Saturn V

Step-by-Step

Version 1.5

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FORWARD

I expected this foreword to praise the incredibly detailed research, or the precision of the writing style that went into this book, all of which I solidly endorse. But after reading it all in one sitting -- I have come away with an entirely separate emotion.

MARK SCHULMAN's *Saturn V Step-by-Step* is an extremely unusual book. While it appears at first sight to be nothing more than an amazingly (even obsessively) detailed guide to the complex process of getting three people to the Moon, it is also a novel of sorts. It follows the tradition of "the story arc" -- with a gentle beginning, a buildup of tension as the moment of launch approaches, and relaxation as our heroes reach orbit -- then more cycles of tension and release.

As an engineer, I felt the pressure that the 400,000 people who worked on Apollo must each have felt as each tiny milestone came and passed successfully -- the feeling of tension as "that sensor wire that I soldered to that circuit board has to do its job NOW!" -- then the relief when it actually did -- is palpable throughout.

At a normal adult reading speed of about a page every minute and a half, the timescale of this story starts off with weeks going by at every page -- then days, then hours, minutes, seconds, tenths -- and ultimately hundredths of a second per page. You read for a page the first three quarters of an inch of the Mighty Saturn V's journey.

For any red-blooded tech geek, this is a roller-coaster ride!

-- Steve Baker
Fellow Red Blooded Tech Geek
December, 2024

ABOUT THIS DOCUMENT

I was inspired to write this document when I found it difficult to find information about the entire process of launching a Saturn V. When I just couldn't find what I wanted, I spent about two years poring over documents and articles, trying to assemble a coherent timeline of what it took to launch and fly a Saturn V, and that timeline is presented here. I've also added background information on the Saturn V and Apollo lunar missions, for those who may not be familiar with some of the terminology.

-- Mark Schulman
November, 2024

Acknowledgements

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INTRODUCTION

It's not hyperbole to suggest that the Saturn V rocket is perhaps the most awe-inspiring machine humans have ever built. For the people who have had the great good fortune to stand within a few miles of one of the thirteen Saturn Vs as it clawed its way into the sky, "awe" is the only word that will do. The heat, the light, the smoke, the ripples racing across the water as the shockwave heads outward, midnight turning into morning -- to the people who have seen the Saturn V when it comes to life, the world will never be the same after it finally sinks in that humans built this thing: 3,200 tons of machinery, climbing ever-faster into the sky, and carrying three fearless and possibly-insane humans to another world.

Well, then.

How in the world does this thing work?

Presented below is the step-by-step timeline of one of the Saturn Vs. We pick up the story as the individual pieces leave the factory, headed for the Kennedy Space Center in Florida, destined for a launch three-quarters of a year later. We'll follow the rocket through testing, assembly, more testing, launch, Earth orbit, and departure for the moon. The story ends when the last piece of that Saturn V heads off into a solar orbit, or, depending on the mission, crashes into the moon.

We'll start with some background information that's helpful in understanding the assembly and launch of a Saturn V. For those unfamiliar with the Saturn V, these first sections introduce some basic terminology, describe the buildings where the spacecraft and vehicles are assembled, describe the launch windows which determine when a launch can take place, and introduce one of the most useful instruments in the spacecraft that helps the crew understand what is going on as they ride atop millions of pounds of explosives.

Terminology

A comprehensive glossary appears at the end of this document, but these are the terms that are used throughout this document:

CM	**Command Module.** The top portion of the CSM. (See *Appendix A, Figure 2 - Apollo CSM, Lunar Module, and Launch Escape Tower*.) The three crew members begin and end the mission in this spacecraft.
CSM	**Command and Service Module.** The spacecraft designed to carry the crew of three from the surface of the Earth into Earth orbit, then into lunar orbit, and back to Earth. The CSM consists of the Command Module and the Service Module. Once in lunar orbit, the CSM remains in lunar orbit while the LM descends to the lunar surface. (See *Figure 4 - Lunar Module.*)

IU	**Instrument Unit.** The ring of electronic equipment that makes up the brains of the Saturn V. Among other equipment, the IU contains the LVDC, the computer which controls the Saturn V throughout its flight, and the ST124-M stable platform, the device which enables the LVDC to determine its location and orientation in space. The IU sits just above the third stage, and just below the Lunar Module. (See *Appendix A, Figure 1 - Saturn V Launch Vehicle.*)
LH2	**Liquid hydrogen.** The fuel used in the second and third stages of the Saturn V. This cryogenic (supercold) fuel must be stored at -253°C / -423°F.
LM	**Lunar Module.** The spacecraft that carries two crew members from lunar orbit onto the lunar surface and back. (See *Appendix A, Figure 4 - Lunar Module.*)
LOX	**Liquid oxygen.** One of two propellants used in each of the three stages on the Saturn V. This cryogenic (supercold) fuel must be stored at -183° C / -297° F.
LUT	**Launch Umbilical Tower**, also known as the launch tower, or LUT. The tower is part of the Mobile Launcher, and provides access and umbilical connections to the launch vehicle. (See *Appendix A, Figure 5 - Mobile Launcher*.)
LVDC	**Launch Vehicle Digital Computer**. The computer which controls the operation of the Saturn V throughout its flight, beginning just before liftoff. The LVDC is located in the Instrument Unit (see above).
ML	**Mobile Launcher** consists of a Launcher Base and a Launch Umbilical Tower. The mobile launcher is the structure on which the components of a Saturn V are assembled, transported to the launch pad, and launched. (See *Appendix A, Figure 5 - Mobile Launcher*.)
S-IC	The first stage of the Saturn V. (Pronounced "ess-one-see".)
S-II	The second stage of the Saturn V. (Pronounced "ess-two".)
S-IVB	The third stage of the Saturn V. (Pronounced "ess-four-bee".)

The Buildings

At the Kennedy Space Center there are two important buildings involved in readying a Saturn V for launch.

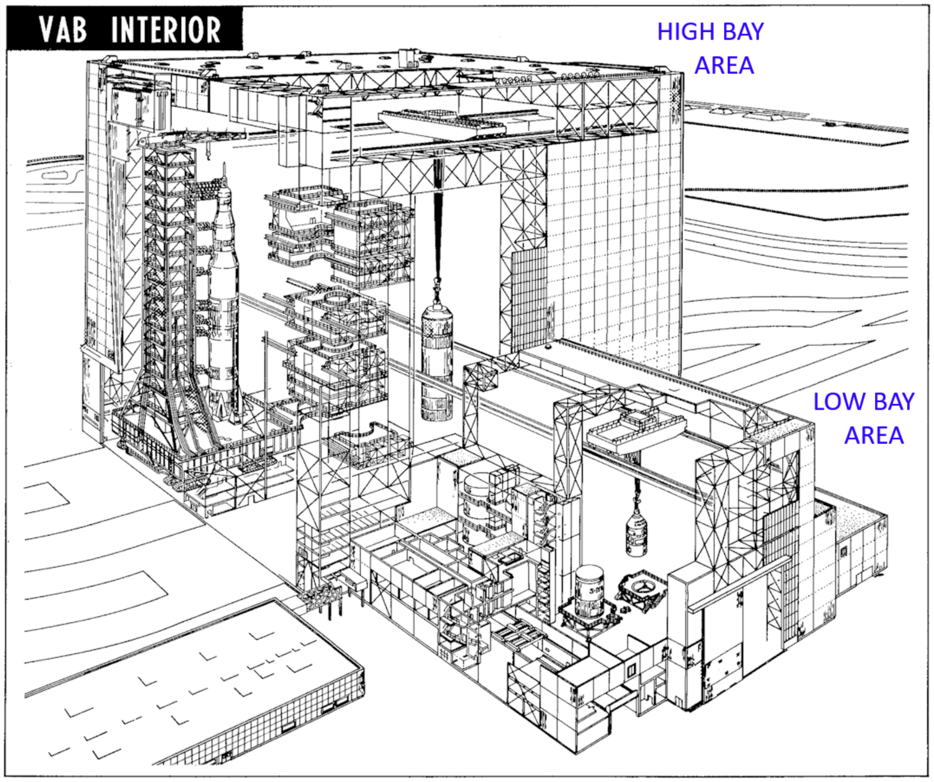
The Manned Spacecraft Operations Building (MSOB) is the first stop for the two spacecraft when they arrive at the Kennedy Space Center. Each spacecraft is tested and the major pieces are assembled in the MSOB. After testing and assembly, the Command and Service Module (CSM) and the Lunar Module (LM) are mounted in the Spacecraft LM Adapter (SLA), and the combined assembly is transported to the Vehicle Assembly Building (VAB) for stacking atop the Saturn V.

Apollo 11 crew departs MSOB for the pad

The MSOB also contains the astronaut dormitories, where the crew stays before a launch, and the facilities where the crew members "suit up". The iconic photos of crews departing for the launch pad are taken in front of the MSOB.

The MSOB was originally known as the Operations & Checkout (O&C) building, and that informal title was used throughout the Apollo program. In 2014 it was renamed the Neil Armstrong Operations and Checkout Building. This historic building is still in operation today.

The Vehicle Assembly Building (VAB) is the arrival point for the Saturn V's components. Located at Kennedy Space Center, just north of the MSOB, it is within the VAB that the Saturn V components and the spacecraft are stacked to form a finished vehicle.



The VAB provides space in which the individual components that make up a Saturn V -- the three stages, the Instrument Unit, and the spacecraft -- are stacked to form a complete Saturn V. The components are stacked atop a Mobile Launcher (ML), and the entire structure -- the mobile launcher and the completed Saturn V -- is transported to the launch pad atop a crawler-transporter.

The VAB consists of two major areas: High Bay and Low Bay. The Low Bay contain eight areas, 210 feet high, providing space to receive Saturn V upper stages and perform checkout functions on these stages. The four High Bay areas, 525 feet high, provide facilities in which the components for a Saturn V can be stacked atop a mobile launcher (ML). Saturn V components enter through the doors in the low bay area, and some remain here for testing (described below). Eventually the components make their way into the high bay area, where they are stacked on a mobile launcher (ML) to form a completed Saturn V.

The VAB had the capacity to have four Saturn Vs in the process of assembly at one time, although during the Apollo program there were never more than three high bays in use at any one time. After the Apollo program, the VAB was used to assemble the Space Shuttles and the SLS launch vehicles.

Construction of the VAB was completed in 1966, and it remains in use today.

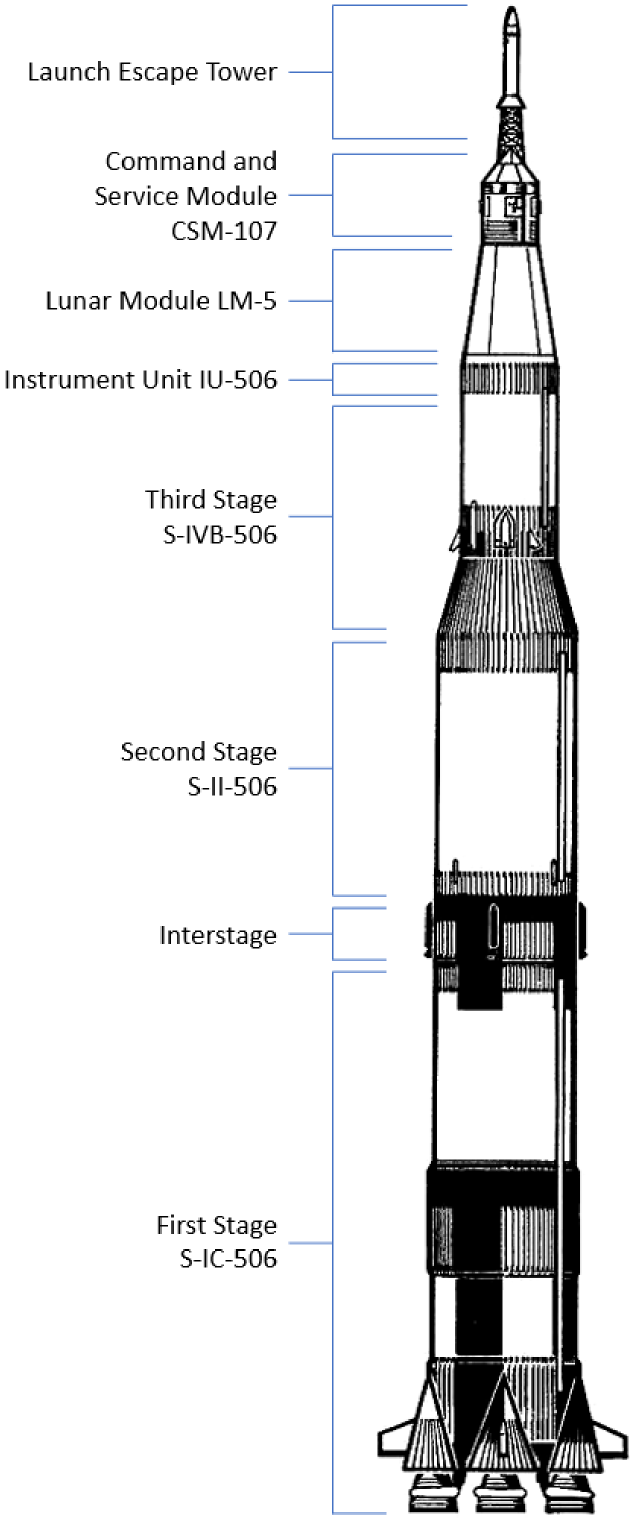
Apollo 11

The timeline below uses Apollo 11 as an example, and follows the preflight preparation and launch of Apollo 11. Most aspects of all the Saturn V launches were the same for all missions, but differences are mentioned as needed. Apollo 11 is perhaps the most well-known example of an Apollo lunar mission, so if we have to pick one, why not that one?

Apollo 11 launched at 9:32 am Eastern Daylight Time on July 16, 1969 from Launch Complex 39A at the Kennedy Space Center. The Saturn V used for Apollo 11 is the sixth flight-worthy Saturn V built, and so gets the designation **SA-506**. ("SA" is "Saturn Apollo", the "5" indicates a Saturn V, and the "06" indicates the 6th rocket in the Saturn V series.)

The Apollo 11 Lunar Module (named "Eagle") is the fifth flightworthy LM built, but only the fourth to actually fly -- LM-2 never flew. Because it is the fifth production LM, Eagle has the designation **LM-5**. During launch the Lunar Module is enclosed in the Spacecraft LM Adapter (SLA). (See SLA in the glossary.)

The Apollo 11 Command and Service Module (named "Columbia") has the designation **CSM-107**. Each CSM is assigned a 3-digit number. The first digit is either a "0" (indicating the first version of the CSM, known as "Block I") or a "1" (indicating the second version, known as "Block II"). Columbia's "107" indicates that it is the 7th of the Block II CSMs. (The first version of the CSM, the Block I, was originally intended for early Earth-orbit testing. Apollo 1 was supposed to fly on a Block I CSM (CSM-012), but a fire in the Apollo 1 CM during a prelaunch test took the lives of the first Apollo crew in January, 1967. No Block I CSM ever flew with a crew.)



Launch Windows

The timing for an Apollo lunar launch wasn't random. In order to meet certain criteria, missions had to be launched within specific times, known as *launch windows.* For a given lunar landing site, a launch window of a few hours occurred each month. The exact time when each launch window occurred was dictated by these factors:

- NASA wanted to land during the site's early morning, when shadows were long, making it easier to see objects on the lunar surface. Different locations on the moon experience morning at different times, just as locations on Earth do.
- Each lunar mission was launched into Earth orbit, and on the second orbit the S-IVB performed an engine burn known as *translunar injection* (TLI), which sent the S-IVB and the spacecraft hurtling toward the moon. Orbital mechanics dictates that translunar injection has to take place over a point on earth known as the moon's *antipode* -- the point in the orbit that is exactly opposite the spot where the moon will be when the spacecraft arrives at the moon. Apollo mission rules required that TLI occur over the Pacific Ocean for safety reasons, and S-IVB systems dictated that TLI had to happen on either the second or third orbit. (All Apollo flights performed the TLI burn on the second orbit.)
- NASA required that its tracking station at Goldstone, California, be able to see the landing site during the LM's descent to the lunar surface.

The result of these factors was that each month there was a specific day and a narrow range of a few hours in which an Apollo mission had to launch in order to land at a specific site.

Apollo 11 mission planners originally selected five possible landing sites. Sites 1 and 4 were ruled out, leaving three potential landing sites, landing sites 2, 3, and 5. Here are the launch windows during July and August, 1969, which would permit a landing at one of these three sites:

Launch Date	Landing Site	Launch Window (EDT)
July 16	Site 2 - Sea of Tranquility	9:32 am - 1:54 pm
July 18	Site 3 - Sinus Medii	11:32 am - 2:02 pm
July 21	Site 5 - Ocean of Storms	12:09 pm - 2:39 pm
August 14	Site 2 - Sea of Tranquility	7:45 am - 12:15 pm
August 16	Site 3 - Sinus Medii	7:55 am - 12:25 pm
August 20	Site 5 - Ocean of Storms	9:55 am - 2:35 pm

As it turned out, Apollo 11 launched at the very beginning of the first window, on July 16, 1969, at 9:32 am, and landed at Site 2, on the Sea of Tranquility.

For more information on launch windows, see Robin Wheeler's article on Apollo Flight Journal:

https://www.nasa.gov/history/afj/launchwindow/lw1.html

LV ENGINES Lights

During a launch one of the most useful indicators on the Apollo CSM control panel is the set of lights labeled LV ENGINES. These five yellow lights, numbered 1 through 5, enable the crew to monitor the status of the active stage and its engines. This set of indicator lights is mentioned several times in the timeline below, and is worth an explanation.

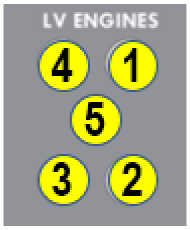
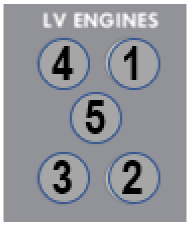
The five lights represent the engines in the active stage. When the first or second stage is the active stage, all five lights are used. The third stage has only a single engine, so when it is the active stage, only the #1 light is used.

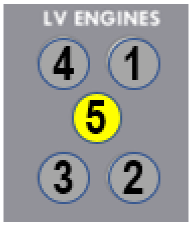
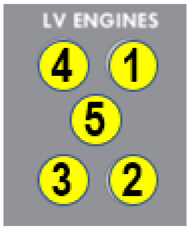
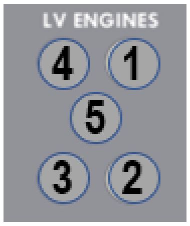
The simple view is that as each stage becomes active, the light for each engine is **on** when that engine is **not** producing thrust. Thus, during most of the Saturn V's ascent to orbit, when one of the stage's engines are all firing, all the lights should be **off**. If one of the lights comes on, that is an indication that the corresponding engine has been shut down or failed.

Additionally, the logic circuitry behind these lights also looks at the staging signals. When the LVDC jettisons a stage, all the lights are turned off.

The result is that during the normal operation of each stage, all of these lights come on and go off **twice**, indicating important events happening to each engine.

As an example, consider the five F-1 engines in the first stage, using the Apollo 11 timeline below. Here's what the crew sees as the first stage does its job:

	T-4m 10s	**Engines armed.** Just over 4 minutes before liftoff, the first stage engines are armed. The five lights come on, indicating that the stage is now armed but not producing any thrust. For the second and third stages, the lights come on when the LVDC sends the command to each engine to begin the start sequence.
	T-1.6s	**All engines running.** With less than 2 seconds left until liftoff, as each engine reaches full thrust, the light for that engine goes out, indicating that the engine is producing proper thrust. Seconds later, liftoff occurs. During most of the two and a half minutes that the first stage burns, with all engines producing thrust, all the lights are out.

	T+2m 15s	**Center engine cutoff.** In order to ease the g forces on the crew, LVDC shuts down the center engine about half a minute before the other engines. As the center engine's thrust drops below 90%, the #5 light comes on to indicate loss of thrust in that engine.
	T+2m 42s	**Outboard engine cutoff.** The first stage's job is done. The LVDC shuts down the four outboard engines (1 through 4) and as each engine's thrust falls below 90%, the corresponding light comes on.
	T+2m 42s	**Staging.** Less than a second later, the LVDC sends the command to separate the first stage from the vehicle. As the stage slips away, the five engine lights go out in unison.

The same sequence is repeated as each stage becomes the active stage.

Fun fact: The movie *Apollo 13* took some artistic license with these lights. The movie showed the lights lit while a stage's engines were burning, the exact opposite of how they actually worked. When the second stage's center engine shut down early, which actually happened on Apollo 13, the movie showed the #5 light flashing. In real life, none of these lights ever flashed, and the lights should be off while the engines in the active stage are burning. The writers for the movie thought the audience would better understand what was going on if the lights were on while the second stage was burning, so that's what the movie showed.

Notations

Throughout the timeline below, times are given in hours, minutes and seconds. A minus (-) indicates time before liftoff, and a plus (+) indicates time after liftoff.

For example ...

-3m 7s

... indicates 3 minutes 7 seconds before liftoff, while ...

+2h 35m 20s

... indicates 2 hours 35 minutes 20 seconds after liftoff.

A tilde (~) before a time indicates an approximate time, so ~+40s would indicate approximately 40 seconds after liftoff.

ASSEMBLING THE VEHICLE

We pick up the story about three-quarters of a year before launch, as the spacecraft and components that make up the Apollo 11 launch vehicle begin to arrive at the Kennedy Space Center.

Each component will undergo extensive testing. The Command and Service Module (CSM), the Lunar Module (LM), and the Saturn V each have their own assembly and testing process before they are combined into a single vehicle. The timeline below begins as three separate timelines -- the CSM, the LM, and the Saturn V -- and becomes a single timeline when the CSM and LM are stacked atop the Saturn V to form a completed launch vehicle.

The timeline for each lunar flight was similar to Apollo 11's timeline.

Command and Service Module

The Command and Service Module (CSM) is manufactured by the North American Aviation in Downey, California (later North American Rockwell, and later part of Boeing). The Apollo 11 crew will fly aboard CSM-107, and we follow it from the time it completes its final testing at the factory in October, 1968.

