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Saturn V

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Introduction

The Saturn V rocket is an iconic symbol of humanity's exploration of space. It is the largest and most powerful rocket ever built, standing at a towering 363 feet tall and capable of generating more than 7.5 million pounds of thrust. It was developed by NASA in the 1960s. The Saturn V was an important part of the Apollo program, which aimed to land humans on the moon and return them safely to Earth. It was used for all manned Apollo missions, including the historic Apollo 11 mission, during which Neil Armstrong and Buzz Aldrin became the first humans to walk on the moon. But the Saturn V was more than just a means of getting to the moon. Its development and application represented a watershed moment in human history, as well as a symbol of our boundless curiosity and desire to explore the unknown. The Saturn V and Apollo programs legacies continue to inspire future generations of scientists, engineers, and space enthusiasts, and serve as a reminder of the incredible potential of human ingenuity and determination.

History Saturn V

The Florida landscape around the Kennedy Space Center trembled as Apollo 11 launched on its historic mission to carry the first astronauts to the Moon on July 16, 1969, at 9:31 am EDT. Although the skyscraper-sized rocket that made this possible is among the most well-known inventions of the 20th century, the Saturn V's construction wasn't straightforward. Its development is a tale of great technological ingenuity laced with engineering conservatism, politics, intramural conflict, and working on a project that no one had more than a vague picture of until unexpectedly late in the day.

The moon rocket is a magnet for superlatives, as anybody who has ever visited one of the remaining Saturn Vs on exhibit at the Kennedy Space Center in Florida or the Johnson Space Center in Texas, will attest. It not only provided the essential technology for arguably the largest event to occur since a fish first tried to swim out of the water, but it also amassed an incredible number of records that still stand today.

The Saturn V is the highest rocket, surpassing both the Statue of Liberty and the clock tower housing Big Ben at a height of 363 feet (110.6 m). With a weight of 6,540,000 lb (2,970,000 kg), it is also the largest and most powerful rocket to ever take flight. It could launch a payload of 310,000 lb (140,000 kg) into low Earth orbit and 107,100 lb (48,600 kg) on a trajectory to the Moon with a first stage thrust of 7,891,000 lb (35,101 kN).

Picture of Saturn V

If that weren't enough, it's also the biggest flying machine ever constructed in addition to being the biggest liquid-fueled rocket. The most potent engine to enter service is the F-1 first stage engine. Almost 300,000 workers from 20,000 private businesses worked on the building of the 13 Saturn Vs that flew as well as their 19 Saturn I and Saturn IB siblings spanning the whole continental United States. Moreover, it remains the only one to have successfully sent men into deep space and is acknowledged by NASA as the first real space vehicle.

There is yet more. 32 Saturn launches have taken place, and not even one failed or lost a payload. That's an amazing record given that NASA engineers and astronauts were constantly in awe whenever one took off rather than exploding on the launch pad.

Born of chaos

Yet the Saturn V's backstory is what makes it so amazing. Its creation, for such a revolutionary machine, was both quick and horrifyingly difficult. The first Saturn V launched in November 1967, only five years after the Apollo mission was given the go-ahead. The Saturn V was developed from 1960 to 1962 at NASA's Marshall Space Flight Center (previously the Army Ballistic Missile Agency (ABMA)) in Huntsville, Alabama, under the direction of rocket pioneer Wernher von Braun and Arthur Rudolph.

It would be amazing enough, but this was only the surface of an incredible saga that involved a staggering number of simultaneous advancements, difficult choices, political squabbling, global crises, and pushing the frontiers of science and engineering. The development of the

Saturn V was in the middle of a confluence of events, including interservice rivalries, the Cold War, the Space Race, departmental competition, new agencies springing up, and the whole project being tossed around like a hot potato - and all while trying to hammer together an unprecedented partnership between government and private enterprise.

Just to spice things up, there's also a story of a rocket that, once the choice was taken, no one was really sure what to do with or how to accomplish it.

The first glimmer

When Nazi-Germany launched its V-2 ballistic rocket during the Second World War, the Saturn V's history officially began. The V-2, which was created in Peenemunde in Germany, was the most significant liquid fuel rocket ever constructed. The Saturn V may really be seen of as a Super V-2 in many aspects because of how much its design influenced later development.

Picture of V-2 Rocket

Wernher von Braun and 700 other top German rocket experts submitted to the US Army in the closing stages of the war. As a part of Operation Paperclip, they were surreptitiously sent to the United States along with truckloads of blueprints and hundreds of V-2 rockets. Because he believed the US possessed the resources and flexibility to let him pursue his dream of eventually creating a moon rocket, Von Braun had picked the US to surrender to, but the US administration had other plans.

The Germans were imprisoned to White Sands, New Mexico, where they were only allowed to play with seized V-2s, instruct US engineers in rocket science, and produce short-range ballistic missiles for the Army, far from supporting von Braun's aspirations. Once the ABMA was established in 1956, von Braun's team achieved advancements in rocket design that were so significant that the government appointed them a watchdog whose responsibility was to ensure that von Braun's team didn't "accidentally" send a satellite into orbit. The US Air Force was building ICBMs to carry nuclear bombs while also managing the official massive rocket program.

The US Department of Defense then concluded in late 1956 that it required a rocket large enough to launch significant, ill-defined payloads into orbit. The booster required to be able to raise weights weighing between 9,000 and 18,000 kilograms (19,800 to 39,680 lb) and be easily and cheaply constructed. The ABMA accepted the challenge in April 1957 and investigated the viability of building a rocket, named the Super Jupiter, that could produce a thrust of around 1.5 million lb (6,672 kN), which was 10 times more powerful than any rocket in the inventory at the time.

Picture of Super Jupiter Rocket

Von Braun's crew first intended to employ a single enormous engine, but ultimately opted to use four smaller but no less enormous engines, which became known as the F-1. A single engine would have taken significantly longer to construct, even though it would have been lighter, simpler, and less likely to fail than a group of engines. The Super Jupiter, however, was only a theory and some calculations at this stage and was probably never going to be constructed.

As part of the nation's participation in the 1957 International Geophysical Year, President Dwight Eisenhower declared that the United States would launch a man-made satellite into orbit. The Vanguard project, a civilian initiative to modify a Navy sounding rocket to the point where it could launch a grapefruit-sized satellite into orbit, emphasized the benign character of the mission.

This would have been great, except that the Soviet Union launched the first satellite, the Sputnik, into orbit in October 1957. To further emphasize its argument, they launched two more satellites in addition to Laika, the first dog to live in space.

Public terror followed official calm as a result. Sputnik didn't surprise the US government, which was privately relieved and because it meant that the communists would have no justification to protest US launches. But because the USSR was seen as being somewhat backwards and had just launched a missile into space that might have just as well, included a nuclear payload, directed at New York or Washington, the press and the general population throughout the free world erupted into a frenzy.

This was made worse by the fact that Vanguard was elevated from a minor national priority to a leisurely scientific endeavor. It didn't help matters when the rocket exploded on the launch pad on the first attempt, giving the Russians a huge propaganda triumph and the Americans a loss of credibility.

On the other hand, Von Braun had planned for six Jupiter missiles to be hidden away for "storage experiments" because he had foreseen something similar. Von Braun said anxiously that he could launch a satellite in 90 days as Sputnik One sailed above. ABMA already had a Jupiter-rocket at Cape Canaveral ready to launch the first US satellite, Explorer I, on January 31, 1958, when the second Vanguard attempt failed. This Jupiter-rocket is now known as Juno-1.

Saturn, NASA, and ARPA

The Sputnik event sparked a national response in the US and elevated space to a key priority. The Advanced Research Projects Agency (ARPA, now DARPA) was established in February 1958 to aid promote research and technology initiatives by slicing through the US government's maze of internal politics and red tape. Eisenhower gave the go-ahead for the National Aeronautics and Space Administration (NASA) to be established in April of that year to take over the civilian space program.

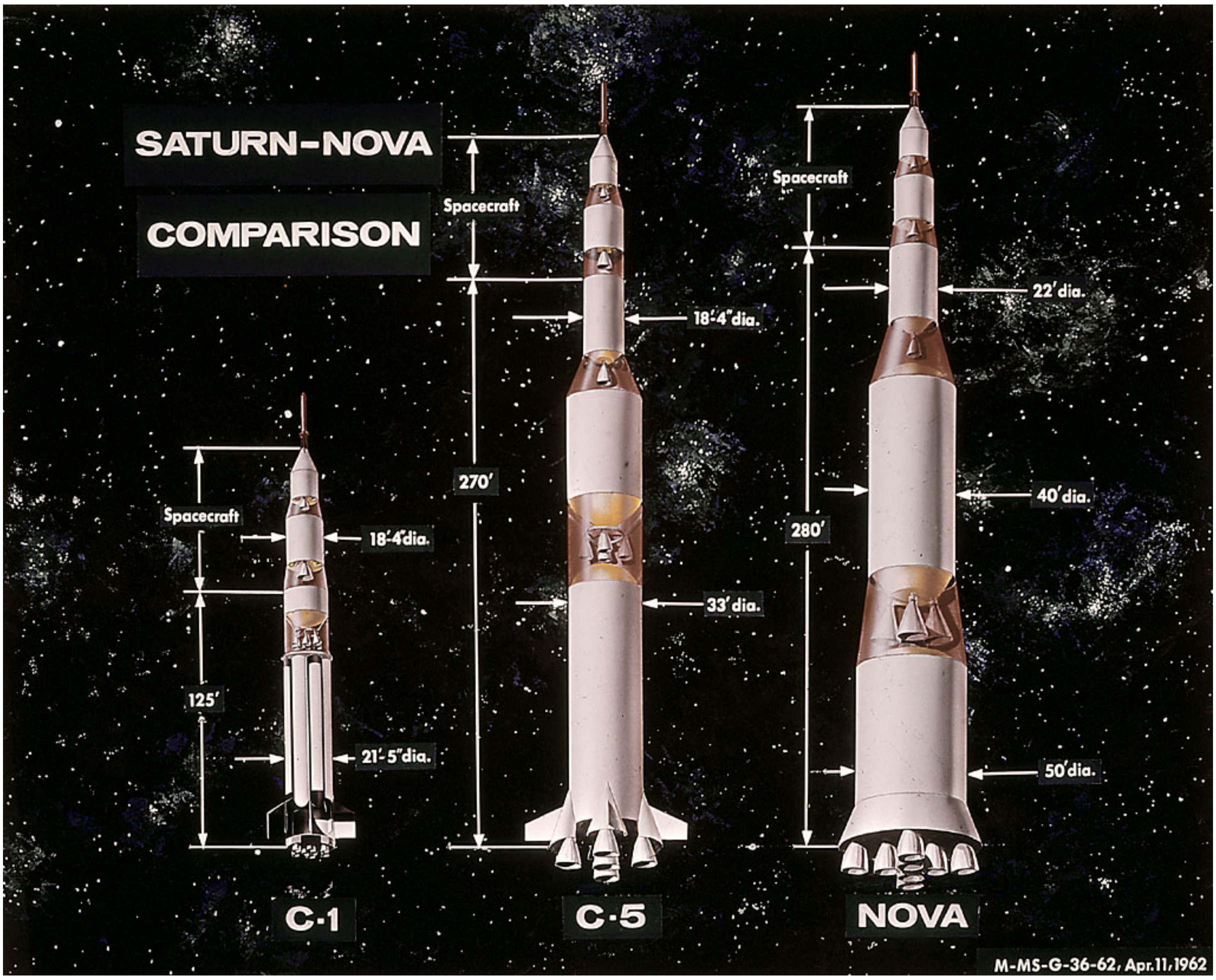
When ARPA agreed to fund the Super Jupiter project, which is now known as the Juno V, in August 1958, it gave the ABMA's endeavor a boost. This was critical because the military was considering abandoning the massive rocket project since it had lost its appeal. Then, in 1960, it gave NASA the entire thing without providing a single cent in exchange.

At this time, von Braun's crew had been relocated to NASA's Marshall Space Flight Center, the ABMA had been disbanded and the rocket's name had been formally changed to Saturn

(MSFC). Furthermore, even if Saturn was still primarily a concept, the engineers knew better which direction to proceed in.

Which Saturn?

The fact that there were at least five or six rockets in the 1960 Saturn project is one illustration of its lack of concentration. At this stage, Saturn was to be a family of multi-mission rockets with a variety of payload and mission combinations. Technically, there were five different types designated C-1, C-2, C-3, C-4, and C-5 plus a mega rocket called the Nova, that, had it ever advanced beyond the concept stage, would have dwarfed the Saturn V.



Picture of Saturn C-1, V and Nova

No one was entirely sure what the Saturns were intended to accomplish or how they were supposed to do it, which is why there were so many rockets. Also, there was no obvious route for developing them. Even though there are six different types of rockets, keep in mind that these are only the main groups. Even the specialists formerly struggled to distinguish between the numerous versions of each of them. There were Saturns with one, two, three, or four stages. Some featured a single engine, while others had clusters. Several of them were repurposed military rockets. Some were completely new. Some had solid boosters or strap-on rockets. A planner's worst nightmare, really.

The largest issue, though, was what the purpose was. For whom and why did the von Braun team create the Saturn? Initially, it was intended for the military community, but they quickly lost interest, opted to follow their own plan, and threatened to reduce financing. Afterwards, von Braun's group and the Saturn were handed over to NASA, but the young space agency had no clue what to do with a massive rocket or even what its ultimate design should be.

When NASA informed the US Congress that it could place a crew in orbit around the Moon in ten years and a manned lander on its surface shortly after, things began to come into focus. The organization discovered that a decade was roughly the correct timeframe for big initiatives, albeit this timescale was not based on any reliable data.

Then, on May 25, 1961, President Kennedy delivered his historic State of the Union speech to Congress, as any fan of Space Race history is aware. "Our nation should commit itself to attaining the objective, before this decade is through, of landing a man on the Moon and returning him safely to the Earth," he said, pledging the United States to be the first to orbit the moon.

Picture of Kennedy’s historic speech

Kennedy's speech had all the necessary drama to embark a great nation on a momentous journey, but as far as the Moon was concerned, what came next was seven months of debate and wrangling. Despite the President's orders, NASA lacked its own rockets and

Programs Mercury and Gemini relied on military vehicles that were woefully inadequate for the task.

