Saturn V:
The birth of the moon rocket

The Saturn V is the world's most powerful operational rocket

On the 16th July, 1969 the Florida landscape around the Kennedy Space Centre shook as Apollo 11 lifted off on its historic mission to take the first astronauts the Moon. The skyscraper-sized rocket that made this possible is one of the most recognizable machines of the 20th century, but the building of the Saturn V wasn't that simple. Its birth is a story of brilliant technical innovation tinged with engineering conservatism, politics, in-fighting, and having to work on a project that no one had more than a hazy conception of until surprisingly late in the day.

If you've ever visited one of the surviving Saturn Vs on display at the Kennedy Space Centre in Florida or the Johnson Space Centre in Texas, you can understand that the moon rocket is a magnet for superlatives. Not only was it the key technology for possibly the biggest event since a fish decided to try leaving the ocean, but it racks up an amazing collection of records that hold to this day.

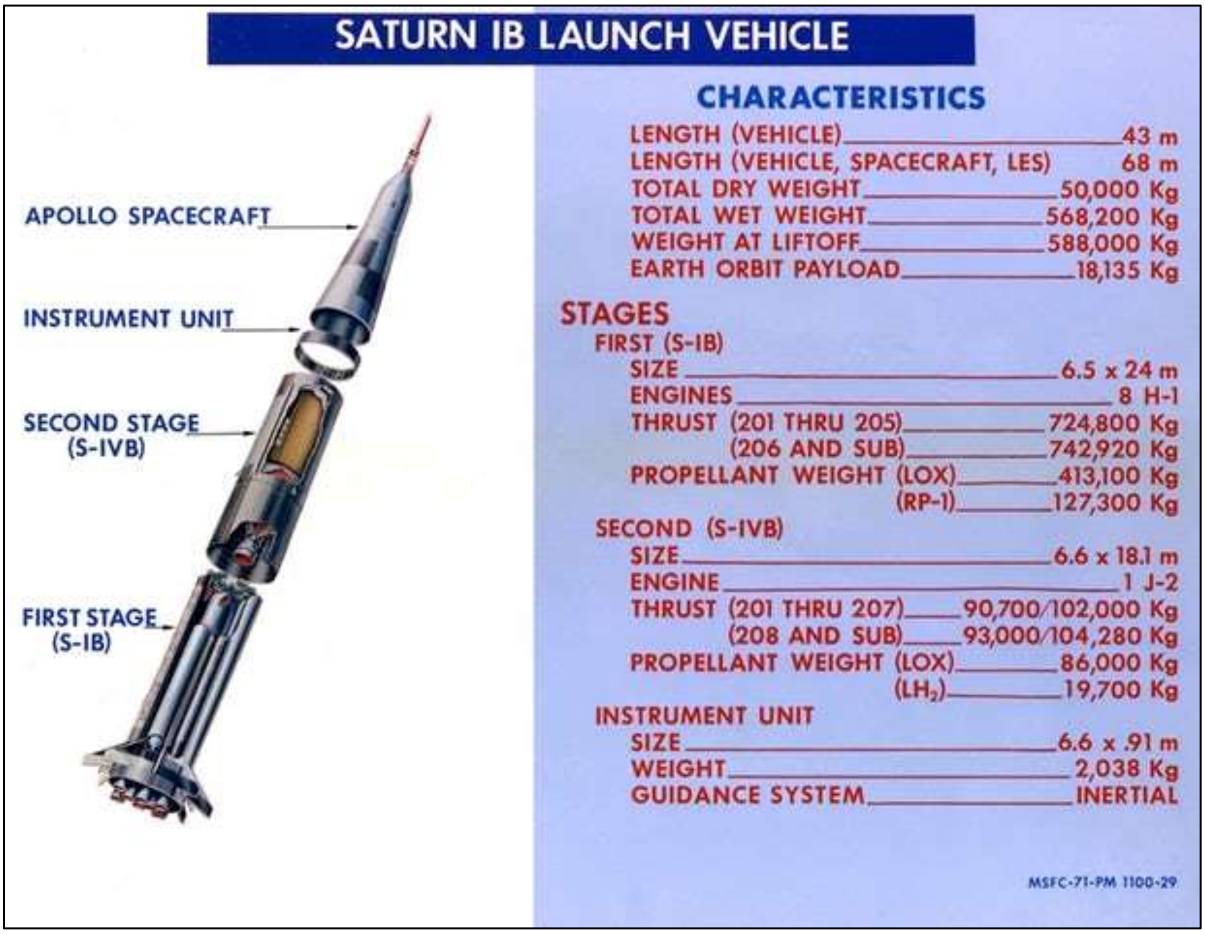
At a height of 363 ft (110.6 m), the Saturn V is the tallest rocket, standing higher than the Statue of Liberty or the clock tower housing Big Ben. It's also the heaviest rocket, weighing in at 6,540,000 lb (2,970,000 kg) and the most powerful ever to go into operation. With a first stage thrust of 7,891,000 lb (35,101 kN), it could hurl 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.

If that isn't enough, it's also not only the largest liquid-fueled rocket, but the largest flying machine ever built. Its F-1 first stage engine is the most powerful to go into service. The construction of the 13 Saturn Vs that flew and their 19 smaller Saturn I and Saturn IB siblings, involved 20,000 private firms and over 300,000 people spread across the continental United States. In addition, it is regarded by NASA as the first true space vehicle and is still the only one to send astronauts into deep space.

And there's more. Out of 32 Saturn launches, not a single one ended in failure and not a single payload was lost. Considering that NASA engineers and astronauts were always amazed every time one lifted off instead of blowing up on the pad, that's an incredible record.

Born of chaos.

But what is truly remarkable about the Saturn V is the story behind it. For such a revolutionary machine, its birth was both short and frighteningly complicated. Designed from 1960 to 1962 at NASA's Marshall Space Flight Centre (previously the Army Ballistic Missile Agency (ABMA)) in Huntsville, Alabama under the direction of rocket pioneer Wernher von Braun and Arthur Rudolph, the first Saturn V flew in November 1967 – with a lead time of only five years after getting the green light for the Apollo mission.



That would be impressive enough, but behind this was a story of unbelievable complication involving a bewildering number of parallel developments, complex decision-making, political in-fighting, international crises, and pushing the boundaries of science and engineering to their limits. Not so much a moving target as a moving target shooting at other moving targets, the development of the Saturn V was at the centre of a convergence of events, including interservice rivalries, the Cold War, the Space Race, departmental competition, new agencies springing into being, 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 make things interesting, it's also a story of a rocket that no one was really sure what to do with or how to do it, once the decision was made.

The first glimmer.

The story of the Saturn V begins during the Second World War when Nazi Germany deployed its V-2 ballistic missile. Developed at Peenemunde in Germany, the V-2 was the most important liquid fuel rocket ever built, and its design had so much influence on later work that the Saturn V can, in many ways, be regarded as a Super V-2.

In the final days of the war, Wernher von Braun and 700 top German rocket scientists surrendered to the US Army. They, along with truckloads of plans and hundreds of V-2 rockets, were secretly shipped to the United States as part of Operation Paperclip. Von Braun had chosen the Americans to surrender to because he thought that the US had the freedom and resources to allow him to carry on his goal of ultimately building a moon rocket, but the US government had other ideas.

Far from backing von Braun's ambitions, the Germans were confined to White Sands, New Mexico, where they were restricted to playing with captured V-2s, teaching US engineers rocket science, and making short-range ballistic missiles for the Army. In 1956, the ABMA was founded and von Braun's team made improvements in rocket design that were so advanced that they were assigned a government overseer whose job it was to make sure von Braun's team didn't "accidentally" launch a satellite into orbit. Meanwhile, the official large rocket program was being carried out by the US Air Force, which was developing ICBMs to carry nuclear weapons.

Then, in late 1956, the US Department of Defence decided that it needed a rocket big enough to lift large, vaguely-specified payloads into orbit. The main requirement was that the booster had to be able to lift loads of to 19,800 to 39,680 lb (9,000 to 18,000 kg) and could be built quickly and at low cost. In April 1957, the ABMA took up the challenge and looked into the feasibility of making a rocket called the Super Jupiter that could develop a thrust of about 1.5 million lb (6,672 kN) – 10 times more powerful than any rocket in the then-current inventory.

Originally, von Braun's team's idea was to use one huge engine, but it was later decided to use four smaller, yet still gigantic engines that went down in history as the F-1. Though a single engine would have been lighter, simpler and would have been less prone to failure than a cluster of engines, it would take much longer to develop. However, at this point the Super Jupiter was little more than a concept and some calculations and was likely never to be built.

The turning point came when President Dwight Eisenhower announced that the United States would place an artificial satellite into orbit as part of the country's contribution to the 1957 International Geophysical Year. To emphasize the peaceful nature of the launch, the project, called Vanguard, was a civilian effort that would upgrade a Navy sounding rocket to make it suitable to send a grapefruit-sized satellite into orbit. This would have been all well and good, but in October 1957 the Soviet Union launched the first satellite, Sputnik, into orbit and to make the point stick, it sent up a second and a third, as well as the first living creature in space, the dog Laika.