277 days before launch (October 12, 1968)	**CM system tests.** The final system tests are completed on the Command Module (CM) and Service Module (SM) at the North American factory in Downey, California.
222 days before launch (December 6, 1968)	**CSM integration tests.** Integration testing on the combined Command and Service Module (CSM) is completed at the North American factory.
182 days before launch (January 15, 1969)	**CSM quads arrive.** The CSM quads -- the packages of four maneuvering thrusters -- arrive at the Kennedy Space Center. They will be installed on the Service Module once it arrives at KSC. 
175 days before launch (January 22, 1969)	**CM and SM arrive at KSC.** The Apollo Command Module (CM-107) and the Service Module (SM-107) arrive by air at the Kennedy Space Center, and are taken to one of the checkout cells in the MSOB for testing.
168 days before launch (January 29, 1969)	**CM and SM mated.** The Command Module (CM-107) and the Service Module (SM-107) are physically mated to form CSM-107.
167 days before launch (January 30, 1969)	**CM side hatch configuration.** The side hatch on the Command Module is configured to allow access to the spacecraft during testing.
165 days before launch (February 1, 1969)	**CM and SM electrically mated.** The Command Module and Service Module are electrically mated.
163 days before launch (February 3, 1969)	**CM forward hatch tests.** The forward hatch of the Command Module leads into a short tunnel on the front of the spacecraft. When the CM and

	LM are docked, this tunnel provides access between the two spacecraft. The hatch is now tested for proper functionality, including testing for possible leaks.
162 days before launch (February 4, 1969)	**CM and SM batteries installed.** The Command and Service Module's batteries are installed. While the CSM gets the vast majority of its electrical power from three fuel cells (see -68h), batteries provide power during critical times: • Three entry/postlanding batteries, located in the Command Module, provide electrical power to the Command Module for the hour or so between the time that the SM is jettisoned and the spacecraft splashes down. The fuel cells are located in the Service Module, and once the SM is jettisoned, the CM must use batteries for its electrical power. • Two SM jettison control batteries, located in the SM, provide power to jettison the SM. • Two "pyro" (pyrotechnic) batteries, located in the CM, are used to ignite various explosive devices. Explosive devices serve a variety of purposes on the spacecraft. Various parts of the spacecraft are held together with bolts containing explosive cartridges, and detonating these cartridges causes the bolts to separate. Parachutes are also deployed using explosive devices. These devices are extremely reliable, and their successful operation is so critical that a dedicated pair of batteries provide power for igniting these devices. • Beginning with Apollo 14, a large auxiliary battery was installed in the SM, to provide emergency power if the fuel cells shut down, as they did on Apollo 13.
161 days before launch (February 5, 1969)	**CM couches installed.** The couches (seats) and the struts that support them, are installed in the CM.
158 days before launch (February 8, 1969)	**The spacecraft is powered up.**
156 days before launch (February 10, 1969)	**COAS is aligned.** The COAS (Crewman Optical Alignment Sight) is the optical sight that the crew uses when docking with the LM.
155 days before launch (February 11, 1969)	**Docking test.** A simulated docking test is performed. **Simulated altitude tests.** Among the crucial tests during spacecraft testing are the altitude tests. The entire spacecraft is placed in a high-altitude chamber, ensuring that it can withstand exposure to space and that there are no leaks in the pressurized areas. A simulated altitude test is performed, with the prime crew (for Apollo 11, Neil Armstrong, Buzz Aldrin, and Mike Collins) inside the spacecraft. The following day another simulated altitude test is performed, with the backup crew (James Lovell, William Anders, and Fred Haise) inside the spacecraft.

151 days before launch (February 15, 1969)	**Altitude test.** The first altitude test is performed, with no crew inside the spacecraft.
149 days before launch (February 17, 1969)	**Combined system test.** The combined system test for the spacecraft is completed.
120 days before launch (March 18, 1969)	**CSM altitude test with prime crew.** The next altitude test is performed, with the prime crew in the spacecraft.
115 days before launch (March 23, 1969)	**CSM altitude test with backup crew.** The final altitude test is performed, with the backup crew in the spacecraft.
96 days before launch (April 11, 1969)	**CSM mounted on SLA.** A few days ago -- on April 5 -- the LM was installed inside the SLA (the platform and conical shroud that protects the LM during launch). The CSM is now mounted atop the SLA.

Lunar Module

The Lunar Module was built by Grumman Aircraft in Bethpage, New York. The Apollo 11 mission will use LM-5. We follow LM-5 from the time it finishes its final testing at the factory.

268 days before launch (October 21, 1968)	**LM integration tests.** Integration tests are completed on Apollo 11's Lunar Module (LM-5) at the Grumman factory.
215 days before launch (Dec. 13, 1968)	**LM engineering evaluation acceptance test.** The final engineering evaluation acceptance test is completed for the LM at the Grumman factory.
190 days before launch (January 7, 1969)	**LM shipped to KSC.** LM-5 is ready to ship from the Grumman factory in Bethpage, New York, to the Kennedy Space Center (KSC) in Florida.
189 days before launch (January 8, 1969)	**Ascent stage arrives at KSC.** The ascent stage of LM-5 -- the top portion of the vehicle -- arrives at the Kennedy Space Center, and is taken to the Manned Spacecraft Operations Building (MSOB).
187 days before launch (January 10, 1969)	**SLA arrives at KSC.** SLA-14 arrives at the Kennedy Space Center. The SLA is the *spacecraft LM adapter* -- a structure made up of a base and four panels which form a cone that covers the LM during launch. The SLA is taken to the MSOB for checkout. (See SLA in the glossary.)
185 days before launch (January 12, 1969)	**Descent stage arrives at KSC.** The bottom portion of LM-5 -- the descent stage -- arrives at the Kennedy Space Center, and is taken to the Manned Spacecraft Operations Building (MSOB). Some pieces are still missing from the descent stage, however – in particular, the landing legs are missing.
156 days before launch (February 10, 1969)	**LM leak tests.** Leak tests are performed on the LM's cabin, contained within the ascent stage.
155 days before launch (February 11, 1969)	**Docking mechanism test.** A 2-day mechanical test is run on the LM's docking mechanism.

152 days before launch (February 14, 1969)	**LM stages mated.** The LM ascent and descent stages are mated.
149 days before launch (February 17, 1969)	**LM combined system test.** LM-5 combined system test completed.
147 days before launch (February 19, 1969)	**LM landing radar installed.** The LM's landing radar is installed. This critical piece of equipment enables the LM's computer to accurately determine its altitude above the lunar surface during landing, as well as its descent velocity. The landing radar is crucial to a successful landing -- mission rules dictate that a landing cannot be attempted without a functioning landing radar.
142 days before launch (February 24, 1969)	**MESA installed.** The Modular Equipment Stowage Assembly (MESA) is installed. The MESA is a large tray attached to the LM's descent stage which contains all of the equipment that the crew will use while working on the lunar surface. Mounted on the MESA is the TV camera that automatically captures the crew's first steps on the moon.
137 days before launch (March 1, 1969)	**LM combined system test.** A two-week series of comprehensive tests, known as the combined system test, is completed.
130 days before launch (March 8, 1969)	**Simulated altitude tests.** Two simulated altitude tests are performed on the LM, the first on March 8th, and the second two days later.
123 days before launch (March 15, 1969)	**Leak tests.** Two leak tests are performed on the LM, the first on March 15th, and the second two days later.
121 days before launch (March 17, 1969)	**Unmanned altitude test.** An unmanned altitude test is performed on the LM in a vacuum chamber.
117 days before launch (March 21, 1969)	**Altitude test with prime crew.** An altitude test performed on the LM with the Prime Crew (Armstong and Aldrin) in the cabin.
103 days before launch (April 4, 1969)	**Landing gear installed.** The LM's landing legs are installed.
102 days before launch (April 5, 1969)	**LM installed in SLA.** The LM is installed inside the SLA. (See SLA in the glossary.) The LM will remain inside the SLA until several hours after liftoff, when the vehicle is on the way to the moon.
98 days before launch (April 9, 1969)	**SLA explosive devices installed.** Explosive devices are installed in the SLA. The bolts that hold the four SLA panels together, as well as the bolts that will hold the CSM to the top of the SLA during launch, have explosive cartridges in them. Once the S-IVB has boosted itself and the two spacecraft toward the moon, the crew will push a button that detonates explosive cartridges, severing these bolts. This action jettisons the panels enclosing the LM, and releases the CSM from the top of the SLA.

Saturn V

The Saturn V consists of four main components:

- The S-IC, the first stage of the rocket, manufactured by Boeing at NASA's Michoud Assembly Facility in Louisiana.
- The S-II, the rocket's second stage, manufactured by North American Aviation in Seal Beach, California.
- The S-IVB, the rocket's third stage, manufactured by McDonnell Douglas in Huntington Beach, California.
- The Instrument Unit (IU), a ring of electronic equipment, including the rocket's computer (the LVDC), manufactured by IBM's Federal Division in Huntsville, Alabama.

Apollo 11 flew on the 6th Saturn V, designated SA-506.

178 days before launch (January 19, 1969)	**Saturn V third stage arrives at KSC.** The Saturn V third stage (S-IVB-506) arrives at the Kennedy Space Center. The S-IVB was manufactured by Douglas Aircraft in Huntington Beach, California, and then tested near Sacramento. Following testing, depending on the mission, the S-IVB was either shipped by barge through the Panama Canal to the Kennedy Space Center, or carried by air directly to KSC. Of the three stages, the S-IVB was the only stage that could be shipped by air, aboard a specially-modified aircraft known as the Super Guppy. (See Super Guppy in glossary.) Arriving at KSC, it is taken to one of the checkout cells in the Vehicle Assembly Building (VAB) low bay area for testing.
160 days before launch (February 6, 1969)	**Saturn V second stage arrives at KSC.** The Saturn V second stage (S-II-506) arrives at the Kennedy Space Center by barge from the Mississippi Test Facility (MTF) near New Orleans. The S-II was manufactured by North American Aviation in Seal Beach, California. From California the S-II was shipped by barge through the Panama Canal to NASA's Michoud Assembly Facility in Louisiana, and from there shipped to the MTF, where it underwent testing, including static engine firing. Once testing was complete, it was taken by barge to the Kennedy Space Center. Having arrived at the Kennedy Space Center, it is taken to one of the checkout cells in the VAB's low bay.
146 days before launch (February 20, 1969)	**Saturn V first stage arrives at KSC.** The Saturn V first stage (S-IC-506) arrives by barge at the Kennedy Space Center. The first stage was built by Boeing at NASA's Michoud Assembly Facility in Louisiana. The finished S-IC was then taken for testing to the Mississippi Test Facility (MTF) near New Orleans, where it underwent testing, including static firing. It was then shipped by barge to KSC. Apollo 11's first stage, S-IC-506, by coincidence, now arrives at KSC exactly 7 years to the day after the flight of John Glenn, the first U.S. astronaut in orbit.
145 days before launch (February 21, 1969)	**S-IC erected on mobile launcher.** The S-IC (the Saturn V first stage) is erected on the Mobile Launcher (see *Appendix A, Figure 5 - Mobile Launcher*), which has previously been positioned in one of the high bays in the Vehicle Assembly Building (VAB). The umbilicals are installed and various checks are made, including electrical continuity, pneumatic, fuel system, LOX system, and engine leak checks.

139 days before launch (February 27, 1969)	**Saturn V Instrument Unit arrives at KSC.** The Saturn V Instrument Unit (IU-506) arrives at the Kennedy Space Center aboard a specially-modified cargo aircraft -- the Super Guppy -- and is taken to one of the checkout cells in the VAB low bay area.
134 days before launch (March 4, 1969)	**S-II erected.** The S-II (the Saturn V second stage) is stacked on top of the first stage. The umbilicals are connected from the launch tower to the vehicle, and various tests are performed, including leak tests.
133 days before launch (March 5, 1969)	**S-IVB erected.** The S-IVB (the Saturn V third stage) and the Instrument Unit are stacked on top of the second stage. The umbilicals are connected from the launch tower to the vehicle, and various tests are made, including leak tests. IU equipment, including the various communication and navigation devices, are checked.
132 days before launch (March 6, 1969)	**Boilerplate installed.** Boilerplate 30 (BP-30) is stacked atop the Saturn V. With the CSM and the LM still undergoing assembling and testing in the MSOB, a dummy spacecraft, known as a *boilerplate,* serves as a stand-in until the actual spacecraft are in place.
121 days before launch (March 17, 1969)	**LVDC and stable platform installed.** The LVDC and ST124-M stable platform are installed in the Instrument Unit. The Launch Vehicle Digital Computer (LVDC), built by IBM's Federal Division, is the crucial brains of the Saturn V. Once liftoff occurs, the fate of the Saturn V is entirely in the hands of the LVDC. The ST124-M is a "stable platform", a collection of high-precision gyroscopes, accelerometers, and servo motors which are able to detect the rocket's acceleration and hold a platform in a fixed orientation relative to the stars, regardless of how the rocket moves. The measurements that the ST124-M sends to the LVDC enable the LVDC to determine the rocket's exact location, velocity, and orientation.
111 days before launch (March 27, 1969)	**Launch Vehicle (LV) Propellant Dispersion/Malfunction Overall Test (OAT) completed.** The Propellant Dispersal System (PDS) is essentially the rocket's self-destruct mechanism, able to destroy the vehicle in case it goes wildly off-course and threatens a populated area.
104 days before launch (April 3, 1969)	**Swing arm overall test (OAT).** A simulated countdown tests the nine swing arms on the Launch Umbilical Tower (LUT), verifying that the umbilicals will disconnect from the launch vehicle at the proper time and that the swing arms will retract as designed.

Combined Launch Vehicle in the VAB

127 days before launch (April 11, 1969)	**Boilerplate removed.** The spacecraft boilerplate (BP-30), which had been installed on March 6th, is now removed from the Saturn V.
93 days before launch (April 14, 1969)	**CSM/SLA/LM moved to VAB.** The combined CSM/SLA/LM is moved to the VAB and stacked on top of the Saturn V.

89 days before launch (April 18, 1969)	**Launch vehicle explosive devices installed.** The launch vehicle explosive devices are installed. As with both spacecraft, parts of the Saturn V are held together with various devices which contain explosive cartridges. When a part is to be jettisoned -- for example, when stages separate -- igniting the appropriate explosive cartridges causes the bolts to separates and jettisons the desired part. These explosive devices are installed at this point over the course of several days.
72 days before launch (May 5, 1969)	**CSM mated to Saturn V.** The CSM is electrically connected to the launch vehicle.
71 days before launch (May 6, 1969)	**Launch vehicle OAT.** Launch vehicle overall test completed.
63 days before launch (May 14, 1969)	**Launch vehicle plugs-in overall test.** The launch vehicle plugs-in overall test completed. The test is referred to as "plugs-in" because the umbilicals connecting the vehicle to the launch tower remain connected throughout the test, rather than disconnecting at liftoff as they would during a real launch. **Launch vehicle plugs-out overall test.** For early Saturn V launches, through Apollo 8, the "plugs-in" test was followed by a "plugs-out" overall test, in which the umbilicals disconnected, just as they would for launch.
58 days before launch (May 19, 196)	**Launch escape system installed.** The launch escape system (LES), including the boost protective cover (BPC), are installed. The boost protective cover would protect the spacecraft from the blast from the launch escape rocket, if it were ever used.
57 days before launch (May 20, 1969)	**Launch vehicle moved to launch pad.** The Saturn V, stacked on the Mobile Launcher, is transferred from the VAB to the launch pad, Launch Complex 39A, by the crawler-transporter. Although only three miles separate the VAB and the launch pad, the trip takes 8 hours. **Launch vehicle mated to pad.** After arriving at the launch pad, the mobile launcher is mated to the launch pad, which involves connecting it to the ground supply of electrical power, and the lines which provide hydraulic fluid, and through which propellants will be supplied to the launcher for loading onto the Saturn V.

LAUNCH PREPARATION ON THE LAUNCH PAD

The Mobile Launcher now sits on the launch pad at Launch Complex 39A (LC-39A), and the Saturn V remains on top of the Mobile Launcher. Testing and other activities continue for almost two more months.

55 days before launch (May 22, 1969)	**MSS moved to pad.** The Mobile Service Structure (MSS) is transferred to the launch pad (for Apollo 11, this was Pad 39A). The Mobile Service Structure (MSS) is a large steel structure, 402 feet high, which can provide workers with access to parts of the launch vehicle that are inaccessible from the Mobile Launcher. There is only one MSS, but it can be moved between the two launch pads by the crawler-transporter. When not in use, the MSS is parked near the crawlerway (the roadway that connects the pads with the Vehicle Assembly Building), approximately 7,000 feet from the launch pads. The crawler-transporter now picks up the MSS and takes it to Pad A to help prepare Apollo 11 for launch. **Ground electrical supply connected.** About this same time, the ground supply of electrical power is connected to the launch vehicle and spacecraft.
53 days before launch (May 23, 1969)	**EASEP/ALSEP installed in LM.** The lunar surface experiments package is loaded on the LM's descent stage. On Apollo 11, the experiments package was known as EASEP (Early Apollo Surface Experiment Package); on the other lunar landing missions, a larger experiments package was carried, known as ALSEP (Apollo Lunar Surface Experiments Package). The EASEP and ALSEP packages were built by Bendix Aerospace.
40 days before launch (June 6, 1969)	**Flight Readiness Test.** The Saturn V Flight Readiness Test (FRT) is completed.
34 days before launch (June 12, 1969)	**Launch Readiness Review.** Representatives from the major departments involved in launching Apollo 11 gather to review the status of the launch operations, and determine that the launch can proceed toward a scheduled launch on July 16.
29 days before launch (June 17, 1969)	**Flight Readiness Review.** Another review, more comprehensive than the Launch Readiness Review, takes place. This review involves all groups involved in the mission.
21 days before launch (June 25, 1969)	**S-IC fuel load.** The first stage is loaded with RP-1 fuel, a highly-refined form of kerosene. At this point the launch is still three weeks away, but RP-1 can be safely stored in the S-IC's fuel tank from now until launch. The S-IC fuel tank holds 209,000 gallons, or 1.4 million pounds, of RP-1. The fuel on the second and third stages is liquid hydrogen (LH2). LH2 cannot be loaded into its tanks until just a few hours before launch -- it is cryogenic, and must be kept at a temperature of -253°C / -423°F. The oxidizer for all three stages is liquid oxygen (LOX), and it too is cryogenic. It will be loaded into the tanks just a few hours before launch.

Hypergolic propellant load. The propellants used in the CSM, the LM, and the maneuvering units on the third stage (known as the APS) are hypergolic -- that is, the fuel (Aerozine 50) and oxidizer (nitrogen tetroxide) ignite on contact, without the need for an ignition system. The hypergolic propellants can be stored at room temperature, and around this time, the hypergolic propellants are loaded aboard the spacecraft and the third stage APS. The propellants are nasty substances -- toxic, corrosive, and carcinogenic -- but the ability to store them at room temperature and burn them without the need for an ignition system makes them worth the risk. All personnel not directly involved in the propellant load must clear the pad during this hazardous operation.

14 days before launch
(July 2, 1969)

Countdown demonstration test (wet). The countdown demonstration test (CDDT) is the final prelaunch test that verifies that the launch vehicle and ground support equipment are ready for launch. The test is performed in two phases, known as **wet** and **dry**.

The wet countdown demonstration test is the lengthier test, a complete dress rehearsal of getting the vehicle ready for launch. All the tasks for a real launch are performed, with the following exceptions:

- There is no crew onboard the spacecraft, and the cabin is not pressurized for launch.
- The vehicle self-destruct system is not armed.
- Engine igniters and other explosive detonators (such as the detonators that would separate stages of the launch vehicle) are not present.

The launch vehicle’s cryogenic propellants are loaded aboard the vehicle (hence the description “wet test”), just as they would be for an actual launch. The test terminates when the countdown reaches -8.9s, which is the point at which the process of starting the engines would begin for a real launch.

13 days before launch
(July 3, 1969)

Countdown demonstration test (dry). The dry countdown demonstration test rehearses the last few hours of the countdown, starting the count at -6h. The test differs from the previous wet test in these ways:

- The crew is aboard the spacecraft.
- At the appropriate time, the cabin is pressurized with the same 60/40 oxygen/nitrogen mix that would be present for a real launch.
- Cryogenic propellants (liquid oxygen and liquid hydrogen) are not loaded as they were for the wet test.
- During a real launch, swing arm #9, which provides access to the spacecraft, is fully retracted at T-5 minutes. During this test, the swing arm is moved to the fully-retracted position and then is immediately returned to the spacecraft.
- As with the wet test, the igniters and other explosive detonators are not present.

For the Saturn V, the test terminates at -4m, which is shortly before the terminal count sequencer (TCS) starts the terminal countdown. However, in the spacecraft, the simulation continues and includes a simulated launch.

COUNTDOWN BEGINS

This first part of the countdown is known as the *pre-count operation*. During this time, various equipment is installed, the CSM's fuel cells are activated, and more testing is performed. This phase runs from -130h to -28h. The main countdown starts at -28h.

The timeline here outlines some of the activities during the pre-count operation.

6 days till launch (July 10, 1969)	**Pre-count operation started.**
-130h	**The CSM is powered up.** At this point, its electrical power is supplied by ground equipment.
-109h	**Safe and Arm (S&A) devices certified.** In the case of a dire emergency, the Saturn V has a self-destruct system. Each stage has a set of explosive charges, known as the Propellant Dispersion System (PDS), which -- when fired by a remote command from the ground -- destroys the vehicle. The PDS on each stage can split its propellant tanks open, dispersing the propellants and resulting in an explosion that destroys the vehicle. Such a command would hopefully be sent only after the Command Module and its crew were safely away from the vehicle. The PDS on each stage includes a safe & arm (S&A) device, which can physically block the firing signal that detonates the PDS. The S&A devices ensure that the PDS cannot be activated while pad workers are present before launch. At this point, the S&A devices are not yet installed in the vehicle. Engineers check the devices to make sure they will operate as designed, and certify that they are ready for flight. They will be installed in the Saturn V about 7 hours from now. Note that the certification is valid for seven days -- if the launch is delayed beyond that time, the devices have to be removed from the Saturn V and recertified. The actual explosives that are able to blow the stages apart won't be installed until much closer to launch, at -10h.
-102h	**Safe and Arm (S&A) devices installed.** The S&A devices (see -109h for details) are installed in each stage of the launch vehicle.
-93h	**S-IC ordnance installed.** The ignitors for the first stage engines and the first stage retrorockets are installed.
-88h 30m	**Installation of final ordnance.** Pad crews begin the process of installing the explosive devices that are used throughout the vehicle. This includes detonators for separating stages, rocket motor igniters, and the hypergolic cartridges used in the start process of igniting the F-1 engines.
-79h	**Spacecraft tanks pressurized.** The launch pad is cleared of non-essential personnel for the next 13 hours as tanks in the LM and CSM are brought up to flight pressure.
-68h	**Fuel cell activation.** The process begins of starting the three fuel cells in the Service Module. Each **fuel cell** combines hydrogen and oxygen to produce

electricity and water. The electricity produced by the fuel cells provides almost all of the electrical power needed by the Command and Service Module (CSM) throughout the mission. While the LM is docked with the CSM, the fuel cells also provide power to the LM and recharge the LM batteries. The water produced by the fuel cells provides drinking water for the crew, as well as water for cooling.

The entire process of starting the fuel cells will require about a day and a half, and begins with a conditioning phase that prepares them to be able to provide their full rated power to the spacecraft. This conditioning phase lasts several hours (3.5 hours on Apollo 11, longer on some flights).

Exactly when fuel cell activation occurred varied from one flight to another -- on Apollo 8, the fuel cells weren't activated until -48h.

Ground equipment will continue to supply power to the spacecraft until -3h, at which time the fuel cells provide the CSM's power until almost the very end of the mission. About 15 minutes before reentry, the Service Module, which contains the fuel cells, is jettisoned. For the remaining half-hour or so of flight, which includes reentry and landing, three batteries in the Command Module, known as the *entry/post-landing batteries*, provide power for the Command Module. These batteries continue to provide power for a short time after landing.

-63h 15m **Range safety code plugs installed.** During a Saturn V launch, the controllers on the ground have very little direct control over the rocket or the spacecraft -- the computer is controlling just about everything. However, one person -- the Range Safety Office (RSO) -- can take one very important action: send a radio command to destroy the vehicle using the Propellant Dispersion System (PDS. See -109h.) The Apollo program took place during the height of the Cold War, and there was a serious concern that the Soviet Union might send a fake signal to try to destroy the vehicle. To prevent this, the RSO sets a specific secret pin configuration in a set of range safety code plugs, which are installed in each stage in the equipment that receives and decodes the self-destruct command. Without knowing the settings in the code plugs, it's impossible to send a valid self-destruct command. These code plugs, with the correct pin settings, are now installed in each stage of the Saturn V. However, the PDS won't be armed until 5 minutes 30 seconds before liftoff.

-62h **Saturn V's stages powered up.** Each of the Saturn V's stages are powered up, using power supplied by ground equipment. Ground crews run tests of the self-destruct systems, as well as other tests. The stages are then powered back down.