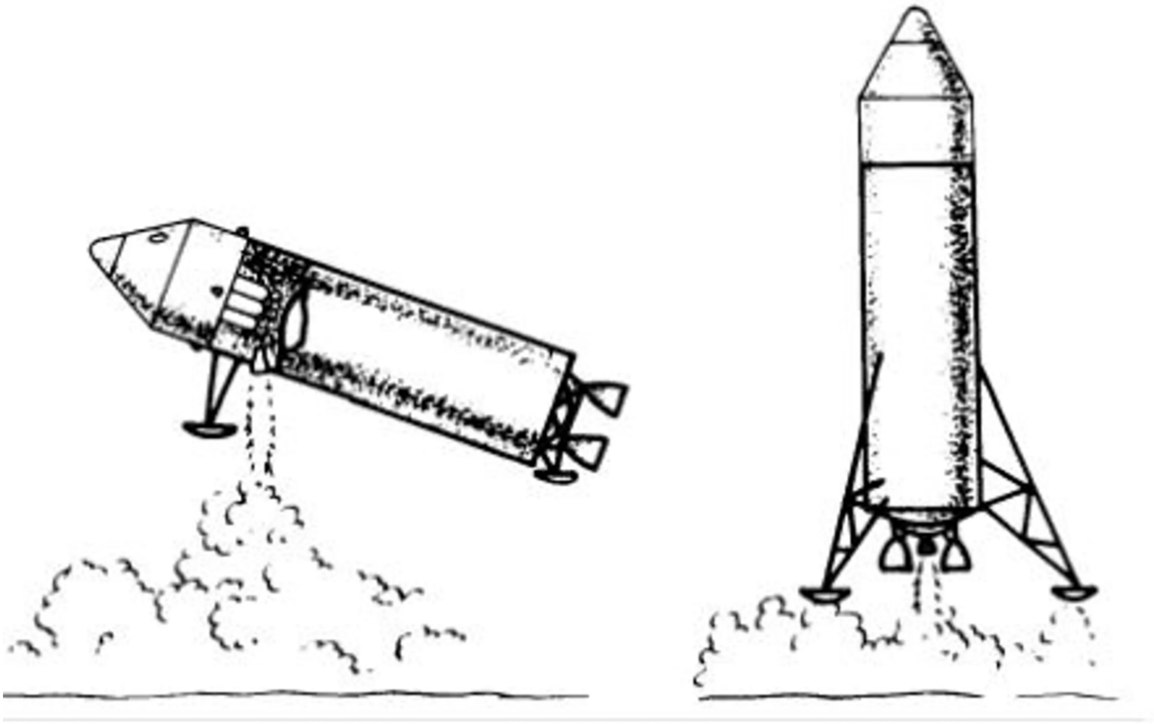
Saturn's many configurations were constantly shifting from month to month. Versions with three stages were reduced to two. As the C-I changed, the C-I and the C-IB emerged. The Nova was formerly the preferred option. Strap-on boosters for solid fuel at another. That was well-ordered pandemonium. Perhaps the Moon program would make a difference. Maybe.

Getting to the Moon

Because there are several different ways to reach the Moon, each requiring a separate rocket, there were several changes made to the Saturn during its development. Moreover, NASA was examining four options in 1961.

Direct Acents

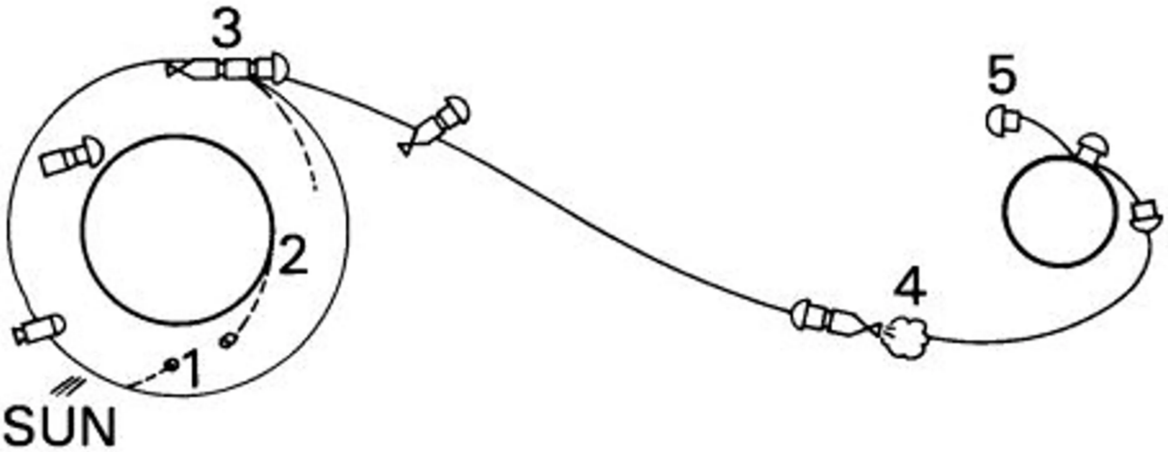
The first and most popular technique is referred to as Direct Ascent. The Direct Ascent scenario, which is the most straightforward approach, calls for creating a self-contained spacecraft that would be sent into orbit by a massive rocket. Without entering lunar orbit, the spacecraft would go directly to the Moon and settle there. The complete spacecraft or an ascending stage would launch, return to Earth, and land or splash down at the end of the mission.



This mission profile is very good, but it has one significant flaw: the spacecraft is incredibly heavy due to the enormous engines, fuel tanks, and other equipment it requires. This referred to a 90-ton moonship (99 tons). According to the von Braun team's calculations, this would need the use of a completely new booster named the Nova, which would be larger than the Saturn V and require new, powerful engines. And to make matters worse, it would have delayed the US arrival well into the 1970s.

Earth Orbit Rendezvous

The Earth Orbit Rendezvous mission entails putting the moonship together in orbit, as the name implies. Then it would take off towards the Moon, land, and then come back. One alternative would be to launch an empty ship into orbit, then use a subsequent rocket to fill it up for the voyage. In any event, smaller rockets than the Saturn V would be required for this.

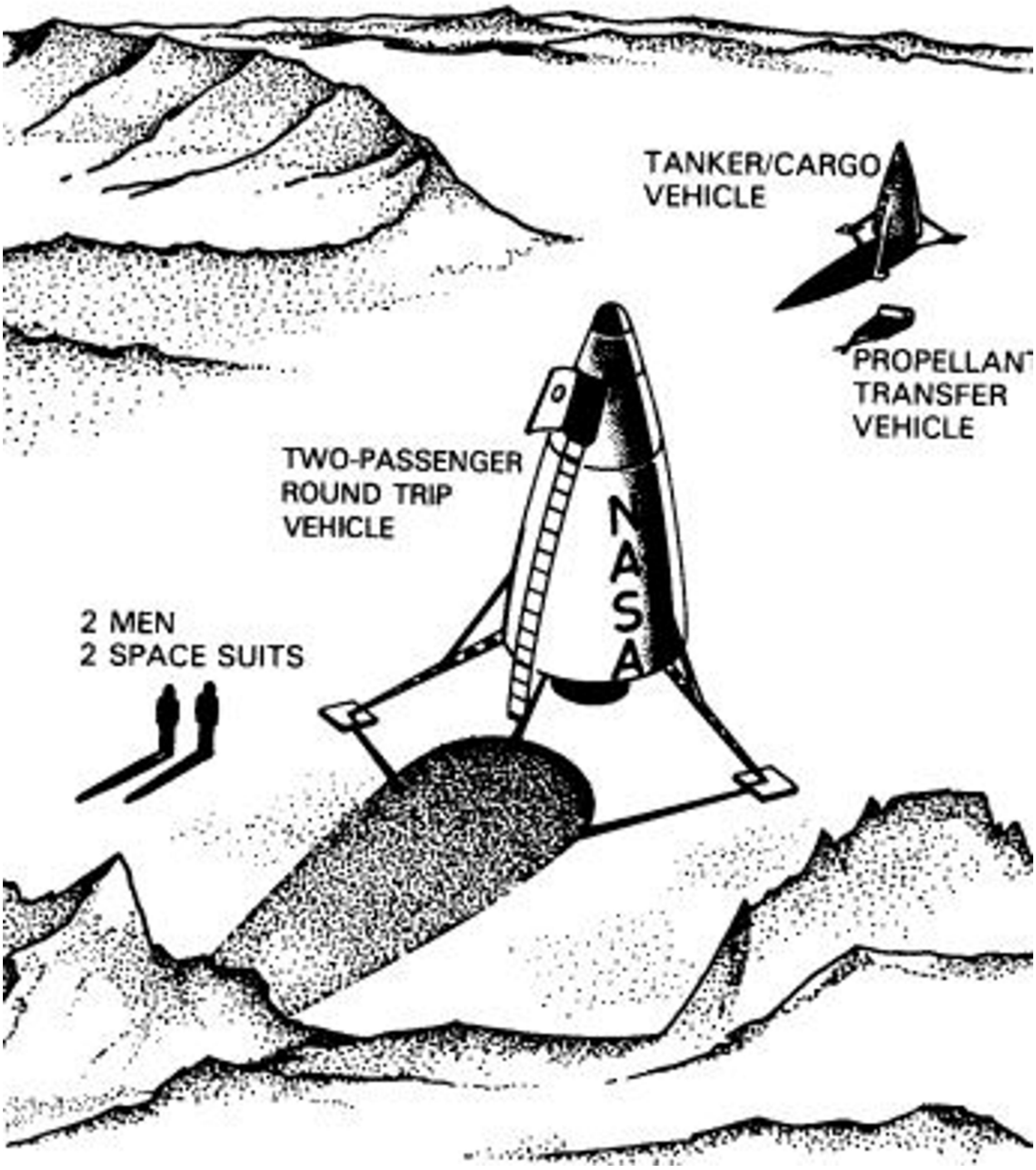


1. Place propulsion unit in parking orbit
2. Place manned spacecraft in chasing elipse
3. Launch assembled vehicle into lunar orbit
4. Brake vehicle for lunar landing
5. Return to earth

For this, two or more rocket launches would have been necessary, followed by a rendezvous in Earth orbit, followed by either docking or refueling. While such meetings are commonplace in the modern era, they were uncharted ground in 1961. Never before has two spacecraft collided in orbit or even docked. Also, at the time, rocket technology was still primarily experimental, so there was always a chance that one of the vehicles may malfunction and get stranded in orbit with nothing to replace it. This can result in the loss of two spacecraft instead of just one.

Lunar Surface Rendezvous

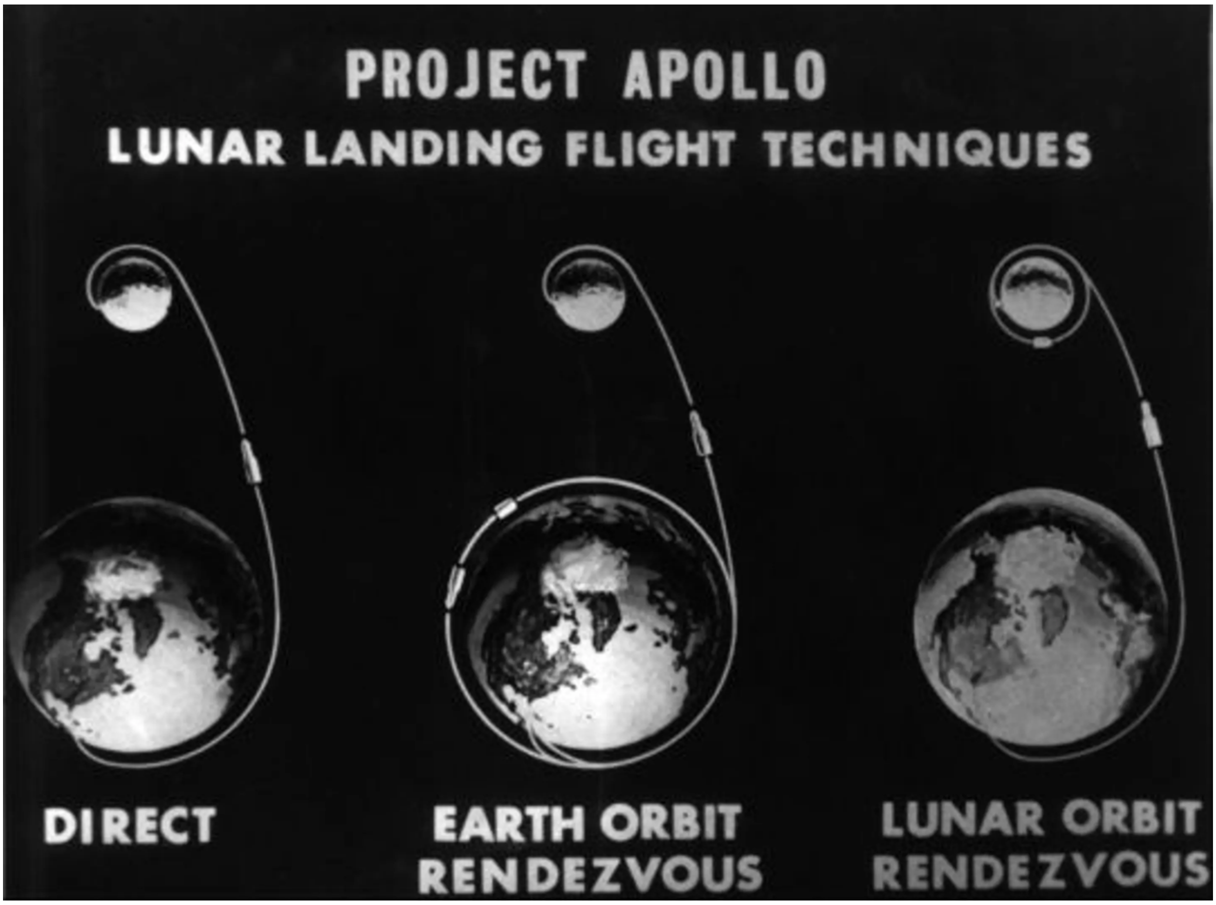
A fleet of unmanned spacecraft carrying food, fuel, and a vehicle capable of returning to Earth would be launched to the Moon during the Lunar Surface Rendezvous. A tiny, manned lander would land during the trip, and the astronauts would then use the return spacecraft to get back to Earth. Again, fewer rockets would be required.



The Earth Orbit Rendezvous had the same issue as the Lunar Surface Rendezvous, except that it was worse. A small number of spacecrafts only required to enter the same orbit simultaneously for the Earth Rendezvous scenario. To complete the Lunar Surface Rendezvous, autonomous landers would have had to land on the Moon first, then repeat the feat numerous times in the same location before a manned landing, a second craft's launch, and finally one more landing. It goes without saying that this provided far too many potentials for mission-ending mishaps.

Lunar Orbit Rendezvous

A single spacecraft is sent into lunar orbit as part of a mission called a Lunar Orbit Rendezvous. A tiny lander descends, lands, and then returns the astronauts, using a yet smaller ascending stage while the mothership stays in orbit. The ascent stage and mothership make a close encounter, the astronauts return, the ascent stage is discarded, and the mothership lands on the planet.



If that seems familiar, it's likely because the Apollo program picked it, but choosing it wasn't simple. Yet a choice had to be made, and quickly.

Mission chosen

The Direct Ascent mission was first favored because to its simplicity and the absence of risky procedures like an orbital rendezvous. Many team members (including von Braun) advocated for an Earth orbit rendezvous whereas Langley engineer John Houbolt and NASA Administrator George Low campaigned for a lunar orbit rendezvous when the Nova rocket required for such a mission proved to be unworkable.

Von Braun had to use a great deal of diplomacy to stop both, the victors and losers in the dispute from engaging in personal animosity, because the fighting got so bad that President Kennedy had to step in at least once.

The most affordable and quickly produced option was ultimately decided to be the lunar orbit rendezvous. As a result, the final design phase of the Saturn's development could begin, followed by its construction and testing. On January 10, 1962, NASA declared that the

Saturn C-5, now known as the Saturn V, would go into production. This would include a new S-II second stage powered by five J-2 engines, a new S-IC first stage with five F-1 boosters instead of the original four, and an S-IVB third stage with a single J-2 engine. The Lunar Excursion Module (LEM) and the Apollo Command Service Module, as well as the rocket's "brains," would be carried by that third stage.