The result was official calm and public panic. The US government wasn't surprised by Sputnik and was even secretly relieved, because it meant that the communists wouldn't have grounds to object to American launches but the press and the public across the free world went into a tizzy because the USSR was regarded as relatively backwards and now it had fired a missile into space that could just as easily have carried a nuclear warhead aimed at New York or Washington.

What made it worse was the fact that Vanguard went from a leisurely scientific enterprise to a top national priority. It didn't help matters when the first launch attempt resulted in the rocket blowing up on the pad, presenting the Soviets with a massive propaganda victory and the Americans with a loss of credibility. Von Braun, on the other hand, had anticipated something like this and had arranged for several Jupiter missiles to be tucked away for "storage tests." When Sputnik I flew overhead, von Braun rather impatiently said that he could put up a satellite in 90 days. When the second Vanguard attempt failed, ABMA already had a Jupiter, now called Juno-1, at Cape Canaveral ready to send the first US satellite, Explorer I, into space, which it did on January 31, 1958.

NASA, ARPA, and Saturn

The Sputnik incident galvanized the US response and made space a top priority. In February 1958, the Advanced Research Projects Agency (ARPA, now DARPA) was founded to cut through the US government's tangle of in-fighting and bureaucracy to help advance science and technology projects. That April, Eisenhower authorized the formation of the National Aeronautics and Space Administration (NASA) to take over the civilian space program.

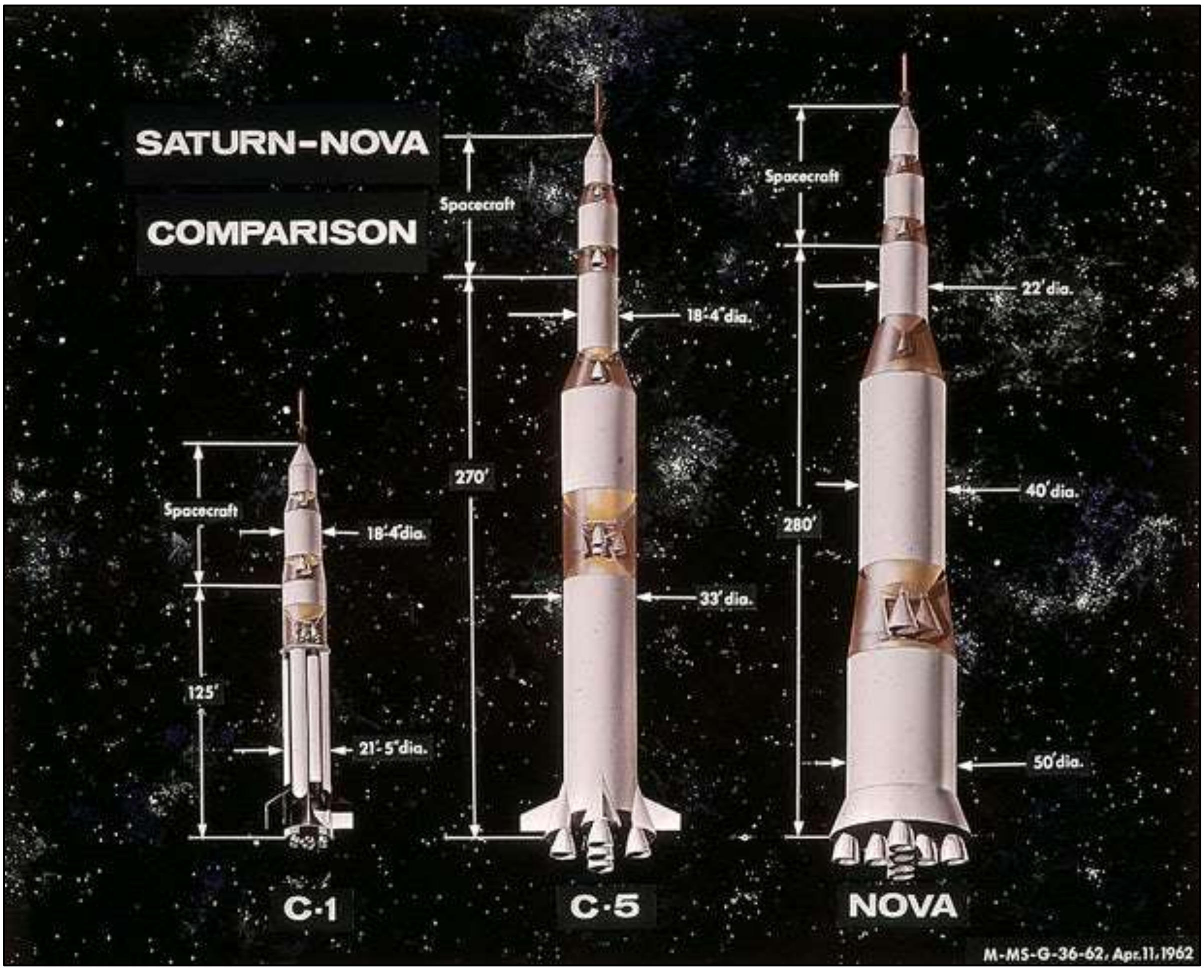
In August 1958, the ABMA's Super Jupiter effort – now called the Juno V – got a boost when ARPA committed money to the project. This was important because the military was losing interest in the giant rocket and mulling the idea of shutting down the project. Then, in 1960, it handed the whole thing over to NASA without a penny to go with it.

By this time, the name of the rocket was officially changed to Saturn, the ABMA was dissolved, and von Braun's team was transferred to NASA's Marshall Space Flight Centre (MSFC). In addition, though Saturn was still largely a concept, the engineers had a better idea about which way to go.

Which Saturn?

One example of the unfocused state of the Saturn project in 1960 was that there wasn't just one rocket, but at least five or six. At this point, Saturn was to be a family of multi-mission rockets in a number of configurations to handle different payloads and missions. Officially, there were five types designated C-1, C-2, C-3, C-4 and C-5, plus a Nova super rocket that would have dwarfed even the Saturn V had it ever got past the drawing board stage.

The reason for so many rockets was because no one was very clear on what the Saturns were supposed to do, or how they were supposed to do it. Also, there was no clear path to developing them. If six different rockets seems like a lot, bear in mind that these are just the major categories. At one point, there were so many variations of each of these that even the experts couldn't keep them straight. There were one-stage Saturns, two-stages, three, or four. Some had one engine, some had clusters. Some were modified military rockets. Some were brand new. Some had strap-on rockets or solid boosters. It was a planner's nightmare.



But the biggest problem was, what was the mission? What was the von Braun team designing the Saturn for, and why? In the beginning, it was for the military community, but they soon lost interest and preferred to go with their own program and threatened to cut funding. Then control of von Braun's team and the Saturn was transferred to NASA, but the fledgling space agency hadn't the slightest idea of what to do with a giant rocket, much less what its final design should be.

Things started to come into focus in January 1960, when NASA told the US Congress that it could put a crew into orbit around the Moon inside of 10 years and a manned lander on its surface shortly thereafter. This timeframe wasn't based on anything solid, but the agency found that a decade was about the right time-frame for ambitious projects. Then, as any aficionado of Space Race history knows, President Kennedy made his historic State of the Union address to Congress on May 25, 1961. He dedicated the United States to getting to the Moon first, saying, "This nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon, and returning him safely to the Earth."

Kennedy's speech had all the suitable drama for setting a great nation on a historic mission, but what followed, as far as the Moon was concerned, was seven months of head-scratching and arguing. Despite the President's instructions, NASA didn't have any rockets of its own, and the military vehicles it was relying on for Projects Mercury and Gemini weren't anywhere near up to the job.

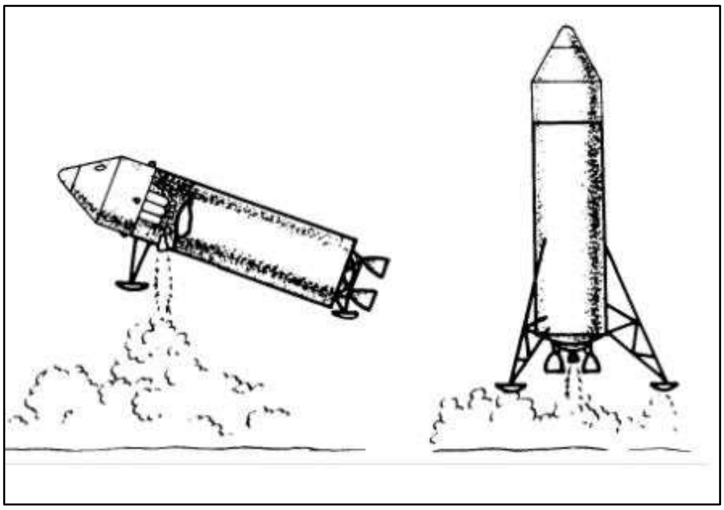
As to Saturn, the multiple configurations were changing from month to month. Three-stage versions became two-stage. The C-I transformed into the C-I and the C-IB. The Nova was favoured at one point. Solid fuel strap-on boosters at another. It was organized chaos. Maybe the Moon program would change all this. Maybe.