-28h **Main countdown started.** The main portion of the countdown for Apollo 11 starts at 5:00 pm on July 14, 1969, with the countdown clock set to T-28h. If all goes well, liftoff will occur at 9:32 am on July 16. Despite the fact that the count starts at T-28 hours, the launch is actually about 40.5 hours away. There are two built-in holds during which the countdown clock is stopped.

-27h 30m **Install launch vehicle flight batteries.** For the next few hours, workers will install the batteries that will power each stage of the Saturn V. Each of the three stages, as well as the Instrument Unit, has its own independent power system, each with a unique design, and its own batteries. All batteries are zinc-silver oxide batteries, and most are 28-volt. The following table lists the arrangement of batteries in the three Saturn V stages and the Instrument Unit (IU):

S-IC	Two 28-volt batteries, one weighing 22 lb. and the other weighing 55 lb.
S-II	Four identical 28-volt batteries, each weighing 165 lb.
S-IVB	A total of seven 28-volt battery modules, arranged into four batteries. Three of them are 28-volt, and the fourth is 56-volt.
IU	Four 28-volt batteries, each weighing about 165 pounds.

It took several hours to install all of the batteries.

LM stowage and closeout. For the next 12 hours, workers will finish the job of loading equipment on the LM, and seal the hatches. However, as explained later, the vent valve on LM's top hatch is intentionally left open. (See +55s.)

~-24h

Saturn V power-up. To preserve the batteries for flight, the ground support equipment (GSE) begins providing power to all stages of the Saturn V. Ground equipment will continue to supply electrical power to the vehicle until 50 seconds before launch.

Wind monitoring. Data on the winds at the Kennedy Space Center (KSC) begin to be regularly reported to the Huntsville Operations Support team at the Marshall Space Flight Center in Huntsville, Alabama. The team runs computer simulations to make sure that the winds are within acceptable limits, and reports the results to the Launch Control Center at KSC.

-23h 30m

LVDC powered up. The Launch Vehicle Digital Computer (LVDC) is powered up.

-23h 15m

Test of the CM's ability to take over guidance. The LVDC normally controls the Saturn V's flight by itself. The computer in the Command Module – the CMC – monitors the Saturn V's trajectory during flight. If the LVDC fails, the CMC can take over steering of the vehicle. The launch team now tests the ability of the S-IVB to accept steering commands from the CMC in the event of a failure of the LVDC.

-19h

Preparation of swing arms. Crews began preparing equipment in the nine swing arms (also known as "service arms") which connect the launch tower to the Saturn V and the spacecraft. (See *Appendix A, Figure 5 - Mobile Launcher*, as well as *Appendix D - Mobile Launcher Connections*.)

LM supercritical helium. The LM crews finish topping off the supercritical helium (She) tanks in the LM. Helium was used in both spacecraft and in the Saturn V as a pressurant to maintain pressure in propellant tanks. Helium is preferred for this purpose because it is completely non-reactive, and it is a gas even at supercold liquid hydrogen and liquid oxygen temperatures.

-17h 45m	**Holddown arm safety pins.** The Saturn V's entire weight (once fueled, 6.478 million pounds for Apollo 11) rests upon four holddown arms (see +0.3s). Pad crews begin pulling safety pins from holddown arms.
-17h	**Swing arms pressurized.** Over the next hour, the hydraulic systems on the nine launch tower swing arms are pressurized. **Hammerhead crane retraction.** On the very top of the launch tower is a Hammerhead crane, which is no longer needed. The crane is rotated into its parked position, 90° away from the Saturn V.
-15h 30m	**Q-ball cover installed.** At the very top of the Saturn V stack -- at the tip of the launch escape tower -- is the **Q-ball**. In flight, eight tiny holes (referred to as "ports") in the nose of the Q-ball enable it to measure the rocket's *angle of attack* in all directions. (See -1h 20m for more information about the Q-ball.) Until now, the mobile service structure (MSS) has protected the Q-ball from the elements, but the MSS will shortly be removed from the launch area. Because it is absolutely crucial that no debris get into any of the eight ports in the Q-ball, a two-piece styrofoam cover is now placed on the Q-ball to protect it from debris. The cover will be yanked away from the Q-ball seconds before liftoff. (See -8.9s.)
-15h	**F-1 engine plumbing loaded with ethylene glycol.** For the next two hours, the thrust chamber tubes and manifolds in the first stage F-1 engines are filled with an ethylene glycol solution. At engine ignition 15 hours from now, this solution helps to smooth out the ignition sequence when the engines are started.
-12h	**Swing arm 3 retracted.** Most of the swing arms contain umbilicals that provide propellants, electrical power, or data connections to the launch vehicle. Swing arm 3 -- which provides access to the aft end of the second stage -- is different in that it only provides a platform that allows pad workers to have physical access to the second stage. With the countdown reaching the point at which most workers are going to be cleared from the launch pad area, this swing arm is no longer needed and can be retracted. This event happened at very different times on different flights. (See *Appendix A, Figure 5 - Mobile Launcher*.)
-11h 30m	**Install launch vehicle destruct devices.** Components of the propellant dispersion system (PDS), which can destroy the launch vehicle in an emergency, are installed.
-10h	**Begin moving the mobile service structure (MSS) to its park site.** Having completed its job, the MSS begins the trip to the MSS's parking spot, about a mile from the launch pad, carried by one of the crawler-transporters. (For more information about the MSS, see "55 days before launch.")
-9h 30m	**Environmental switch from air to gaseous nitrogen.** The environmental systems aboard the Saturn V switch to gaseous nitrogen. Up until this point, the spaces containing equipment and electronics inside each Saturn V stage have been air conditioned with air supplied by ground equipment. This air conditioning maintains proper temperature and humidity around crucial components and electronics. As a fire safety measure, the ground equipment now begins supplying gaseous nitrogen instead of air. With no oxygen available

in the conditioning gas, a stray spark is less likely to develop into a fire. Note that this nitrogen environment is for spaces inside the Saturn V only, not the spacecraft.

-9h **Scheduled 11-hour hold.** At noon on July 15, 1969, the countdown clock is stopped for 11 hours. This 11-hour period provides workers with an opportunity to work on any problems discovered. If necessary, the hold can be extended to provide time to resolve any issues. On Apollo 11, the count resumed 11 hours later, at 11pm on July 15.

-8h 57m **Begin S-IC lox tank purge.** Before the process of loading liquid oxygen into the first stage tank, the air in the tank is flushed and replaced with gaseous nitrogen. This process will continue for two and a half hours, through -6h 27m.

The tanks on the second and third stage go through a similar process. The table below shows each tank, and what gas was used to replace the air in the tank.

STAGE	PROPELLANT	PURGED WITH	START	END
S-IC (1st stage)	liquid oxygen	nitrogen	-8h 57m	-6h 27m
S-II (2nd stage)	liquid oxygen	nitrogen	-7h 39m	-7h 4m
S-II (2nd stage)	liquid hydrogen	helium	-8h 34s	-8h 18m
S-IVB (3rd stage)	liquid oxygen	helium	-7h 43m	-7h 28m
S-IVB (3rd stage)	liquid hydrogen	helium	-7h 31m	-4h 11m

-8h 30m **Backup crew enters the Command Module.** The backup crew (on Apollo 11, James Lovell, William Anders, and Fred Haise) enter the Command Module to begin prelaunch checks. At this point, their task is to make sure that every switch and circuit breaker in the Command Module is set to a specific predetermined position, so that powering up and testing the Command Module starts from a known state.

-7h 42m **S-II liquid hydrogen (LH2) tank preconditioning.** The lengthy process -- almost 3 hours -- of preconditioning (chilling) the second stage (S-II) liquid hydrogen tank begins. Pouring supercold liquid hydrogen (-253°C / -423°F) into a tank at room temperature would be the equivalent of pouring water into a red-hot metal tank -- the liquid would boil explosively and the tank would be stressed by the extreme temperature change. Preconditioning chills the tank and prepares it to receive the supercold liquid hydrogen. This process is completed at -4h 54m.

-7h 28m **S-IVB LOX tank precool.** Filling of the third stage liquid oxygen (LOX) tank now begins, at a rate of 500 gallons per minutes. This initial slow fill rate is intended to condition the tank to accept the supercold (-297° F / -183° C) liquid oxygen. Slow fill continues until the tank is 5% full, which requires about 4 minutes.

-7h 24m **S-IVB LOX tank fast fill.** Loading of the third-stage LOX tanks continues at a faster rate, 1,000 gallons/minute. This rate continues until the tank is 98% full.

-7h 7m **S-IVB LOX tank slow fill.** With the third stage LOX tank now 98% full, the flow rate is reduced to 300 gallons/minute until the tank is full, which requires about 3 minutes.

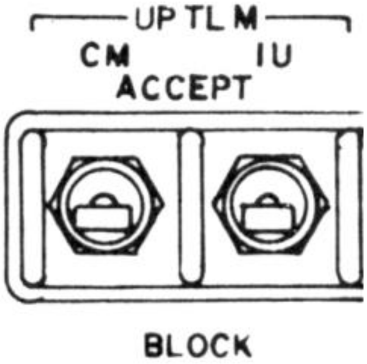
-7h 4m	**S-II LOX tank loading.** The process of loading LOX into the second stage LOX tank begins. As with the third stage tank, loading begins with a slow fill rate, 500 gallons/minute, to condition the tank to accept the supercold liquid oxygen. This continues until the tank is 5% full, which takes about 10 minutes. At -6h 54m, fast fill begins. The fill rate is increased to 5,000 gallons/minute, and continues until the tank is 98% full, which requires about 24 minutes. Finally, the last 2% is filled at a rate of 1,000 gallons/minute, and requires about 3 minutes.
-6h 45m	**IMU powered on.** The ST124-M inertial measuring unit, which will enable the IU to determine the rocket's position, attitude, and velocity, is powered on.
-6h 27m	**S-IC LOX tank loading.** The process of loading LOX into the first stage LOX tank begins. As with the second and third stage tanks, loading begins with a slow fill rate, 300 gallons/minute, to condition the tank to accept the supercold liquid oxygen, followed by 1,500 gallons/minute slow fill rate for 17 minutes, at which point the tank is 6.5% full. Fast fill then proceeds at 10,000 gallons per minute, and continues through -4h 57m, about 48 minutes, at which point the tank is 95% full. The last 5% is filled at 1,500 gallons/minute.
-5h 45m	**S-IVB and S-II LOX tank replenish.** Although the LOX tanks on the second and third stages have been filled, they will not stay that way. The LOX tanks are insulated, but heat from the environment inevitably seeps in. Allowing some of the LOX to boil away carries away this excess heat and allows the remaining LOX to remain at its supercold temperature (-297° F / -183° C). As some of the LOX boils away, it is constantly replenished from the ground supply, at a rate of up to 100 gallons/minute for the second stage, and up to 30 gallons/minutes for the third stage. The propellant tanking computer system (PTCS) monitors the level in the tank and replenishes as necessary. This replenishment continues until about 3 minutes before launch, when the tanks are sealed and pressurized.
-4h 54m	**S-II LH2 (liquid hydrogen) precool.** The process of slowly loading liquid hydrogen into the second stage tank begins, conditioning the tanks to accept the supercold liquid hydrogen (-423°F/-253°C). The process will continue until -4h 36m.
-4h 11m	**Q-ball power and heaters on.** The very uppermost component on the Saturn V -- at the top of the launch escape tower -- is the Q-ball. During flight the Q-ball measures the force of the oncoming air from all sides, and can accurately determine the angle at which the rocket is traveling into the oncoming air. (See -1h 20m for more information about the Q-ball.) Power is now applied to the Q-ball and the heaters are turned on. The heaters will ensure that ice does not form in the Q-ball's air inlets before or during flight.
-4h 11m	**S-IVB LH2 precool.** The process of filling the third stage hydrogen tank begins with a fill rate of 500 gallons/minute. This initial slow fill rate is intended to condition the tank to accept the supercold (-423° F) liquid hydrogen. This rate continues until the tank is 5% full, a process which requires about 13 minutes, ending at -3h 58m.

-3h 58m	**S-IVB LH2 fast fill.** The fill rate on the third stage liquid hydrogen tank is increased to 3,000 gallons/minute, and continues until the tank is 98% full. This process requires about half an hour, ending at -3h 33m.
-3h 45m	**Crew awakened.** In the MSOB, the crew -- for Apollo 11, Neil Armstrong, Buzz Aldrin, and Michael Collins -- are awakened. The time is 4:15 am Eastern Daylight Time. They have spent the night in the Manned Spacecraft Operations building.
-3h 33m	**S-IVB LH2 slow fill.** With the third stage liquid hydrogen tank at 98% full, the fill rate drops to a maximum of 500 gallons/minutes until the tanks are full, a process that requires about 5 minutes and ends at -3h 28m.
-3h 33m	**S-II LH2 replenish.** The third stage liquid hydrogen tank is now full. From now until about 3 minutes before launch, hydrogen will slowly boil off from the tank, and will be replenished as needed at a rate up to 300 gallons/minutes. The propellant tanking computer system (PTCS) monitors the level in the tank and replenishes as necessary. This process continues until -3m 6s, when the tank is sealed and pressurized.
-3h 30m	**Scheduled countdown hold.** The countdown holds at -3h 30m for the next 1 hour 32 minutes. This scheduled hold time gives the pad crews a chance to work on any problems that have cropped up or catch up any tasks that are running behind. For Apollo 11, this hold begins when the countdown reaches -3h 30m at 4:30 am. The countdown will resume at 6:02 am.
Holding at -3h 30m	**Breakfast**. At about 5 am, the crew sits down for a traditional prelaunch breakfast of orange juice, tenderloin steak, scrambled eggs, toast, and coffee. They are joined by the Director of Flight Crew Operations, Deke Slayton -- essentially the astronaut's boss -- and Bill Anders, the CMP on the Apollo 11 backup crew. Side note: The breakfast served to flight crews before launch goes back to the earliest U.S. manned flights, and it's easy to assume that the crews were served steak and eggs merely to honor tradition and because in the 1960s this was considered a pretty fancy breakfast, perfect for starting a very busy day. All of that is true, but there's a more practical reason for these specific foods: they're low residue -- that is, they contain very little fiber, and keep bowel movements to a minimum. By launch day, the astronauts have been eating similar low-residue foods for days. Bowel movements in the cramped Command Module and Lunar Module are no fun -- privacy is non-existent, and the process is not for the squeamish. A low-residue diet ensures that the crew won't have to deal with such processes while they're still getting used to being in space. **Suit up.** Around 5:40 am, the crew proceeds to the suit room to don their space suits. Once sealed in their suits, the crew breathes pure oxygen. During launch the pressure in the suits and in the spacecraft cabin drops rapidly from sea level pressure (14.7 psi) to normal spacecraft pressure of about 5 psi. By prebreathing pure oxygen for several hours, the crew ensures that by launch-time the nitrogen dissolved in their bloodstreams is gone. Otherwise, dissolved nitrogen can come out of solution, forming bubbles that can be extremely painful and

	even lethal. The suitcase that each crew member can be seen carrying on their way to the launch pad contains a supply of oxygen. **Open Command Module**. About 5:50 am the pad crew opens the hatch of Command Module, and the backup LMP (Fred Haise on Apollo 11) enters the Command Module for initial checks, in anticipation of the crew's arrival. The countdown is still holding at -3h 30m.
-3h 30m	**Scheduled hold ends.** On Apollo 11, the countdown resumes at 6:02 am Eastern Daylight Time.
-3h 28m	**S-IVB LH2 replenish.** From now until shortly before launch (-3m 6s) liquid hydrogen is allowed to boil off as needed, and is replenished to keep the tank at flight level. The propellant tanking computer system (PTCS) monitors the level in the tank and replenishes as necessary.
~-3h 5m	**Crew departs for the pad.** At the MSOB the crew boards the van for the 8-mile trip to the launch pad (LC-39A on Apollo 11). The trip will take about 15 minutes.
-3h	**Spacecraft to internal power.** The three fuel cells in the Service Module, which provide electrical power to the CSM throughout most of the mission, were activated 65 hours ago. Until this point, the CSM has been drawing its electrical power from the launch pad. The fuel cells now begin providing all of the spacecraft's electrical power, although the ground power source remains connected. The switchover to fuel cells occurred at very different times on different missions -- on Apollo 8 it happened as late as -2h, and on Apollo 10 the switchover occurred 12 hours before launch!
-2h 40m	**Crew ingress.** The crew takes one of the launch tower's high-speed elevators (600 ft/min) to the 320-foot level. Armstrong and Collins board first, crossing swing arm #9 to the White Room. The White Room is the small room at the end of swing arm #9 that butts up against the Command Module hatch. While Armstrong and Collins are entering the spacecraft, Aldrin waits in the elevator. The Commander boards the spacecraft first, taking the left couch. This is normally followed by the LMP in the right couch, and finally the CMP in the center couch. However, on Apollo 11, Buzz Aldrin (the LMP) took CMP duties and sat in the center couch for launch, and Michael Collins took LMP duties and sat in the right seat for launch. Aldrin and Collins swapped jobs for launch because Aldrin had trained as backup CMP for Apollo 8 and had trained in the center couch for that position. This swap in duties only applied to the launch -- once in space, Aldrin resumed LMP duties and Collins resumed CMP duties.
~-2h 30m	**Go/no-go wind recommendation.** The wind monitoring team in Huntsville makes a final recommendation as to whether or not the winds are acceptable for launch. Even if the recommendation is "no go", the weather team at the Kennedy Space Center can continue to monitor the winds and the launch may proceed if conditions improve.

~-2h 24m **Crew aboard.** All three crew members are aboard the spacecraft. Fred Haise (backup CMP on Apollo 11) and a suit technician are also aboard the spacecraft for a short time, helping the crew connect their suits to the spacecraft's oxygen supply and communication system.

~-2h **The spacecraft hatch is closed.** The CM's hatch is closed and sealed. The air in the spacecraft's cabin begins to be swapped for a mixture of 60% oxygen and 40% nitrogen at sea level pressure. The crew's suits, however, are hooked directly to the spacecraft's oxygen system, and the crew members continue to breathe pure oxygen.



~-1h 55m **MCC command checks.** Mission Control in Houston tests its ability to communicate via radio with the spacecraft.

Interesting to note that most of the data transmissions are telemetry from the spacecraft to Mission Control. While Mission Control can receive enormous amounts of telemetry data from the spacecraft, it has almost no control over the spacecraft. If a ground controller wants a specific piece of equipment to be turned on or off, they can't do it themselves -- they have to ask the crew to do it. This lack of ground control is intentional, since transmissions aren't encrypted, and without safety measures, pretty much anyone with a big-enough transmitter could send a signal to the spacecraft.

Ground controllers occasionally need to send data and commands to the Command Module Computer, but can do so only with the crew's permission. A switch on one of the CM's control panels (the left switch in the diagram above) determines whether commands and data from the ground are accepted or blocked. The switch spends the vast majority of the mission in the BLOCK position. When the ground wants to send data or commands to the computer, they ask the crew to move the switch to the ACCEPT position, send the commands and data, and then have the crew move the switch back to the BLOCK position. This is only done during non-critical phases of the mission, when unauthorized commands wouldn't endanger the mission or the crew.

-1h 51m **EDS test.** The crew now begins a lengthy test, about 30 minutes, of the Emergency Detection System (EDS). During the first two minutes of flight, the EDS automatically monitors the path of the rocket, and can abort the mission if the rocket goes astray. The EDS lights are on the left panel, so this test primarily involves the Commander (Armstrong on Apollo 11), who is in the left couch. See +0.63s for a description of the EDS.

~-1h 31m **Boost Protective Cover hatch.** The boost protective cover (BPC) covers the Command Module and would protect it from the blast of the launch escape rocket in the event of a launch abort in the first 3-and-a-quarter minutes of flight. A hatch in the BPC allows access to the Command Module hatch. The pad closeout crew now closes the hatch in the BPC.

~-1h 20m	**Q-ball test.** The very uppermost component on the Saturn V -- at the top of the launch escape tower -- is a device called the Q-ball. During flight, this device senses the oncoming air through eight holes, and can very precisely determine the rocket's *angle of attack* -- that is, the angle at which the rocket is travelling into the oncoming air. During the first few minutes of flight, this angle must be very small or the aerodynamic forces can destroy the vehicle. At this point in the countdown, the Q-ball receives a simulated command, which is read out in the spacecraft by the crew, to look for any inaccuracies in the Q-ball. The Q-ball is so named because its basic function is to measure air pressure from different directions, and in aerodynamic calculations, the variable "Q" represents pressure.
~-1h 5m	**White Room crew is clear.** At the end of swing arm #9 is the White Room, a small room connected to the CM's side hatch. As the countdown has progressed, workers in the White Room have helped prepare the Command Module, helped the crew get settled, and finally sealed the spacecraft for launch. Having completed their job, the White Room personnel now leave the pad.
~-1h 2m	**SPS gimbal check.** The large engine at the base of the Service Module, known as the Service Propulsion System (SPS), is mounted on gimbals that allow it to change the angle of its thrust. Two servo motors are used to control the direction of the thrust. The crew now runs through a test of these motors to make sure that the SPS can be gimballed properly.
-1h	**S-IC fuel level adjustment.** During fuel loading on the S-IC, which happened days ago, the tank was deliberately overfilled. The overfilling was done because the fuel would receive some amount of chilling effect from the adjacent LOX tank. For the next 25 minutes the fuel level will be drained to the proper level for flight. **S-IVB cold helium and engine control system pressure checks.** **Tests of the S-IVB propellant utilization (PU) system.** (See +2m 48.5s for information about the propellant utilization system.)
-57m	**Azimuth laying.** Proper navigation for the Saturn V depends on it knowing its precise orientation at launch. A crucial aspect of knowing its orientation was knowing its *azimuth* -- that is, which direction any point on the side of the rocket was facing. The Saturn V was placed on the mobile launcher with what was known as Position II facing the launch tower. The four fins on the first stage were labeled A through D, and Position II was the spot halfway between the fins A and B. When the Saturn V and the mobile launcher sat on the launch pad, the launch tower was to the north of the Saturn V, so fin B pointed northwest, and fin A pointed northeast.

	But this general orientation was not nearly accurate enough -- the Saturn V's guidance system needed to know the rocket's azimuth to a small fraction of a degree. About 700 feet from the mobile launcher, on the median of the approach ramp to the launch pad, is a bunker-like building known as the Azimuth Alignment Building. Within the building is an autocollimator theodolite, an optical device that can measure angles very accurately. The theodolite contains a light source which fires a beam of light at a tiny window in the side of the Saturn V's Instrument Unit. This beam of light strikes two prisms in the inertial measuring unit (IMU). A servomotor can move one of these prisms. By moving one of the prisms and measuring the angle of the light reflected back to the theodolite, the ground control computer can determine the Saturn V's azimuth to within better than 20 arc seconds. The system can even measure and account for swaying in the vehicle caused by wind as it sits on the launch pad. This alignment process will continue until just before liftoff.
-55m	**Pad closeout crew clears the pad.** The final launch pad crews leave the pad area.
-43m	**CM access arm parked.** The #9 swing arm on the mobile launch tower provides the pad team with access to the spacecraft, and enables the crew to enter (or leave) the spacecraft. The arm is now retracted to the parked position, 12 degrees from the spacecraft, which works out to about 5 feet between the swing arm and the spacecraft. In this position the arm could be rapidly returned to the spacecraft in an emergency. The arm remains in this parked position until T-5m, when it will swing to its fully-retracted position, 180° from the spacecraft.
-42m	**Launch Escape Rocket armed.** The crew locks their shoulder harnesses, and the Commander arms the Launch Escape System (LES). In a pre-launch emergency, the crew now has the option of calling back swing arm #9 and evacuating the spacecraft, or using the LES to whisk the spacecraft away from the launch vehicle. **IU gimbal checks.** The LVDC tests its ability to steer the vehicle by swiveling the four outboard F-1 engines in the first stage.
-40m	**Range safety command checks.** Like most big rockets, if the Saturn V had ever gone off course, ground controllers had the ability to destroy it. Each stage of the Saturn V had a system called the *propellant dispersal system* (PDS). When commanded by the Range Safety Officer (RSO), the PDS could split open all the propellant tanks, resulting in an explosion that would destroy the Saturn V. The hope, of course, is that the Command Module would be whisked to safety by the launch escape rocket or by the spacecraft's Service Propulsion System engine. The propellant dispersal system is currently disarmed, and won't be armed until T-5m 30s, but at this point ground controllers run a test to ensure that if the range safety officer has to fire the PDS, the signal can actually reach the launch vehicle.

