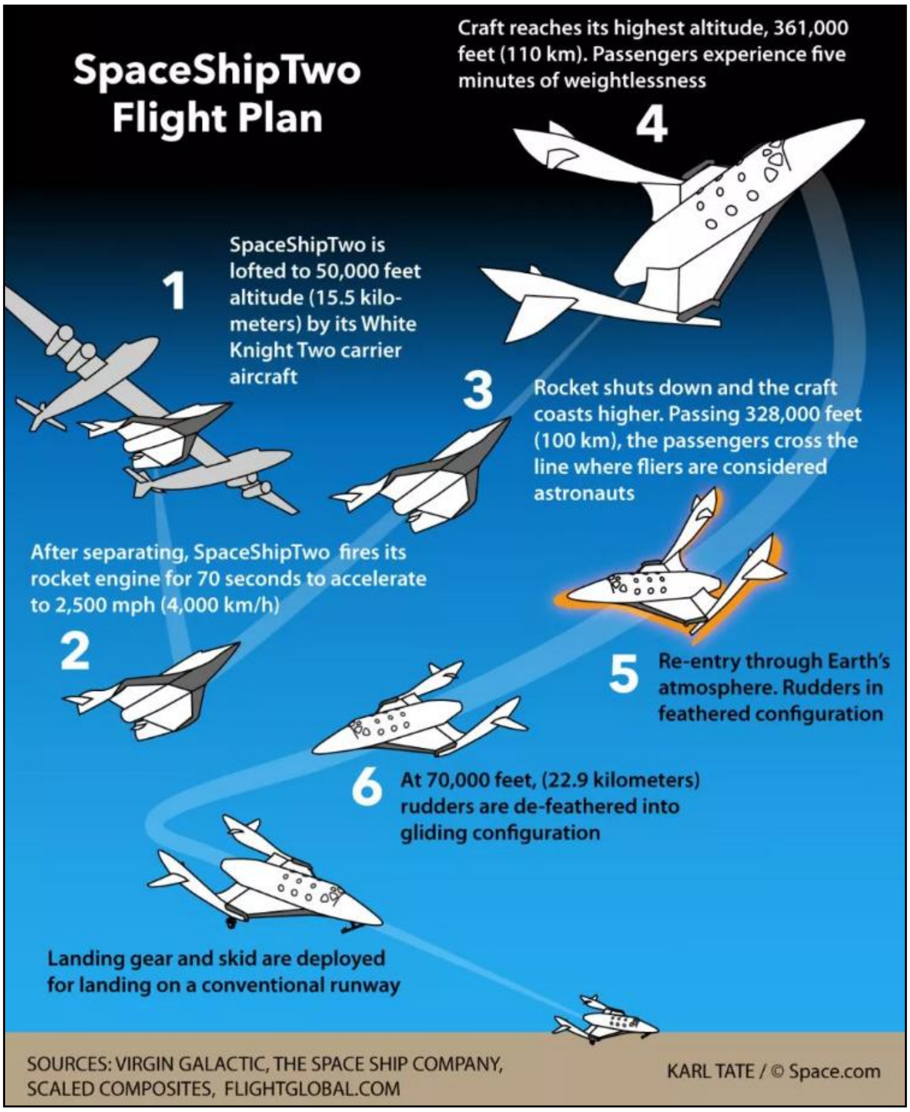
Mid-flight, when the spaceplane is preparing for re-entry, the booms, pivoting just behind their front ends, are raised, bringing the aft ends of the tailplanes up by 60º or more. This brings the stabilisers into the airstream at a high angle, impeding the flow of (admittedly thin) air and providing additional drag depending on the angle, the drag increasing as the spaceplane descends into denser air. This assists in slowing the spaceplane down and contributes to stability. At an altitude of about 70 000 feet or 22.9 kilometres, the booms are lowered to the horizontal position, making the stabilisers also horizontal. In this way they contribute to lift, which assists the main wings as the spaceplane now has to glide to the Spaceport runway unpowered.