Getting to the Moon

The main reason for all this chopping and changing in developing the Saturn was that, like skinning a cat, there's more than one way to get to the Moon and each requires its own rocket. And in 1961, NASA was evaluating four ways.

Direct Ascent

The first and most favoured method is called Direct Ascent. The simplest of methods, the Direct Ascent scenario requires building a self-contained spacecraft that a giant rocket would send into space. The craft would fly directly to the Moon, then land on the surface without going into lunar orbit. At the end of the mission, either the entire spaceship or an ascent stage would lift off, return to Earth, and land or splash down.

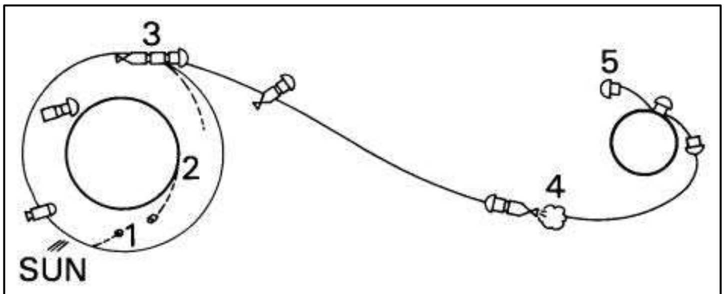


This is a perfectly sound mission profile, but it suffers from one major drawback – the spacecraft is extremely heavy due to the large engines, fuel tanks, and other gear it needs. This meant a moonship that weighs 90 tonnes. The von Braun team calculated that this would require a radically new booster called the Nova, that cranked so much thrust that it would dwarf even the Saturn V and would need new monster engines. Worse, it would have set back the American landing until well into the 1970s.

Earth Orbit Rendezvous

As the name suggests, the Earth Orbit Rendezvous mission involves assembling the moonship in orbit. After this, it would fly to the Moon, land, and then return. Alternatively, an unfueled ship would be launched into orbit, then fueled for the journey by a second rocket. In any case, this would need smaller rockets than the Saturn V.

This would have required two or more rocket launches followed by a rendezvous in Earth orbit, then either docking or fuelling. Such rendezvouses are common in the 21st century, but in 1961, it was unknown territory. Two spacecraft had never met in orbit, much less docked with one another. In addition, rockets in those days were still largely experimental and there was always the risk of a malfunction, which could result in one spacecraft stuck in orbit and nothing to meet it. This could mean losing two spacecraft for the price of one.

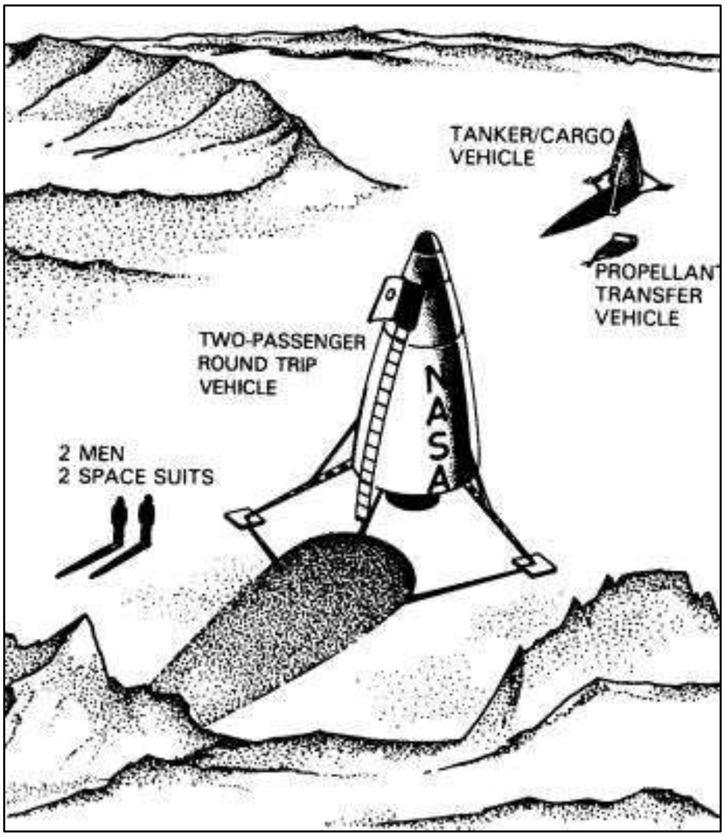


1. Place propulsion unit in parking orbit
2. Place manned spacecraft in chasing elipse
3. Launch assembled vehicle into lunar orbit
4. Brake vehicle for lunar landing
5. Return to earth

Lunar Surface Rendezvous

In the Lunar Surface Rendezvous, a fleet of unmanned ships would be sent to the Moon with supplies, fuel, and a craft capable of returning to Earth. During the mission, a small manned lander would touch down and the astronauts would use the return ship on the surface to get back. Again, the rockets needed would be smaller.

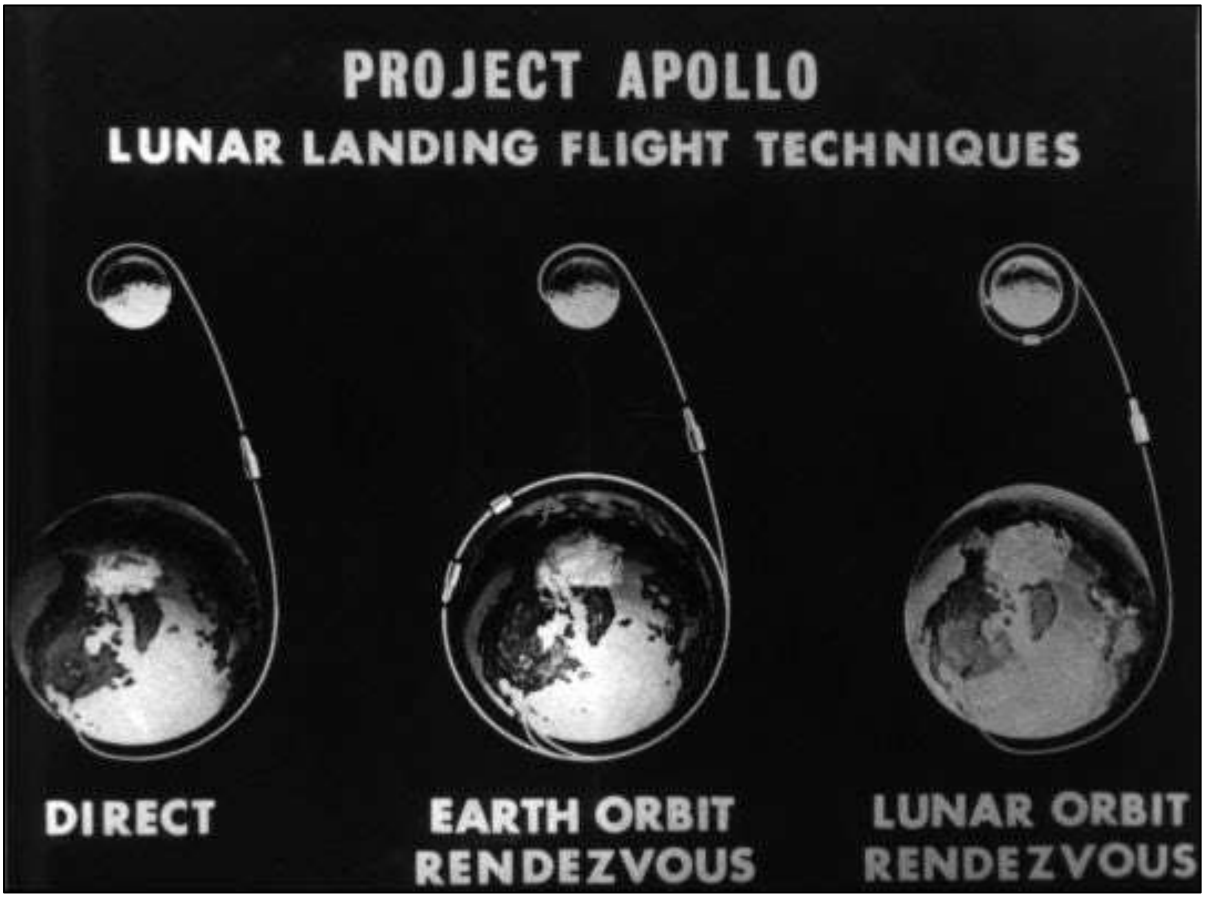
The problem with the Lunar Surface Rendezvous is the same as the Earth Orbit Rendezvous, only worse. The Earth Rendezvous scenario only needed to get a few spacecraft into the same orbit at the same time. The Lunar Surface Rendezvous would have required landing on the Moon using autonomous landers (which had never been done before), and then repeating the feat several times in the same spot, followed by a manned landing, and then a lift-off in a second craft. Needless to say, this offered too many opportunities for mission-killing incidents.



Lunar Orbit Rendezvous

Lunar Orbit Rendezvous is a mission where a single spacecraft is sent into lunar orbit using a single launch vehicle. While the mothership remains in orbit, a small lander makes the descent, lands, and then returns the astronauts using an even smaller ascent stage. The ascent stage rendezvouses with the mothership, the astronauts transfer back, the ascent stage is jettisoned, and the mothership returns to Earth.