~-40m	**CSM RCS pressurization.** The CMP begins the process of pressurizing the Service Module's reaction control system (RCS) thrusters, which consists of four quadrants, each with four 100 -pound-thrust rockets on the side of the Service Module. The CMP pressurizes the system and relays the status to the Spacecraft Test Conductor. **Auxiliary Propulsion System (APS) pressurization.** Third stage steering, as well as maneuvering of the Saturn V in orbit, is accomplished with a set of thrusters known as the APS. That system is now pressurized and made ready for flight.
-31m 30s	**Test of S-II and S-IVB chilldown pumps.** In the second and third stages, several minutes before the engines in these stages can be started, chilldown pumps circulate a small amount of the supercold propellants (LOX and liquid hydrogen), conditioning the lines for the onslaught of supercold propellants. A test is now run of those chilldown pumps.
-30m	**Power transfer test.** Throughout the countdown, the Saturn V's electrical power needs have been supplied by ground equipment, in order to preserve the batteries in each stage of the Saturn V. Just before launch, the launch vehicle will disconnect from the ground electrical supply and begin to use its own batteries for electrical power. To ensure that each stage can make this switch and run on batteries, the three stages and the Instrument Unit (IU) now switch over to battery power. The three stages remain on battery power for 30 seconds, while the Instrument Unit remains on battery power for 3 minutes. They then switch back to ground power to preserve the batteries. The final switch to internal power will occur at -50s.
-30m	**LM switch to internal power.** Up until this point, the LM has been drawing what little power it needs from ground equipment -- first from a piece of equipment known as the *vehicle ground power supply* (VGPS), and later directly from the launch tower. At approximately T-30 minutes, the LM disconnects from the ground power supply and begins running on its own batteries. The LM has two batteries in the ascent stage and four batteries in the descent stage. (Later fights, beginning with Apollo 15, added a fifth battery to the descent stage.) Two of the descent stage batteries -- numbers 1 and 4 -- now begin to supply all the LM's power, and will continue to do so until the LM and CSM are docked and on the way to the moon, several hours from now. With the LM's batteries fully charged, and the LM's current power needs so meager, connecting the LM's power system to the full capacity of each battery would actually result in an over-voltage. A low-power tap on each battery enables the LM to use only 17 of the 20 cells in each battery, ensuring that the voltage from each battery is not too high. For the next 20 minutes, controllers will examine the telemetry from LM systems to ensure that they are ready for flight, and at about T-10 minutes will shut down the LM's telemetry, preserving the LM's power over the next few hours.

-22m	**S-II start tank chilldown**. Each of the five J-2 engines in the second stage contains a start tank -- a tank of pressurized gaseous hydrogen that is used to spin the pump turbine as the engine is started. The 17-minute process now begins of chilling the hydrogen to operating temperature. T-22m is an important point in the countdown, known as a *recycle point*. From this point forward, if a hold longer than a few minutes is called, then the countdown will be reset to T-22m. Once the terminal countdown sequencer (TCS) starts at -3m 7s, **any** interruption to the countdown requires that the countdown be stopped and returned to T-22m.
-20m 30s	**Final Saturn V telemetry system checks.**
-15m	**CSM disconnects from ground power.** Although the CSM fuel cells have been carrying the spacecraft's power load for hours, ground sources have been connected and available. The CSM now disconnects from the pad's electrical system, with the three fuel cells in the Service Module providing all its electrical power from now on.
-15m	**S-IVB engine thrust chamber purge.** The third stage engine's thrust chamber is purged with gaseous helium, ensuring that there are no propellants in the thrust chamber while the first and second stages are operating.
-14m 30s	**S-IVB start tank chilldown**. The third stage J-2 engine contains a start tank -- a tank of pressurized gaseous hydrogen that is used to spin the pump turbine as the engine is started. The 9-minute process now begins of chilling the hydrogen to operating temperature.
-13m 30s	 **Rotational hand controllers armed.** Next to the Commander's left hand is a handle known as the *translation controller* (shown at the right). During launch, it allows the Commander to abort the mission. (See +1m 57s for details on how this control works.) Prior to launch, in the event of a catastrophic accident, the hand controller would allow the Commander to fire the launch escape rocket, which would quickly pull the Command Module away from the Saturn V. Once clear of the rocket, the Command Module would descend on parachutes and splash down in the Atlantic Ocean.
-13m	**S-II engine thrust chamber purge.** The thrust chambers on the five second stage engines are purged with gaseous helium, ensuring that there are no propellants in the second stage thrust chambers while the first stage is operating.
~-11m	**Top off of ethylene glycol solution in first stage plumbing.** At -15h, the thrust chamber tubes and manifolds in each of the five first-stage engines were filled with a solution of ethylene glycol. At this point, over the next four minutes, 50 gallons of ethylene glycol are added to ensure that the plumbing is filled with ethylene glycol. The ethylene glycol solution helps to smooth out the ignition sequence when the engines are started. (See -15h)

-10m **S-IVB engine thrust chamber chilldown.** The chilling process of third stage's engine begins, preparing it for the supercold propellants that will surge into the thrust chamber when the third stage engine is started, about 19 minutes from now (+9m 9s).

-10m **Latch fuel cell reactant valves.** The fuel cells in the Service Module provide almost all the power for the CSM throughout the mission by reacting hydrogen and oxygen to form water and generate electricity. Each fuel cell has a set of reactant valves which allow hydrogen and oxygen to flow into the fuel cell. The fuel cells can only be started by ground equipment -- once launch has occurred, if the reactant valves for a fuel cell are closed, the fuel cell becomes permanently shut down.

Each reactant valve has two solenoids, an "open" and a "close." When power is applied to the "open" solenoid, it pulls the valve open; when power is applied to the "close" solenoid, it closes the reactant valve. During most of the mission, no power is applied to either solenoid, and the valve simply stays where it is, which is "open" on a normal mission. However, whenever there is a chance of vibration -- such as during launch -- there is a concern that the vibration could accidentally jostle a reactant valve closed, permanently shutting down the associated fuel cell.

About 10 minutes before launch, the LMP places the FC REACT VLVS switch in the LATCH position. This applies constant power to the "open" solenoid for each fuel cell reactant valve, causing the "open" solenoid to hold the valve open, and preventing vibrations during launch from accidentally shutting down any of the fuel cells.

Side note: Mechanical forces actually **did** cause reactant valves to close on Apollo 13. When one of the oxygen tanks ruptured at 55 hours into the Apollo 13 mission, the force of the tank failure caused the oxygen reactant valves for fuel cells 1 and 3 to close. Nobody realized this at the time, and the controllers on the ground lost precious time pondering whether to shut down fuel cells 1 and 3, not realizing that these fuel cells were already as good as dead because of the closed reactant valves.

∼-10m **LM telemetry power down.** Testing is complete on the LM telemetry system, and the LM is powered down. It will remain in this very low-power state for the next few hours, until the spacecraft is on its way to the moon.

-8m **S-II engine thrust chamber chilldown.** The five J-2 engines in the second stage begin the chilldown process by flooding the thrust chamber in each engine with supercold gaseous helium, preparing the thrust chambers for the supercold propellants that will surge through them when the second stage engines are started, less than 11 minutes from now (+2m 43s). This cold helium is vented into the interstage, anrea between the first and second stages. To prevent equipment in this area from freezing, warm gaseous nitrogen is fed into the interstage area through swing arm #2.

-8m **Prepare to launch.** Up to this point, the Saturn V's computer -- the LVDC -- has been under the control of the ground control computer (GCC). The GCC now

	sends the “prepare-to-launch” (PTL) signal to the LVDC. The LVDC runs a self-test on itself and related equipment in the Instrument Unit, and prepares to take control of the launch vehicle.
-7m	**EDS placed in launch mode.** The Emergency Detection System (EDS) is placed in the launch mode. The EDS monitors the launch during the first two minutes of flight, and will automatically abort the mission if it detects a catastrophic problem. (See the introduction for First Stage Boost for more information on the EDS.)
-5m 45s	**Final GO/NO-GO for launch.** Launch controllers are polled one last time to ensure that there are no problems in the Saturn V or in the spacecraft.
-5m 30s	**S&A (safety & arming) devices armed.** The safety & arming devices on the propellant dispersion system on each stage are now in the armed position, making it possible for the Range Safety Officer to destroy the vehicle in an emergency.
-5m 30s	**S-IVB start tank pressurization.** The third stage’s engine contains a start tank which contains gaseous hydrogen, used to spin the engine’s turbopump turbine as the third stage engine’s starts up. (See *Appendix C - Starting the J-2 Engine* for more information.) The hydrogen in the start tank is now brought up to flight pressure, a process which will continue until -5m.
-5m	**Retract and lock CM access arm.** Swing arm #9 on the Mobile Launcher, which provides access to the CM and the crew, moves to the full retract position, 180 degrees away from the Saturn V.
-4m 37	**S-II start tank pressurization.** The second stage’s five engines each contain a start tank which contains gaseous hydrogen, used to spin the engine’s turbopump turbine as the second stage engines start up. (See *Appendix C - Starting the J-2 Engine* for more information.) The hydrogen in the start tanks is now brought up to flight pressure, a process which will continue until -3m 7s.
-4m 30s	**Terminal Countdown Sequencer (TCS) armed.** Events are moving rapidly now. In the last 3+ minutes before launch, events occur too rapidly for humans to handle manually. The last 3+ minutes of the countdown will be handled automatically by the Terminal Countdown Sequencer (TCS). The TCS issues commands at the proper time to various pieces of equipment and receives status signals that events are proceeding as planned. If events don’t take place successfully within the proper amount of time, the TCS stops the countdown. The TCS is now armed, preparing it to start the final phase of preparing for launch --the terminal countdown -- in less than a minute and a half. (See -3m 7s for information about the TCS.)
-4m 10s	**F-1 engines armed.** The five LV ENGINES lights illuminate on the CM instrument panel, indicating the five first stage F-1 engines are armed.
-3m 32s	**Verify Program 02.** The CMP verifies that P02 is running on the Command Module computer (CMC). Program 02 is known as “Gyrocompassing” and is used before launch to keep the stable platform (which contains the gyroscopes) in the proper orientation for launch.

-3m 24s

VERB 75. The spacecraft computer -- known as the Command Module Computer, or CMC -- is currently running Program 02 (P02), a prelaunch program that constantly updates navigational parameters in the computer. When the LVDC detects that liftoff has occurred, it sends a signal, known as the *liftoff discrete*, to the CMC. When the CMC sees this signal, it switches to Program 11 (P11), known as the Earth Orbit Insertion Monitor, whose job is to enable the crew to monitor the Saturn V's performance.

The CMC DSKY

If, for some reason, the LVDC fails to send the liftoff signal when liftoff occurs, the crew can enter the key sequence VERB 75, ENTR to tell the CMC that launch has occurred. However, that sequence requires pressing four keys, a difficult task at a stressful moment. Just in case this manual process should be necessary, the crew now presses VERB 75, but does not press ENTR. If the CMC does not get the liftoff signal when liftoff occurs, the crew can then just press the ENTR key to tell the CMC to immediately switch to P11.

The liftoff discrete was successfully sent by the LVDC and received by the CMC on every Saturn V launch, so pressing the ENTR key was never necessary.

TERMINAL COUNTDOWN

-3m 7s

Start automatic sequence. The final events of the countdown are handled automatically by the Terminal Countdown Sequencer (TCS), a piece of equipment located in the Mobile Launcher.

At -3m 10s, a Boeing engineer in the Launch Control Center (LCC), sitting at the S-IC Firing panel, holds down the FIRING COMMAND button. As the countdown reaches -3m 7s, the ground control computer looks to see if the FIRING COMMAND button is being depressed, and if it is, the ground control computer starts the TCS.

From this point forward, the rapid sequence of events in the final countdown happens without human intervention.

The TCS sends out a series of commands to various pieces of equipment at specific times, and receives automated confirmation as each command is completed. Various combinations of confirmations are combined to indicate that a necessary condition exists -- for example, “Propellants Pressurized”, or “S-IC (first stage) Ready for Launch” -- and if certain conditions aren’t met by certain times in the countdown, the TCS halts the countdown.

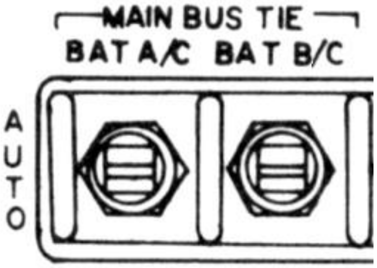
The TCS isn’t really a computer in the modern sense of the word, even though it seems to be making decision like a computer would. Its sole function is to activate various electrical relays on a rigid timetable during the final minutes of the countdown. Some of these relays send commands to various pieces of equipment, which causes the equipment to execute some task and send confirmations to the TCS. Relays in the TCS are wired in such a way that if certain confirmation signals are not present at certain times, then the TCS sends a signal to stop the countdown.

From this point in the countdown, a simple hold cannot be called -- that is, it’s impossible to pause the countdown and then resume where it left off. If the TCS finds a problem, a *cutoff* results -- the countdown is stopped. If the problem can be resolved quickly, then the countdown clock must be reset to T-22m and the countdown resumed from that point.

Throughout the Apollo program, the TCS only failed once, requiring a halt to the Apollo 17 countdown. A faulty component (a diode) in the TCS caused it to fail to command pressurization of the third stage liquid oxygen tank. A console operator saw that the tank was not being pressurized and started the process manually, but the manual process failed to energize an interlock relay, which caused the TCS to stop the countdown at T-30 seconds. Over the next couple of hours, a work-around was developed that involved a jumper (located in a panel in the Launch Control Center) bypassing the relay that wasn’t being energized. After a 2-hours 40-minute hold, the countdown was reset to T-22 minutes and proceeded to a successful launch.

-3m 7s

S-II liquid oxygen tank prepressurization. Up to this point, vent valves in all fuel and liquid oxygen tanks have prevented pressure from building in the tanks. Each of the tanks must be pressurized for flight, and the first tank to be

	pressurized is the S-II liquid oxygen tank. The vent valves on the S-II liquid oxygen tank are closed, and helium -- supplied by ground equipment -- is added to the top of the tank to bring the tank up to flight pressure. This pressure in the tank is required in order to provide what is known as “net positive suction head” (NPSH) at the turbopump inlets for engine start. This pressurization process for the S-II LOX tank continues until T-30 seconds.
-2m 47s	**S-IVB liquid oxygen tank prepressurization.** The next tank to be pressurized is the S-IVB liquid oxygen tank. The vent valves on this tank are closed, and helium from the ground supply begins to be added to the tank, reaching an internal tank pressure of 38 to 41 psi.
-2m 15s	 **Service Module radiator glycol bypass.** Launch is just a bit more than two minutes away, and the crew has a few last tasks to attend to. The equipment in the Service Module is cooled by circulating a water/glycol mixture around equipment and through a set of radiators, which wrap around the outside of the Service Module. However, during launch aerodynamic friction causes the radiators to heat up. If the water/glycol fluid continued to circulate through the radiators during launch, it would actually have the effect of heating the equipment in the Service Module instead of cooling it. The Commander (sitting in the left-hand couch) pulls the PRIMARY GLYCOL TO RADIATORS handle, which causes the water/glycol coolant to bypass the radiators. Circulation through the radiators will be restored once the spacecraft is in orbit.
-1m 37s	**Prepressurization of S-IC fuel tank, S-II liquid hydrogen tank, and S-IVB liquid hydrogen tank.** The process of pressurizing the tanks continues with the fuel tanks on each stage. The process of pressurizing the S-II liquid hydrogen tank is completed at T-30 seconds. Pressurization of the S-IVB liquid hydrogen tank with helium to a pressure of 31 - 34 psi is completed at T-8.9 seconds, and the S-IC fuel tank at T-4.1 seconds.
-1m 15s	 **Electrical bus tie.** The CSM has two main electrical power distribution systems, known as Main Bus A and Main Bus B. The LMP flips two switches that tie all three CSM batteries to both power distribution systems to ensure that all equipment in the CSM has power during launch.
-1m 12s	**Prepressurization of S-IC liquid oxygen tank.** The final propellant tank, the S-IC lox tank, begins the prepressurization process. This process will continue through the remainder of the countdown until umbilical disconnect at liftoff.
-1m	**Water deluge system start.** The water deluge system begins the process of trying to protect the launch pad from the inferno that is about to hit it in less than a minute. The process begins as the system starts dumping water at the

	rate of 15,000 gallons/minute from six nozzles on the flame deflector in the flame trench just below the Saturn V.
-1m	**Pad comm off.** Throughout the countdown, each crewmember has been connected to the mobile launcher's intercom system, so that workers on the pad can talk directly to the crew. The pad workers have long since left the area, and the intercom that would allow crewmembers to talk to pad workers is now disconnected from the audio system.
-50s	**Saturn V transfer to internal power.** The Saturn V disconnects most of its equipment from the launch pad electrical power supplies and now depends on its own batteries. However, the power to start the first stage engines still comes from ground power supplies. Each stage of the Saturn V has its own independent electrical power system and its own batteries -- the Saturn V is not so much a single rocket as it is a collection of three independent stages, under the coordination of the Instrument Unit. Nowhere is this more evident than in the design of the electrical system -- the design of each stage's electrical system is quite different, including the number and arrangement of batteries.
-45s	**Start recorder.** A tape recorder in the Command Module is placed in the record mode by the CMP. This recorder, known as the DSE (Data Storage Equipment), records spacecraft telemetry as digital code, and on a separate track records the crew's onboard conversations. Mission Control can download the tape's contents at a time that suits them. It is primarily intended to record crew conversations during those times in the mission when a good radio link cannot be maintained with Earth (such as when behind the Moon or during powered flight). The start times varied from one mission to another -- on Apollo 16 the recorder was started at about T-3m.
-41s	**GDC align.** The crew performs a "GDC align". The primary device that the CSM uses for navigation is the IMU (Inertial Measuring Unit), a platform which contains gyroscopes and accelerometers which can detect changes to the spacecraft's attitude and motion. A backup navigation system uses simpler and less-accurate sensors, known as the BMAGs (body-mounted attitude gyros). A device known as the GDC (Gyro Display Coupler) gets information from the BMAGs. When both the primary and backup systems are working -- as they are required to be in order to launch -- then the primary system will have more accurate navigation information. The Commander presses the GDC Align pushbutton, which tells the GDC to transfer the more-accurate IMU information to the GDC. The spacecraft navigation systems have nothing to do with steering the Saturn V -- the equipment in the Instrument Unit does that -- but the spacecraft's navigation system enables to the crew to check that the LVDC is steering the vehicle correctly. For the crew, there's nothing to do now but sit back and enjoy the ride. GDC align is the last action taken by the crew before launch.

~-40s	**F-1 checkout valve to ENGINE position.** The first stage engines have been using hydraulic fluid (known as RJ-1) supplied from ground equipment. Until now, used hydraulic fluid was returned to the ground through one of the umbilicals. With engine start only a half-minute away, a valve in each engine called the *checkout valve* moves into the ENGINE position, so that used hydraulic fluid is fed into the engine turbopump instead of returning it to the ground supply.
-30s	**Retract swing arm #1**. Mobile launch tower swing arm #1 -- one of several access points connecting the ground equipment to the first stage -- is retracted away from the launch vehicle and locked.
-22s	**Guidance release alert.** The terminal countdown sequencer sends a "guidance reference release (GRR) alert" to the LVDC and the ground control computer (GCC), notifying them that an event known as Guidance Reference Release will occur within a few seconds. The LVDC begins running the flight control program, and sends a signal to the ground control computer that the LVDC is running the flight software.

FIRST STAGE ENGINE START

Designation	S-IC
Manufacturer	Boeing Company
Dimensions	33 ft diameter, 138 ft long
Weight	288,650 lb. dry, 5,022,262 lb. at launch
Engines	Five F-1 engines
Thrust	1,530,000 lbf each, 7,650,000 lbf total
Burn time	2.7 minutes

It's showtime. In just seconds, the Saturn V will come to life as the terminal countdown sequencer begins the process of starting five of the most powerful engines ever built. For sheer power, no engine of any kind -- rocket engine nor any other type of engine -- at the time could touch the F-1 engine. For comparison, *each* of a Saturn V's five F-1 engines produces more thrust than all the engines on six 747 jumbo jets combined. Eventually the solid-fuel Space Shuttle Solid Rocket Booster would produce more thrust than a single F-1 engine (2.8 million lbf), as would the 4-chamber Soviet RD-170 rocket engine (1.63 million lbf), but the F-1 remains the most powerful single-chamber liquid-fuel rocket engine ever built.

-16.97s **Guidance Reference Release (GRR), Time Base 0.** Jack King (at right), the "Voice of Apollo", announces "Guidance is internal". This cryptic phrase announces that in a very real sense, the Saturn V has just become a space vehicle, even though no engines are running yet and the rocket hasn't moved an inch.

At T-16.97 seconds, the terminal countdown sequencer sends the Guidance Reference Release signal to the Saturn V's computer, the LVDC. The Saturn V's stable platform -- a piece of equipment in the IU which contains a set of three gyroscopes and three accelerometers -- is unlocked and allowed to move freely. The platform senses the rocket's movement and detects changes in the Saturn V's attitude and velocity, and begins sending updates to the LVDC. The LVDC takes the information from the gyroscopes and accelerometers, and sends signals to servo motors that keep the platform absolutely stationary in relation to the stars. The platform thus remains in a fixed orientation with respect to space as the rocket moves around it. The IU can now sense its movement through space, and can sense that it is actually moving at over 940 miles per hour, as the Earth rotates underneath it. This is the moment that the Saturn V begins navigating as a space vehicle.

On some later Apollo launches, the Public Affairs Officer announced this event with the phrase "guidance release" rather than "guidance is internal."

This event marks Time Base 0, or T0, in the LVDC, the first of nine crucial landmarks within the computer's software. All the events within the Saturn V from now until liftoff -- now 17 seconds away -- are choreographed in reference to this instant in time.

-16.2s **Swing arm #2 retract.** Swing arm #2 -- which connects the mobile launcher to the top of the first stage -- disconnects from the launch vehicle and moves into the retracted position.

This event is more significant than it might appear, because the ability to hold the countdown now disappears. For the past 8 minutes the second stage has been chilling its five J-2 engines and venting supercold helium into the S-IC/S-II interstage, the space between the first and second stages (see -8m). What has prevented this supercold gas from freezing the equipment in this area up until now is heated gasous nitrogen being fed into the interstage area through swing arm #2. With swing arm #2 now retracted and its toasty-warm gaseous nitrogen gone, the temperature in this area is going to start dropping, and the equipment at the top of the first stage can only tolerate these cold temperatures for a short time. The Saturn V now has only two options: launch 16 seconds from now, or scrub the launch for the day.