The approval of two additional rockets was given in addition to the Saturn V. The Saturn I and Saturn IB, which were based on the Saturn C-1, were created as parallel development rockets to test elements of the Saturn V hardware, conduct preliminary flight tests, launch the first Apollo astronauts, and bring the Apollo spacecraft into orbit. The last two were especially crucial since Apollo needed to be finished before the Saturn V was operational.

The two-stage Saturn I and IB are an excellent example of the Saturn program's conservatism and the need to save costs on a Moon project that would soon be as expensive as a small war. Their initial stages, which were much smaller than the Saturn V and had five "demilitarized" H-1 engines, were based on the older Juno and Redstone rockets. Eight Redstone’s' worth of liquid oxygen and RP-1 rocket fuel tanks were grouped around a Juno tank with greater oxygen to reduce the expense of designing and constructing new fuel tanks. The IB was somewhat higher than the other design to carry more propellant.

The S-IV or S-IVB was the rocket's second stage. The S-IVB had one J-2 engine in place of the six RL-10 engines that powered the S-IV. Ironically, the S-IVB was the first stage to fly and was technologically the most sophisticated since it had to be able to fire twice and make intricate course adjustments, while being the third stage of the Saturn V and bearing the number IV.

Questions outstanding

Several choices beyond the fundamental ones demonstrated the state of the art in rocketry in the early 1960s. The Saturn rockets were intended to exclusively run on liquid oxygen and RP-1, which is manufactured from kerosene. As a result, the Saturn V would have been an extremely tall and awkward rocket that may have crashed while in flight. As the Americans had limited experience with it and most of their information came from the Germans, von Braun opposed the use of liquid hydrogen as a substitute in the upper stages. It was also incredibly costly because its characteristics were still little known and there wasn't much of a manufacturing business.

Abraham Silverstein, who had experience with liquid hydrogen in the 1950s and was confident of its applicability, was responsible for this shift. After some time, he managed to speak past von Braun and other important experts, especially considering that the Air Force was already developing a hydrogen-powered rocket named Centaur. In fact, the development committee's viewpoint changed so drastically that hydrogen was chosen for both the second and third stages.

Where to launch the lunar missions was another choice that had to be decided. No existing location was adequate, thus a location had to be chosen where appropriate facilities could be constructed. This would have a significant impact on both the Saturn V's construction process and fundamental design. The von Braun team was concerned that the rocket would need to be made for disassembly and airlifting, with all the trouble that would entail before Cape Canaveral was decided upon. This was due to the fear that NASA would choose a remote island in the Pacific Ocean, as the government did for nuclear weapon tests.

Picture of Cape Canaveral

Introducing the Saturn V

The Saturn V and its smaller brothers' fundamental designs had been essentially finalized by 1963 as they entered manufacture and testing. Despite the conservative design ethos that relied as heavily as possible on already-existing technologies, the enormous size of the rocket necessitated several innovative advances.

For instance, welding was a persistent issue. The issue of neatly joining metal while yet assuring that it can withstand extreme variations in stress and temperature has always been there in aerospace engineering, but the Saturn V brought it to an entirely new level. When a weld needs to be 100 feet long, it becomes much more difficult to construct and check welds made of unusual aluminum alloys that are only a few inches long.

Then followed the engines. The J-2 was among the most technologically sophisticated, and the F-1 was larger than any other. Creating and testing these presented a variety of challenges. For instance, the issue of "combustion instability" kept coming up. Alternatively, to put it another way, the gasoline and oxygen would refuse to combine correctly, causing the engine to hiccup horribly before spontaneously igniting.

This necessitated many redesigns of the fuel injector and other parts, as well as the development of unusual methods for recreating the effect, such as the creation of miniature grenades that would be timed to detonate in the combustion chamber. The situation deteriorated to the point that the engineers were forced to engage in some extremely complex theoretical work, and von Braun recommended to institutions that they support PhD students who choose to specialize in the issue.

The enormous rocket was also quite sensitive, which was another factor. Although being 35 floors high, rigorous clean room requirements had to be always upheld. The risk of debris getting into a weld, or a fuel line was present, but there was also the possibility that the oil on a single fingerprint might ignite a fatal explosion if it came into touch with liquid oxygen.

Notwithstanding these issues, the Saturn V was built in a remarkably short amount of time, especially when you consider that it had to be modified often to include the findings of the S-I and S-IB tests. At three significant production facilities spread across the United States, it soon started to take shape.

The need for this division of work arose from NASA's quick realization that the task was well above its capabilities. Instead, the von Braun team at Marshall would handle development and first manufacturing, then a private contractor would handle the actual building of each step. This occasionally worked successfully, like when Boeing worked on the SC-I, but it also occasionally failed, as with North American Aviation (NAA), which built the S-II stage so poorly that NASA had to require a significant restructuring.

Boeing constructed the S-IC bottom stage, which was 138 feet (42 meters) tall and 33 feet in diameter (10 m). It only weighed 287,000 lb (130,000 kg) when empty, but 5,040,000 lb when filled with RP-1 and liquid oxygen (2,290,000 kg). This fueled the five F-1 engines, which produced 7,891,000 lb (35,100 kN) of power for only 168 seconds, lifting the rest of the rocket and the rocket itself off the launch pad and accelerating it to speeds greater than the speed of sound.

Strangely, despite its enormous size and the magnificent, blazing scream of its ignition, it had the reputation of being an "old man's ride," with less of the shaking and noise that astronauts experienced in the crew capsule during Mercury and Gemini missions. Even the Apollo astronauts said that they had to examine the instrument panel to determine whether they had taken off or not.

The second level, S-II, was 81.5 feet (24.8 meters) high and was contracted out to NAA. It featured five Rocketdyne J-2 engines that fired for 360 seconds and weighed 88,400 pounds

(40,100 kilograms) when it was empty and 1,093,900 pounds (496,200 kilograms) when it was fully fueled. The construction of the third stage was the most challenging. Not only were there specific problems, including composite tank linings, which the contractor finally resolved by consulting with surfboard producers, but it also consistently had issues with project management and quality assurance.

The S-IVB was the third stage of the Saturn V. It was created by the Douglas Aircraft Corporation, reaching a height of 61.6 feet (18.8 meters) and a diameter of 21.7 feet (6.6 m). Moreover, it was considerably lighter than the preceding stages, weighing just 271,000 lb (123,000 kg) when fully fueled. It had a single, highly developed J-2 engine that was special among Saturn-rockets because it could burn twice: once for 165 seconds to put the third stage into orbit, and a second time for 335 seconds to put the Apolla spacecraft with its cargo on the trajectory to the moon.

The Instrument Unit, which was located in a ring underneath the cone-shaped Lunar Module, was another distinctive aspect of the S-IVB. This computer, built by IBM in Huntsville, Alabama, was in charge of managing the whole rocket from liftoff until the S-IVB was abandont before reentry into earth atmosphere, almost during the entire mission. This ring served as the Apollo spacecraft's structural foundation and included the environmental control units, the guiding system, the gyroscopes, the electronics cooling system, and the tracking system. Due to the engines being mounted on gimbals with swivel function, the Saturn V was able to make the necessary changes by comparing the acceleration and attitude of the rocket to the designed flight profile.

The Launch Escape Tower was mounted on top of the Apollo Command Module at the top of the Saturn V. In the case of a mission abort, this included a solid rocket motor that could separate the Command Module and transport it to a secure location and release its parachute.

The Propellant Dispersion System (PDS), which has the euphemistically termed function of protecting the Kennedy Space Center and the neighborhood from a Saturn V explosion on the launch pad, was used in conjunction with this escape device. The rocket had the potential explosive force of two kilotons of TNT or the output of a tactical nuclear bomb due to the enormous amount of fuel and liquid oxygen within.

The three stages of the Saturn V were outfitted with explosives that the range safety officer could explode via a radio signal because a detonating Saturn V would have been one of the largest man-made non-nuclear explosions in history. A safety feature would have kept the engines running for the first 30 seconds of flight in an emergency so that it might acquire altitude. The engines would then be turned off, and a second signal would rip apart the tanks, releasing the fuel and liquid oxygen, preventing them from mingling and burning. The third S-explosives IVB's would be permanently turned off when it reached orbit if there was no emergency.

A logistical nightmare

Even if the Saturn V were amazing on its own, the logistics involved would be a logistical nightmare. The rocket wasn't an independent entity, rather, it was the focal point of an extensive infrastructure network that included significant installations in states like Alabama, Louisiana, Mississippi, Kansas, Washington, California, Florida, and others.

Although being created in Huntsville, the Saturn V quickly outgrew the facility, even after it had been considerably expanded. There was a demand for more locations, but they couldn't be set up just anyplace. They needed to be far enough from crowded regions to be close to convenient transit. The locations needed to be far enough south that ice wasn't an issue because these transit ways were frequently rivers.

The Michoud Assembly Facility (MAF), a failing sugar plantation that was used for manufacturing during the Second World War and the Korean War, was one of the locations picked. This required not only the biggest structures in the state to be built as new facilities and rocket test platforms, but also the relocation of hundreds of families from a nearby town with extremely significant compensation payments.

Additional locations were the Bay St. Louis, Mississippi, Mississippi Test Facility (MTF), the Slidell Computer Facility, the Edwards Air Force Base, California, NASA Rocket Engine Test Site, and the Seal Beach, California, Production Facilities Stage. Not to mention the numerous roads, railway lines, barges, ships, particular airplanes, dockyards, and other necessary transportation infrastructure.

The launch site and mission control in Houston, Texas, came next. After the President was assassinated in 1963, Cape Canaveral was transformed from a rocket base into a real spaceport known as the Kennedy Space Center. This required the construction of a launch control facility, fueling stations, massive launch pads, and one of the largest structures in the world by volume, the Vehicle Assembly Building (VAB), which is so big that it would rain inside without air conditioning.

Picture of Vehicle Assembly Building

Even nature needed to be controlled. A single net could easily catch mosquitoes by the pound in Cape Canaveral's dense mosquito swarms, which made it hard to walk around without wearing a full body suit, gloves, and a mask. Engineers constructed dams that inundated the streams until they were deep enough for enormous shoals of minnows to spawn and consume the mosquito larvae, preventing them from tormenting the workers.

As if that weren't bad enough, pigeons plagued the space center, nesting in the bigger structures and pecking at the moon machines. Biologists ultimately came up with the notion of giving the pigeons a medicine that temporarily immobilized them and terrified them enough to flee, after trying everything up to killing them.

Testing

NASA's persistent testing had a major role in the Saturn V's success. The world's biggest rocket didn't allow for the thousands of hours of flight testing that an airliner typically undergoes before being deemed airworthy. In order to conduct early flight testing, the space agency constructed the S-1 and S-1B and conducted countless ground tests on each engine, component, system, and subsystem. This was given credit for the Saturn V's excellent safety record together with strong dependability and quality assurance systems. Testing accounted for 50% of the whole program.

The program was so successful that on the first Apollo 4 mission, all three Saturn V stages flew together in a "all up" configuration rather than being tested separately. The fact that there was just one in-flight issue prior to the manned flights, when Apollo 6 encountered "pogoing" when the second stage burned, serves as evidence of the success. One of the J-2 engines started to vibrate and became unstable, which may have led to the rocket's demise. For whatever reason, a second engine also shut down along with the first one, which put the third stage in the incorrect orbit.

The causes behind this were straightforward, the engine's defective spark igniter, which was also the cause of the vibration. The igniter would freeze up from the cryogenic fuel during ground tests, but in orbit there is no air there is no water vapor, so this wasn't noted. Without ice, the igniter can move and result in an incorrect engine burn.

Crossed wires caused the computer to attempt a correction but instead delivered the signal to the incorrect engine, which is why the second engine went down. The issue was resolved by installing the faulty wire such that it couldn't reach any engines other than its own.

Assembly

Simply putting the Saturn V together needed a lot of engineering and thought. Up until that point, building a rocket typically involved transporting its component parts to the launch pad and assembling them there before fueling. A new strategy had to be developed because that wasn't viable for a massive rocket like the Saturn V, especially in Florida or when a high rate of launches is needed.

The VAB, which could accommodate up to four Saturns at once, was chosen by NASA as a novel method to build the Saturn V far from the launch pad in a secure location. But first, the stages had to travel a variety of ways to reach Florida. To get the S-IC to Cape Canaveral, it had to be transported by barge up the Mississippi River, then by sea through the Gulf of Mexico and into the Atlantic Ocean. The S-IVB was airlifted in a bulbous cargo plane known as the Super Guppy because of its resemblance to a pregnant tropical fish, whereas the S-II was produced in California and transported via ship through the Panama Canal.

Before final assembly and placement on the Saturn V, the individual components were examined upon arrival at the VAB. The finished rocket was subsequently loaded onto a massive tractor called a "crawler transporter" (CT), which transported it three miles (4.8 km) to Launch Complex 39. There, it was protected by the Mobile Service Structure (MSS), which had a movable clean room, lifts, fueling, and power systems, as well as a sizable slide for gantry crew evacuation to a specific bunker in the case of a launch emergency.

Lift-off

Following all of this, it comes as a surprise to hear that each Saturn V's lifespan was just around 20 minutes long, plus, or less some time spent in orbit. The launch of a Saturn V, however, was a far cry from any planet-wide fireworks display.

Picture of Saturn V lift-off

The most stunning parts of a Saturn V launch were also the most straightforward and hazardous. The first stage's flight was dominated by aerodynamic forces because of the Saturn V's enormous weight. Therefore the S-IC didn't accomplish much more than keep the rocket steady in its first stages. It followed a pre-planned flight path, and any deviations were detected by the onboard computers and corrected by the second and third stages.

One of the most terrifying things about the Saturn V was that it took a full 12 seconds to clear the launch tower. The pad was three miles from anything because the consequences would have been devastating if it had hit the tower or the engines had failed. The rocket was set up to tilt 1.25 degrees away from the tower to lessen the likelihood of touching it. It rolled to its flying angle and eventually pitched down to a more horizontal position as it ascended to a height of 430 feet (130 meters).

The Saturn V reached hypersonic speed after two and a half minutes of launch. The first stage, now depleted of fuel, was propelled away from the rest of the vehicle by solid rockets and explosive charges. Before the five J-2 engines fired, similar rockets on the second stage gave it a shove to make sure that all the fuel was in the bottom of the tanks. Before disengaging and crashing into the Atlantic Ocean off the coast of West Africa, the second stage burned for six minutes, increasing the speed to 15,300 mph (24,623 km/h).

The third stage was now operational. It began by accelerating the remaining vehicle to 17,500 mph (28,164 km/h) during its first burn, then stopped when the spacecraft entered a parking orbit around the Earth. It stayed there for as many as three orbits while the crew and ground control evaluated the systems before choosing whether to move further. The J-2 engine would fire a second time if the go-ahead was granted, placing the spacecraft and its cargo in a translunar insertion orbit.

The Saturn V had completed its mission at this point. The Lunar Module would be docked with by the Apollo mission crew, who would then adjust its path to launch it toward the Moon as the third stage arced safely out of the way to avoid a collision.