If that sounds familiar, that's because it was the one chosen for the Apollo program, and deciding on it was anything but easy. But the decision had to be made, and soon.



Mission chosen

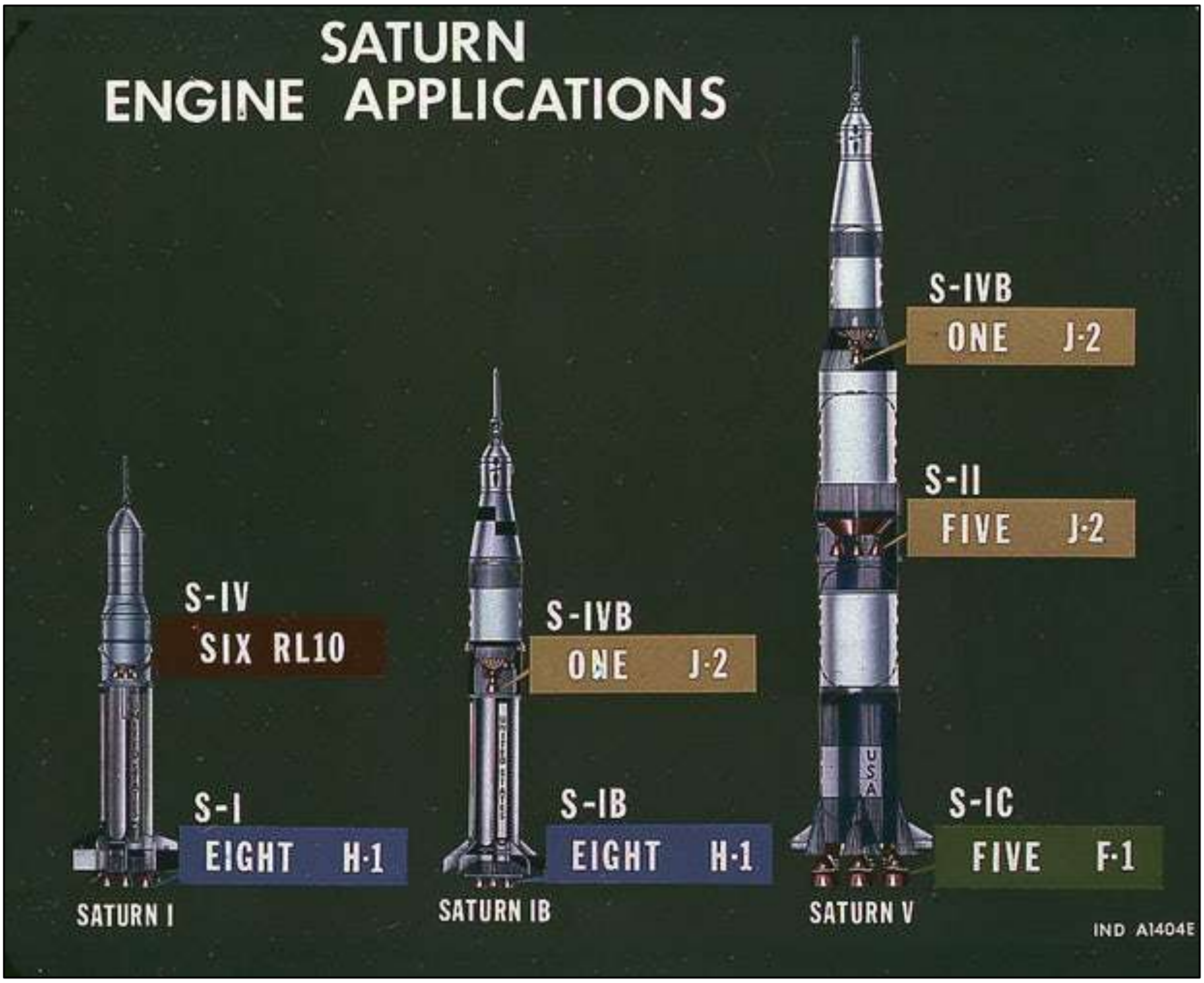
At first, the Direct Ascent mission was preferred for its simplicity and the fact that it didn't require using untested manoeuvres like an orbital rendezvous. When the Nova rocket needed for such a mission proved infeasible, many team members (including von Braun) championed an Earth orbit rendezvous, while Langley engineer John Houbolt and NASA Administrator George Low fought for the lunar orbit rendezvous.

The fighting became so bitter that President Kennedy personally intervened at least once, and von Braun had to exercise a lot of diplomatic skill to prevent both winners and losers in the argument from indulging in personal hostility.

In the end, the lunar orbit rendezvous technique was selected as the most cost-effective and quickest to be developed. As a result, development of the Saturn could finally move into the final design, followed by building and testing. NASA announced on January 10, 1962, that production would begin on the Saturn C-5, now referred to as the Saturn V. This would consist of the S-IC first stage with five F-1 boosters instead of the original four to provide plenty of extra power, a new S-II second stage powered by five J-2 engines, and the S-IVB third stage with a single J-2 engine. That third stage would be carrying the Apollo Command Service Module and the Lunar Excursion Module, as well as the "brains" of the rocket.

Along with the Saturn V, two more rockets were authorized. Based on the Saturn C-1, the Saturn I and Saturn IB were designed as parallel development rockets to test some of the Saturn V hardware, perform preliminary flight tests, carry the Apollo spacecraft into orbit, and send up the first Apollo astronauts. The latter two were particularly important because Apollo had to be fully developed by the time the Saturn V came online.

The two-stage Saturn I and IB illustrate the conservative nature of the Saturn program and the imperative to save money on a Moon project that would soon cost as much as a small war. Much smaller than the Saturn V, their first stages were based on the earlier Juno and Redstone rockets, and used five "demilitarized" H-1 engines. To save on the cost of designing and building new fuel tanks, the tanks from eight Redstones to carry RP-1 rocket fuel and liquid oxygen were clustered around a Juno tank with more oxygen. The difference between the two configurations was that the IB was slightly taller, to carry more propellant.

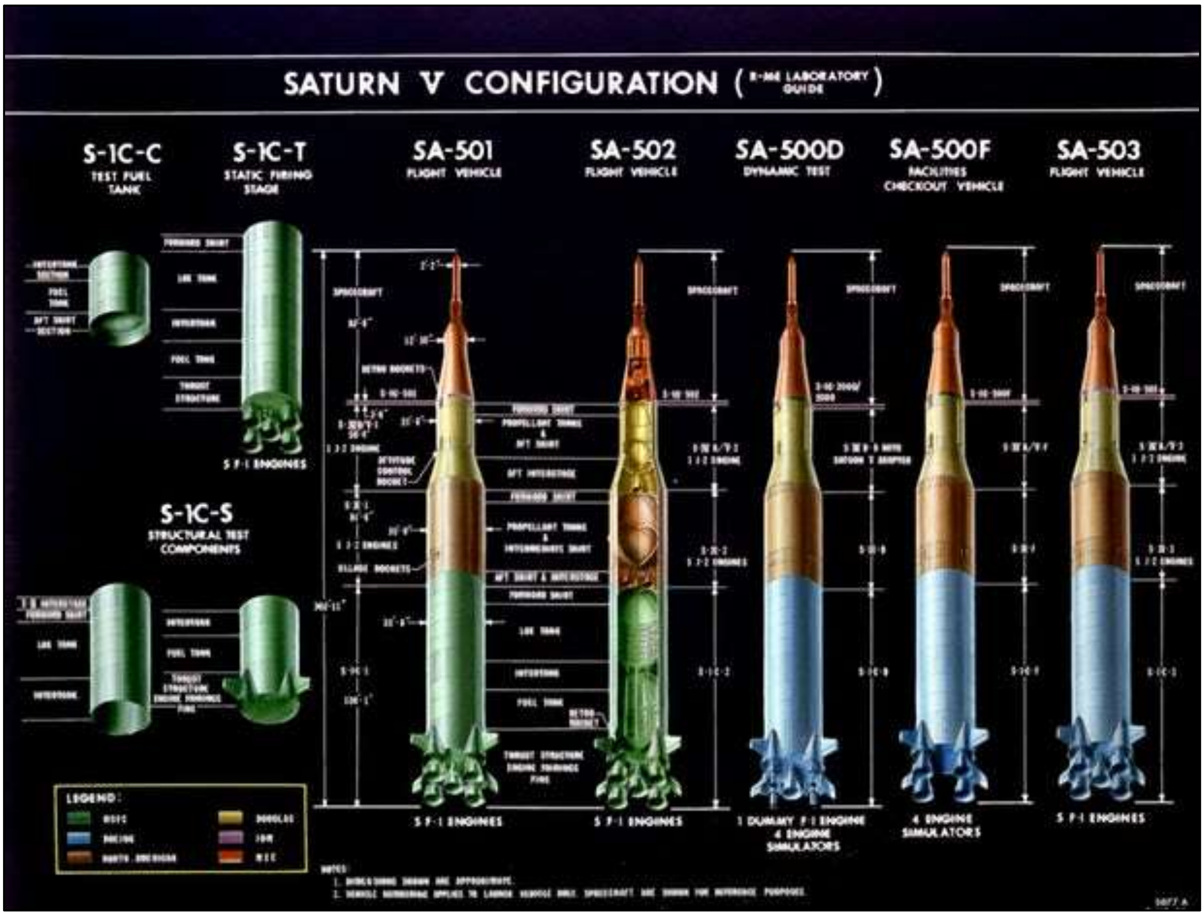


The second stage of rocket was the S-IV or S-IVB. The S-IV used six RL-10 engines, which were replaced with a single J-2 engine in the S-IVB. The irony is that though the S-IVB made up the third stage of the Saturn V and carried the number IV, it was actually the first of the stages to fly and was technologically the most advanced because it had to be able to fire twice and carry out complex course corrections.