-15s **Swing arms 4 - 8 unlocked.** Of the nine swing arms that connect the launch tower to the Saturn V, four have already been retracted, but five swing arms (4 - 8) are still connected to the vehicle. A signal from the terminal countdown sequencer unlocks the remaining five swing arms. They remain connected to the launch vehicle, and will retract automatically at liftoff.

-8.9s **Ignition sequence start.** The automatic sequencer begins the process of starting the engines. For a detailed discussion of the process for starting each engine, see *Appendix B - Starting the F-1 Engine*.

The Q-ball with its cover in place.

Q-ball cover retracted. At the top of the launch escape tower is the Q-ball. During flight, the Q-ball measures the vehicle's *angle of attack* -- that is, the angle at which the rocket is travelling into the oncoming air – by measuring the pressure through eight tiny holes in the Q-ball.

At -15h 30m, a two-piece styrofoam cover was placed over the Q-ball to prevent debris from getting into the holes. The two halves of the cover are held together by a large rubber band. The ends of the rubber band are connected with a short piece of copper wire. With liftoff less than 10 seconds away, a steel cutter mechanism now cuts the copper wire, allowing the two halves to separate. A mechanism on the launch tower pulls the two pieces of the cover away from the vehicle toward a pulley attached to the Hammerhead crane, exposing the Q-ball.

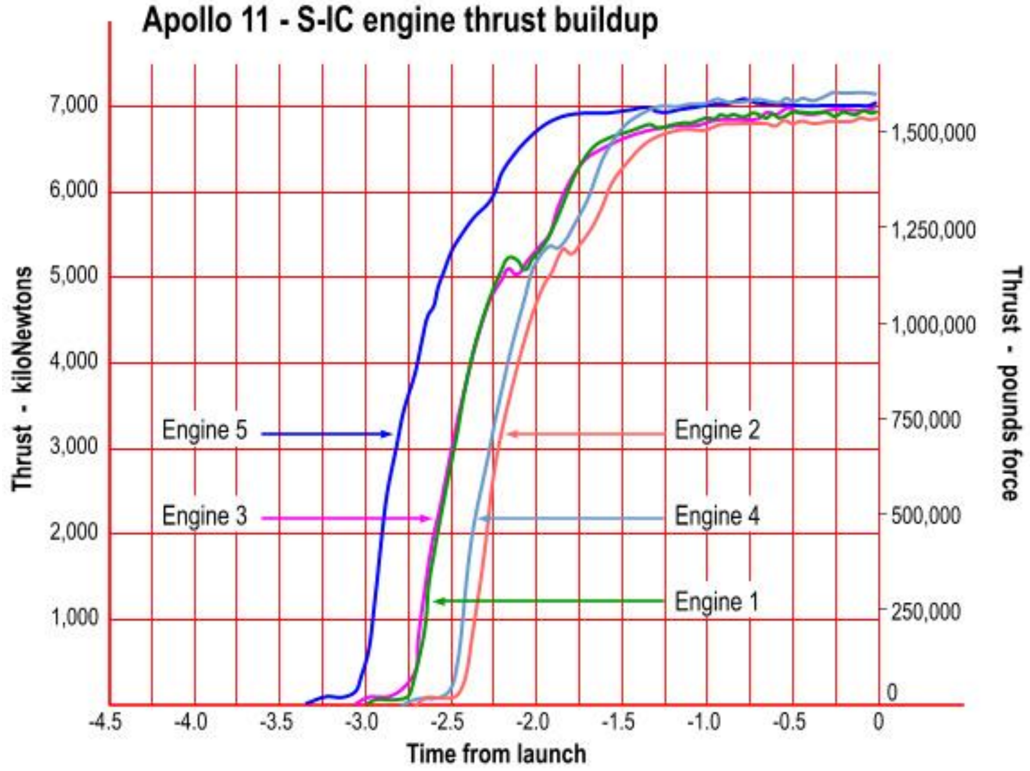
During flight, heaters in the Q-ball ensure that ice does not form in the holes in the Q-ball.

-6.4s **First engine start.** The terminal countdown sequencer begins issuing Engine Start commands for the five F-1 engines. In order to lessen the strain on the vehicle, the start commands are staggered. The start command is first sent to the center engine (#5), then to engines #1 and #3 (which are opposite each other), and finally to engine #2 and #4. On Apollo 11, these are the start times for each engine:

Engine 1	Engine 2	Engine 3	Engine 4	Engine 5
T-6.23 sec.	T-5.95 sec.	T-6.07 sec.	T-5.97 sec.	T-6.52 sec.

-1.6s

All engines running. The thrust builds in each engine.



As the thrust in each engine increases, the pressure increases inside each engine's thrust chamber, as well as in the injection manifolds which supply fuel and oxidizer to the engine. Pressure switches inside each engine's RP-1 (fuel) injection manifold are tripped when the injection pressure reaches about 1060 psi. These switches produce a "Thrust OK" signal to the LVDC, telling the LVDC that that engine is at full thrust. When all five engines are generating "Thrust OK" signals, the LVDC sends the "All Engines Running" signal to the ground control computer.

Up until this point, the engines have been fed hydraulic fluid (known as RJ-1) from the ground through an umbilical. As each engine's turbopump comes up to speed, the pressure produced by the fuel causes valves to disconnect the ground supply of hydraulic fluid. From that point on, each engine uses a small amount of fuel (RP-1) as its hydraulic fluid.

In the CM, as each engine comes up to thrust, the associated LV ENGINES light goes out, indicating that the engine has reached at least 90% of its rated thrust.

-1s

Liftoff detection active. With liftoff just a couple of seconds away, the LVDC begins watching for the signal that the IU umbilical has disconnected, signaling that liftoff has occurred. The LVDC ignores any earlier signals, because liftoff cannot possibly have occurred any earlier than this moment, so any earlier signal that the IU umbilical has disconnected would indicate a failure of some kind.

-50ms

Launch commit. As the countdown reaches T-50 milliseconds, launch commit occurs -- past this point, the launch cannot be stopped. A liftoff is going to occur.

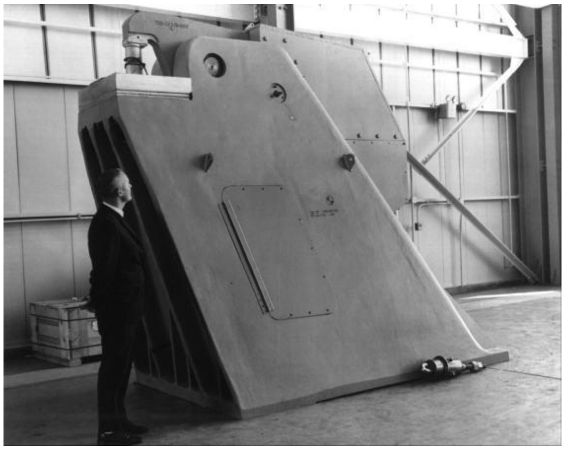
+0 **Range Zero.** The countdown has ended and the mission has officially begun. Times for everything that occurs for the rest of the mission are measured from this instant.

The five F-1 engines are voraciously thirsty. The first signal to start the first engine was sent only a little more than 6 seconds ago, and the Saturn V is still firmly rooted to the launch pad, but already the five F-1 engines have burned through over 43 tons of propellant, the equivalent of two and a half tanker trucks-full.

Water deluge system. For the last minute, the water deluge system has been dumping water on the flame deflector, the huge metal structure underneath the Saturn V's engines, which funnels exhaust out either side of the launch pad. Now the system begins dumping 7,500 gallons per minute on the launch tower swing arms, and at T+2 seconds, 29 nozzles will begin spraying water on the deck of the mobile launcher.

+0.3s **All holddown arms released** (first motion). The Saturn V rests on the launch pad on four massive holddown arms. The holddown arms have the ability to support the weight of the entire fully-fueled rocket as it sits on the launch pad, and also to hold it down with all engines running.

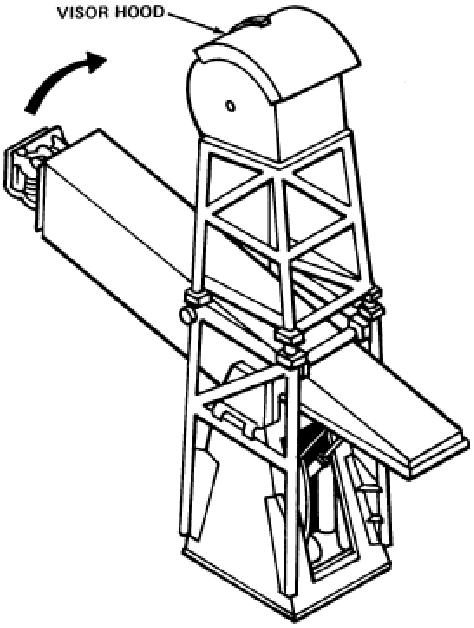
Once full thrust is confirmed, the countdown sequencer activates two pneumatic systems which release high-pressure helium into a mechanism that releases the launch vehicle.



While the hold down arms can restrain the vehicle for a few seconds before liftoff, trying to hold down the rocket from this point would be catastrophic -- no matter what, the vehicle must be released. If the mechanical mechanisms holding down the vehicle don't release it within 0.18 seconds, explosive charges release the vehicle.

In order to reduce stress on the vehicle, the rocket isn't suddenly released -- rather, controlled release mechanisms on each holddown arm restrain the vehicle as it rises through the first six inches. Each mechanism consists of a tapered pin anchored to a bracket on one of the holddown arms and a die attached to the launch vehicle. As the launch vehicle rises, the pin is drawn through the die, and the energy required to extrude the pin through the die slows the vehicle slightly. Once the pins come out of the dies, the rocket is free of the launch pad. Normally two controlled release mechanisms are used on each of the four holddown arms, but each holddown arm can support twice that number.

At the base of the rocket are three tail service mast (TSM) assemblies, which provide many of the umbilical connections between the first stage and the mobile launcher. (See *Appendix D - Mobile Launcher Connections*.) At liftoff each TSM swings rapidly out of the way and a hood encloses the end of the mast to prevent it from being destroyed by the blast of the rising rocket.



+0.3s **Final swing arm retractions**. Five of the nine swing arms are still attached to the vehicle. Once the vehicle rises 3/4 of an inch, over the next fraction of a second switches are triggered that cause the umbilicals in the swing arms to disconnect from the vehicle. This in turn triggers retraction of the swing arms, which now begin to quickly swing out of the way of the launch vehicle.

Fun fact: In the movie *Apollo 13*, the riveting liftoff scene shows the swing arms swinging out of the way one-by-one. In real life, the swing arms moved away from the launch vehicle in almost perfect unison.

+0.63s **Liftoff, IU umbilical disconnect. Time Base 1.** The umbilical connecting the Instrument Unit to the ground equipment disconnects. The LVDC senses this disconnection, and takes it as the signal that launch has occurred.

The IU umbilical disconnect starts Time Base 1 (T1) in the LVDC software, the second crucial landmark in the process of launching the Saturn V. All the events that follow during the first stage burn are choreographed in reference to this moment.

Determining that liftoff really has occurred is crucial. There is always a chance that the IU umbilical has become disconnected by some means other than liftoff, which could send a false liftoff signal to the LVDC. To prevent a false liftoff signal, the LVDC will not start T1 until at least 16 seconds after *guidance reference release* (GRR), which occurred at about T-17 seconds. If the LVDC has not received the umbilical disconnect signal within 17.5 seconds after GRR, it looks at its vertical accelerometer. If it sees an acceleration of at least 1 g, it assumes liftoff has occurred, despite not having received an umbilical disconnect signal.

The LVDC sends a signal to the Command Module Computer (CMC), telling it that liftoff has occurred. The CMC begins running Program 11 (P11), which monitors the Saturn V's progress and presents this information to the crew.

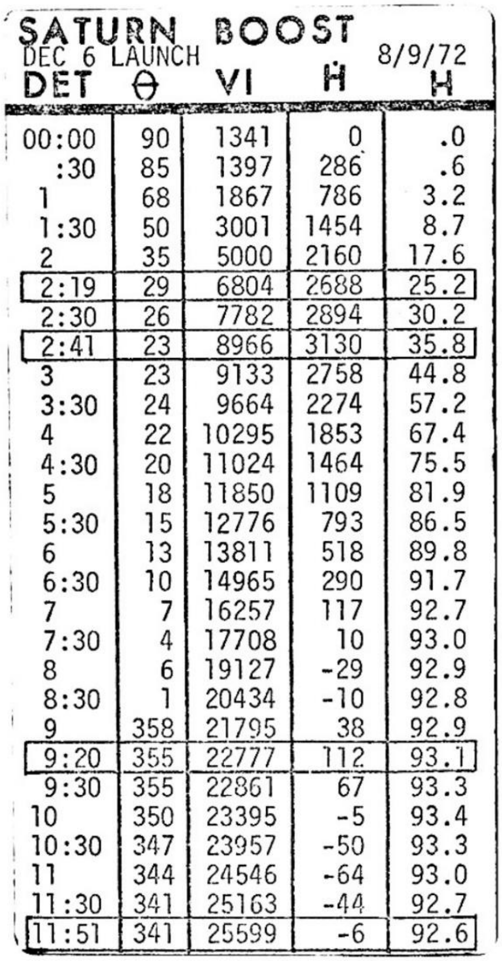
	In the Command Module, the LIFT OFF light illuminates and the mission timer starts counting, confirming to the crew that the IU umbilical has disconnected. The crew reports “The clock is running” -- a phrase that has been synonymous with liftoff since the early days of the U.S. space program.

FIRST STAGE BOOST

During ascent the Saturn V is entirely under the control of the LVDC. The primary task of the crew and Mission Control is to monitor the flight. At the same time that the LVDC is actively controlling the Saturn V, the computer in the Command Module is running its own program (known as Program 11, or P11) and displaying flight information to the crew. The crew has a set of preprinted cue cards which show predicted flight values. The crew compares the predicted values against what the computer is showing them to determine if the Saturn V is staying on its predicted course.

The cue card at the right is for Apollo 17. As an example, the third line shows that at one minute into the flight, the rocket should be traveling at an angle of 68° from horizontal, should have a velocity of 1,867 feet/second (1,276 mph or 2,049 km/hr.), should be gaining altitude at a rate of 786 feet/second (a value known as “H-dot”), and should be at an altitude of 3.2 nautical miles (a value known as “H”, which simply stands for “height”).

Interesting fact: You might expect the launch vehicle to start with a velocity of zero. However, the top line of the cue card shows the vehicle’s velocity at liftoff -- time 00:00 -- to be 1,341 feet/second (941 miles/hr., 1,471 km/hr.). This value is the rotational speed of the Earth’s surface at the Kennedy Space Center. At liftoff the Saturn V already has about 7% of the velocity it needs for orbit, thanks to the rotation of the Earth.



SATURN BOOST
DEC 6 LAUNCH 8/9/72

DET	θ	VI	$\dot{H}$	H
00:00	90	1341	0	.0
:30	85	1397	286	.6
1	68	1867	786	3.2
1:30	50	3001	1454	8.7
2	35	5000	2160	17.6
2:19	29	6804	2688	25.2
2:30	26	7782	2894	30.2
2:41	23	8966	3130	35.8
3	23	9133	2758	44.8
3:30	24	9664	2274	57.2
4	22	10295	1853	67.4
4:30	20	11024	1464	75.5
5	18	11850	1109	81.9
5:30	15	12776	793	86.5
6	13	13811	518	89.8
6:30	10	14965	290	91.7
7	7	16257	117	92.7
7:30	4	17708	10	93.0
8	6	19127	-29	92.9
8:30	1	20434	-10	92.8
9	358	21795	38	92.9
9:20	355	22777	112	93.1
9:30	355	22861	67	93.3
10	350	23395	-5	93.4
10:30	347	23957	-50	93.3
11	344	24546	-64	93.0
11:30	341	25163	-44	92.7
11:51	341	25599	-6	92.6

Abort modes. From liftoff through ascent to orbit, the flight passes through a series of abort modes. At any given time, the current abort mode determines how the spacecraft would react if a launch abort is required.

The first group of abort modes -- IA, IB, and IC -- make use of the *launch escape system* (LES), which contains a powerful rocket motor that can pull the Command Module away from the launch vehicle. An abort in one of these modes ends with the Command Module descending on parachutes and splashing down in the Atlantic Ocean.

At liftoff the active abort mode is **abort mode IA** (pronounced “one-alpha”), and is active from liftoff until T+42s. During this stage of flight, the launch vehicle is flying mostly vertically. If an abort becomes necessary, the main rocket motor of the LES pulls the spacecraft away from the launch vehicle, and a smaller pitch control motor steers the CM eastward, out of the flight path of the rocket and out over the Atlantic Ocean. Five seconds after the abort begins, the highly dangerous hypergolic propellants of the Command Module's RCS would be quickly and automatically dumped overboard. The LES and the Command Module’s apex cover are jettisoned about 14 seconds into the abort, the drogue parachutes are deployed 2 seconds later, and the main parachutes are deployed 28 seconds after the abort was initiated.

Emergency detection system (EDS). In the early stages of the flight, while the rocket is in the thickest part of the atmosphere, things can go catastrophically wrong very quickly. If the rocket's path goes even slightly astray, the aerodynamic forces on the vehicle could destroy the vehicle before humans might realize that there is a problem and react to it. For the first 2 minutes of flight, the emergency detection system (EDS) monitors the rocket's path and will immediately execute an abort if certain events occur. The EDS calls an abort if any of these failures occur:

- A structural failure occurs between the Instrument Unit (the top-most component of the Saturn V, where the computer is located) and the CSM.
- Two or more of the first stage's F-1 engines drop below 90% thrust.
- The launch vehicle pitches or yaws more than 4 degrees per second, or rolls more than 20 degrees per second.

Engine shutdown inhibit timer. At launch, a 30-second timer is started in the IU which prevents the EDS from shutting down any first stage engines under any circumstances in the first 30 seconds of flight, even if the engine appears to be failing. Loss of an engine this early in the flight could cause the rocket to fall back onto the pad. The hope is that even an engine that appears to be failing may be providing some thrust, and near the ground the vehicle cannot afford to give up any available thrust.

+1.7s	**Begin tower clearance yaw maneuver.** For the first few moments of flight, the rocket rises directly next to the launch tower. With the tower only a few feet away, a sudden gust of wind or the loss of thrust from one of the F-1 engines closest to the umbilical tower (known as the "towerside" engines) could cause the vehicle to impact the umbilical tower. Simulations showed that if the vehicle were pointed "straight up" the reaction time to get the CM away from the launch vehicle using the launch escape system was marginal at best. At T+1.7s, the vehicle yaws 1.25 degrees away from the launch tower, lessening the chance of an impact due to wind, and providing more time for an abort in the event of a towerside engine failure. The initial yaw maneuver makes the stack rotate around its center of gravity. At launch, the center of gravity is about 30 meters above the rocket's base, midway along the S-IC LOX tank. The crew is at the end of a lever arm 67 meters long. Even the 1.25° of motion adds up to 5 or 6 feet of sideways movement in the CM in just a few seconds.	
~+4s	**Tower clear.** As the rocket rises above the launch tower, the launch team at the Kennedy Space Center has done its job. Control passes from the Launch Control Center at the Kennedy Space Center to the Mission Control Center in Houston.	
+9.7s	**End yaw maneuver.** Having cleared the tower, the Saturn V yaws back to vertical.	
+11.85s	**CMC starts calculations.** The computer in the Command Module -- the CMC -- begins performing guidance calculations, enabling the crew to monitor the vehicle's path.	
+13.2s	**Begin pitch and roll maneuver.** Any rocket begins its flight vertically (straight up/down), but needs to slowly pitch over during its ascent so that it is eventually	

traveling horizontally, parallel to the Earth's surface. The direction in which the rocket pitches over determines its orbit around the Earth, and this angle, measured clockwise from north, is known as the **azimuth**.

Theoretically a rocket could pitch in any direction, but limitations in the LVDC's software required the Saturn V to have a specific pitch axis. As an analogy, consider a human being who wants to bow. Humans can comfortably bow along a pitch axis (the direction they are facing). If a person is facing west, but wants to bow to the south, the person would "roll" (change the direction he/she is facing) to south, and then bow. The Saturn V did the same thing.

Because of the way that the Saturn V sits on the launch pad, its pitch axis is oriented such that if it begins pitching after launch, it will pitch directly to the east (90°). However, each Apollo flight needed to get into a specific orbit, and that required it to pitch in a specific direction, known as the *flight azimuth*. For Apollo 11, that azimuth was 72.124°. At 13.2 seconds after launch, having cleared the launch tower, the rocket begins to roll 17.876° northward, which will allow it to pitch along the required flight azimuth. For each flight, the required azimuth was calculated ahead of time and programmed into the LVDC.

Once this roll is complete, the Saturn V begins the slow process of pitching from vertical to horizontal -- a process that takes about eight and a half minutes. The crew is in a "heads-down" attitude -- that is, their heads are oriented toward the ground, and their feet away from the Earth.

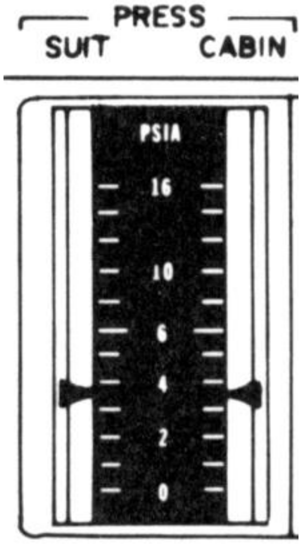
Open-loop guidance. During all of first stage boost, the LVDC is running in a mode known as "open loop" or "polynomial" guidance. (This mode is also sometimes referred to as "pre-iterative" guidance mode, or "time-tilt" guidance.) At this point in the flight, the goal is to get the launch vehicle up above the bulk of the atmosphere without allowing aerodynamic forces to overstress the vehicle's structure. Although the LVDC roll maneuver has aimed the vehicle in the proper direction, throughout open-loop guidance the LVDC doesn't worry about the vehicle getting slightly off-course -- there will be time later (during second stage boost) to get the vehicle back on the precise trajectory it needs. This mode is known as open-loop guidance because the LVDC is issuing commands based strictly on time, without any regard to where the vehicle is and how much it is straying from its desired course.

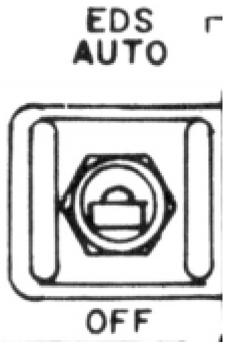
Once the roll program has been completed, the LVDC does not issue further yaw or roll commands. It runs through a preprogrammed pitch maneuver that slowly causes the vehicle to pitch over. During the 2 minutes 41 seconds of first stage boost, the LVDC will slowly pitch the rocket over from vertical (90°) to 23° from horizontal.

By the end of first stage boost, the rocket will have cleared most of the atmosphere and will be on approximately -- but not exactly -- the right course, and will have done so without overstressing the vehicle.

+20.6s **S-IC outboard engine cant.** The LVDC aims the four outboard engines slightly away from the centerline of the vehicle. It does this in case an outboard engine fails, so that the resulting off-center thrust would be nearer to acting through the center-of-mass of the vehicle.