The end of an era

Since the height of the Space Race, there has never been anything like the Saturn V. The Skylab space laboratory was launched into orbit by the last one in 1973. All that is left of the booster's legacy are two flight-rated Saturn Vs on display in Texas and Florida, five S-IVBs that were intentionally crashed on the Moon for seismic experiments from Apollo 8 to Apollo 12, the remains of five more S-IVBs that orbited the Sun from Apollo 13 to Apollo 17, and a few other odds and ends strewn about in museums and storage facilities.

Would it possible to create a Saturn V today? No, according to NASA. The extensive infrastructure and tools required to build the enormous rocket have all been destroyed, consigned to museums, or found new uses, despite the fact that all of the blueprints are still present on microfilm and the development and construction of the rocket have been meticulously documented. The project's creators, both men and women, have also all either retired or passed away.

Alternatively, creating a new rocket from scratch would be easier and less expensive. Because of this, SpaceX is developing the BFR, NASA is developing the Space Launch System (SLS), and there are even rumors that China is developing a powerful rocket to compete with the Saturn V. The Saturn V will undoubtedly be replaced by a launch vehicle that is more potent in the future, but because to its historical significance, it will continue to serve as the benchmark.

History Apollo Missions

According to NASA, the Apollo program included 11 space missions in all starting in 1961, six of the other seven missions successfully landed humans on the moon, and four of those missions tested technology. In 1968, the first crewed flight took place, and the last mission was carried out in 1972.

12 men had explored the moon's surface by the time the Apollo missions came to conclusion, conducting research and collecting rocks to send back to scientists on Earth. More than 50 years after being gathered, these materials are still being used to produce new discoveries.

The space race, a struggle between the capitalist U.S. and the communist Soviet Union over dominance in space, started in 1957 and gave rise to the Apollo program. In his infamous 1961 "Moon Address" at Rice University in Texas, U.S. President John F. Kennedy challenged the newly established NASA to put men on the moon and return them safely to earth at the beginning of the race, when the Soviets took the lead.

NASA's Mercury mission, which operated from 1959 to 1963 and sent one-person teams into orbit to test whether people could live and function in space, served as the foundation for Apollo. The agency's Gemini program, which spanned from 1962 to 1966 and comprised two-person missions testing several maneuvers and parts necessary for landing on the moon, came after that.

According to Spaceflight Insider, the Apollo program needed a massive effort and employed some 500.000 people in the United States. According to the Planetary Society, the program's lifetime costs came to a total of $28 billion, or around $283 billion when adjusted for inflation.

During Apollo, NASA created a number of innovative vehicles, most notably the Saturn V rocket. The Saturn V, one of the largest launchers ever to fly, had three stages and was as tall as a 36-story skyscraper.

The Apollo command module, a three-person spacecraft that carried the astronauts to the moon and back, was mounted atop the rocket. The ship's interior had about the same amount of space as a vehicle, making the roughly week-long lunar journeys a little uncomfortable.

The lunar module, which sent two people to the lunar surface and made a shaky landing there, was the last. The top section of the lunar module started its engine and ascended to the command module for the return to Earth after surface excursions were over and crew had returned inside.

The Saturn I rocket, a scaled-down version of the Saturn V used for testing the program's engines and components, was created for the initial Apollo tests. The first astronauts were scheduled to launch on Apollo 1, but a wiring spark caused a fire to spread across the command module during a launch rehearsal, killing the crew of three.

The software underwent significant changes to the command module as a result of the failure, which served as a turning point. Before NASA attempted to launch additional people into space once more, it had been more than 18 months. Six unmanned flights were launched by the organization at that period to examine the Saturn V rocket's performance.

The following significant event in the history of the program occurred during Apollo 7 with the first successful crewed launch. Even though the crew spent the whole journey in Earth orbit, the mission proved that using the Saturn V rocket to launch humans into space is safe.

While the crew of Apollo 8 did not set foot on the moon's surface; instead, they just circled it, it was the first mission to take people all the way there. The crew took turns reading from the Book of Genesis during the event, which took place on Christmas Eve in 1968, and they also took the famous photograph of our globe known as "Earthrise," which is credited with influencing the environmental movement.

The Apollo 11 mission, in which the first astronauts stepped foot on the moon, marked the pinnacle of the Apollo program. On July 20, 1969, astronauts Michael Collins piloted the command module Columbia over the lunar surface while astronauts Neil Armstrong and Buzz Aldrin descended to its surface. After he walked onto the moon, Armstrong famously said, "That's one small step for a man, one giant leap for mankind." Before heading back to the command module, the astronauts were on the ground for 21 hours and 36 minutes.

The Apollo 13 mission is recognized as the one that avoided a serious catastrophe thanks to perseverance and inventive engineering solutions. The award-winning film "Apollo 13" about the crew's misadventure highlighted their struggles even though they never made it to the surface of the moon.

Early in the 1970s, the Apollo program was abandoned due to its enormous cost and dwindling public interest. Congress members and President Richard Nixon made the decision to divert money intended for Apollo to other causes, including as the Vietnam War. Harrison "Jack" Smith, a geologist, participated on Apollo 17, the program's final mission, and was the first to discover significant rock specimens to transport back to Earth.

In order to send people to the moon for the first time since the conclusion of the Apollo program, including female crew members, NASA is now developing the Artemis mission. By 2028, Artemis hopes to have established a permanent human presence on the moon after its initial landing in 2024.

The synopsis of each Apollo mission is as follows:

Apollo 1 - January 27, 1967, Roger B. Chaffee, Edward White, and Virgil "Gus" Grissom had all participated in NASA's Mercury or Gemini missions in the past. The three men died as a consequence of an accident involving the highly oxygenated air within their capsule, a stray spark, and the hatch being impossible to open from the interior of the vessel.

Apollo 4 - Nov. 9, 1967, maiden launch of NASA's massive Saturn V rocket without crew.

Apollo 5 – January 22, 1968. First lunar module launch into orbit was an unmanned operation.

Apollo 6 - April 4, 1968, last mission of the Apollo program without crew. The mission was intended to test the Saturn V's capacity to put men into a lunar trajectory. The mission was only partially successful since the rocket suffered from severe vibrations during launch.

Apollo 7 - October 11, 1968, The first Apollo crew was composed of astronauts Walter M. Schirra, Donn Eisele, and R. Walter Cunningham. The astronauts tested various parts of their command module for 11 days in Earth orbit rather than moving toward the moon.

Apollo 8 - 21 December 1968, The first humans to depart low-Earth orbit were the astronauts Frank Borman, Jim Lovell, and William Anders. They traveled around the moon before returning to Earth. They took off on their historic flight in a hurry. After just one crewed journey around the Earth, NASA authorities decided at the last minute to proceed toward the moon to swiftly establish their technological advantage over the Soviet Russians.

Apollo 9 - 3.03.1969, Throughout their 10-day trip, astronauts James McDivitt, David Scott, and Russell "Rusty" Schweickart stayed in Earth orbit to test docking techniques that would be essential for a moon landing.

Apollo 10 - May 18, 1969, Eugene Cernan, John Young, and Thomas Stafford came incredibly near to making a lunar landing. Their mission, which functioned as a practice run for Apollo 11, required traveling to our natural satellite and lowering the lunar module to within around 50,000 feet (15,000 meters) of the moon's surface.

Apollo 11 - 16 July 1969, Neil Armstrong, Edwin E. "Buzz" Aldrin, and Michael Collins accomplished a first for humanity when they reached the moon and sent two astronauts walking over its surface. There are still traces of Armstrong and Aldrin's historic footprints on the lunar regolith.

Apollo 12 - November 14, 1969, After surviving two lightning strikes during launch, the astronauts Charles "Pete" Conrad, Alan Bean, and Richard Gordon arrived to a different location on the moon than Apollo 11 and touched down in the Ocean of Storms. Conrad and Bean, two moonwalkers, stopped by the Surveyor 3 probe, which NASA had sent to the moon two years earlier.

Apollo 13 - April 11, 1970, The mission was ruined after an oxygen tank exploded 56 hours during Jim Lovell, Fred Haise, and John Swigert's voyage to the moon, causing injuries to the spacecraft. The crew had no choice but to dive inside the lunar module and use it as a lifeboat to circle the moon without touching down. They subsequently made it back to Earth without incident. Lovell had completed a previous lunar orbit on Apollo 8, making this his second lunar orbit.

Apollo 14 - 31 January 1971, the best-remembered accomplishment of astronauts Alan Shepard, Edgar Mitchell, and Stuart Roosa is hitting golf balls on the moon. While Shepard was the first American in space, he and his co-pilots had some of the least amount of flying experience among the Apollo astronauts, earning them the affectionate moniker "the three rookies."

Apollo 15 - July 26, 1971, the lunar roaming vehicle, often known as the moon buggy, was sent to the moon for the first time during a mission that included astronauts David Scott, James Irwin, and Alfred Worden. The crew was educated to recognize various rocks and formations that would aid Earth scientists in reconstructing the history of our planet and its natural satellite. Their mission placed a strong emphasis on geological work.

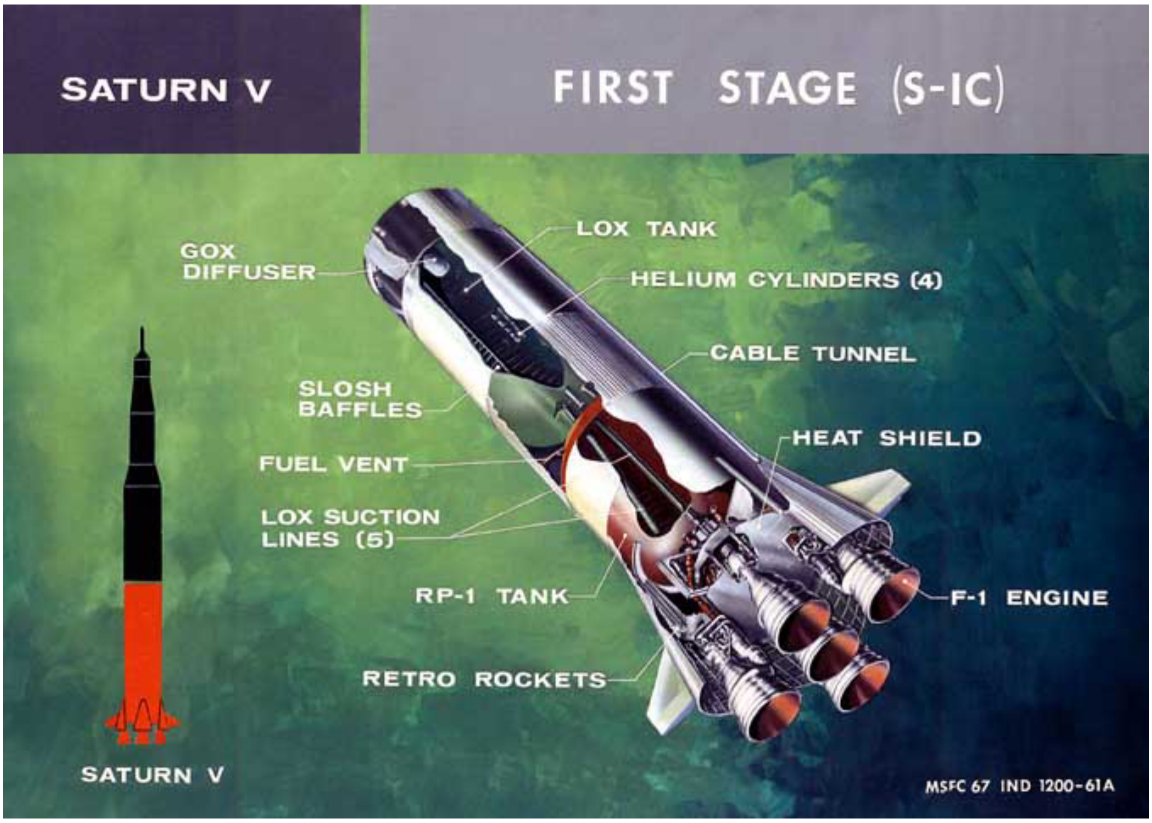
Apollo 16 — 16 April 1972, during their mission, astronauts John Young, Charles M. Duke, and Thomas Mattingly touched down on the Descartes highlands and looked for volcanic materials. Scientists were surprised to discover few volcanic materials, which showed that the region had not been produced by volcanic activity.

Apollo 17 - December 7, 1972, the last humans to visit the moon were astronauts Ronald Evans, Harrison Schmitt, and Eugene Cernan. The astronauts' mission maintained the emphasis on science, with the longest stay on the lunar surface and the biggest sample collection of any in the program.

Technic Saturn V

The S-IC first stage

The S-IC is the biggest and heaviest stage made for liquid fuel. Although having a take-off mass of 1.870 t, the Block A of the N-1, its Soviet cousin, was roughly 400 t lighter. Even by the standards of today, the S-IC is a sizable stage. Its length is 42.1 meters, and its width is 10.1 meters. Built by Boeing, it is propelled by five Rocketdyne F-1 engines. It had an original value of 450 million US dollars when the contract was first granted on December 15th, 1961. To lower the danger associated with development, it was decided to power the S-IC using oxygen and paraffin. The RL-10 engine was in development in 1961 and had a 67 kN thrust while hydrogen stages were not yet operational. It was possible to find paraffin-burning engines with 800 kN of thrust, and such rockets already existed. The transition to engines with 6,000–8,000 kN of thrust was thus significantly smaller. Second, hydrogen has a far higher volume than paraffin. Because of this, the second stage is nearly as large as the first. A first stage powered by hydrogen and weighing around 1.500 t would have been roughly three times as large although using less fuel, measuring 15 m in diameter and 60 m high. The Soviet N-1 using just kerosene/oxygen for all stages, seems significantly smaller than a Saturn V, although weighting the same which is due to the difference in density.



Picture of the S-IC

The paraffin tank is located in the bottom tank and is 13.1 meters long with a 768,4 meter3 capacity. It can carry 590 tons of paraffin theoretically. Like the oxygen tank, it is pressurized with nitrogen while in transit under 1.8 bar. Helium is utilized during the journey. In the oxygen tank, four 878 l cylinders with a 213 bar pressure each, hold 400 kg of helium (the low temperature of -183 degrees in the oxygen tank increases the density). Each cylinder has a 56 cm diameter and a 6 m length. In the paraffin tank, valves maintain a 3 bar pressure. To keep the lines in the paraffin tank cold and to remove air from the oxygen tank, helium is also used before takeoff. Gas bubbles in the lines caused by oxygen evaporating on the heating lines were what they sought to prevent. The oxygen tank is connected to the paraffin tank by 12 pipes, each measuring 42 cm in diameter. For protection from paraffin freezing on them, these are insulated.

The biggest tank in the rocket is the 19,50 m long oxygen tank above. It is 1.250 m3 in size and takes 1.204 m3 of oxygen. It pressurized with helium at 1.8 bar prior to launch. A portion of the oxygen is then heated using heat exchangers on the engines before being supplied as gas into the tank. This calls for around 18,1 kg of oxygen every second, which consequently keeps the tank pressure between 1,2 and 1,6 bar.