Questions outstanding

Beyond the basic decisions were others that showed the state of the art of rocketry in the early 1960s. In the original design of the Saturn rockets, they were to only use RP-1, which is made from kerosene, and liquid oxygen. This would have made the Saturn V a very tall and ungainly rocket that might have toppled over in flight. The alternative was to use liquid hydrogen in the upper stages, but von Braun was opposed on the grounds that the Americans had little experience with it and most of their knowledge came from the Germans. Additionally, its properties were still poorly understood, and there wasn't much of an industry for manufacturing it, so it was very expensive.

This changed thanks to Abraham Silverstein, who had worked with liquid hydrogen during the 1950s and was convinced of it suitability. Eventually, he was able to talk around von Braun and other key scientists – especially in light of the fact that the Air Force was already working on a rocket called Centaur that used hydrogen. In fact, the opinion of the development committee swung so far around that hydrogen was selected for the second stage as well as the third.



Another decision that had to be made was where to launch the moon missions from. No current site was suitable, so somewhere had to be selected where proper facilities could be built. This would have huge consequences not only on how to build the Saturn

V, but also on its basic design. Before Cape Canaveral was settled on, the fear was that NASA would select a remote island in the Pacific Ocean, like the government did for nuclear weapon tests, and the von Braun team was worried that the rocket would need to be made for disassembly and airlifting, with all the trouble that would entail.

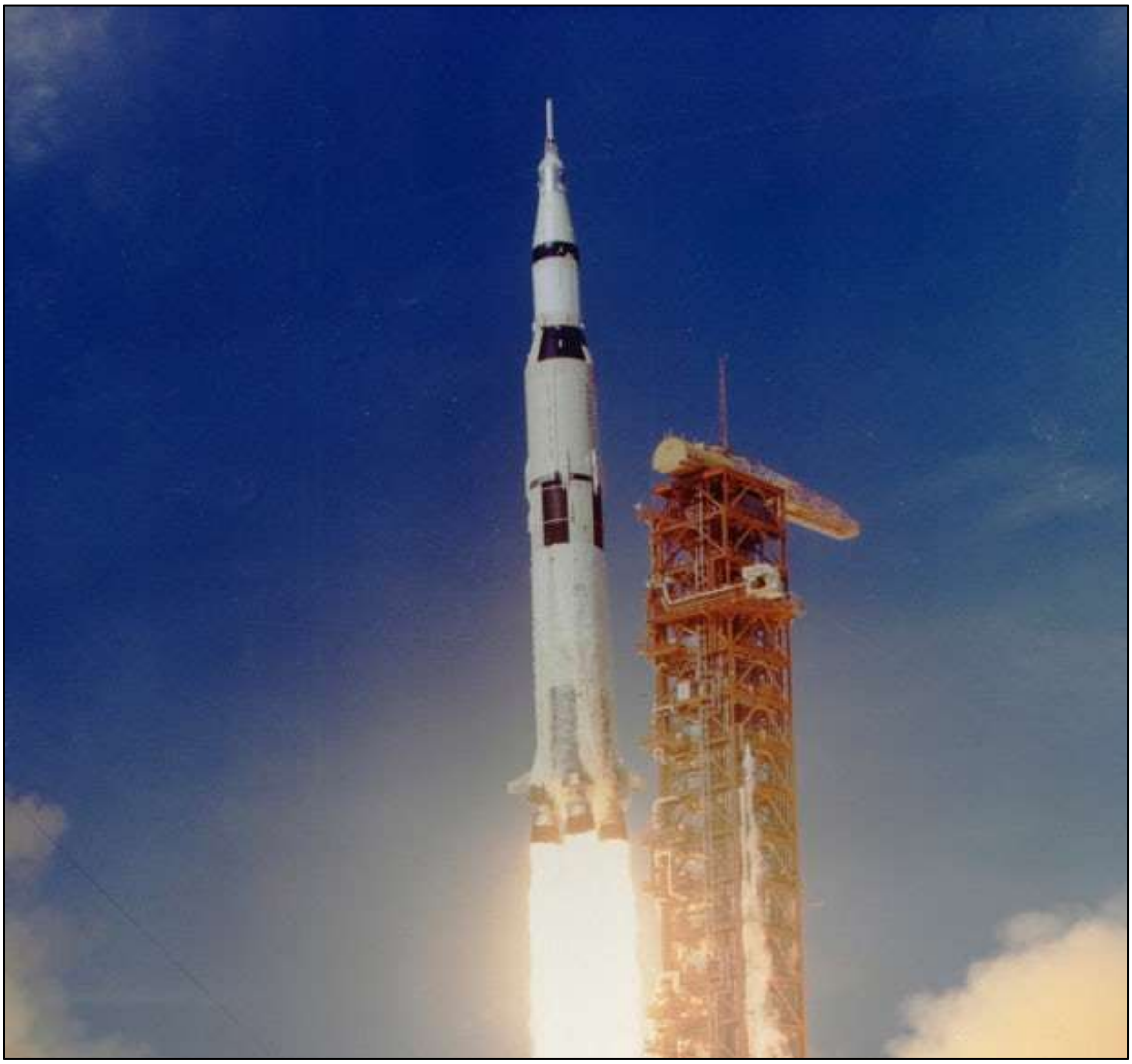
Introducing the Saturn V

By 1963, the basic design of the Saturn V and its smaller siblings had been largely settled as it moved into production and testing. Though the design philosophy had been one of being conservative and relying as much as possible on existing technologies, the sheer size of the rocket required many radical innovations.

To take one example, welding was a constant problem. Joining metal smoothly while still ensuring it can take massive changes in stress and temperature is always an aerospace engineering challenge, but the Saturn V introduced a whole new scale. A weld in an exotic aluminium alloy might be relatively simple to make and inspect when it was only a couple of inches long, but when it has to be a hundred feet long, that's another matter entirely.

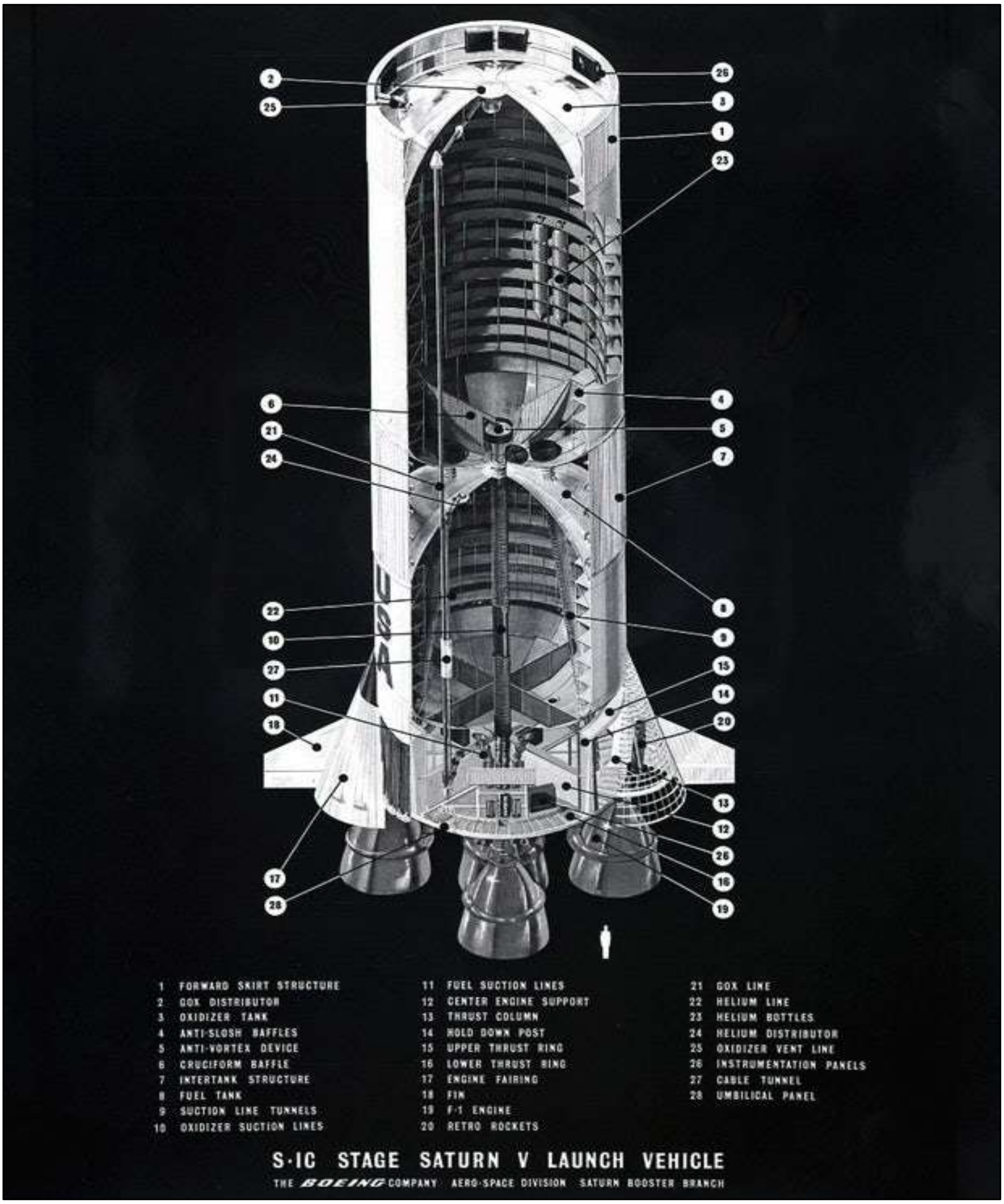
Then there were the engines. The F-1 was bigger than any before and the J-2 was one of the most advanced. Building and testing these introduced all manner of difficulties. For example, one problem that kept cropping up was called "combustion instability." Or, to put it another way, the engine would develop horrible hiccoughs as the fuel and oxygen would refuse to mix properly, before spontaneously combusting.