+30s	**Engine shutdown inhibit timer expires**. A 30-second timer in the IU was started at liftoff. This timer prevented the EDS from shutting down any first stage engines under any circumstances. That timer now expires. In the event of a single engine failure, the EDS can now shut down the failing engine in an attempt to salvage the mission. Two failed engines will cause the EDS to abort the mission. **Water deluge decrease.** Back on the launch pad, the water deluge system has been trying to dissipate the enormous heat that the Saturn V left behind. The rate at which water is flooded onto the launcher deck decreases to 20,000 gallons per minute, and this rate will continue until 5 minutes after launch.
+36.5s	**Apollo 12 hit by lightning.** Apollo 12 was the only Apollo mission launched during bad weather, and the spacecraft was twice hit by lightning -- once at +36.5 seconds, and again at +52 seconds. The two lightning strikes caused the spacecraft fuel cells to be disconnected from the spacecraft busses (power distribution systems), the loss of several sensors, and loss of the CM's inertial platform, which meant that the spacecraft essentially didn't know where it was. However, the spacecraft and the Saturn V have separate navigational systems, and the Saturn V's system was unaffected. The flight into Earth orbit proceeded as planned. The crew restored fuel cell power at +2m 22s, and the spacecraft electrical system performed normally for the rest of the mission. On all other Apollo manned missions, the crew used the spacecraft's navigational system as a double-check on the Saturn V's guidance system. However, with the loss of the spacecraft's inertial platform, this was not possible on Apollo 12. Once the spacecraft was in orbit, the spacecraft's platform was realigned and the spacecraft's navigational system perform normally for the rest of the mission.
+42s	**Abort Mode IB** ("one Bravo"). The launch vehicle is now at an altitude of about 9,800 feet. Mission Control notifies the crew that the flight has entered abort mode IB. As with all mode I aborts, in the event of an abort, the launch escape system (LES) would pull the Command Module away from the launch vehicle, followed by a landing in the Atlantic Ocean. A mode IA abort required the LES's pitch control motors to steer the Command Module out over the Atlantic Ocean to ensure a water landing. However, by this point the rocket is "feet wet" (a Navy term meaning that the flight is over water), so there is no longer a need in the event of an abort to steer the Command Module over the ocean using the pitch control motors. If an abort occurs in this mode, the LES main motor would pull the CM away from the rocket and the LES canards would deploy. The canards are small aerodynamic surfaces which flip the CM into a blunt-end forward (BEF) attitude -- that is, the CM is falling backward, with the crew facing away from the direction of travel. The canards are necessary because testing indicated that the CM/LES combination is stable in a tower-first attitude, and so may not flip over on its own. A blunt-end forward attitude is necessary for safe parachute deployment. Mode IB will be in effect until the launch vehicle reaches an altitude of about 100,000 feet (30.5 km or 16.5 nautical miles).

+55s	 **Cabin pressure drop.** At about this time -- between 13,000 - 15,000 feet -- the cabin pressure indicator (shown at right) in the CM begins to show a decrease in cabin pressure. The CM's cabin pressure relief valve has been open since launch, allowing the pressure inside the spacecraft to be vented as the pressure of the outside air drops. When the falling cabin pressure reaches about 5 psi, the cabin pressure relief valve will be closed, sealing the cabin. At launch the cabin atmosphere consists of a mix of 60% oxygen with 40% nitrogen, but the spacecraft's environmental system is slowly replacing this mixture with pure oxygen. Below the Command and Service Module, the Lunar Module cabin is encountering its own pressure drop. The vent valve on the top hatch of the LM has been intentionally left open, and as the launch vehicle climbs higher, air pressure inside the LM cabin is decreasing as air is lost to the outside. However, unlike the CM, the LM's vent valve stays open throughout ascent, and within a few minutes the LM cabin will be a vacuum. The LM won't be repressurized for almost 4 hours, when its cabin will be initially pressurized with oxygen from the CM.
+1m 6.3s	**Mach 1.** The vehicle now passes the speed of sound. Altitude is about 25,500 feet, or 4.2 nautical miles.
+1m 23s	**Maximum dynamic pressure** (Max Q). During ascent so far, the increasing speed of the vehicle has caused the aerodynamic forces to steadily increase, until at this point the aerodynamic forces reach their maximum value of 735.17 lb./ft^2, a point known as *maximum dynamic pressure*, or *Max Q*. The vehicle's altitude is 7.3 nautical miles. From this point forward, although the vehicle's speed continues to increase, the rapidly thinning air results in an overall falling of the aerodynamic forces on the vehicle.
+1m 31s	**Maximum bending moment.** The rocket continues to slowly pitch over, and as a result it travels into the oncoming air at a slight angle. This oncoming air tries to bend the rocket. At about a minute and a half into flight, the rocket experiences its maximum bending moment, about 32,200,000 lbf-in. From this point forward, the rapidly-thinning air results in a decrease in bending forces on the vehicle.
+1m 57s	**Abort Mode IC** ("one Charlie"). The flight enters abort mode IC as the vehicle reaches 100,000 feet altitude (30.5 km, or 16.5 nautical miles). Mission Control notifies the crew. This abort mode will be in effect until the launch escape system is jettisoned less than a minute and half from now. In the event of an abort, the previous abort mode (IB) depended on the canards at the top of the launch escape tower to flip the Command Module around so that it was flying *blunt end forward* (BEF), the necessary position for deploying the parachutes. However, the vehicle is now flying in atmosphere too thin for the canards to have sufficient aerodynamic effect to turn the CM around. If an abort occurs in Mode IC, as soon as the launch escape rocket has pulled the Command Module away from the rocket, the tower and the boost protective cover are jettisoned, and the CM uses its RCS thrusters to turn spacecraft around so that it is flying blunt end forward.



EDS to manual. Up to this point, the launch vehicle status and trajectory have been monitored by the Emergency Detection System (EDS), which could quickly and automatically abort the mission if the vehicle experienced structural failure or its path deviated from its planned trajectory. In the dense lower atmosphere, a problem could turn into a catastrophe before humans could react. Now that the bulk of the atmosphere has been left behind, a problem is less likely to turn catastrophic so quickly, and there is more time for humans to analyze problems and react. The Commander flips the EDS switch to OFF, disabling EDS. Aborts will now occur only with the crew taking deliberate action.

Next to the Commander's left hand is a handle known as the *translation controller* (shown at the right). During most of the mission, this controller is used to manually maneuver, but during launch it has an entirely different function: manually aborting the mission. When abort mode IA, IB, or IC are active, turning the handle counterclockwise for less than 3 seconds shuts down the Saturn V's engines. Turning it counterclockwise for 3 seconds or more shuts down the engines **and** fires the launch escape system motor, pulling the CM away from the rest of the vehicle. However, recall that during the first 30 seconds of flight the engines cannot be shut down under any circumstances, as a loss of thrust so early in the flight could cause the launch vehicle to crash.

Aborting a mission is obviously not a decision to be taken lightly, and the Commander takes this action only after receiving two independent indications that a rapid malfunction is taking place. These malfunction indications are known as **abort cues**.

Fun fact: In the movie *Apollo 13*, the translation controller had the word "Abort" printed on it and an arrow indicating the direction to turn the controller to abort the mission. Those markings were strictly for the movie audience's benefit -- the real controller does not have these markings. The Commander is fully aware of what this controller does during launch, and no markings are necessary!

+2m 15.2s **S-IC center engine cutoff.** Throughout its first stage boost, the launch vehicle is accelerating at an increasing rate. Most importantly, the S-IC is becoming lighter as it burns through its propellants (at the rate of 16.5 tons per second), and since thrust remains the same while the vehicle is getting lighter, it accelerates at an ever-increasing rate. In addition, the F-1 engines become more efficient in the thinning air, increasing the S-IC's thrust by up to 20%. The result is that the g-forces on the crew have been steadily increasing since launch, and are now close to a crushing 4 g. The LVDC shuts down the center engine (engine #5) to prevent the g forces on the crew from becoming unbearable. This event is known as CECO (center engine cutoff). With the center engine shut down, the force on the crew drops to close to 3 g.

On the CM control panel, the center (#5) LV ENGINES light comes on, indicating loss of thrust in that engine. The LIFT OFF light also goes out, as another confirmation that center engine cutoff has occurred.

The launch vehicle now weighs about 2.45 million pounds. The launch vehicle has an altitude of 23.8 nautical miles, is 25.1 nautical miles from the launch site, traveling at 6,492.8 ft/second.

+2m 15.27s **Start of Time Base 2.** When the computer senses that the center engine has been successfully shut down, it marks Time Base 2, the next crucial milestone within the computer. The events of the next 25 seconds or so are choreographed from this moment.

+2m 40s **Tilt arrest.** Since +13 seconds, the LVDC has been slowly pitching the vehicle over. The Saturn V began its flight vertically (pitch angle 90°), and over the past approximately 2 minutes 40 seconds of flight has slowly pitched toward the horizontal, and is now flying at about 23°. With the complex process of staging coming up, the LVDC freezes the vehicle's pitch, an event known as *tilt arrest*. The goal is to keep the vehicle on a perfectly straight path so that as pieces of the launch vehicle are jettisoned during the staging process, the risk of a jettisoned stage impacting the launch vehicle is minimized. Tilt arrest continues until Iterative Guidance Mode (IGM) begins, about 45 seconds from now.

+2m 41.6s **S-IC outboard engine cutoff.** The LVDC shuts down the remaining four engines (#1 - #4) on the S-IC when sensors indicate that it is about to run out of either RP-1 fuel or LOX. Each tank contains four optical depletion sensors, which become uncovered as the propellant level in the tank approaches depletion. The LVDC receives a signal when any two of the four sensors in either tank are energized. When the LVDC receives the signal from either tank, it sends commands to the four outboard engines to shut down.

As the engines shut down, the LV ENGINES lights for engines 1 through 4 come on in the CM to indicate loss of thrust in those engines.

The first stage tanks are not completely dry -- by the time the engines have completely stopped producing thrust, there are still almost 40,000 pounds of LOX and 30,760 pounds of fuel that will go unused. From the time the five F-1 engines were started until the time they shut down, the engines guzzled 3.27 million pounds of LOX and 1.4 million pounds of fuel.

The vehicle now weighs 1.82 million pounds. Altitude is 35.7 nautical miles. The vehicle is 50.5 nautical miles from the launch site, traveling at 9,068.6 ft/second.

+2m 41.66s **Start of Time Base 3.** The LVDC senses that the S-IC outboard engines have successfully shut down, and starts Time Base 3. The staging events which will begin a half-second from now and all of second stage boost are choreographed in relation to this moment.

S-IC maximum inertial acceleration. Just as the engines are shutting down, the crew experiences the maximum g force that they will experience during launch (3.94 g for Apollo 11).

Throughout first stage flight, the ever-increasing acceleration has caused the entire rocket to be compressed and shortened just a little bit. As the first stage shuts down and the rocket’s acceleration drops to zero, the massive rocket releases this compression, like a tight spring being released. The crew is thrown violently against their restraining straps. On Apollo 13, Fred Haise remarked (half an hour later): “When that [the first stage] shut down, man, I thought I was going through the instrument panel. I'll tell you, that was -- I was so surprised.” Jim Lovell, who had been through a previous Saturn V launch on Apollo 8, replied, “I should have warned you.”

With the 4 g acceleration of the first stage now passed, the rest of the ascent will be considerably gentler on the crew, never exceeding 2 g.

+2m 42.1s **S-II ullage motor ignition.** On all manned Saturn V flights up through Apollo 14, four small solid rocket motors, mounted on the bottom of the second stage on a section known as the *interstage*, ignite, each with 23,000 pounds of thrust, and burn for about 4 seconds. By imparting a small acceleration to the vehicle, these rockets cause the liquid hydrogen and liquid oxygen propellants in the second stage to be pushed to the bottom of their respective tanks, ensuring that propellant can be drawn from the tanks and into the five J-2 engines.

On the very first Saturn V launch -- the unmanned Apollo 4 -- there were eight ullage motors. This turned out to be overkill, and the number of ullage motors was dropped to four for the unmanned Apollo 6 mission, and the manned Apollo 8 through 14.

Later Saturn V rockets -- beginning with Apollo 15 -- did away with the S-II ullage motors. The S-II’s propellant tanks were pressurized before launch with gaseous helium, and it turned out that this pressure was enough to force propellant to the bottom of the tanks so that the engines could be started. Once the engines were started, acceleration continued to push the propellants to the bottom of the tanks.

As the ullage motors ignite, the first stage is still connected to the second stage, but that will change in 2/10ths of a second.

+2m 42.3s **S-IC/S-II separation command and retro motors.** The LVDC sends the command to ignite the explosives that will separate the first stage from the interstage, the large metal ring attached to the bottom of the second stage. At the same time, eight retro rockets mounted in the conical fairings near the base of the S-IC ignite. Each retrorocket has a thrust of 88,600 pounds. The retrorockets firing upward on the first stage and the ullage rockets firing downward on the second stage pull the stages apart. This event is known as *first plane separation*.

On the CM’s main control panel, the five LV ENGINES lights go out, indicating staging.

The red SII SEP (S-II separation) light also illuminates, another indication to the crew that staging has occurred.

The vehicle has an altitude of about 205,000 feet (about 33.7 nautical miles).

The S-IC, now separated from the rest of the vehicle, reaches its maximum velocity of 7,882.9 ft/sec. The stage’s inertia continues to carry it upward after separation, even though its engines have shut down. The first stage will continue to travel upward for almost another minute and 45 seconds, reaching its maximum altitude at +4m 29s.

SECOND STAGE BOOST

Designation	S-II
Manufacturer	North American Aviation [see endnote 1]
Dimensions	33 ft diameter, 81.5 ft long
Weight	80,220 lb. dry, 1,060,415 lb. at launch
Engines	Five J-2 engines
Thrust	230,000 lbf each, total 1,150,000 lbf
Burn time	6.1 minutes

The S-II -- the Saturn V's second stage -- is the underappreciated workhorse of the mission. The first stage got the Saturn V off the launch pad and above most of the atmosphere, but getting into orbit isn't just about getting high above the ground -- more importantly, it's about going really fast. The S-II must accelerate the vehicle to almost orbital velocity. The second stage will burn for 6.1 minutes, almost 2.5 times longer than the first stage.

+2m 43s **S-II engine start command.** The LVDC sends the command for the S-II's five J-2 engines to start. In the CM, the five LV ENGINES lights come on, indicating the engine start command for the S-II. For details on the process of starting the five J-2 engines, see *Appendix C - Starting the J-2 Engine*.

+2m 46.1s **S-II ullage motor termination.** The second stage ullage motors have done their job, and are spent.

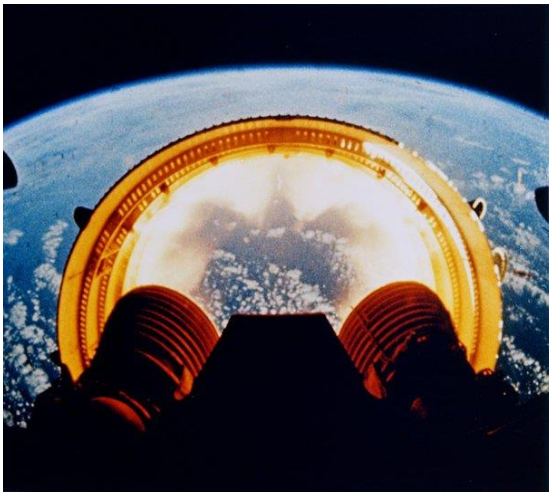
+2m 46.2s **S-II mainstage.** It takes a few seconds for each J-2 engine to come up to full thrust and stabilize. As each engine reaches at least 65% thrust, it sends a signal known as "Thrust OK" to the LVDC. In the CM, the associated LV ENGINES light for that engine goes out.

The circuitry is armed for jettisoning the interstage, the metal ring at the bottom of the second stage. This event, known as *second plane separation*, occurs in about 30 seconds.

+2m 48.5s **Activate propellant utilization (PU) system.** A valve on each J-2 engine enables the LVDC to vary the amount of LOX (liquid oxygen) fed into each engine. Changing the flow rate of LOX into the engine, while the fuel flow rate remains the same, changes the engine mixture ratio (EMR) -- that is, the ratio of LOX to fuel that gets burned in the engine.

When each engine starts, the mixture ratio is set to 5 : 1 -- five parts LOX to 1 part fuel. The PU system now increases the LOX flow, changing the mixture ratio to 5.5 : 1, a mixture ratio that yields the maximum thrust. The mixture ratio will remain at 5.5 : 1 until +8m 18s.

+3m 12.3s **S-II second plane separation (interstage).** Since tilt arrest at +2m 40s, the LVDC has been flying the vehicle perfectly straight, damping out all horizontal motion. The LVDC now sends a command to the second stage to sever the tension ties that hold the interstage to the S-II. The interstage -- also known as the *skirt* -- is a ring of metal that held the first and second stages together and on which the S-II ullage motors are mounted. The interstage now slips off, clearing the second stage engines by mere inches. This event is known as *second plane separation*.



In the Command Module, the S-II SEP light goes out, an indication to the crew that the interstage separation has occurred.

Note that getting rid of the interstage was more critical than it might seem. With the interstage in place and the second stage engines burning, the temperature around the engines rises rapidly. Failure to jettison the interstage could cause catastrophic overheating, and such a failure required the mission to be aborted. However, on the very last Saturn V launch, the unmanned flight which put the Skylab orbital workshop into Earth orbit, the interstage failed to separate, and the second stage still managed to do its job successfully.

+3m 17.9s **Launch escape system jettison.** Four seconds after jettisoning the interstage, the crew throws a set of switches that jettisons the unused Launch Escape System (LES), which includes the Boost Protective Cover (BPC). For the first time in the flight, all the windows in the spacecraft are uncovered.

Abort Mode II. With the LES gone, if an abort occurs now, the CSM as a whole would separate from the rocket and use either the RCS (if the launch vehicle is stable and not in danger of exploding) or the Service Module’s SPS engine to pull clear of the rocket, using the RCS to maintain attitude. The CM would then separate from the SM, and use its RCS thrusters to orient the CM for parachute deployment and a splashdown in the Atlantic.

+3m 24.1s **Iterative Guidance Mode (IGM) Phase 1.** Until this point, the LVDC has been in “open loop” guidance (also known as “polynomial” guidance). The LVDC has been flying the vehicle using a preprogrammed sequence of maneuvers. These maneuvers are supposed to keep the vehicle on the planned trajectory, but the computer makes no effort to make sure these maneuvers follow the exact planned trajectory. The priority until now has been to ensure that the aerodynamic forces on the vehicle

	remained within limits as it traversed the thick lower atmosphere. The vehicle was bound to get a little off-course during this early phase of flight. With the vehicle now above most of the atmosphere -- essentially in space -- and beyond any reasonable aerodynamic forces, it is time to get the vehicle back on track. The LVDC now begins repeatedly comparing the vehicles current position and velocity to the desired trajectory, and steers the vehicle toward the desired trajectory. This mode is known as Iterative Guidance Mode (IGM), or *closed loop guidance*. The IGM program within the LVDC has several phases to adjust to the changes in thrust and the loss of the vehicle's mass during ascent. The LVDC steers the launch vehicle by gimbaling the four outboard J-2 engines – that is, by altering the angle at which they point. By altering the direction of the engines, the computer alters the direction of the force applied to the launch vehicle.
+3m 42s	**Guidance converged.** Since iterative guidance mode (IGM) began about 18 seconds ago, the LVDC has been steering the vehicle toward the correct trajectory. How long it takes to get the vehicle onto the desired trajectory varies from one mission to another, and depends on how far off-course the vehicle got before IGM started. On Apollo 11, the vehicle is on its desired trajectory 18 seconds after IGM started. Mission Control tells the crew that "guidance has converged," indicating that the vehicle is now on the proper path. (On some flights the report was, "Steering has converged.")
+4m 22.6s	**S-II LOX step pressurization.** During second stage (S-II) engine burn gaseous oxygen is bled from the LOX turbopump and funneled back to the top of the LOX tank to maintain pressure in the tank. A regulator controls the pressure by limiting the amount of gaseous oxygen returned to the tank. At +4m 22s, the regulator is commanded to move to the fully open position, allowing the maximum amount of oxygen to flow into the tank. The pressure in the tank will begin to rise. When it reaches a maximum pressure of 42 psi, vent valves will dump excess gaseous oxygen overboard, maintaining the pressure at 42 psi. This maximum pressure is reached about 6 minutes after engine ignition. The increase in tank pressure helps to maintain LOX flow out of the tank, and reduces engine thrust oscillations. (See +7m 40.6s for an explanation of these oscillations, known as "pogo".)
+4m 29s	**S-IC apex.** The discarded S-IC has been carried higher and higher by inertia, and now reaches its maximum altitude of about 62 nautical miles. It begins its 4.5-minute plunge toward the Atlantic Ocean. The S-IC falls in an "engines down" orientation.
+5m 26s	**S-IVB to COI (contingency orbit insertion) capability.** Mission Control notifies the crew that they now have what is known as *S-IVB to COI capability*. For a normal lunar mission, the S-II still has 3 minutes 42 seconds left to burn at this point, but the launch vehicle is now traveling at a sufficient speed that the CSM can achieve Earth orbit if the S-II fails at this point. In order to achieve orbit, the second stage would be jettisoned, and the third stage would burn to exhaustion. The CSM would then separate from the third stage, and use its large Service Propulsion System (SPS) engine to finish the job of achieving orbital velocity. With the third stage and the LM gone, a trip to the moon is now impossible. Instead, the crew would stay in Earth orbit, performing an

	alternate and distinctly less-exciting mission. Every Apollo lunar mission had a contingency mission planned out, just in case this scenario happened. It never did.
+5m 30.6s	**Apollo 13 S-II center engine shutdown.** During second stage flight on Apollo 13 a condition known as *pogo* (see +7m 40.6s for details) caused longitudinal vehicle oscillations -- that is, the vehicle started rapidly speeding up and slowing down, up to 15 times each second. Pogo was not a new phenomenon. It was characteristic of the Saturn V second stage, and had been experienced on previous Saturn V flights, but the strength of the oscillations on Apollo 13 was unexpected. The oscillations caused the pressure in the center engine thrust chamber to rise and fall by as much as 225 psi. The pressure variations caused the engine's "Thrust OK" sensor switch (see -1.6s for a discussion of this switch) to drop out. This led the LVDC to think that the S-II center engine had failed, and the LVDC shut down the center engine 2 minutes 12 seconds early. The mission as a whole was unaffected -- the four S-II outboard engines continued to function normally, and burned a little longer to make up for the center engine's early shutdown.
+6m	**SPS gimbal motor start.** Abort modes from here on depend on firing the large engine on the Service Module -- the Service Propulsion System (SPS) engine. Four motors, known as the SPS gimbal motors, aim the SPS. The motors are attached to clutches and jack screws, enabling them to rotate the engine so that its thrust is directed precisely through the CSM's center of mass. The CDR flips four switches, which start these motors, so that the SPS engine can be properly aimed in the event it is needed during an abort. Starting each gimbal motor requires a large slug of electrical power, so the CDR waits a second or so between throwing each switch, to ensure that the CSM's power system is not overloaded. The CMP monitors the voltage on the electrical system to ensure it remains in the proper range.
+7m 40.6s	**S-II center engine cutoff.** The LVDC intentionally shuts down the S-II center engine. The S-II center engine is shut down early to avoid a type of potentially-catastrophic oscillation known as *pogo*. Pogo in a rocket causes the vehicle to surge forward and then slow down in a rapidly-repeating cycle. The effect is named after the bouncing child's toy, the "pogo stick". All rocket engines have some instability that causes their thrust to randomly increase and decrease slightly in the normal course of operation. In some rockets, a slight increase in thrust chamber pressure causes an increase in thrust, and if conditions are "right", the thrust increases and decreases in a rapidly-repeating and self-sustaining cycle. In extreme situations these oscillations can destroy the vehicle. Pogo wasn't a problem unique to the Saturn V -- most notably, the U.S. Titan rocket initially had severe problems with pogo. Engineers realized that they could lessen the chance of pogo getting started during S-II boost if they decreased the thrust toward the end of the S-II burn. Starting with