An interstitial area enclosed with a honeycomb structure offers isolation from the paraffin tank. Unlike previous launch vehicles, the tank's interiors are netted with formers and stringers to lessen sloshing of the gasoline. A 6,60 m long intermediate tank portion strengthened by formers is positioned between the two tanks. The cylindrical tank components are constructed of aluminum alloy 2219 and undergo a 24-hour heat-treating process at 163 degrees to boost their strength.

The F-1 was the final NASA-developed engine using kerosene/oxygen propellants. The center engine is fastened to the thrust frame while the other engines are gimbaled by six degrees. Several rings make up the thrust frame, which is coated in corrugated sheet metal. It distributes the rocket's thrust from the engines, which it absorbs and is the heaviest component of the rocket, weighing 24 t. It is positioned over the 12-ton paraffin tank and made up of two hemispherical domes and cylindrical tank sections, each with eight segments. A common distribution line for all engines is served by ten lines that can each provide up to 1.000 liters of paraffin per second. There are trace quantities of triethyl aluminate near the bottom of the lines, encircled by a membrane. Triethyl aluminate entered the combustion chambers ahead of paraffin when the valves were opened, rupturing the membranes so that it could meet oxygen. Triethyl aluminate, unlike paraffin, ignites instantly when combined with oxygen, making the ignition of the engines both simple and efficient.

Across models, there were some differences in the fuel load. 1.550.440 kg of oxygen and 646.685 kg of paraffin were used on Apollo 11. 8 retrorockets, which are situated at the bottom end of the stage under the engine cowlings, are launched when the first stage has completed its task after 150,8 seconds of burn time. Each generates a 337 kN thrust for 0,541 seconds. Each of them uses 121 kg of fuel. Detonating cables cut off the connection to the S-IC at the same moment. The empty stage is slowed down by the retros at 14 m/s, which causes it to regress.

Titanium was used to construct the fins and engine cowlings, which were exposed to the exhaust flow and required resistance to temperatures of up to 1.100 °C. Because the rocket will be operated by humans, the fins were designed considerably smaller than on the Saturn IB. Without the fins, the rocket may have tipped over with the rescue tower before it had time to transfer the capsule to a safe distance if the control system had failed.

The electrical systems were powered by two batteries with capacities of 640 and 1.250 Ah. The batteries weighed 310 and 520 kg, and the on-board voltage was 28 V. From the stage to the ground, a 20 Watt transmitter sent 900 readings continually. While having its own electrical system, power supply, and telemetry transmitter, the S-IC was controlled by the IU. The other phases were the same.

Two color TV film cameras that were mounted above the engines and recorded the first two flights were also there. Via the use of a fiberglass bundle, an internal picture of the LOX tank was overlaid on the camera. The separation from the S-II was captured on film by a second set of 16 mm cine cameras. The cameras and their two buoyant canisters were launched 24 seconds after stage separation. After a parachute drop, they splatted into the South Atlantic.

Boeing was given the go-ahead to construct the S-IC on December 15th, 1961. Nevertheless, MSFC started the development process. At this point, the C-5 would have five engines instead of the four that were initially planned, which was a significant choice. The S-initial IC's design would have been capable of sending 41 tons to the moon, the second design, which has five engines, can send 46 tons. Later, Von Braun said that Apollo was rescued by its conservative design since it turned out that the spacecraft was significantly "overweight."

The size of the S-IC was the main challenge in its development. Lightweight sheets needed to be joined together in precise curves, which required the development of brand-new tools and assembly processes. Like the S-II, the welds in particular posed challenges because they had to be flawless while being extremely lengthy. After all, the alloy utilized in the 2219 aluminum alloy was more suitable for welding than the S-II alloy. Other methods, such chemically deforming the tank's curved end parts, were unsuccessful. There were eight of these components, totaling up to 27,6 m2, in each tank dome. So they went back to hydraulic forming. A method was created for the lengthy tank portions that eclectically burned and distorted the components while also aging and hardening the plates. In this manner, a 5 tons plate was reduced to a 1 ton, 60 mm thick, 3,4 x 8 m sheet. The tungsten inert gas (TIG) welding procedure was used to create the weld seams as with the S-II. Due to the later S-IC's start, it was possible to learn from the S-II's mistakes and, most important, to improve the environment. In air-conditioned spaces with humidity levels below 50% and temperatures below 25 degrees, welding was done. Teams of 10 to 15 specialists each, worked during three shifts only on the control of the welds. To weld the tanks and establish the 10 km of weld seams, however took 7-9 months.

Liquid oxygen is quite reactive despite its low temperature. On the tank walls, even trace concentrations of organic molecules, such as those in perspiration, are sufficient to trigger a local response. Another issue arose because of the need to make extremely clean workpieces that were many square meters in size. The pieces were rinsed with deionized water, followed by the application of nitric acid to oxidize any remaining organic remains before the acid was removed with further deionized water. After drying, a procedure was used to remove the top few micrometers of the layer. The pieces were then dried with hot, filtered air that was devoid of oil. The pieces were then cleaned with specialized chemicals in a washing facility that was 12 m wide and 6,7 m high.

Only the testing for the last stage took ten weeks. For instance, in the hydrostatic test, the tank was topped out with water before being put under 105% of the nominal pressure. The LOX tank was stretched by 1,3 cm with this 5% over average. The S-IC experiments using all 5 F-1 engines were the most impressive ones. At Huntsville, there were two 124 m tall test stands for this purpose. They were encircled by four walls that were 12 m thick. A total of 1.600 steel struts measuring 30 cm each carried the electricity. 782 m3/min of water was sprayed over the standby two systems, and 1.100 m3/min went into the flame shaft. The S-IC test consumed as much water in 5 minutes as a small city of 10,000 people do in a day. The first S-IC testing started in 1965, and in 1966, all 5 engines could be checked for the entirety of their working period.

A launch pad test model, an engine test model, a static test model and the first two flying specimens were all produced at the Marshall Space Center. Industry produced the models that were later used first on Apollo 8. Five of them are still being stored by NASA at the NASA Michoud Assembly Facility.

The F-1

The F-1's beginnings are older than those of the Saturn V. An order for a study of an engine with 1,5 million pounds of thrust was issued with Rocketdyne in 1955. (6,7 million newtons). A first order for the preliminary development of this engine was placed in the middle of 1958. The Saturn V wasn't even a concept at that point. It was able to test a combustion chamber and generate 4,45 MN of force for 200 ms in early 1959. A full-size model was created in May 1960, and the first test of the combustion chamber was conducted on April 6, 1961, less than 27 months after the project's inception and even before Gagarin's flight and Kennedy's announcement to travel to the moon. 7.295 kN of force was obtained by the prototype.

Picture of the F-1

The F-1's technological layout was quite traditional. The requirement for human missions was evident even before the development process began. Thus, reducing risk was the main goal. The propellants and technology employed by the F-1 were tried and true. New standards are only set by the alloys used. The F-1 was designed from the ground up to have the maximum dependability and the least amount of complexity. The F-1 was meant to be reunitable yet only required one ignition during a mission. The F-1 and J-1 engines were to be reused in the initial designs for a space shuttle. To save development costs, at the time, it was stated that both engines could be used ten times.

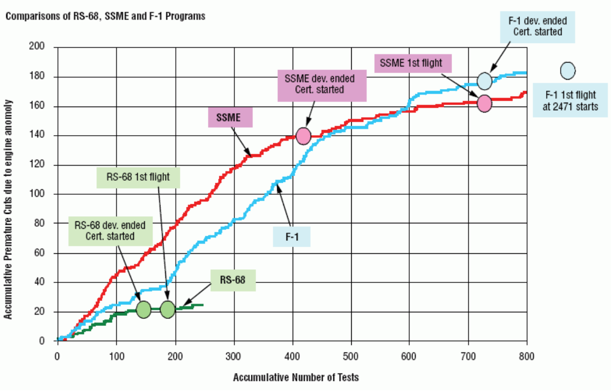
The injector head initially seemed to be the major source of issues. The copper injector head was enormous, much like the entire engine. The injector's task was to spray oxygen and paraffin like a huge shower head so that they could burn thoroughly without having too much paraffin or oxygen. The F-1 had a head with 3.700 orifices for the paraffin and another 2.000 for the oxygen, whereas previous rockets had injectors with 100 or 200 orifices. Although the combustion was unstable, the instability only vanished when the fuel supply was turned off, which was not a practical action for an engine. Nonetheless, the H-1 injector's specs had been followed while creating the F-1 injector, which had only been theoretically expanded. The H-1 solution, however, could not be applied to the F-1. The injector's structural reinforcements were the initial advancements. Then they used a scaled-down model that had been sliced in half and used high-speed cameras to observe the combustion. Yet like with the H-1, the "bomb tests" were the most successful. After the injectors were adjusted, it appeared as the issue had been solved, but on June 28, 1962, an F-1 engine was damaged while being tested. "The situation has reached a new magnitude," Von Braun said. The testing was stopped, and a committee was formed to look into the matter. The findings were made public in November 1962. Von Braun did not think highly of the prior strategy: "Due to a lack of appropriate design criteria, the industry has been obliged to develop injector and combustor technology almost entirely empirically. Because a solution that works for one engine system typically does not work for another, this technique is not only expensive and time-consuming, but it also does not further our understanding." In other words, the issue was never truly recognized, instead, several solutions were explored until the instability was resolved. This prevented the transfer of experience from one engine to another and was both expensive and time-consuming. This was most evident in the F-1, which employed an enlarged H-1 injector. They addressed the issue from two angles since they were short on time and believed the Russians were further along. First, through a scheme that provided universities doctorate and habilitation projects while critically examining combustion. Second, by altering the settings, they attempted to pinpoint the precise cause of the F-1. Baffle plates enhanced the combustion behavior, but the engines did not fully recover when bombs were added, as it turned out. Enlarging the perforations and altering the angle of the oxygen and fuel supplies to one another led to a noticeable improvement. Without needing to conduct hundreds of tests, it was feasible to explore the phenomena relatively specifically through experiments using explosive devices of various sizes and placements. The vulnerability and duration over which a bomb may create instability could be gradually decreased. This was 1.600 milliseconds at the beginning of the testing and 100 milliseconds at the conclusion. It was also discovered that the copper injectors were oxidizing where they connected to the steel casing. The answer was to seal the surface by applying a gold coating. The tremors eventually stopped. Yet no cause was ever identified.

Cracks in the tubes used to cool the combustion chamber in the first half of 1965 made the injector issues worse. It was necessary to strengthen the tubes and test the new combustion chamber once more.

The F-1 turbopumps presented a challenge to another team. They pumped gasoline into the combustion chamber at a rate of several thousand liters per second under extreme pressure. The Rocketdyne idea included a shared shaft for the fuel pump, oxidizer pump, and turbine. The propellants cooled the bearings. The oxidizer pump needed to be heated, otherwise the bearings would have frozen at -180 degrees. Paraffin at a flow rate of 10 l/s was used to lubricate the engine's many moving components. The fuel pump produced 57.392 l/min of paraffin, while the oxidizer pump produced 102.230 l/min of liquid oxygen. The turbine that powered both pumps had a total output of 41 MW, was 816 degrees hot at one end, and was -183 degrees cold at the other. They moved a 77 kilogram of gas per second. There was a total of 11 failures in this case as well. Initially, a defect in the oxygen pump's design became apparent: the impeller broke and needed to be totally redone. The reasons of the other 9 failures, all of which resulted in explosions, were excessive turbine acceleration and friction between stationary and moving elements. However unlike with the injectors, all the issues were resolved rather fast. In the end, they had a turbopump with a low sensitivity to failure and extremely few components.

The combustion chamber testing went surprisingly well. It was constructed using 178 primary and 356 secondary nickel alloy X-750 tubes that were welded together. Before it reached the injector, 30% of the fuel passed through the tubes, cooling the combustion chamber. The 900 m of tubes that made up the combustion chamber's overall structure had to endure a pressure of 79 bar. This high combustion pressure made it possible to use the fuel effectively without having to stretch the nozzle excessively. An expansion of the nozzle was shortly installed to boost performance. Via openings in a hose that encircled the nozzle halfway up, the turbine exhaust gases were directed into the nozzle, increasing the fuel output. The engines were enclosed in a "cocoon" to shield them from the engine's own exhaust fumes. A J-57 gas turbine engine with an afterburner was pointed at the shroud in a wind tunnel to evaluate the quality and determine whether it could resist it. The gases finally exited the nozzle at 1.260 degrees Celsius in temperature. The engine's size offered further benefits. For instance, connecting hydraulics to the fuel lines would make it simple to rotate the outside engines. By alone, the high flow provided enough power to swing the engine. The paraffin and oxygen tank's tank pressure might be maintained by using a heat exchanger to vaporize helium and oxygen using the heat from the turbine exhaust.

More testing was done on the F-1 than any other engine. The chart details the outcomes of three engines' qualifying programs: the F-1 from the Saturn V, the SSME from the Space Shuttle, and the RS-68 from the Delta IV. The Y-axis displays the number of premature engine shutdowns, while the X-axis displays the number of tests (summed). The test program was completed after 180 tests since the RS-68 was employed in an unmanned rocket. After 730 testing, the SSME test program came to an end. After 2.471 tests, the F-1 test program! The graphic would need to be three times wider to demonstrate this point. This one number demonstrates the importance that NASA and Wernher von Braun placed on safety.



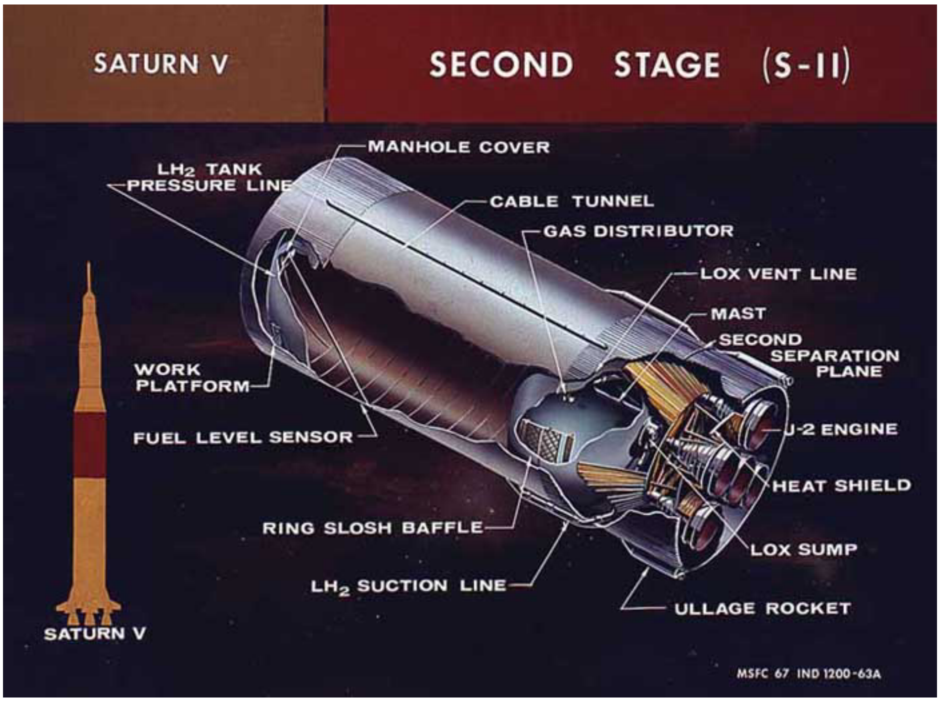
65 of the 98 engines that were created for the mission were launched. 56 more engines were evaluated. Throughout development and manufacturing, there were a total of 2.771 firings, 1.110 of which were for the whole firing time, lasting a total of 239.124 seconds, or almost 66 hours. 34 complete stage S-IC tests were performed, 18 of which lasted longer than the full burn period (15.534 seconds). According to estimates, the entire cost of developing the F-1 was $1,77 billion (in 1991 dollars). The test stands for the stages and engines received at least as much funding. In a 1995 interview, Valentin Mishin, the man in charge of the N-1, the Russian equivalent of the Saturn V, admitted that the N-1's development had made a big mistake by only testing individual engines and never the entire first stage because there wasn't enough funding to construct such sizable ground facilities.