Dealing with this required frequent redesigns of the fuel injector and other components, as well as coming up with odd ways of simulating the effect by making tiny grenades that would be set to blow up in the combustion chamber. Things got so bad that the engineers had to indulge in some very high-level theoretical work, and von Braun suggested to universities that they should encourage PhD students to specialize in the problem.



Then there was the fact that the giant rocket was incredibly touchy. It may have been 35 stories tall, but strict clean room standards had to be maintained at all times. Not only was there the danger of debris ending up in a weld or a fuel line, but the oil from a single fingerprint could cause a deadly explosion if it came into contact with liquid oxygen. Despite these problems, the construction of the Saturn V took place with remarkable speed – especially when you consider that it had to constantly be updated to include the results of the S-I and S-IB tests. Soon it began to take shape at three major manufacturing sites across the United States.

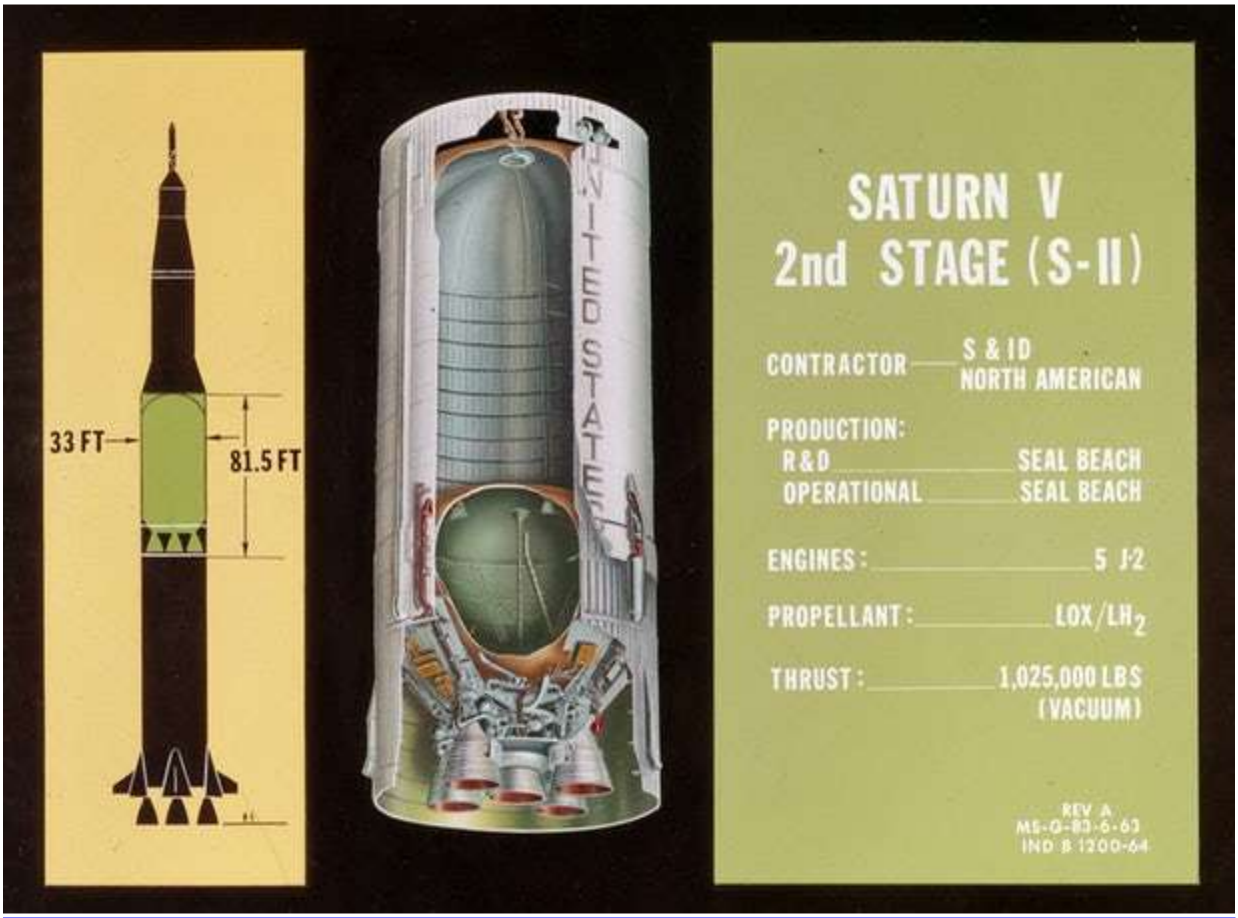
This division of labour was necessary because NASA soon found that the job was far beyond its capacity. Instead, the von Braun team at Marshall would undertake development and initial production, then the actual construction of each stage was farmed out to a private contractor. Sometimes this worked well, like when Boeing worked on the SC-I, but it also had its failures, such as with North American Aviation (NAA), which did such a poor job in building the S-II stage that NASA had to demand a massive reorganization.



The bottom stage, the S-IC, was built by Boeing and stood 138 ft (42 m) tall and had a diameter of 33 ft (10 m). Empty, it weighed only 287,000 lb (130,000 kg), but when loaded with RP-1 and liquid oxygen it tipped the scales at 5,040,000 lb (2,290,000 kg). These fed the five F-1 engines as they generated 7,891,000 lb (35,100 kN) of thrust for a mere 168 seconds, as it lifted itself and the rest of the rocket off the pad and accelerated it to beyond the speed of sound.

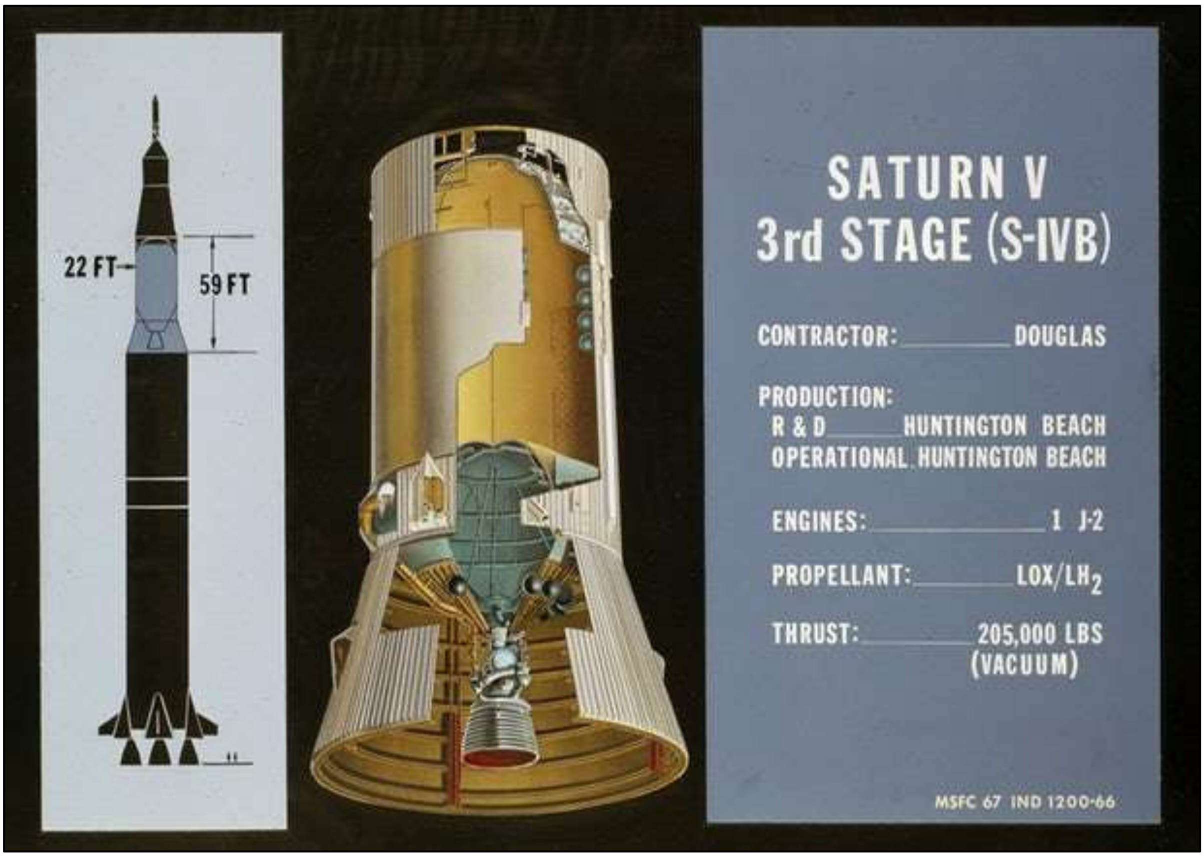
Oddly, despite its great size and the spectacular, fiery roar of its ignition, it had the reputation of an "old man's ride" with little in the way of the vibration and noise inside the crew capsule that astronauts experienced during Mercury and Gemini. The Apollo astronauts even said that they couldn't tell if they'd lifted off unless they checked the instrument panel.