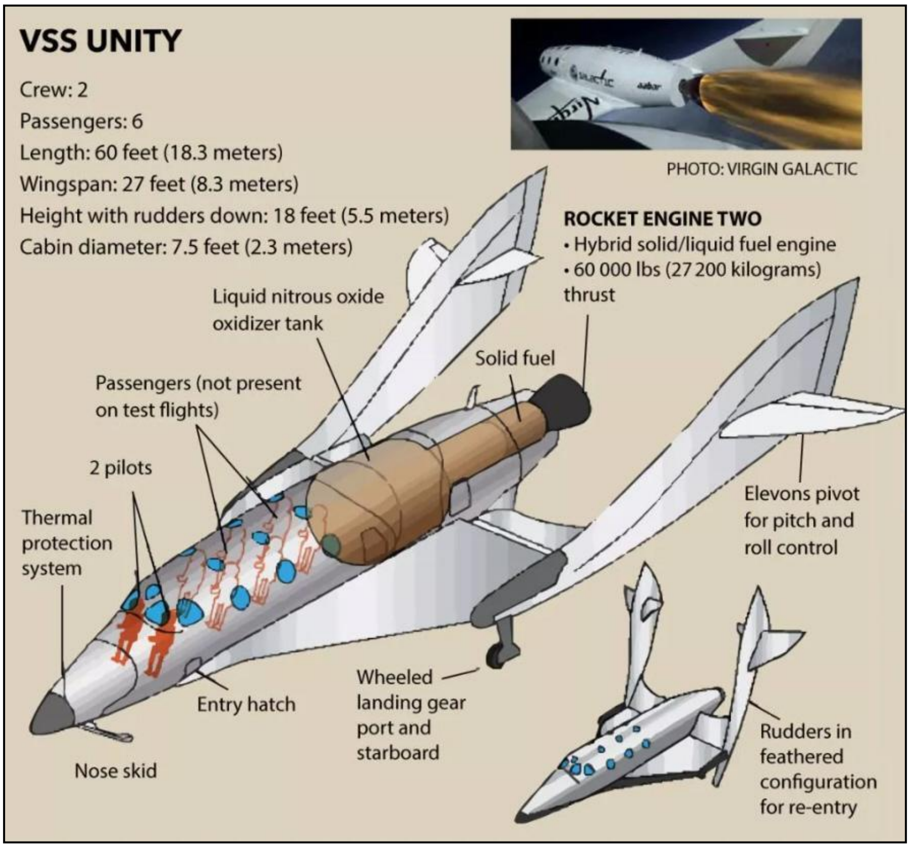
To slow the vehicle when preparing to touch down, the booms are raised slightly as seen above and on the next page, to act as flaps or air brakes, and to avoid the tailplanes striking the runway. It lands nose-up on two wheels located near the ship's centre of gravity, and the wheel brakes are applied gently so that when almost stopped the spaceplane leans forward until the sprung nose skid makes firm contact with the ground.




STARBOARD RUDDER
SOYUZ TO SCALE
NON-FEATHERED
TAILPLANE
ELEVON
BOOM TRUNNIONS
SPACESHIP ONE TO SCALE
PORT BOOM
ROLL THRUSTER
BOOM FIN
RM2 ROCKET ENGINE
SOLID FUEL
NITROUS OXIDE TANK
CABIN
WING
ROLL THRUSTER
STARBOARD BOOM
HORIZONTAL STABILISER
HUMAN TO SCALE


Tailbooms rotate to configure craft for re-entry
Rudder - operated by pilot's pedals to control direction
Elevons – operated by pilot's centre stick for pitch and roll control


SpaceShipTwo Flight Plan
1 SpaceShipTwo is lofted to 50,000 feet altitude (15.5 kilometers) by its White Knight Two carrier aircraft
2 After separating, SpaceShipTwo fires its rocket engine for 70 seconds to accelerate to 2,500 mph (4,000 km/h)
3 Rocket shuts down and the craft coasts higher. Passing 328,000 feet (100 km), the passengers cross the line where fliers are considered astronauts
4 Craft reaches its highest altitude, 361,000 feet (110 km). Passengers experience five minutes of weightlessness
5 Re-entry through Earth's atmosphere. Rudders in feathered configuration
6 At 70,000 feet, (22.9 kilometers) rudders are de-feathered into gliding configuration
Landing gear and skid are deployed for landing on a conventional runway
SOURCES: VIRGIN GALACTIC, THE SPACE SHIP COMPANY, SCALED COMPOSITES, FLIGHTGLOBAL.COM
KARL TATE / © Space.com


VSS UNITY
Crew: 2
Passengers: 6
Length: 60 feet (18.3 meters)
Wingspan: 27 feet (8.3 meters)
Height with rudders down: 18 feet (5.5 meters)
Cabin diameter: 7.5 feet (2.3 meters)
PHOTO: VIRGIN GALACTIC
ROCKET ENGINE TWO
• Hybrid solid/liquid fuel engine
• 60 000 lbs (27 200 kilograms) thrust
Liquid nitrous oxide oxidizer tank
Solid fuel
Passengers (not present on test flights)
2 pilots
Thermal protection system
Elevons pivot for pitch and roll control
Entry hatch
Wheeled landing gear port and starboard
Nose skid
Rudders in feathered configuration for re-entry

The second commercial spaceflight (*Galactic 02*) took place on 10 August 2023. It carried three crew and three passengers. Two passengers were a mother and her student daughter (*right*) from the island of Antigua – they won their seats in a fundraising competition by *Space for Humanity*, an organisation seeking to democratise space travel. The third was an 80-year-old former Olympian canoeist with Parkinson's Disease. They were Virgin Galactic's commercial astronauts Nos. 11, 12 and 13.