Five test stands were constructed at Rocketdyne for the F-1. The initial experiments were still conducted without a turbopump, necessitating the use of overpressure in the tanks to create the necessary pressure. Tanks were constructed for this use, each carrying 6 t of fuel enough for 20 seconds of operation and made of steel plates that were 13 cm thick. At Huntsville, test stands for the whole S-IC were constructed. The initial test was conducted on April 16, 1965. The F-1 was approved for human flights on September 6, 1966, while the S-IC received flight certification on November 15, 1967. With a variant with 6.672 kN of ground thrust, the first 4 flights (2 test flights and the manned missions Apollo 8+9) were made. The ones after it made use of one with 6.770 kN of thrust.

Vacuum thrust for each F-1 was close to 800 t. The Saturn IB's eight engines put together cannot match its power. Every second, 1.790 kg of oxygen and 788 kg of paraffin are burned. A single F-1 turbine can generate 44 MW of electricity, and its blades spin at a speed of 5.550 revolutions per minute. For blending the fuel, the injection head contains 3.700 holes. The combustion temperature is 3.200 degrees Celsius, and the combustion chamber pressure is 60 bar. The combustion chamber is additionally coated with a mineral covering, resembling asbestos, that resists heat conduction in addition to being cooled by the paraffin moving in tubes surrounding it. The exhaust gases from the gas generator, which are 650 degrees hot, were passed over the nozzle neck in a film to cool the stainless-steel nozzle. Each engine weighed 8.361 kg, stood 5,8 m tall, and had a maximum diameter of 3,72 m. Upon takeoff, it produced 8.750 MW of electricity, which is a significant increase above nuclear power. Around 13 t of gasoline were used each second by all 5 engines. A total of 2.100.000 kg of fuel were burned in less than 3 minutes. An engine with 1,5 million pounds of thrust was the intended aim (6.720 kN). Each F-1 successfully produced a vacuum thrust of 7.740 kN and a ground thrust of 6.815 kN in practice. Despite this, a Saturn launched relatively slowly since only 1,2g of acceleration was present. To stop the acceleration after 135 seconds, the middle engine was turned off. For 165 seconds, the four outer engines ran. The engine’s flame jet was roughly 300 m in length during takeoff. The sound alone had around 500 MW of energy. The launch pad experienced 160 db of noise as a result. This was only topped by the Space Shuttle, which launched with a noise level of 168 db. Tiles from the ceiling paneling fell from the broadcast studio five kilometers distant during the first Saturn V launch, and seismic monitoring stations more than two thousand kilometers away still picked up the tremors.

The S-II

The beginnings of the S-II's are also older. With various payloads, a family of Saturn rockets was envisioned. The Saturn I, IB, and V were given the designations C-1, C-2, and C-5, respectively. Intermediate steps were still being thought about in 1961. The S-II, with a diameter of 6,5 m, a length of 22,5 m, and four J-2 engines, was to be the C-2's second stage. Without entering orbit, the C-2 planned to transport an Apollo spacecraft without a supply module to a swing-by of the moon. 20,4 tons were intended as the payload for an Earth orbit.



Picture of the S-II

The Apollo program underwent a redesign in June 1961. This means that an Apollo spacecraft always needs to carry a supply unit, increasing its weight from 6,8 tons to 13,6 tons. With a payload of 36,3 t into Earth orbit, the S-II was now intended as a second stage for the C-3 because it was too heavy for a C-2 and a moon trip. The diameter was expanded to 8,13 m. Later, the MSFC raised this to 9,14 m. After a tender between 30 businesses on September 11, 1961, North American Aviation was chosen to produce the stage under these terms.

The $300 million development and manufacturing deal. The S-II stage used five of the same engines as the S-IVB stage. It had a 10,01 m diameter and a length of 24,80 m, just as the S-IC. In comparison to the S-IVB, the mixing ratio of hydrogen and oxygen averaged 5,3 to 1. An interstage adaptor that was 5,4 meters long and 5.200 kg in weight joined the S-II and S-IC. This adapter was two pieces for the first two test flights and Apollo 8, thereafter it was simply one piece. Unlike earlier launch vehicles, the adapter stayed on the S-II and was only disengaged 30 seconds after the S-II was ignited as the four outer J-2 engines reached a thrust level of 90%.

The S-II was built with somewhat greater power than the S-IVB, and a lot more work was put into reducing empty mass than with the S-IVB, which was the second stage of the Saturn IB and was meant to be completed earlier. The S-II stage was the one that employed the most cutting-edge procedures and underwent the most optimization of all three phases.

The S-II, for instance, used an integrated tank with a shared intermediate floor. Due to the removal of the intertank portion, the stage 3 was 4 tons lighter and 3 meter shorter. First, it was thought impossible to construct a tank this size in one single piece. The 6 m long tank's individual sections were difficult to weld due to the low temperatures, which required extremely high manufacturing accuracy. Weld seams were to be put with a 0,33 mm precision throughout a length of 6 m. The longest single-piece junction was 31,4 m, making the overall length of the welded joints 710 m. As was previously reported, there were significant delays in perfecting the welds. The tank’s component pieces were built of the aluminum alloy 2014 T6, which was not thought to be weldable. Yet, only welded pieces could withstand low temperatures and be light at the same time without leaking. At the Marshall Flight Centre, Werner Kurs (a Peenemünde native and part of Von Braun's crew) invented tungsten inert gas (TIG, also known as WIG) welding. At 1.650–2.780 °C, Tungsten electrodes (made by American Tungsten) were used to weld the sheets. The metal was shielded from corrosion and oxidation by helium. To check the welds, new techniques were created, such as X-ray fluoroscopy.

Individual curved metal sheets measuring 6 m long and 2,6 m broad made up the oxygen tank. Yet there was no technique available to distort such large pieces. A 211 m3 tank was constructed for the development of explosive deformation underwater. They were connected at the top by circular parts, and then the spherical end was affixed. To achieve the exactly predetermined curve form, the insulating layer of phenolic resin in honeycomb structure was first put on the LOX side and then after welding the tank on the hydrogen side with an autoclave. The honeycomb fabric used to wrap the tank domes, ranged in thickness from 0,79 mm at the periphery to 13 cm in the center.

The hydrogen tank was made up of distinct transverse rings, as opposed to the oxygen tank. The five upper ones were each 2,4 m tall, the lowest one was only 69 cm high. 636 bolts that transferred forces and connected it to the engine portion gave the required stability. The oxygen tank's volume of 331.000 liters was more than tripled to a volume of over one million liters.

The insulation was at the interior, same as with the S-IVB. The insulation S-II's issues were the ones that persisted the longest throughout the stage's development. The initial solution was composed of sizable chunks of phenolic resin honeycomb structure filled with isocyanate foam. A phenolic laminate and tedlar plastic were used to bind these. Experiments revealed that when the tank was full, trapped air was led to the link being weaker. By using helium to clean the tank prior to filling, this could be avoided. Nevertheless, it was expensive, and didn't always function well., North America invested a lot of time and money to find a different answer, which they found by omitting the honeycomb layer and just applying the insulation. This was much easier and even straightforward. They turned to spray the insulation after delivering the initial phases, using solid insulation.

372.415 kg of oxygen and 71.770 kg of hydrogen were carried on Apollo 11. (Mixing ratio 1:5,19). The five J-2 engines produced between 5.100 and 5.155 kN of force. As for the other stages, the central engine was turned off 30 seconds earlier than the outlying ones. The four outer engines were pivotally placed on the five 25 m diameter circular framework.

The S-II featured two blocks of four retrorockets each, and they used solid fuel like their S-IC counterparts did. The stage was propelled by four rockets, each with a force of 95,7 kN, which allowed for a "clean" separation from the S-IC. Before ignition, they also gathered the propellants in the tanks. The upper stage adapters with the other four 170,1 kN thrusters slowed the stage down as it detached from the S-IVB. In addition to the primary helium system in the engine section, the structure also had a reserve system with five cylinders on the exterior. Each contained helium under 210 bar of pressure. Auxiliary systems, propellants and the helium, weighed a combined 1.184 kg.

The S-II employed the J-2's mixture ratio change technology, just as the S-IVB of the Saturn IB. The engine started with a mixing ratio of 5,0:1 and after 2,5 seconds cruised to the greatest level, 5,5:1, which had the most thrust (1.020 kN per engine) and had the highest mixing ratio. When the stage was nearly empty, it was feasible to change the propellant usage ratio to 4,5:1 which was done (Apollo 8) 280 seconds after launch, reducing thrust to 807 kN and increasing the specific impulse to a high of 4.270 m/s. This schedule was largely maintained throughout the flights, however the precise moment when the mixing ratio was dropped changed depending on the mission.

There was a desire for greater payload for Apollo early in the development process. In 1964, it was uncertain if the LM lunar lander would ever be able to achieve the desired weight since Apollo was too heavy. In the future, they planned to transport more payloads like experiments for the CSM or a lunar mobile. Saturn had to lose weight as a result. To add 1 kilogram of payload, you have to:

The S-IVB needed to weigh 1 kg less.

The S-II needed to weigh 5 kg less.

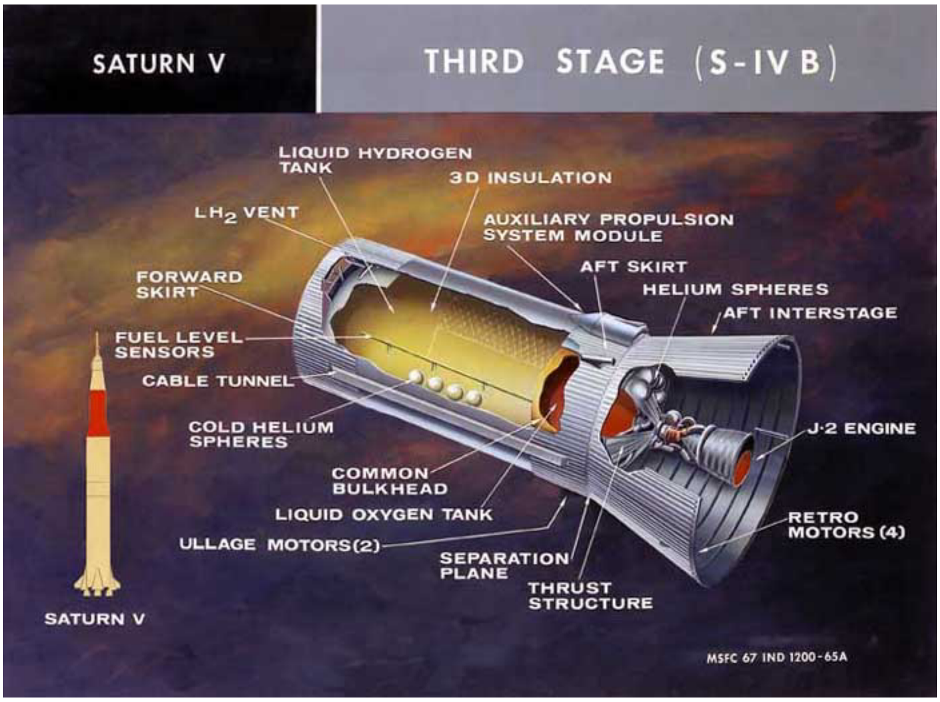
The S-IC needed to weigh 14 kg less.

The construction of the S-IVB had already progressed too far for significant changes. It makes little sense to reduce the weight S-IC's by 14 kg in order to gain merely 1 kilogram in payload. Hence, the S-II was left and a program to make it lighter started in the middle of 1964. Still empty, the S-II of Apollo 8 weighed 40.188 kg. Just 35.383 kg was the weight of the Apollo 15 S-II. The tanks only weighted 3% of their capacity, which was less than the tank from the Space Shuttle.

Throughout the testing, S-II encountered various issues, of which some may have been prevented. General Samual C. Phillips pushed on forgoing the stage's dynamic test in favor of further combined static testing to keep the schedule in spring 1965. On July 29, 1966, improper welds were found, and one S-II detonated during a combined static/dynamic test on September 19, 1965. Peak loads on the tail portion reached 144%. The S-II program already was more than three months behind the schedule and by this a "Tiger Team" looked into the program and came to the major conclusion that there were severe communication issues. Management lacked a thorough understanding of the problem and was not receiving the information they need. It was decided to hold a daily 45-minute meeting to discuss concerns and progress. Things appeared to be getting better and a static test of 350 seconds took place on 25.5.1966, and it was successful. Yet the S-II detonated less than three days later. After the static test, the hydrogen tank had been pressurized with helium to a pressure far higher than the specification to identify leaks. Around the explosion site, small fractures and, worse than this, comparable cracks in serial manufacturing copies were found. As a result, the Saturn V's initial launch had to be delayed.

The S-IVB

The S-IVB produced by McDonnell Douglas was built similarly to the Saturn IB's S-IVB in most respects. The primary modification permitted free flying periods of up to 4.5 hours thanks to better insulation. The step adapter was modified too by reducing the diameter of the S-II from 10,01 m to 6,60 m. The S-II also received a step adapter adaptation which was thrown away together with the S-II. The oxygen to hydrogen mixing ratio of the Saturn V's S-IVB was typically 4,8 to 1. They never changed it, unlike with the S-II, and constantly ran the stage at a ratio of 5. This gave a ratio of 4,8:1 when combined with the hydrogen required for cooling and auxiliary systems.



Picture of the S-IVB

This was also the case since hydrogen losses during the course of the 1,5 to 4,5 hour Earth orbit were included. A loss of 1.306 kg of propellant was anticipated for Apollo 11. The S-IVB transported 19.732 kg of hydrogen and 87.101 kg of oxygen on this voyage. There were also two jettisonable engines for fuel collection and eight more engines in auxiliary systems for storage control. There were two systems with three engines each producing a thrust of 667 N for steering along the axes of pitch, yaw and roll, and one engine each with a thrust of 336

N for the O2/H2 pre-burner to start the gas generator. These devices had 1.249 kg of fuel in their own tanks.

With the S-IVB of the Saturn IB, it became unnecessary to set the scene again as Helium was heated to create pressure in the tanks. The gas generator and turbine then were initiated by the O2/H2 pre-burner. The S-IVB was tested on Apollo 9 to see if it could fire three times because after the CSM and LM were separated, standard lunar missions only needed two ignition sequences. The S-IVB was set on an escape route once this was successful.