The second stage, S-II, was contracted out to NAA and was 81.5 ft (24.8 m) high. With an empty mass of 88,400 lb (40,100 kg) and 1,093,900 lb (496,200 kg) when fuelled, it had five J-2 engines built by Rocketdyne that burned for 360 seconds. It was the most difficult of the three stages to build. Not only did it present odd problems such as composite tank linings that were only solved when the contractor hired surfboard makers to provide expertise, but it suffered from constant difficulties with project management and quality control.



The third stage of the Saturn V was the S-IVB. Built by the Douglas Aircraft Company, it topped out at 61.6 ft (18.8 m) and had a diameter of 21.7 ft (6.6 m). It was also much lighter than the other stages with a mass of only 271,000 lb (123,000 kg) fully fuelled. It had a single advanced J-2 engine that was unique for the Saturns in that it could fire twice – the first time for 165 seconds to place the third stage in orbit, and a second time for 335 seconds to send it and its Apollo spacecraft payload to the Moon.

One other unique feature of the S-IVB was the Instrument Unit that sat in a ring beneath the cone that housed the Lunar Module. Built by IBM at Huntsville, Alabama, this was the computer that controlled the entire rocket from before lift-off until the S-IVB was discarded. This ring acted as a structural base for the Apollo spacecraft, and housed the environmental units, guidance system, gyroscopes, electronics coolant system, and tracking system. It was this that allowed the Saturn V to compare the acceleration and attitude of the rocket against the programmed flight profile and to make the proper corrections using engines that were set on gimbals that allowed them to swivel.

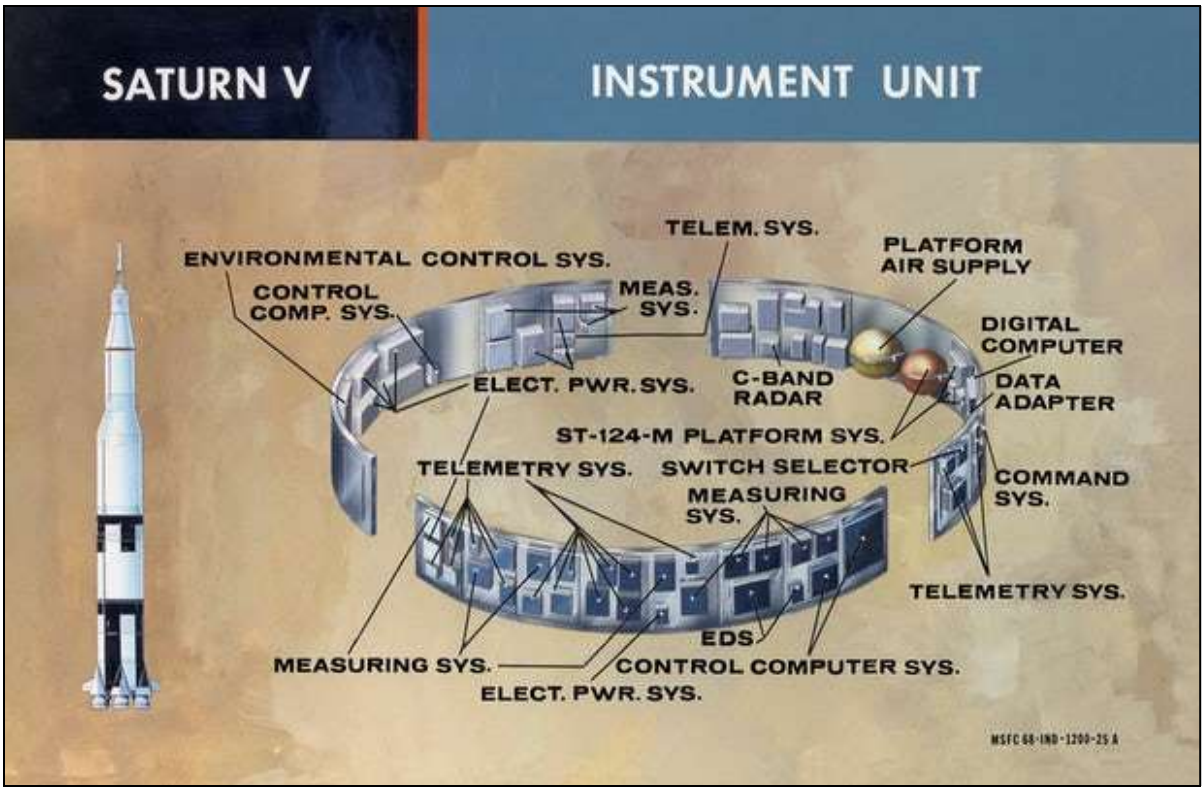


At the apex of the Saturn V and riding on top of the Apollo Command Module was the Launch Escape Tower. This incorporated a solid rocket motor that, in the event of a mission abort, could detach the Command Module, and carry it a safe distance away so it could deploy its parachutes.

This escape device worked with the euphemistically named Propellant Dispersion System (PDS), which was designed to protect the Kennedy Space Centre and surrounding communities from a Saturn V exploding on the pad. Due to the huge amount of fuel and liquid oxygen aboard the rocket, it had the potential explosive force of two kilotons of TNT or the output of a tactical nuclear weapon. Since a detonating Saturn V would have been one of the biggest man-made non-nuclear explosions in history, all three stages of the Saturn V were equipped with explosives that the range safety officer could detonate using a radio signal. In the event of an emergency, a safety system would have kept the engines operating for the first 30 seconds of flight to allow it to gain altitude. A signal would then shut down the engines, and a second signal would tear open the tanks in such a way that the fuel and liquid oxygen would disperse to prevent them from mixing and igniting. If no emergency occurred, a third signal would permanently shut down the explosives on the third S-IVB when it reached orbit.

A logistical nightmare

The Saturn V would be impressive on its own, but behind its story is a logistical nightmare. The rocket didn't exist on its own, but was the sharp end of a huge infrastructure footprint with major installations in Alabama, Louisiana, Mississippi, Kansas, Washington state, California, Florida, and others.



Though the Saturn V was developed at Huntsville, it was soon too large for the facility even when it was greatly expanded. New sites were needed, but they couldn't be plopped down just anywhere. They needed to be away from populated areas, yet near easy transportation routes. Since these tended to be waterways, the sites had to be far enough south that ice wasn't a factor.

One area chosen was the Michoud Assembly Facility (MAF) at New Orleans – a failed sugar plantation that was used for manufacturing during the Second World War and Korean War. Adapting this not only meant building new plants and rocket test stands that were the tallest buildings in the state, but moving hundreds of families from a nearby town with very generous compensation payments. Other sites were the Mississippi Test Facility (MTF) at Bay St. Louis, Mississippi; the Slidell Computer Facility at Slidell, Louisiana; the NASA Rocket Engine Test Site at Edwards Air Force Base, California; and production facilities stage at Seal Beach, California. That's not even mentioning the various roads, railway lines, barges, ships, special airplanes, dockyards, and all manner of other transport facilities required.

Then there was mission control in Houston, Texas and the launch site. Cape Canaveral was upgraded from a rocket base into an actual spaceport called the Kennedy Space Centre after the assassination of the President in 1963. This meant installing a launch control site, fuelling centres, giant launch pads, and the erection of one of the world's largest buildings by volume – the Vehicle Assembly Building (VAB) – which is so large that if it weren't for the air conditioning, it would rain inside.

Even nature had to be tamed. Cape Canaveral had swarms of mosquitoes that were so thick that it was impossible to move about without a full set of clothes, gloves, and mask and a single net could collect the insects by the pound with no trouble. To keep them from torturing the workers, engineers built dams that flooded the waterways until they were deep enough to breed massive shoals of minnows to eat the mosquito larvae.