The third commercial flight (*Galactic 03*) flew on 8 September 2023. On board was Ken Baxter, a Las Vegas real estate magnate who bought the first ticket in 2004 and waited 19 years for his ride. He documented his experience here. Four weeks later, the fourth flight (*Galactic 04*) took place on 6 October with a British advertising executive, an American astronomy educator and a Pakistani lady on board. On 2 November the *Galactic 05* flight took place with two research scientists and a space tourist as passengers with the two pilots and astronaut instructor. On 26 January 2024, *Galactic 06* flew two Americans, an Austrian and a Ukrainian lady to the edge of space in a 90-minute trip. On 8 June 2024, *Unity* flew for the last time with *Galactic 07* carrying a Turkish astronaut and three space tourists. It has now been permanently grounded.

The company is now concentrating its financial resources on accelerating construction of their Delta-class spaceplanes which look similar but are far more sophisticated 'under the hood'. Each Delta craft will be capable of flying up to twice per week. That's an eight-fold increase over *Unity*, which was designed to fly about once per month at most. In addition, each Delta vehicle can carry six paying customers per flight. As a result, every Delta spaceplane will be able to generate twelve times more revenue per month than *Unity*, so progressing to the Delta vehicles seen below makes good financial sense. Virgin Galactic hopes to have two Deltas flying regularly by 2026.

Once those new vehicles enter service, Virgin Galactic could be flying paying customers to suborbital space every day. There is a demand – a ticket to ride on a suborbital mission with the company currently costs $ 450 000, and over 1000 people have booked seats so far. The intention is to make travel to the Kármán line (the threshold of space, altitude 100 kilometres, beyond which the fliers are considered to be "astronauts"), or even Earth orbit, become less rigorous or even routine for more people.

Unity has been lifting off from Spaceport America in New Mexico, Virgin Galactic's commercial hub. After the vehicle's final flight next year, many company employees will be transferred from the site to a new factory in Phoenix, Arizona, which will help build the Delta-class vehicles. Virgin Galactic aims to begin flight tests of the first Delta spacecraft in 2025 and to bring that vehicle into service in 2026, with others to follow over the ensuing months and years.

Virgin Galactic has one main competitor in the suborbital space tourism business – **Blue Origin**, founded by Jeff Bezos, who also is founder and current executive chairman of Amazon. He is worth $200 billion. Blue Origin has a rocket-capsule combination called *New Shepard*, which is a fully reusable, vertical take-off, vertical landing (VTVL) space vehicle composed of two modules: a pressurised crew capsule and a booster rocket that they call the propulsion module. The fuel is liquid hydrogen and liquid oxygen. It is controlled entirely by on-board computers, without input from ground control or a human pilot. The rocket is designed to take passengers into suborbital space inside a crew capsule. The capsule features six large observation windows, one per seat.

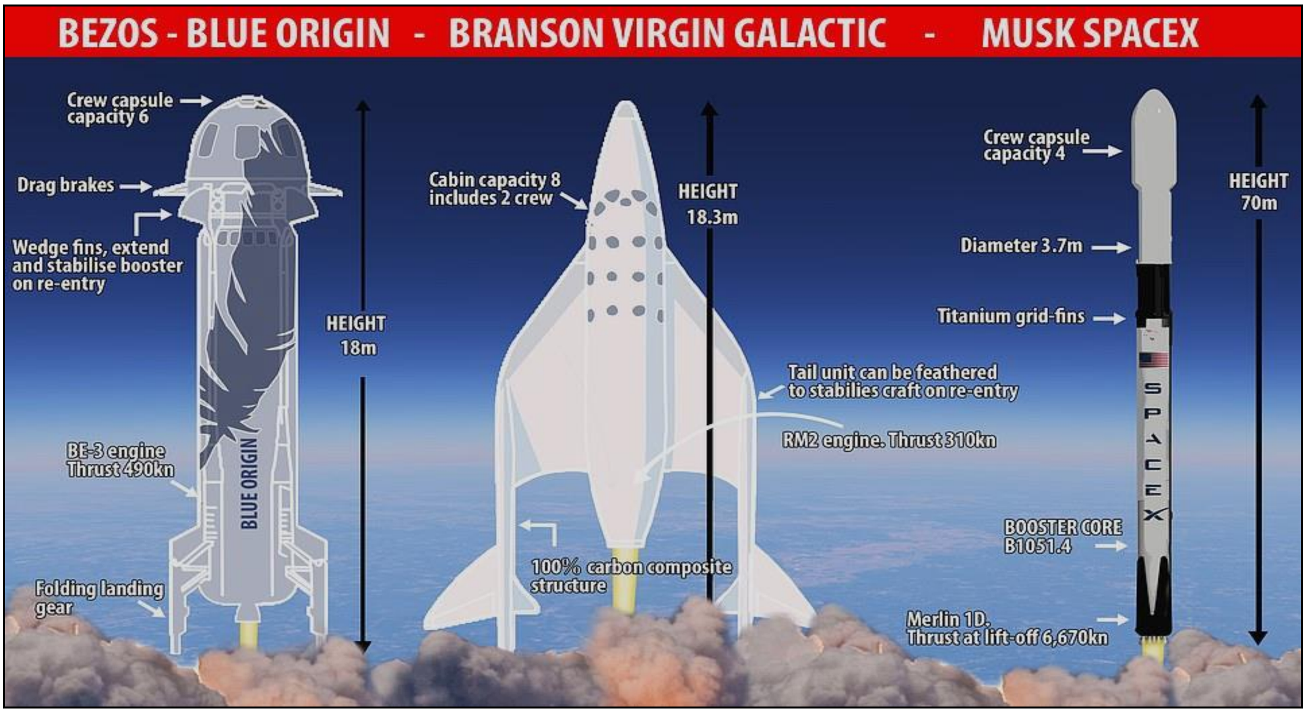
In November 2015, it was the first reusable rocket to successfully make a soft landing on the ground (see above), beating the more famous *SpaceX Falcon 9* booster by several weeks. By June 2021, it had made 15 uncrewed test launches. *New Shepard* went on to launch with paying passengers on six 10-minute trips to the Kármán line, the first three with four aboard, the following three with six. Jeff Bezos went on the first crewed mission, NS-16, on 20 July 2021. One passenger, Evan Dick, has flown twice, on NS-19 and NS-21.