Two sets of four curved aluminum surfaces each made up the connection to the CSM, which was made of an 8,5-meter-long cylinder with a base diameter of 6,60 meters and a tip diameter of 3,91 meters. They were 4,2 mm thick and covered in a cork coating that was 0,7 mm thick to insulate them from the frictional heat of the environment. The LM was folded inside of this compartment. The surfaces were discarded after the craft entered earth orbit, and then the CM docked with the LM and decoupled from the S-IVB. The fairing used weighted 1.815 kg.

The S-IVB often is described as follows: It was the first to employ the J-2 engine, which produced 15 times greater thrust than the RL-10 engine of the Saturn I and consumed hydrogen and oxygen. When it was initially deployed on the Saturn V, the S-IVB was already proved because it had flown with the Saturn IB previously.

A stage that was more than twice as heavy as the S-IVB could be carried by one engine if the moon landing was to be done directly. An S-IVB would then stay in Earth orbit for 30 days but two rockets would have been needed for this, one to launch an S-IVB with all of its fuel and put into Earth orbit and another to launch a considerably heavier lunar spacecraft. Nevertheless, this need was dropped when the procedure was dropped. The diameter S-IVB's had to be enlarged from 5,6 to 6,6 meters, and a somewhat stronger rocket (the C-5 rather than the C-4) was to be used.

The J-2 was 1,578 kg heavy. Advanced J-2s with a thrust of up to 1.020 kN were used on the S-IVB stage of Saturn V with 6,61 m in diameter and 18 m length. It had a single tank, divided into an oxygen tank and a hydrogen tank by an intermediary floor. The J-2's combustion chamber had a pressure of 48,5 bar. 18.000 kg of liquid hydrogen and 87.200 kg of liquid oxygen made up the fuel load. Nevertheless, due to hydrogen's low density, the tank volumes were apportioned differently, the hydrogen tank had a volume of 252.750 liters, whilst the oxygen tank only had a volume of 73.280 liters. 229.000 liters of this tank's total volume were used for the hydrogen tank. The tanks were self-supporting, and the style was more akin to the comparatively large Thor cell than the relatively light Centaur upper stage. The tank was contained in the supporting cell, and its wall thickness ranged from 0,813 to 1,4 mm. Materials included 2014 T6 aluminum alloys (the same as used on the S-II). So how was a 12 m long and 6,6 m broad step to be insulated? They first intended to use balsa wood because it is lightweight, provides good insulation, and is simple to mold. Nevertheless, a quick inventory check revealed that South America lacked sufficient balsa wood for these procedures. They were able to successfully embed a three-dimensional fiberglass matrix in a polyurethane block as a result of their efforts to create "synthetic balsa." The polyurethane insulated while the fiberglass provided the hardness and stability. This structure demonstrated its worth. It could have prevented Columbia's damage from a loose foam block during launch if it had been used on the Space Shuttle. These 30 × 30 cm, 20 cm thick tiles were used to provide the insulation for the hydrogen tank, which was filled with 4.300 of them. A vacuum applied fiberglass net that was used to seal them off kept the detaching tiles from migrating. The S-IVB stage's insulation made it possible to increase the flying duration from 10 minutes to 4,5 hours. The hydrogen tank would have lost 1.100 liters of hydrogen per minute through evaporation without the insulation.

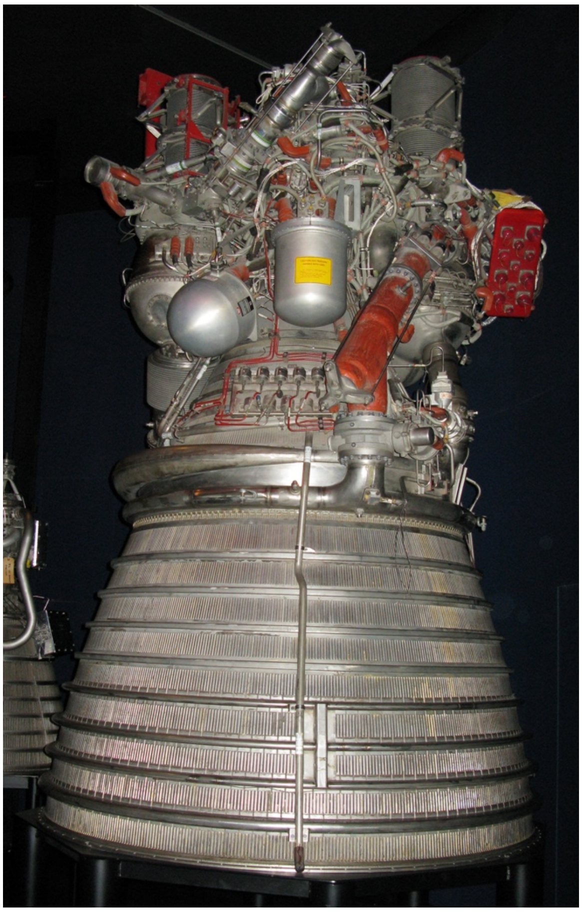
In contrast to the S-IV stage, the Saturn S-IVB stage needed to be reignitable in a vacuum. After one to three earth orbits, the Saturn V was used to launch the Apollo spacecraft to the moon, and after docking, it was used to launch itself into an escape orbit or a lunar impact orbit. The tanks had to be pressurized to do this. For this, an O2/H2 pre-burner was employed. This was a little rocket engine with a thrust range of 71-89 N. Gaseous oxygen and hydrogen that the tanks naturally generated were burnt. The 9 helium cylinder’s valves were opened by the combustion gas, which raised the oxygen tank’s pressure to 2,6-2,9 bar. This was sufficient to inject the gas generator with just the right amount of fuel to start it. The hydrogen tank's pressure of 2,2–2,4 bar could be maintained only by the pressure of the hydrogen gas created by evaporation. The pressure was kept from building up too much thanks to pressure release valves. By opening a tiny line to deliver a small flow of oxygen through these systems before to ignition, the O2/H2 preburner also offered pre-cooling for the oxygen pump and oxygen fuel lines.

Initially, it was believed that the engine could be started by merely opening the valves: Fuel combustion in the gas generator kicks on the turbo pumps. The power of the turbine and the turbopumps grew as a result of pumping more fuel. This, however, proved to be too sluggish. As a result, the S-IVB featured a hydrogen-filled tank with a capacity of 0,1 m3. Its internal helium tank maintains a high pressure in this tank. This gas tank is opened together with the fuel valves and the extra gas swiftly accelerates the turbine. It is fueled on the ground prior to takeoff, then the engine is turned off after the burn period before being refueled from the tanks. The stage must run for at least 50 seconds to fill the tank. This method permits countless reignitions. Moreover, it took the J-2 just 5,0 seconds at a mixing ratio of 4,5:1 and 2,5 seconds at a ratio of 5,0:1 to attain 90% of its rated thrust.

The J-2

The J-2 engine was created before the S-IVB, just like the other engines of the Saturn. NASA granted contracts for the research of engines with 150.000 pounds of thrust in the fall of 1959, on December 15, 1960, this number increased to 200.000 pounds (890 kN). Rocketdyne received the development contract on 1.6.1960. For the first time the need for the highest level of safety for manned flights was included in the final engine building contract, which was signed in September 1960.

The focus was on dependability, and from the first drawing onward, there were ongoing reviews of the work completed to determine whether reliability could be increased. Instead of an engine, a self-starting propulsion system that could be reignited in a vacuum without the aid of any other systems, such as the RL-10, arosed.



Picture of the J-2

The J-2 may change the weight O/H ratio of oxygen and hydrogen in increments of 0,5 between the ranges of 4,0 and 6,0. The range of 4,5 to 5,5 was used in the Saturn carriers. At 1:4,5 (4.270 m/s), the maximum specific impulse is attained. At 1:5,5, the maximum thrust was attained (1.020 kN). The minimum specific impulse was 5,5 (4.148 m/s), while the minimum thrust was 4,5 (807 kN). This method wasn't used to the S-IVB of the Saturn V, just to the S-II and S-IVB of the Saturn IB. In all situations, the goal was to maximize performance. High thrust was required for the second stages, thus upon ignition, the engines were run in the mode that produced the highest thrust. The stage was lighter and thrust became less significant as the fuel was mostly used. With the ability to change to a lower mixture ratio, the fuel could now be used more effectively.

The first batch of the J-2's mixing ratio in the following table is discussed (890 kN nominal thrust version). The relationship between the reduction in specific impulse and the rise in thrust is roughly linear.

Mixing ratio	1:4,5	1:5,0	1:5,5
Thrust (kN) (890 kN version)	806 kN	890 kN	978 kN
Discharge velocity (890 kN version)	4.236 m/s	4.178 m/s	4.119 m/s
Thrust (kN) (1.020 kN version)	827 kN	910 kN	1.030 kN
Outflow speed (1.020 kN version)	4.260 m/s	4.187 m/s	4.148 m/s

The J-2's development happened relatively quickly. As early as November 1961, the oxygen and hydrogen turbopumps saw their initial test runs. The first combustion chamber ran for 2,57 seconds in March 1962, still without turbopumps or regenerative cooling. A burning duration of 250 seconds was attained on October 4th, 1962. As it had already been determined to employ the J-2 in the S-IVB, Rocketdyne was given a contract on January 7, 1962, to produce 55 test and production units up to 1965.

This contract was renewed in July 1966. The task of creating an expanded J-2 with a 230.000-pound thrust was given to Rocketdyne (1.023 kN). There were now 155 engines available. It was used on the Saturn IB starting with AS-208 and the Saturn V starting with AS-504. It was initially given in the spring of 1968. Early J-2 models continued to use a notional mixing ratio of 1:5, whereas later models used a higher ratio of 1:5,5.

	SA 201-203	SA 204-207 und SA 501-503	SA 208 ff und SA 504 ff
maximum thrust	889 kN	1.000 kN	1.023 kN
Maximum burning time	500 sec	500 sec	500 sec
minimum specific impulse	4.099 m/s	4.109 m/s	4.129 m/s
Dry weight J-2	1.637 kg	1.637 kg	1.642 kg
Area ratio	27,5:1	27,5:1	27,5:1
Mixing ratio	5,0:1	5,5:1	5,5:1

The J-2 underwent extensive testing. Most of the testing were conducted between December 1965 and January 1966 to adhere to the schedule properly. There were 203 tests in all, with a total burn duration of 33.579 seconds (corresponding to about 60 missions). The normal running period was just 470 seconds and only needed two starts, however one engine was started 30 times and burned for 3.774 seconds. New tests were also conducted in vacuum chambers that replicated the environment at 305 km altitude. A J-2's minimum service life was specified at 3.750 seconds. In contrast, the RL-10 had a minimum life of 1.680 seconds and was not required to fulfill such strict dependability standards.

The J-2 development progressed more smoothly than the stages, the F-1 and H-1 engines and the stages. The injector was the only issue, Rocketdyne's designs tended to burn out. Now, the MSFC insisted on bringing in the Pratt & Whitney engineers who were working on the RL-10 injector. The injector was made electrochemically porous as a practical approach. It may allow around 5% of the hydrogen to diffuse through it and serve as a cooling layer to shield it from the combustion chamber's heat. The injector had 614 holes, with hydrogen on the exterior and oxygen driven through the center.

Two rows of steel tubes made up the combustion chamber. In order to go from the nozzle end to the injector, hydrogen first traveled via 360 inner tubes and then 180 outside tubes. It was heated throughout the operation from -253 to -162 degrees Celsius, turning gaseous. The flow rate changed from 18 to 300 m/s. Together with the oxygen, the turbine's exhaust gases were also pumped into the combustion chamber.

The oxygen and hydrogen turbopumps were developed for the J-2 to have independent shafts. As a result, the mixing ratio could be adjusted, and they could be placed near to the gasoline lines on the left and right of the engine. This was accomplished by keeping the oxygen pump's output speed between 6.000 and 8.800 rpm. The seven-stage hydrogen pump ran continuously at 27.500 rpm. A two-stage turbine provided the necessary power for both pumps, which were driven by independent shafts. Branching off fuel (0,4 kg hydrogen and 2,3 kg oxygen/sec) was used to lube the pumps.

Total length	3,38 m
Total width	2,04 m
Nozzle diameter	1,96 m
Maximum thrust	1.020 kN
average specific impulse	4.168 m/s
minimum specific impulse	4.148 m/s
maximum specific impulse	4.216 m/s
Thrust on ignition	896 kN
maximum thrust	1.020 kN
nominal burning time	500 s
Mass flow rate LOX	208,2 kg/s
Mass flow rate LH2	37,8 kg/s
Mixture ratio	4,5-5,5:1
Combustion chamber pressure	50-54 bar
Engine weight (dry)	1.578 kg
Thrust to weight	66:1
Area ratio	27,1
Combustion chamber temperature	3.160 °C
LH2 turbopump speed	27.500 U/min
Power LH2 turbopump	7.970 PS
Outlet pressure LH2 turbopump	88 bar
Speed LOX turbopump	8.800 U/min
Output LOX turbopump	2.250 PS
Outlet pressure LOX turbopump	77 bar

Internal Unit

The instrument unit IU of the rocket was located over the S-IVB. It was contained in a ring that was 6,6 meters wide and 91 centimeters high and weighed 2.041 kilograms. In this area were the on-board computer, telemetry transmitter and receiver, gyroscopes serving as inertial platforms, and batteries for the on-board power generation. The safety system also activated the rescue tower in the event that numerous H-1 engines failed, the rocket was spinning violently, or sensors detected cracks in the lines or on the outside skin. A temperature control system that cooled the equipment, using water that evaporated and was discharged into the vacuum, had to be built, due to the equipment's excessive energy consumption at the time. The internal unit of the Saturn IB was too large for a launch vehicle of size since it was the same as the internal unit of the Saturn V. Yet, in keeping with Wernher von Braun's safety guiding principle, the IU could be flight-qualified in this manner and the payload was still adequate for the missions of the Saturn IB.

The Saturn V's ST-124M computer had a capacity of 1,6 m3, weighed 35 kg (114 kg with the flying unit, gyros, and navigation), and consumed 438 watts of electricity. 9.600 computing operations per second, or an average of 11.300 instructions, were carried out (28 bit word width). A division or multiplication took 328 microseconds, whereas an addition took 82 microseconds. It had six memory modules, each containing 4.096 words in 28 bits, and it could add two more modules to its memory. Total bit capacity is 917.504 (32 K words of 28 bits each). The 28 bits were divided into 26 bits for data and 2 bits for memory fault detection. The MTBF was 45.000 hours, which was reliable (Mean Time between Failures). This was incredibly dependable at the time and is now an excellent deal (equivalent to a failure after an average of 5 years). In contrast to the Saturn I, the computer was operational prior to launch and collaborated with the launch center computer during the last-minute tests. The Saturn V's lunar missions needed a maximum working period of 10 hours at a time due to the free-flight phase.

The first integrated circuit-based computer (ST-124) was created in a launch vehicle. A Computer nowadays contains roughly 50 chips, while the ST-124 had 8.918! The total number of parts in the computer, including additional parts (transistors, capacitors, and resistors), was 40.800. The computer, unlike the on-board computers of the Command Module CM and the Lunar Module LM, was built with triple redundancy in accordance with von Braun's safety philosophy and included a tuning mechanism, meaning that if one computer made a mistake, the other two overruled it. Each computer contained two redundant memory modules, making the memory modules an even 6 fold redundant system. The redundant design had yet to provide benefits. The on-board computer of the Apollo 12 spacecraft failed when lightning struck the Saturn V during the launch, yet the Saturn managed to stay in flight. If the IU fails after firing the S-II, the Apollo spacecraft can take over control of the Saturn V. The crew's only other option was to manually launch the escape tower.