If that wasn't enough, the space centre was plagued by pigeons that infested the larger buildings and pelted the moon machines with droppings. After trying everything up to shooting them, biologists finally hit on the idea of giving the pigeons a drug that temporarily paralysed them, which scared them enough to relocate.

Testing

A key factor in the success of the Saturn V was the relentless testing done by NASA. It's normal for an airplane to go through thousands of hours of flight tests before being declared airworthy, but that wasn't practical with the world's largest rocket. So the space agency built S-1 and S-1B for early flight tests and subjected every engine, component, system, and subsystem to endless ground tests.

Combined with stringent reliability and quality assurance programs, this was cited as the reason for the Saturn V's safety record. In fact, testing made up half of the entire program.

The program was so effective that instead of testing the Saturn V stages individually, all three flew together in "all up" fashion on the first Apollo 4 mission. The success is demonstrated by the fact that there was only one inflight problem before the manned flights when Apollo 6 experienced "pogoing" when the second stage fired. That is, one of the J-2 engines became unstable and started to vibrate in a way that could have destroyed the rocket. The engine shut down, but for some reason, a second one did as well, which placed the third stage in the wrong orbit.

The reasons behind this were surprisingly simple. The vibration was caused by a faulty design of a spark igniter on the faulty engine. This wasn't noticed in ground tests because the igniter would frost up from the cryogenic fuel, securing it in place, but in space there's no air, so no water vapor. With no icing, the igniter could shift, causing a faulty engine burn.

As to why the second engine shut down, that was due to crossed wires that sent the signal to the wrong engine when the computer tried to correct. That was solved by making the offending wire too short to reach any engine but its own during installation.

Assembly

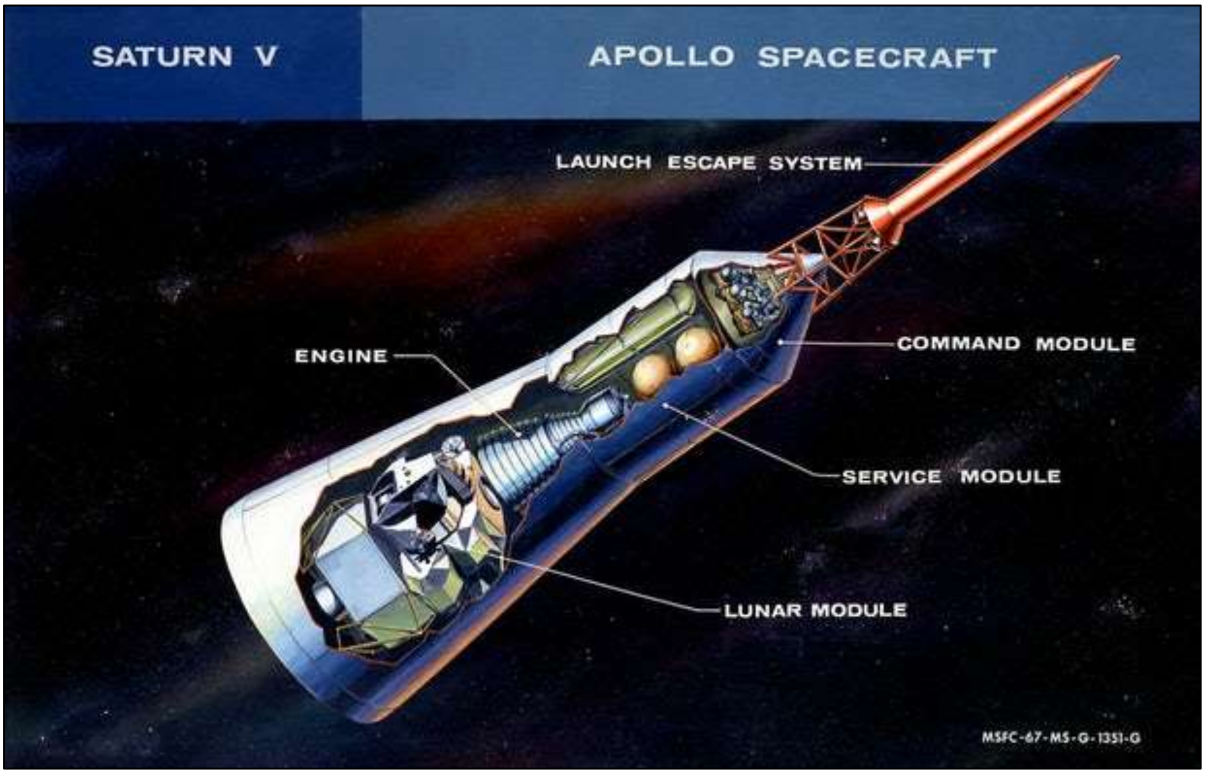
Even assembling the Saturn V required some major thinking and engineering. The usual way of putting a rocket together up until that time was to take the bits to the launch pad and assemble them there before fuelling. That wasn't practical for a monster like Saturn V, especially in Florida, or when a high rate of launches are required, so a new approach had to be found.

NASA opted for a new way to assemble the Saturn V far away from the launch pad in a protected area – the VAB, which could handle up to four Saturns at a time. But before that, the stages had to get to Florida by various routes. The S-IC had to be carried down by barge along the Mississippi River, then by sea through the Gulf of Mexico and into the Atlantic Ocean to Cape Canaveral. The S-II was built in California and went by ship through the Panama Canal, while the S-IVB was airlifted in a bulbous cargo plane called the Super Guppy due to its resemblance to a pregnant tropical fish.

When the various bits arrived at the VAB, they were inspected before final assembly and then lifted into position on the Saturn V. The completed rocket was then set on the Crawler Transporter (CT) – a giant tractor that carried it the three miles (4.8 km) to Launch Complex 39. There, it was enveloped by the Mobile Service Structure (MSS), which included a portable clean room, lifts, fuelling and power systems, and even a giant slide to evacuate the gantry crew to a special bunker in the event of a launch emergency.

Lift-off

After all this, it's surprising to learn that the career of each Saturn V that flew was only about 20 minutes, give or take some time parked in orbit. However, the lift-off of a Saturn V did put any fireworks show on the planet to shame. The first moments of a Saturn V launch were the most spectacular, but they were also the simplest and most dangerous. Due to the massive weight of the Saturn V, the first stage's flight was dominated by aerodynamic forces, so the S-IC didn't do much beyond keep the rocket stable during the first moments. It carried out a pre-programmed flight path and the onboard computers noticed any deviations, which the second and third stages would correct.



One of the most heart-stopping facts about the Saturn V was that it took a full 12 seconds to clear the launch tower. If it struck the tower or the engines cut out, the results would have been catastrophic, which is why the pad was three miles from anywhere. To reduce the chances of brushing the tower, the rocket was programmed to tilt 1.25^0 away. When it reached an altitude of 430 ft (130 m), it rolled to its flight angle and gradually pitched down to a more horizontal position.

Two and a half minutes after launch, the Saturn V was hypersonic. The first stage, now spent of fuel, separated from the rest of the vehicle using explosive charges and solid rockets to push it away. Similar rockets on the second stage gave it a nudge to ensure that all the fuel was at the bottom of the tanks before the five J-2 engines ignited. The second stage burned for six minutes, boosting the velocity to 15,300 mph (24,623 km/h) before separating to crash into the Atlantic Ocean off the coast of West Africa.

Now the third stage came online. During its first burn, it boosted the remaining vehicle to 17,500 mph (28,164 km/h), then cut out as the spacecraft went into a parking orbit around the Earth. There it remained for up to three orbits while the crew and ground control checked out the systems before deciding to proceed. If the green light was given, the J-2 engine would fire for a second time, setting it and its payload in a translunar insertion orbit.

At this point, the Saturn V's job was done. The crew of the Apollo mission would dock with the Lunar Module, then make a course correction that would send it on its way to the Moon while the third stage arced safely out of the way to prevent a collision.

The end of an era

There's been nothing like the Saturn V since the heyday of the Space Race. The last one flew in 1973, when it lofted the Skylab space laboratory into orbit. All that remains of the booster's legacy are two flight-rated Saturn Vs on display in Texas and Florida, five S-IVBs that went into orbit around the Sun during Apollo 8 to 12, the remains of five more that were deliberately crashed on the Moon for seismic experiments during Apollo 13 to 17, and a few odds and ends scattered about in museums and warehouses.

But could we make a Saturn V today? According to NASA, no. Though all of the blueprints still survive on microfilm and the development and construction of the rocket has been carefully documented, the vast infrastructure and tools needed to build the giant rocket have all been destroyed, relegated to museums, or repurposed. In addition, the men and women behind the project are all either retired or have passed away. Instead, it would be much simpler and cheaper to design and build a new rocket from scratch. That's why NASA is working on its Space Launch System (SLS), SpaceX is working on the BFR, and even China is rumoured to be working on a super rocket to rival the Saturn V. No doubt one day a more powerful launcher will be produced, but the Saturn V will be so deeply embedded in history that it will still be the standard against which all others will be compared.