An accident occurred with NS-23 in September 2022, when the booster rocket failed 1 minute 5 seconds after launch. Luckily this was an uncrewed research flight. The capsule activated its emergency escape system after the booster suffered an anomaly just before the vehicle reached an altitude of 9 kilometres. The escape system worked as planned, jetting the capsule away from trouble and allowing it to descend safely to Earth under parachutes. The fate of the booster was not reported, but presumably it was destroyed. This led to a year-long pause in progress while technicians studied the problem and made improvements. An unmanned test flight took place on December 18, 2023, using a modified booster and the same capsule as NS-23. This was completely successful, and flights carrying paying passengers resumed on July 20, 2024. That date was chosen to mark the 52nd anniversary of humans landing on the moon. Bezos was on the flight, along with three other passengers.

For a typical flight, *New Shepard* launches vertically and soars for about two and a half minutes before the main engine cuts off and the capsule separates from the rocket. Passengers are weightless for about four minutes during the 11-minute flight, and are high enough (at an altitude of 93.5 kilometres or 58 miles) to see the curvature of Earth. The spacecraft coasts for a few minutes in space before re-entering the atmosphere and using an autonomous, rocket-powered vertical landing system to touch down tail first.

New Shepard is named after NASA *Mercury* program astronaut Alan Shepard, who was the first American to fly in space in 1961 on what was also a suborbital flight. Up to six people can fly into space at once; the interior volume is said to be large enough for everyone to float and move around. The large windows (1.1 metres high and 0.7 metres wide) will provide a spectacular view of Earth. Passengers aboard the Blue Origin spacecraft, however, will enjoy more than 10 times the amount of room in the capsule than Shepard did in his *Freedom 7* spacecraft, according to the company. In addition to passengers, the spacecraft aboard *New Shepard* can carry standardised experiments of up to 50 lbs. (23 kilograms), with larger options available for custom requests.

Click on this link [“Everyone gets a window seat”](#) for a short look at the interior of the Blue Origin capsule. Click [here](#) to join Jeff Bezos and five others for a 10 minute trip in NS-19 from lift-off to landing.



Latest News:

Each improvement of the *Starship* Raptor engine V1 → V2 → V3 has produced more power and used fewer parts. The latest V3 is fueled with ‘Methalox’, a combination of cryogenic liquid methane and liquid oxygen. The latest V3 engine produces 270 tons of thrust. A 20 million pound thrust *Starship* booster with the Raptor V3 engines will have 2.63 times the power of the *Saturn V*. NASA hopes to test a nuclear fission-powered spacecraft engine by 2027.

27 Jul 2023: The US Congress has held a public hearing on claims the government was concealing a longstanding program that retrieves and reverse engineers unidentified flying objects (UFOs). Three retired military veterans testified before a House Oversight Subcommittee that was the Congress’s latest investigation into the world of UAPs (unidentified aerial phenomena, the term the US government uses instead of UFOs). The US government has begun taking the issue of UAPs more seriously, pushing for more research as the sightings observed could be a national security matter, i.e. they might be unknown aerial surveillance technology used by China to collect intelligence on US defences.

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