	Apollo 10, the LVDC shut down the S-II center engine about a minute and a half before the other four engines. An early shutdown of the center engine helped, but didn't prevent the problem entirely. Pogo oscillations on Apollo 13 caused the center engine to oscillate so much that the LVDC thought it had failed, and the LVDC shut down the center engine about 2.2 minutes early. (See +5m 30.6s.) Ultimately the cure for pogo in the S-II was the installation of a LOX accumulator on the four outboard engines, which absorbed the pressure waves that kept pogo going in the S-II. Note that during the first stage burn, the first stage center engine was also shut down before the other engines (see +2m 15.2s), but for an entirely different reason: to relieve g forces on the crew. The launch vehicle is now at an altitude of 97.3 nautical miles. It is 601.7 nautical miles downrange from the launch site, and traveling at 18,725.4 ft/second.
+7m 40.7s	**S-II maximum inertial acceleration.** The crew experiences the maximum g forces that they will experience during S-II boost, about 1.8 g. This force pales beside the maximum S-IC acceleration, which was almost 4 g.
+7m 41.6s	**S-II LH2 step pressurization.** For the first 5 minutes of S-II burn, gaseous hydrogen has been bled from the engines, funneled into a pressure regulator, and fed into the top of the liquid hydrogen (LH2) tank. This pressure ensures that LH2 can be drawn from the bottom of the tank. The regulator limits the amount of gaseous hydrogen fed into the tank. However, at this moment the regulator is commanded to the fully open position, enabling the maximum amount of gaseous hydrogen to flow into the tank. When the pressure exceeds 33 psi, vent valves dump enough gaseous hydrogen overboard to maintain a pressure of 33 psi. Increasing the tank pressure compensates for the falling liquid hydrogen levels.
+8m 14.8s	**IGM Phase 2 and start of artificial tau mode.** The LVDC enters Phase 2 of Iterative Guidance Mode (IGM). (See +3m 24.1s for an explanation of IGM.) It now enters what is known as *artificial tau mode*. Within the LVDC program, *tau* (the Greek letter τ) represents the amount of time required to burn all remaining propellant mass at a constant mass flow rate. The computed value of tau changes suddenly as the computer switches from one IGM phase to another. Artificial tau mode is used each time IGM switches from one phase to another, and substitutes a value of tau based on predicted performance of the vehicle. This provides a smooth transition between IGM phases and prevents the guidance software from misinterpreting a sudden change in thrust. In this case, artificial tau mode will last about 10 seconds.
+8m 17s	**Level sense arm.** The second stage's four outboard engines are intended to run until the second stage's propellant is exhausted. When that point arrives, a bit less than a

	minute from now, sensors in the tanks will send signals to the IU, causing it to shut down the second stage engines. However, there was a concern that a faulty sensor could cause a premature shutdown of the second stage long before its propellant was exhausted. Consequently, the second stage began its burn with the level-sense system disarmed. The second stage's propellant gauging system now determines that the propellant levels in the tanks are getting low enough that propellant exhaustion is not far off. It arms the level-sense cutoff system, enabling it to detect when one of the propellants is exhausted. On Apollo 11, the propellant exhaustion signal will occur at +9m 8s, or about 51 seconds from now.
+8m 18s	**S-II low engine mixture ratio shift.** The LVDC now adjusts the ratio of fuel to oxidizer in the engines, an event known as *EMR (engine mixture ratio) shift* or *PU (propellant utilization) shift*. For most of the S-II's engine burn, the ratio of LOX to fuel is 5.5 to 1 -- that is, 5.5 parts LOX by mass to 1 part fuel. This mixture ratio produces the maximum thrust for each engine. However, at this mixture ratio, the LOX tanks will run dry before the fuel tanks, leaving a large amount of fuel unused. The S-II will get more overall energy out of its engines if it completely burns all of the LOX and fuel, even if they are not burned at the ideal ratio. The LVDC now commands each engine to switch the LOX/fuel ratio to 4.34 to 1. By lowering the LOX flow at this instant, the computer ensures that the LOX and fuel tanks are exhausted at about the same time. Each of the five J-2 engines has a valve that controls the mixture ratio, known as the *PU valve* (propellant utilization valve), and the computer sends a signal to each PU valve, decreasing the flow of LOX. This reduces the thrust in each engine, but actually increases the specific impulse and the efficiency of the engine. The exact ratio at PU shift varied from one flight to another, and the strategy for computing the point at which to make the PU shift also varied. On earlier flights, the LVDC monitored fuel flow and calculated a point at which the PU shift would ensure that LOX and fuel were fully depleted at the same time. On later flights, the PU shift occurred when the launch vehicle reached a preprogrammed velocity.
+8m 24.2s	**End of artificial tau mode.** (See +8m 14.8s for an explanation of artificial tau mode.)
+8m 33s	**Chi freeze.** With S-II/S-IVB staging about a half minute away, the LVDC stops all rotation of the launch vehicle, an event known as "chi freeze", ensuring that the vehicle travels in a straight path. (This action has the same purpose as "tilt arrest" which occurred just before S-IC/S-II staging.) The guidance system stops introducing any control adjustments -- if the vehicle gets slightly off its trajectory, adjustments can be made later. The goal is to make sure that when staging occurs, the second stage has no sideways motion that might cause it to hit the S-IVB's single J-2 engine.
+9m 0s	**Abort Mode IV capability.** The spacecraft now has the ability to achieve orbit using only the Service Module's SPS engine. If the launch vehicle should fail before reaching orbit, the CSM would separate from the launch vehicle and fire its SPS engine until it achieved orbit. Such an event would mean the loss of the LM and the loss of any

ability to travel to the moon. On each Apollo flight, mission planners had designed plans for an Earth-orbit mission, known as a *contingency mission*, to be used in the event that a Mode-IV abort took place, or that the spacecraft couldn't travel to the moon for any other reason.

Altitude is 100 nautical miles; downrange distance is 883 nautical miles.

+9m 3.7s **S-IC impact.** Nearly six and a half minutes after it was jettisoned, the mammoth Saturn V first stage slams into the Atlantic Ocean. On Apollo 11, the impact site was 357.1 nautical miles from launch site, located at 30.212N, 74.038W -- see +20m 13s for a map showing the S-IC impact location for Apollo 11. For details on other flights, see *Appendix E - All the Saturn V's* for the impact location of the first stages.

+9m 8.2s **S-II outboard engine cutoff.** Each of the two S-II propellant tanks has five sensors that sense when the propellant level in that tank is exhausted. The falling propellant level in each tank uncovers these sensors. When the IU detects that at least two sensors in either tank have been uncovered, it sends commands to the engines to shut down.

The second stage engines have burned for 384 seconds, and in that time have burned through 815,500 pounds of LOX and 147,300 pounds of fuel (liquid hydrogen).

The launch vehicle now has an altitude of 101.1 nautical miles, is 873.1 nautical miles from the launch site, and is traveling at 22,690.6 ft/second.

+9m 8.24s **Start of Time Base 4, start of IGM phase 3.** Time Base 4 starts when the LVDC receives the signal from the S-II that the outboard engines have been shut down, an event known *outboard engine cutoff* (OECO). As a backup, it will also start T4 if the Thrust OK signals drop out, indicating that the S-II engines are no longer producing thrust. The events of staging between the S-II and S-IVB, and the entire S-IVB engine burn are choreographed from this moment.

+9m 8.34s **Engine shutdown signal.** The S-II engines have supposedly shut down -- it was an engine shutdown indication that caused the LVDC to start Time Base 4. However, as a safety measure, a tenth of a second after the start of T4, the LVDC issues an engine shutdown signal to the S-II engines, forcing them to shut down in the event that the LVDC has received a false indication and that any of the S-II engines are in fact still running.

+9m 8.9s **S-IVB ullage motor ignition.** On the aft skirt of the S-IVB are two solid-propellant rocket motors. These motors burn for just under four seconds, and produce 3,390 pounds of thrust each. This small amount of thrust ensures that the propellants in the third stage tanks are settled in the bottom of the tanks, in preparation for third stage engine ignition.

+9m 9s **S-II/S-IVB separation command and S-II retro motors.** The retro motors in the second stage (S-II) fire upward, pulling the second stage away from the third stage (S-IVB). At the same time, the LVDC issues the separation command, firing the explosives that allow the two stages to come apart.

THIRD STAGE BOOST

As the third stage begins its first burn, the vehicle is almost in Earth orbit. At 101 nautical miles altitude, the vehicle already has the altitude it needs for orbit, and at 22,691 ft/second, it has 89% of the speed it needs for orbit. The S-IVB's job now is to burn its single J-2 engine for 2.4 minutes to get the final 2,870 ft/sec. velocity it needs to achieve Earth orbit.

Designation	S-IVB
Manufacturer	McDonnell-Douglas Corp.
Dimensions	21.7 ft diameter, 59.3 ft long
Weight	25,050 lb. dry, 261,576 lb. at launch
Engines	1 J-2 engine
Thrust	225,000 lbf
Burn time	1st burn 2.4 min., 2nd burn 5.6 min.

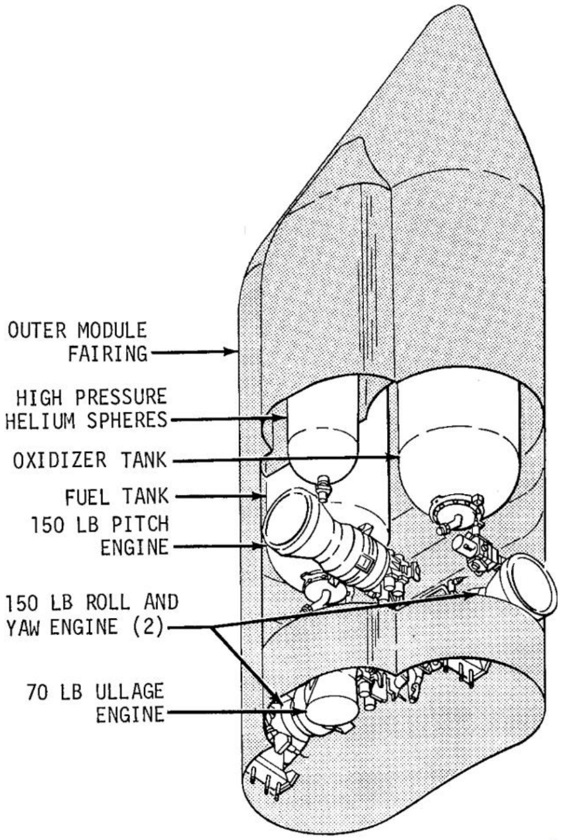
The third stage's single J-2 engine is unique among the Saturn V's main engines in that it is used twice during the mission. During ascent it is used to complete the job of placing itself and the spacecraft in Earth orbit. In a few hours it will be restarted, in a maneuver known as *translunar injection* (TLI), sending itself and the spacecraft on an intercept path toward the moon.

+9m 9.2s	**S-IVB engine start command, first burn**. The LVDC sends the engine start command (ESC) to S-IVB's single J-2 engine. For details on the process of starting the J-2 engine, see *Appendix C - Starting the J-2 Engine.* In the Command Module, the LV ENGINES light for engine 1 comes on to indicate that the start command has been sent to the S-IVB.
+9m 12.2s	**S-IVB ignition.** The S-IVB's single J-2 engine takes about three seconds to get up to full thrust. When the engine reaches 65% of its nominal thrust, the LV ENGINES light for engine #1 goes out on the Command Module's control panel.
+9m 14.7s	**S-IVB mainstage.** The S-IVB's engine reaches full thrust and stable operation. **Start tank refill**. The turbine in the S-IVB's single J-2 engine was started using gaseous hydrogen, stored in a tank known as the *start tank*. (See *Appendix C - Starting the J-2 Engine* for details.) That tank is now empty, the contents of the tank having been used to start the engine. However, in a few hours the engine will need to be restarted for its second burn, known as translunar injection (TLI). A valve in the engine now opens to allow a small amount of gaseous hydrogen to be bled from the engine fuel manifold to refill the start tank.
+9m 15.6s	**Start of artificial tau mode.** The LVDC again enters artificial tau mode, designed to smooth out the transition from one phase of flight to another by preventing the computer from making abrupt steering changes. (See +8m 14.8s for a detailed description.) Artificial tau mode in this case will last about 7 seconds.
+9m 20.34s	**S-II apex.** The discarded S-II reaches the apex of its trajectory at an altitude of 101.9 nautical miles, and begins its almost 11-minute fall toward the Atlantic Ocean. Unlike the first stage, most of the S-II's tanks and other structures will disintegrate upon reentry, but engines and other dense structures will likely survive until impact.
+9m 21s	**S-IVB ullage case jettison.** The two ullage motors are jettisoned from the bottom of the stage to save weight.
+9m 22.4s	**End of artificial tau mode.** (See +8m 14.8s for a detailed description.)

+11m 5.2s	**Begin terminal guidance.** With about 30 seconds remaining until the engine is shut down, the computer enters terminal guidance mode, also known as *chi bar steering.* Until now, the LVDC has given priority to steering the vehicle so that the vehicle winds up in the proper position. However, even more important is that the vehicle winds up with the proper velocity. Terminal guidance mode prioritizes steering the vehicle in such a way that it achieves the desired orbital velocity before engine cutoff.
+11m 31.6s	**End IGM phase 3.** The vehicle has successfully achieved orbit, and the last phase of iterative guidance mode during launch ends in the LVDC. **Begin chi freeze.** With the end of the third stage burn only seconds away, the LVDC halts any rotation of the vehicle.
+11m 39.3s	**S-IVB cutoff.** The third stage's single J-2 engine is shut down. The engine has so far burned for 147 seconds, and in that time has burned through 57,252 pounds of LOX and 11,900 pounds of fuel (liquid hydrogen). However, its work is not done -- unlike the first and second stages, which burned until their fuel was exhausted, the S-IVB's the engine will be restarted at +2h 50m 13s for its second burn, translunar injection, which will send the vehicle on its way to the moon. On the Command Module control panel, LV ENGINES light #1 comes on, indicating loss of thrust in the S-IVB's single engine. The vehicle's altitude is 103.2 nautical miles, and it is 1,422.2 nautical miles downrange. It is traveling at a velocity of 25,561 ft/sec.
+11m 39.6s	**Start of Time Base 5.** The LVDC senses that the third stage engine has in fact shut down. The LVDC sends a cutoff command to the engine, just to make sure that the J-2 really has shut down and that the LVDC hasn't just received a faulty signal.

+11m 39.8s

S-IVB APS ullage engine ignition commands. On the side of the S-IVB, near the bottom of the stage, are two clusters of small maneuvering engines, known as the *auxiliary propulsion system*, or APS. The two APS units are on opposite sides of the S-IVB. The LVDC now fires the ullage engine in both APS units for a minute and a half in order to stabilize the S-IVB and settle the propellants in the S-IVB to the bottom of the tanks.



+11m 49.3s

Parking orbit insertion. On the Command Module instrument panel, the LV ENGINES light for engine #1 (the only engine on the S-IVB) goes out, indicating engine cutoff and insertion into an Earth parking orbit. Michael Collins reports S-IVB engine cutoff, and the Command Module Computer reports that the vehicle is in a nearly circular orbit of 101.4 by 103.6 nautical miles. Telemetry from the IU reports a slightly different orbit of 102.5 by 99.7 nautical miles (189.8 by 184.6 km). Radar tracking from the ground will refine this orbit, and the actual values turned out to be 100.4 by 98.9. The vehicle is traveling at 24,243.8 ft/sec.

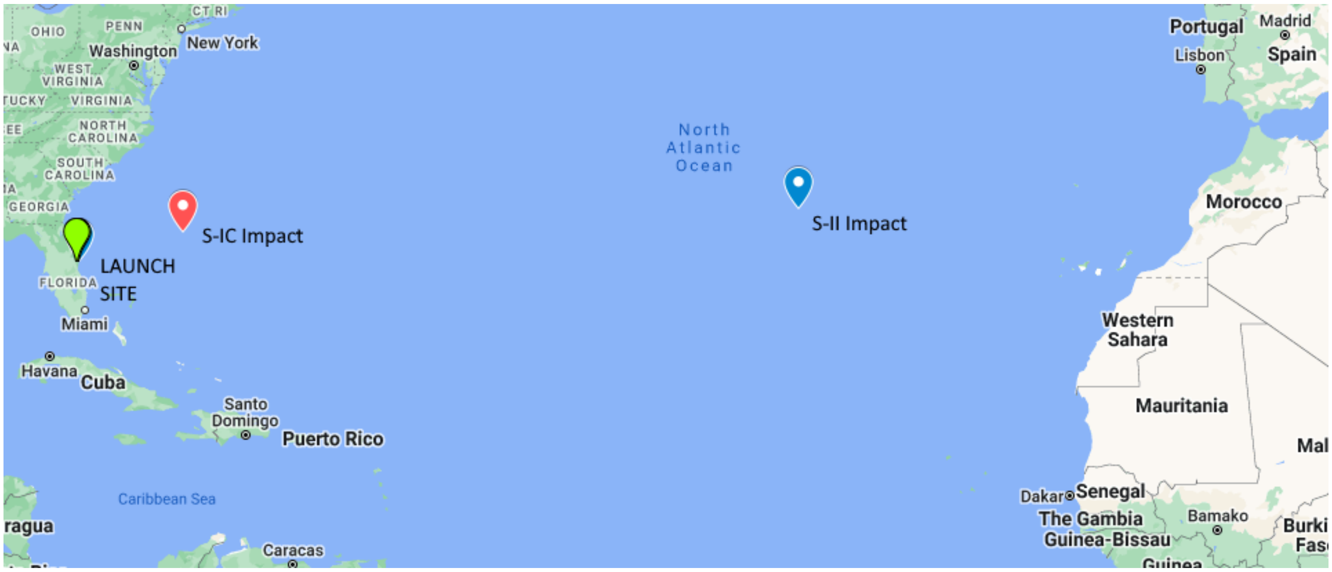
EARTH PARKING ORBIT

The S-IVB is in low Earth orbit, a roughly circular orbit at an altitude of 100 nautical miles. The Lunar Module (LM) is still enclosed in a shroud made up of 4 panels, known as the SLA, with the Command and Service Module (CSM) attached to the top. The crew spends the next orbit and a half (about 2.5 hours) checking the spacecraft and preparing for the S-IVB's second engine burn, known as *translunar injection* (TLI), which will send the vehicle on a path to intercept the moon.

Here are the approximate Earth orbital parameters for the manned Apollo lunar flights (rounded to the nearest nautical mile):

Apollo 8	Apollo 10	Apollo 11	Apollo 12	Apollo 13	Apollo 14	Apollo 15	Apollo 16	Apollo 17
100 x 100	100 x 100	100 x 99	100 x 98	100 x 99	100 x 99	92 x 90	91 x 90	90 x 90

+11m 59.3s	**Begin maneuver to local horizontal attitude.** Ten seconds after engine cutoff, the S-IVB uses its APS maneuvering thrusters to orient itself into the direction it's traveling as it orbits the Earth. While the vast bulk of the Earth's atmosphere is below it, the vehicle is in a very low Earth orbit -- on some missions, as low as 90 nautical miles -- and in such a low orbit there are still a few whisps of an atmosphere, enough to cause a tiny amount of drag. By facing into the direction of travel -- an attitude known as "sharp-end forward" -- this tiny drag is minimized. Because the vehicle is traveling in a circular path as it orbits the Earth, the direction in which the vehicle is traveling is constantly changing. The S-IVB has to use its maneuvering thrusters to adjust its pitch by about 4° per minute in order to continue facing into the direction of travel.
+12m 38.5s	**LH2 continuous vent system (CVS) on.** For the next two hours, as heat seeps into the liquid hydrogen fuel tank, some of the supercold liquid hydrogen remaining in the tank is constantly boiling off. In order to keep the pressure in the tank within limits, some of the hydrogen is vented overboard. These vents are *propulsive vents*, meaning that the vented hydrogen imparts a small thrust to the vehicle. This small continuous thrust helps keep the propellants in the vehicle settled in the bottom of the tank. This venting continues until O2/H2 burner ignition, almost 2.5 hours from now. (See +2h 35m 20.4s.)
+13m 6.5s	**S-IVB APS ullage engine cutoff.** The APS ullage engines have been firing since +11m 39.8s in order to settle propellants in the bottom of the tanks. Their job done for now, they shut off.
+20m 13.7s	**S-II impact.** The second stage, discarded over 11 minutes ago, has reentered the Earth's atmosphere and what's left of it slams into the Atlantic Ocean. For Apollo 11, the impact site was 2,371.8 nautical miles downrange at 31.535N, 34.844W. Not much beyond the engines and thrust structure may have survived reentry. The map below shows the impact locations of the first and second stages for Apollo 11.



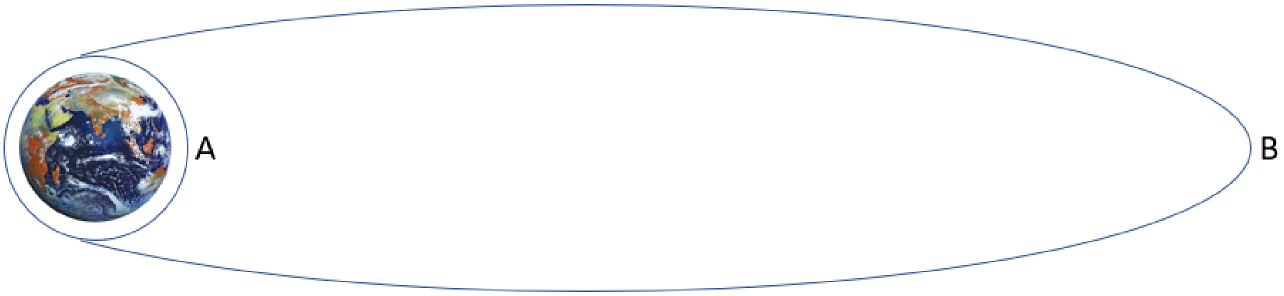
+29m 56s	**Service Module radiator to normal.** Mounted around the outside of the Service Module are two sets of radiators that provide cooling for the CSM -- one set of radiators for the environmental system (i.e., "life support") and one set for the electrical power system. During ascent to orbit, aerodynamic friction can cause these radiators to heat up, defeating the purpose of these radiators. Just before launch, the Commander pulled a handle that caused the cooling fluid to bypass the radiators. The crew now returns the cooling system to its normal operation, allowing the water/glycol coolant to circulate through the radiators.
+38m 46s	**Optics dust cover jettisoned.** In the Command Module's lower equipment bay is a sextant (more properly known as the AOT, or Alignment Optical Telescope), which enables the crew to perform star sightings. See +45m below. Important to note that the AOT is not a scientific instrument and is not used for any kind of research, nor does the crew get any kind of unique view of the stars. Stars in the AOT appear as bright pinpoints of light, just as they would on Earth. The AOT is strictly for navigation.
+45m	**Platform alignment.** The IMU (Inertial Measuring Unit) is a stable platform that enables the Command Module Computer (CMC) to keep track of the CSM's orientation in space. (See Glossary: IMU.) Over time, errors creep in to the IMU alignment. Using star sightings to refine the alignment of the IMU is an important task for the crew while in Earth orbit.  One of the crew members (Mike Collins on Apollo 11) runs program P52 on the Command Module Computer, which leads him through the process of using the AOT to align the IMU. (Photo at right: Jim Lovell using the sextant on Apollo 8.)

For the next two hours, the crew will continue to check out the spacecraft and prepare for the translunar injection (TLI) burn, which will send the spacecraft toward the moon.