A predetermined program was followed during the first stage's operation, and no adaptive compensation for disruptions was implemented. This was not feasible quickly enough with the state of the art at the time, thus the major objective was to get the rocket into orbit. Adaptive course correction was employed starting in the second stage. In order to achieve the desired values, the rocket must continually compare its speed and position to predetermined values and make adjustments as needed. There was one recalculation each second. An alternate course of action was also pursued if there were significant deviances. Once on the second qualifying flight AS-502 (Apollo 6), when POGO oscillations forced the S-II stage to shut down early, and once on Apollo 13, when the S-II stage's center engine failed, this capability rescued a Saturn V mission.

The number of measurements transmitted likewise decreased during the course of the Apollo program. A total of 1.348 measurements were made during Apollo 11. 330 during the first stage, 514 during the second stage, and 200 during the third stage. Moreover, the IU had 221 measures. The values were modulated using PCM and FM and sent analogously. The IU received the orders through digital transmission.

Saturn V

13 launches between 9.11.1967 and 14.5.1973
Payload: approx. 133 t into a 185 km, 28,8° orbit (three-stage),
approx. 90 t into a 440 km, 51,6° orbit (two-stage),
50 t to the moon
Height: 86 m rocket, 110 m with spacecraft and escape tower
Stage 1: S-IC
5 engines F-1
Thrust: 6.733 kN each (sea level), 7.740.5 kN (vacuum)
Total: 33.665 kN, 38.702.5 kN
Firing time: 161 sec.
Take-off mass: 2.286.217 kg
Empty mass: 135.218 kg
Spec. impulse: 2.982 m/s (vacuum), 2.600 m/s (sea level)
Diameter: 10,1 m, length: 42,1 m
Fuel: kerosene/oxygen
Stage 2: S-II
5 J-2 engines
Thrust: 1.031 kN each
Total: 5.155 kN
Burn time: 390 sec.
Take-off mass: 490.778 kg, empty mass: 39.048 kg
Specific impulse (vacuum): 4.160 m/s
Diameter: 10,1 m, length: 24,8 m
Fuel: hydrogen/oxygen
Stage 3: S-4B
1 engine J-2

Thrust: 890 kN
Burn time: 475 sec.
Take-off mass: 119.900 kg, empty mass: 13.300 kg
Specific impulse (vacuum): 4.180 m/s
Diameter: 6,6 m, length: 17,8 m
Fuel: hydrogen/oxygen

Instrument Unit (IU) :
Diameter: 6,6 m, Height: 0,91 m
Mass: 1.800 kg

The J-2S

For NASA, Rocketdyne continued to develop the J-2 from 1965 through 1972. The engine's simplicity and weight savings were the main goals. As a result, the "ullage" engines that were used to pre-accelerate the fuel were eliminated. Solid fuel cartridges were used to kick start the turbine. As a result, the engine was started at a low-thrust region, which collected the propellants. Hydrogen from the engine cooling system was used to drive the turbine in place of the gas generator. In addition, the oxygen, which made up 5/6 of the fuel, was intended to be exhausted by the engine. The stages' remaining fuel was reduced as a result.

As compared to the J-2, the J-2S weighed 1.400 kg, was roughly 180 kg lighter, had a slightly higher specific impulse of 4.275 m/s, and had a higher thrust of 265.000 pounds as opposed to 200.000 pounds (1.178 kN). Similar to the J-2, the J-2S may function in a variety of oxygen to hydrogen ratios. The engine could run at ratios of 5,0 and 4,5 to 1, in addition to the standard 5,5 to 1. For tiny orbital adjustments, it was possible to switch the engine to "idle mode," which had a low thrust.

The Saturn V's payload of 130t (S-IVB +70t propellant and spacecraft) delivered into Earth orbit on a lunar voyage might have been more with more force for low Earth orbits. The J-2S was capable of at least three reignitions, therefore synchronous missions would have also been feasible.

Huntsville still anticipated that 3–4 Saturn V rockets would continue to be produced for a while, and the J-2S was intended to replace the J-2 on subsequent variants. Nevertheless, following the successful Apollo 11 landing in 1969, it was decided to solely employ the Saturn Vs that were already in production.

There were 273 tests altogether, with a combined burn time of more than 30.000 seconds. For testing, six thrusters were produced. The engine was then prepared for certification. This, however, never occurred. It was supposed to be used for the first time on the SA-518 mission, however that mission never happened. The engine was then constantly suggested to be employed for several heavy-lift carriers. According to the most recent plans, it would be used on the Ares I+V launchers for George W. Bush's lunar program. The J-2S will be converted into the J-2X, a high-pressure engine with a greater specific impulse, during the process.

The J-2's many variants have the following technical specifications:

Typ	J-2	J-2X	J-2S
Height	3,38 m	4,70 m	3,38 m
Width	2,04 m	3,05 m	2,01 m
Weight	1.578 kg	2.400 kg	1.400 kg
Thrust	1.020 kN	1.307 kN	1.138,5 kN
Specific impulse	4.216 m/s	4.426m/s	4.275 m/s

The Start

In a short time, the necessary payload for the moon went from 41 to 45 tons. The major cause of this was that the LM could not be constructed as light as needed. The only LM that could land and orbit again was on Apollo 11. The demands, though, kept going up. More soil samples were to be brought back, additional equipment was to be transported, and an automobile was to be placed on the moon. Between 1968 and 1972, the payload (to the moon) was raised from 45 t to 50 t by lightening the rocket. The maximum payload of the Saturn V from Apollo 8 was still 45 t.

There was just one orbital trip, aside from the moon missions, and that was Skylab, whose space station was a modified Saturn V third stage. On this one, the rocket fired without a hitch, but the payload fairing damaged the solar sails during launch, necessitating immediate space station repairs by the first crew.

A Saturn's countdown took 133 hours and 32 minutes, however only 93 of those were countdown time, the remainder were pauses (for delays, sleep breaks and the like).

The three phases flew using three distinct approaches. The S-IC operated in accordance with a predetermined flight profile that was flown without the need of active deviation adjustments. When a certain point with a predetermined height and speed was reached, the firing was terminated. The rationale behind this was because actively compensating for all the factors to which the rocket is subjected would have been too expensive, especially during the first launch period (varying wind speeds, temperatures, pressure conditions). The S-II could now use active computer control because the environment was no longer an issue as the separation point was at such an altitude. Based on the available data for altitude, acceleration, and speed, the computer constantly recalculated the route, choosing in each case the orbit that would allow an Earth orbit to be achieved with the least amount of fuel.

It was crucial to accomplish this while simultaneously making the most use of the S-fuel II's supply. The operating point of the J-2s shifted from a LOX/LH2 of 5,5:1 to 4,8:1 at a given moment when sensors in the tanks signaled the amount of residual fuel that was still available. This made it possible to almost entirely empty both tanks. The S-II was the only stage that entirely burned out.

The S-IVB was the first spacecraft to achieve the 700 m/s necessary for orbit, it did not need to climb much higher. When ground control had computed the data for this maneuver, measured the orbit, and communicated it to the IUS and the CM, the TLI (Translunar Injection) followed (Command Module). After the goal speed was attained, the firing was finished.

Control of the Saturn V was conceivable from the CM, and this capability existed starting with Apollo 11. both manually by the pilot and automatically by the Apollo Guidance Computer. Investigations revealed that even at high accelerations, this was theoretically feasible. The question of whether a lunar mission would have still been conducted if the IUS had failed or if it had been more of a concern to reach Earth orbit safely was left unanswered. The Saturn V was hit by lightning during Apollo 12, on the other hand. The cockpit's warning lights all illuminated, however the IUS was unaffected. The issues were temporarily resolved by turning off the major power source and use the battery-powered auxiliary system. The fuel cells, that the lightning hit, knocked off the bus but could then be reactivated in the first orbit following a thorough inspection.

Time	Event
-00:08.90	Firing command S-IC
-00:05.30	Thrust build-up
-00:01.00	Full thrust, pull back arms
00:00.40	Release the retaining clips
01:25.00	Maximum aerodynamic load
02:15.00	Burning end of middle engine
02:44.80	Burning end outer engines, 44 km altitude, speed=2.750 m/s (9.900km/h)
02:45.30	Separation of the S-IC
02::46.20	Ignition sequence S-II
02:49.20	Engines full thrust
03:15.50	Adapter separation
03:21.20	Escape rocket separation
07:43.80	Central engine burnout
09:16.67	Burn connection external engines, 187 km altitude, speed=6.933 m/s (24.960km/h)
09:17.80	Separation S-II
09:20.80	Ignition S-IVB
09:23.30	Engine has full thrust
11:43.80	Firing port for Earth orbit, 187.8 km × 191.8 km, speed=7.778 m/s (28.000km/h)
2:30:38.10	Reignition S-IVB für TLI
2:30:40.60	Engine has full thrust
2:36:33.80	Burning end of the S-IVB, Altitude: 948 km, speed=10.844,5 m/s (39.000km/h)

General overviews

Costs of a Saturn V

The Saturn V's development expenses came to $6.539,5 million USD. A further USD 900,1 million was allocated for the development of engines, which includes the H-1 in the Saturn I+IB, but not exclusively. A Saturn V's overall production cost was $113,1 million, which was divided as follows:

Stage	Hardware production	Modification	Safety reserve	Ground support	Ground support development	Total million $
S-IC	19,4	0,2	1,4	0,3	0	21,3
S-II	21,0	1,0	3,6	0,6	0	26,2
S-IVB	15,6	0,2	1,2	0,3	0	17,3
IU	10,9	0,9	1,0	0,9	0	13,7
Ground facilities	0	0	0,9	7,5	3,1	11,5
Engines	20,5	0	2,5	0,5	0	23,1
Total	87,2	2,3	10,4	10,1	3,1	113,1

In 1973, a three-stage launch would have cost $216 million, while a two-stage launch would have cost $180 million. In 1969, the Saturn V for Apollo 11 cost $185 million. These launch costs include transportation to the launch platform, a portion of the expenditures of the spaceport, such as the repair and maintenance work required after each launch, and the personnel costs for the technicians in addition to the pure production costs (in the final phase of the countdown alone, 450 people were involved in testing). Four months of preparations were made prior to a Saturn V launch.

How are the expenses divided up? There is an overview for the Saturn IB, and it probably applies to the Saturn V as well:

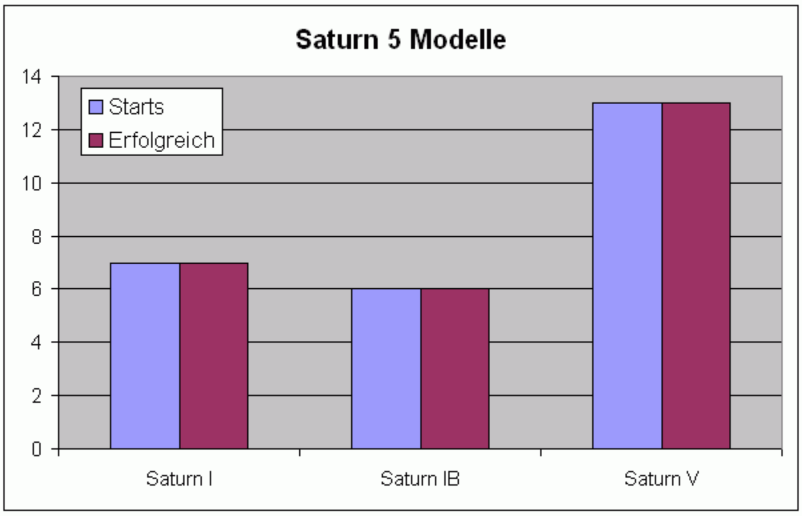
Type	Anteil
Production	65 %
Launch operation	18 %
Ground facilities	12 %
Transport, fuels, railway surveying	5 %
Total	100 %

The production can be further subdivided:

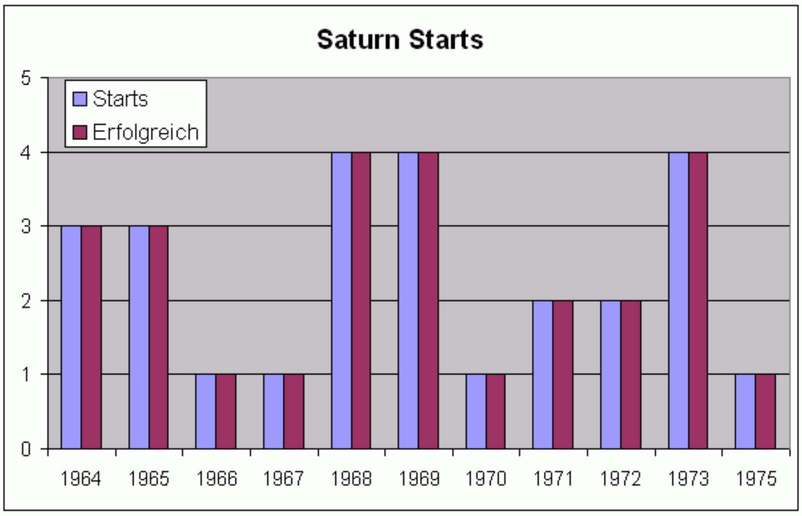
Type	Share of production costs	Share of total costs
Cost of materials	6 %	3,9 %
Quality assurance	66 %	42,9 %
Production and assembly	28 %	18,2 %
Total	100 %	65 %

You can see here very clearly how quality assurance, which is a prerequisite for high reliability, determines the costs.

Starts broken down by model



Starts, broken down by start year:



Conclusion

Undoubtedly, the Apollo mission and Saturn V rocket hold a special place in the hearts and minds of space enthusiasts worldwide. The iconic image of a Saturn V rocket launching into space is one that immediately evokes a sense of wonder and awe. The sheer power and scale of the Saturn V is truly remarkable, and it is a testament to the ingenuity and perseverance of the engineers and scientists who designed and built it. This is also the reason why I have chosen the Saturn V as my topic for my Travail Personnel. During my research, I have discovered that the development and completion of the Saturn V was an extraordinary feat of engineering. From the initial design concept to the final launch, every stage of its development was meticulously planned and executed. The rocket's powerful engines, advanced avionics, and precise guidance systems were all essential components that contributed to its success. Moreover, the speed with which the Saturn V was developed and built is a testament to the dedication and hard work of the engineers and scientists involved. It is incredible to think that the Apollo mission was accomplished in such a short period. It took only a few years from the time President John F. Kennedy set the goal of landing a man on the Moon to the successful Apollo 11 mission in 1969. This achievement is a testament to the incredible talent and dedication of the people who worked on the Apollo program. In conclusion, the Saturn V and Apollo mission will continue to inspire and motivate future generations of space explorers. The technology and engineering feats that were accomplished during this time were nothing short of miraculous. The legacy of the Saturn V and Apollo mission will continue to be felt for decades to come, as humanity continues to explore and push the boundaries of what is possible.

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