TRANSLUNAR INJECTION

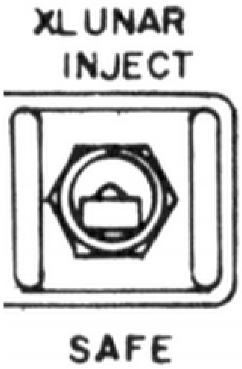
It's time to go to the moon. The S-IVB and the spacecraft attached to it have been in Earth orbit for about two and a half hours. The crew has spent that time thoroughly checking out their spacecraft. In the Instrument Unit, the LVDC has been calculating the moment when relighting the S-IVB's J-2 engine will result in a trajectory that intercepts the moon. That engine burn is referred to as *translunar injection*, or *TLI*.

A widespread misconception is that TLI results in the vehicle breaking free of Earth's gravity. Not true. Before TLI, the S-IVB and the spacecraft are in a roughly circular orbit around the Earth. TLI changes the shape of the spacecraft's orbit around the Earth, from a roughly circular orbit (orbit A below) to a highly elliptical orbit (orbit B). (Image below not even remotely to scale.)



Absent the moon, this new orbit would have the spacecraft climb to an altitude of a few hundred thousand miles over the next few days, and then fall back to a point near the Earth, climb back to a few hundred thousand miles, and repeat endlessly.

However, the new orbit is carefully oriented so that the high point (known as the *apogee*) is near the point where the moon will be in three days' time. At that point an engine burn by the CSM's large SPS engine will enable the CSM, along with the attached LM, to settle into a lunar orbit, a maneuver known as *lunar orbit insertion*, or LOI.



Like most of the Saturn V's journey to the moon, TLI happens automatically unless there is some reason for it **not** to. The simplest and most straight-forward way for the crew to prevent the trip to the moon is with the XLUNAR switch on the main CM control panel. ("XLUNAR" is meant to be an abbreviation for "translunar".)

At various times in the run-up to TLI, the LVDC checks the position of the XLUNAR switch. If the switch is in its normal position -- INJECT -- then the LVDC proceeds with the process of preparing for translunar injection. If the crew has moved the switch into the SAFE position, the LVDC halts the preparation.

Note that flipping the switch to SAFE does not immediately stop the preparation for TLI. The LVDC checks the position of the switch at various times, and will stop the process if the switch is in the SAFE position during one of those checks. Once the time to TLI is less than about a minute, the computer checks the position of the switch every couple of seconds, so the effect is almost immediate.

When the time until TLI gets down to 10 seconds, an event known as *TLI commit* occurs within the LVDC. As far as the LVDC is concerned, we're going to the moon, and the LVDC stops checking the position of the XLUNAR switch. The only way to stop TLI at this point is to use the abort handle (see +1m 57s).

On each mission, there are two opportunities for TLI. The first occurs on the second Earth orbit. If all the checks by the LVDC are acceptable and if the XLUNAR switch is still in the INJECT position, then the translunar injection burn occurs about 2 hours 45 minutes after launch. However, if the crew has moved the XLUNAR switch into the SAFE position, then translunar injections is delayed for one orbit. On the third orbit, about 90 minutes later, if the XLUNAR switch is now in the INJECT position, then the TLI burn will occur. If the switch is again in the SAFE position, then there will be no trip to the moon for this mission. (For all Apollo missions that went to the moon -- Apollo 8, and Apollo 10 - 17 -- TLI occurred during the first opportunity, during the second orbit.)

The S-II SEP Light

On the crowded control panel in the Command Module, there are numerous controls and indicators that do double duty -- they have one purpose during one phase of the mission, and some other purpose during some other phase of the mission. An example of a dual-purpose indicator is the **S-II SEP** indicator light. During launch, the S-II SEP light informs the crew about events involving first and second stage separation (see +2m 42.3s), but with the second stage long gone, the indicator light now takes on an entirely different function which has nothing to do with the second stage. Over the next 9 minutes, the light will come on and go out twice, informing the crew about crucial events surrounding TLI:

- The S-II SEP light comes on when Time Base 6 occurs in the LVDC, and the LVDC begins preparations to relight the S-IVB engine for TLI.
- The light goes out 42 seconds later to indicate ignition of the O2/H2 burner (see +2h 35m 19.8s for an explanation).
- The light again comes on about 8 minutes later, indicating that the ullage burn has started (see +2h 42m 54.5s).
- The light goes out at TLI commit, 10 seconds before the computer sends the engine start command.

+2h 34m 38.2s
(9m 30s to TLI)

Begin S-IVB restart preparations, start of Time Base 6. The TLI burn is approaching. The LVDC will relight the third stage (S-IVB) engine, sending the S-IVB and the spacecraft toward the moon.

The process of preparing the engine for the TLI burn takes exactly 9 minutes 30 seconds. The LVDC computes the time at which it wants to relight the engine, and then computes the time that is 9m 30s before that. That's the moment when the restart preparation needs to begin.

That moment -- 9m 30s before the engine start command -- is now. This moment becomes Time Base 6 (T6) in the LVDC, and the events involved in preparing the engine for restart are choreographed from this instant.

In the Command Module, the S-II SEP light comes on to indicate that S-IVB engine restart preparation has started.

+2h 35m 20s (8m 48s to TLI)	**O2/H2 burner ignition.** The O2/H2 burner takes a small amount of propellant from the third stage tanks -- liquid hydrogen and liquid oxygen -- and burns them to generate heat. The heat is used to warm supercold helium (-410°F / -245°C). The gaseous helium will be used in a few seconds to begin the process of pressurizing the propellant tanks in preparation for engine restart. The O2/H2 burner produces a small amount of thrust (less than 30 lbf), and this thrust helps settle the propellants in the third stage tanks. In the Command Module, the S-II SEP light goes off, indicating to the crew that the O2/H2 burner ignition has occurred. The O2/H2 burner will continue to operate for a little over 7 and a half minutes, until about a minute before engine restart.
+2h 35m 20.4s (8m 48s to TLI)	**LH2 continuous vent system (CVS) off.** The S-IVB's continuous vent system has been on since shortly after the vehicle reached orbit (+12m 38.5s). The system helps maintain the supercold temperature of the liquid hydrogen in the S-IVB's liquid hydrogen tank, and produces a small amount of thrust that keeps propellant settled in the bottom of the tank. However, the priority now switches from keeping the liquid hydrogen cold to pressurizing the propellant tanks, so the continuous vent system is switched off.
+2h 35m 26.3s (8m 42s to TLI)	**LH2 repressurization.** A control valve is opened that allows gaseous helium, warmed by the O2/H2 burner (see +2h 35m 20s), to be routed to the liquid hydrogen (LH2) tank, bringing the tank to the proper pressure for the TLI burn. The LH2 tank pressure will be brought to a pressure of 28 to 31 psi. **LOX repressurization.** Two-tenths of a second later, repressurization begins on the liquid oxygen (LOX) tank, also using gaseous helium that has been routed through the O2/H2 burner. The target tank pressure for the LOX tank is 38 to 41 psi.
+2h 38m 47.2s (5m 21s to TLI)	**LOX chilldown pump on.** LOX begins circulating through the LOX plumbing to condition the lines for the supercold LOX, and to remove gases that may have accumulated there. **LH2 chilldown pump on.** Five seconds later (+2h 38m 52.2s) liquid hydrogen (LH2) begins circulating through the LH2 plumbing to condition those lines.
+2h 42m 8.3s (2m 0s to TLI)	**Engine mixture ratio (EMR) set to 4.5.** The engine mixture ratio determines how much LOX is mixed with fuel in the engine's thrust chamber. In preparation for startup, the ratio is set to 4.5 (that is, 4.5 parts LOX for every 1 part hydrogen). This ratio means that there will be more fuel than can be burned with the available LOX, making the mixture fuel-rich. Although this leaves unburned fuel in the engine exhaust, it results in a gentler engine startup. The engine mixture will be changed to a more efficient ratio just seconds after engine startup.
+2h 42m 54.5s (1m 13s to TLI)	**APS ullage engine ignition command.** The APS ullage engines are ignited to settle the propellants in the hydrogen and LOX tank. The ignition commands for the two engines are staggered two-tenths of a second apart.

	In the Command Module, the S-II SEP light comes on, informing the crew that the APS ullage engines are firing.
+2h 42m 55s (1m 13s to TLI)	**O2/H2 burner off.** The O2/H2 burner (turned on at +2h 35m 20s) has been warming helium to pressurize the tanks in preparation for engine restart. The gases vented by the burner have also provided a small amount of thrust, helping to settle propellants in the tank. The tanks are now pressurized, and with the APS ullage engines now firing, the O2/H2 burner is no longer needed for propellant settling. The burner is switched off.
+2h 42m 55.8s (1m 12s to TLI)	**Ambient repressurization enabled.** Ambient pressurization uses gaseous helium from what is known as the ambient helium tank to help pressurize the tanks. This is unnecessary if the O2/H2 burner has done its job, but this process exists as a backup in case of a failure of the O2/H2 burner. The ambient repressurization system is enabled at this point, and will be started in about 22 seconds.
+2h 43m 18.2s (50s to TLI)	**Ambient repressurization started.** Gaseous helium from the ambient helium tank is fed into the liquid hydrogen and LOX tanks as necessary to ensure the proper operating pressure.
+2h 43m 58.2s (10s to TLI)	**TLI commit.** At this moment, as far as the LVDC is concerned, the decision has been made: The S-IVB and its attached spacecraft are going to the moon. In 10 seconds the LVDC will start the S-IVB's J-2 engine, beginning the TLI (translunar injection) burn. The LVDC stops looking at the XLUNAR switch, which the crew could previously have used to inhibit the TLI burn. On the CM's control panel, the S-II SEP light goes out, informing the crew that *TLI commit* has occurred and that TLI is about to happen. At this point, the only way to prevent the TLI burn is for the Commander to use the translation controller to abort the burn.
+2h 44m 7.6s (0.6s to TLI)	**LH2 and LOX chilldown pumps off.** The liquid hydrogen and LOX chilldown pumps have been circulating liquid hydrogen and LOX through their respective plumbing to prepare them for the flow of supercold propellants. With only 0.6 seconds until engine start, the LH2 chilldown pump shuts down; the LOX chilldown pump shuts down two-tenths of a second later.
+2h 44m 8.2s	**S-IVB engine restart command.** The LVDC sends the command to restart the engine. It will take about 10.5 seconds for the engine to reach full thrust.
+2h 44m 11.2s	**APS ullage engine cutoff.** With the propellants properly settled at the bottom of the tanks, the APS ullage engines are shut down. (The shutdown of the two engines is staggered, a tenth of a second apart.)
+2h 44m 15.4s	**Ambient repressurization turned off.** (See +2h 42m 55.8s for a description of the ambient repressurization system.)
+2h 44m 16.2s	**S-IVB second ignition.** In the J-2 engine, the start tank discharge valve (STDV) opens, allowing gaseous hydrogen to spin the engine's turbopump turbine. This in turn feeds propellant into the engine. (See *Appendix C - Starting the J-2 Engine*.)
+2h 44m 18.7s	**S-IVB mainstage.** The process of starting the engine is complete -- the engine is now running, and producing full thrust.

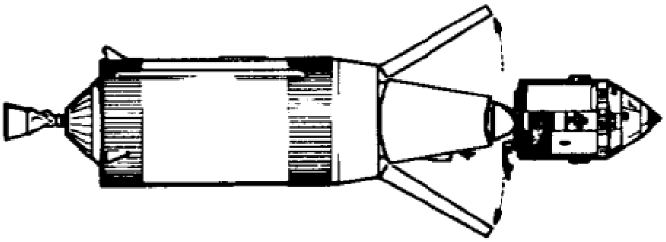
+2h 46m 14.4s	**Engine mixture ratio (EMR) shift.** The engine switches from a mixture ratio of 4.5 (that is, 4.5 parts LOX for every 1 part hydrogen) to a mixture ratio 5.0. The higher ratio of LOX decreases the amount of unburned fuel and increases the engine's thrust.
+2h 48m 48.2s	**LH2 step pressurization.** During third stage engine burn, gaseous hydrogen is bled from the engines, funneled into a pressure regulator, and feed into the top of the liquid hydrogen (LH2) tank. This pressure ensures that LH2 can be drawn from the bottom of the tank. Until now, the regulator limits the amount of gaseous hydrogen fed into the tank. However, at this moment the regulator is commanded to the fully open position, enabling the maximum amount of gaseous hydrogen to flow into the tank. If the pressure in the tank climbs too high, vent valves dump excess hydrogen overboard.
+2h 49m 34.5s	**Begin terminal guidance.** The LVDC enters terminal guidance mode. See +11m 5.2s for an explanation of terminal guidance mode.
+2h 50m 1.9s	**Begin chi freeze.** With engine shutdown less than two seconds away, the LVDC stops maneuvering the vehicle and keeps it pointing in its current direction.
+2h 50m 3.1s	**S-IVB second cutoff command.** Almost 6 minutes after it sent the command to start the S-IVB's J-2 engine, the LVDC now sends the command to shut it down. The vehicle now has an altitude of 173.3 nautical miles, and is traveling at 35,567.6 ft/sec.
+2h 50m 3.3s	**S-IVB engine cutoff interrupt. Start of Time Base 7 (T7).** When the LVDC senses that the S-IVB's engine has shut down, it marks the start of Time Base 7. Even though T7 began when the S-IVB engine shutdown was detected by the LVDC, the LVDC starts T7 by sending a shutdown command to the third stage engine, just to make sure it is really shut down.
+2h 50m 3.8s	**LH2 continuous vent on command.** The S-IVB's continuous vent system (CVS) begins venting hydrogen. (See +12m 38.5s for details of the CVS.) The venting hydrogen relieves pressure in the liquid hydrogen tank, and provides a small amount of thrust. The vent will stay open for about 15 minutes.
+2h 50m 13.1s	**Translunar injection.** The TLI burn is complete, the engine is shut down, and the vehicle is on the way to the moon. It is in a highly elliptical Earth orbit, which will intersect the moon's orbit, and put the vehicle in the same spot as the moon in about three days' time.
+2h 50m 23s	**Begin maneuver to local horizontal attitude.** The APS maneuvering thrusters rotate the vehicle so that it is oriented in the direction of travel.
+3h 5m 3.1s	**LH2 vent off command.** The liquid hydrogen vent is closed in preparation for the next important sequences of events: transposition, docking, and extraction (TD&E).

TRANSPOSITION, DOCKING, AND EXTRACTION

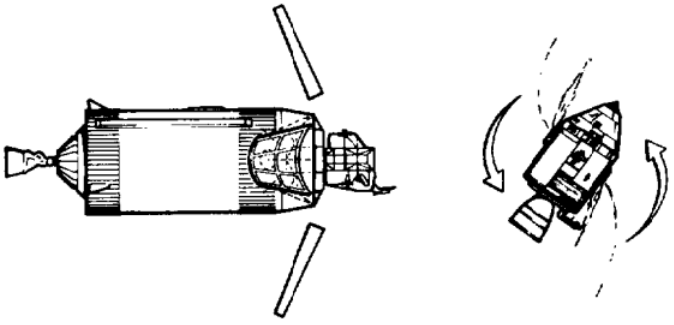
The S-IVB has done its job. The S-IVB, along with the CSM and LM, are on the way to the moon. Over the next hour-and-a-quarter, transposition, docking, and extraction (TD&E) takes place. The CSM separates from the rest of the vehicle, turns around, docks with the LM, and pulls the LM away from the S-IVB. The CSM and the LM then continue on toward the moon separately from the S-IVB. In three days' time, the CSM and LM will enter lunar orbit. Meanwhile, the S-IVB will either slingshot around the moon and enter a solar orbit (Apollo 8, 10, 11, and 12) or intentionally crash into the moon (Apollo 13 through 17).

+3h 5m 3.9s **Begin maneuver to transposition and docking attitude.** The S-IVB maneuvers to an attitude that places the sun over the shoulders of the crew, in order to avoid the CSM casting shadows on the docking mechanism on the LM. This attitude also ensures that the CSM has continuous communication with the Earth during the TD&E (transposition, docking, and extraction) process.

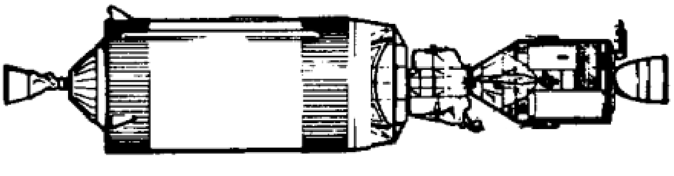
+3h 17m 0s **CSM separation.** The Command Module Pilot (CMP, Mike Collins on Apollo 11) begins applying forward thrust on the CSM's reaction control thrusters. The LM Pilot (Buzz Aldrin on Apollo 11) presses a button that fires explosive devices, which cause the four panels of the SLA (spacecraft LM adapter) to separate from the CSM and the S-IVB. The CSM is now separated from the rest of the vehicle, and begins moving away from the vehicle due to the thrusters. The LM, which is still firmly connected to the top of the S-IVB, is now exposed.



+3h 18m 0s **Transposition.** After traveling a short distance ahead of the S-IVB and its attached LM, the CSM rotates 180° so that its nose is facing the LM. After some quick checks, the CMP fires the CSM's thrusters, causing it to move very slowly toward the LM. (Note that this diagram is not to scale -- the CM retreats much farther from the S-IVB before turning around.)



+3h 24m 3.7s **CSM docking.** The docking probe on the front of the CSM fits into a device on the top of the LM known as the *drogue*. Three latches in the docking probe latch on to the drogue. At this point the two spacecraft are loosely connected, but there is not an air-tight seal between the two spacecraft. The crew engages a retraction mechanism in the docking probe, which pulls the two spacecraft solidly together. Twelve latches at the top of the CSM's docking mechanism engage with the top of the LM, a condition known as "hard dock", and the two spacecraft are solidly



connected. An air-tight seal now exists between the top portions of the two spacecraft. This passageway will eventually allow crew members to pass between the two spacecraft.

+3h 49m **LM pressurization.** The Lunar Module (LM) cabin and the short tunnel connecting the LM to the CSM are currently a vacuum. Before the crew can enter the LM, the LM cabin, and the tunnel must be pressurized.

Every hatch on both the LM and the CM has a cabin dump valve, which enables the crew to equalize pressure on both sides of the hatch. On the LM's top hatch, the cabin dump valve was intentionally left open before launch. As the Saturn V ascended during launch and the outside pressure decreased, the air in the LM cabin escaped through the dump valve. By the time the rocket reached space, the LM cabin was a vacuum.

The two spacecraft are now docked and an air-tight seal exists between the top hatches of the two spacecraft, separated by a short tunnel. The Command Module cabin is pressurized at about 4.5 psi., but the tunnel and the LM cabin are a vacuum. The CSM's forward hatch separates the air in the CSM cabin from the vacuum in the tunnel.

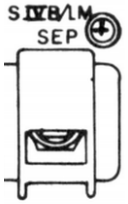
The crew now opens the dump valve in the top hatch of the Command Module, allowing oxygen in the CM cabin to escape into the tunnel connecting the two spacecraft. The open vent valve in the LM's top hatch allows this oxygen to flow from the tunnel into the LM cabin. To make up for the oxygen that is rapidly escaping the CM into the tunnel, three bottles of oxygen in the CM -- each containing a pound of oxygen -- begin dumping oxygen into the CM cabin. As oxygen continues to flow from the CM cabin into the tunnel and the LM, the crew carefully monitors the pressure in the CM to make sure that the oxygen escaping into the tunnel and the LM is balanced by the oxygen being dumped from the oxygen bottles into the CM cabin. This process continues until the CM cabin, the tunnel, and the LM cabin are all at the same pressure, about 5 psi.

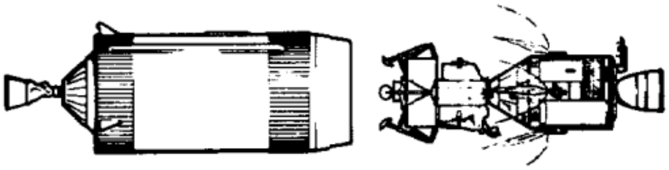
+3h 57m **Latch verification and the CM/LM umbilical.** With the pressure in both spacecraft equalized, the CM's top hatch (more properly known as the forward hatch) can be removed, giving the crew access to the tunnel.

The two spacecraft are supposed to be held together by 12 latches, which engaged as the two spacecraft docked. One of the crew members (in the case of Apollo 11, Buzz Aldrin) checks each latch to make sure that it is properly engaged. He would manually engage any latches that didn't engage automatically, but on Apollo 11 this was not necessary -- as Aldrin inspected the latches, he found that all 12 were engaged.

Now that Aldrin can reach both spacecraft, he hooks up an umbilical that connects the two spacecraft. The umbilical enables the CM to provide electrical power to the LM, preserving power in the LM's batteries. The umbilical also contains other electrical connections, which will become important in a moment.

+4h 16m 59s **Lunar Module extraction.** The crew flips a switch in the Command Module: SIVB/LM SEP. This switch sends a signal through the umbilical connecting the CM and the LM to four explosive devices, each holding one of the LM legs to the top of the Saturn V third stage (S-IVB). Firing these explosive devices releases the LM from the S-IVB. At the same time, the CSM thrusters pull the combined LM/CSM away from the S-IVB.





+4h 40m 1s **Evasive maneuver.** On Apollo 10 and 11, the CSM performed an evasive maneuver at this point, firing the SPS engine in order to put some distance between the CSM and the S-IVB. On later flights, the S-IVB APS burn, described below, served this purpose.

POST-TLI

The S-IVB has done its job: the CSM and the LM are on their way to the moon. What's left for the discarded S-IVB?

Depending on the mission, one of two fates awaits it: **lunar slingshot** or **lunar impact**.

Lunar Slingshot

On the first four manned lunar flights -- Apollo 8, 10, 11, and 12 -- the S-IVB was put into a slingshot trajectory around the moon and entered solar orbit. These four S-IVBs remain in solar orbit to this day.

The S-IVB's job over the next couple of hours is to get on the proper path to slingshot around the moon, and to vent all of the remaining hydrogen and oxygen. The J-2 engine is no longer needed, and the remaining hydrogen and oxygen are now a safety hazard for the S-IVB.

+4h 51m 7.6s	**Start of Time Base 8** (T8). Time Base 8 begins the process of putting the S-IVB on a slingshot trajectory around the moon. It is the only Time Base that doesn't happen automatically within the LVDC -- it is initiated by ground command. **Initiate maneuver to slingshot attitude**. As T8 begins, the LVDC begins maneuvering the S-IVB to the proper attitude for the slingshot maneuver burn.
+4h 51m 8s	**LH2 continuous vent system on.** The continuous vent system (CVS) begins venting liquid hydrogen. This venting imparts a small, continuous thrust to the S-IVB, and is the first step in adjusting the S-IVB's velocity so that it passes behind the moon.
+5h 3m 7.6s	**LOX dump.** The S-IVB began dumping its residual supply of liquid oxygen through the engine bell. This dump, which lasts 108 seconds, imparts a thrust to the vehicle. The helium bottles, which were crucial earlier to keeping the pressure up in the tanks, is now dumped too. With the pressure in the propellant tanks gone, the main engine is officially dead.
+5h 25m 0.6s	**H2 non-propulsive vent.** A set of non-propulsive hydrogen vents are opened on the liquid hydrogen tank to accelerate the process of getting rid of the hydrogen fuel. Non-propulsive vents are arranged in such a way that they don't produce any net thrust. The continuous vent system -- which does produce thrust -- is still active, and between the two systems, all the hydrogen in the tank will be vented.
+5h 37m 47.6s	**APS ullage engine ignition command.** The S-IVB's APS ullage engines are burned for 4 minutes 40 seconds, giving the S-IVB the velocity it needs to slingshot around the moon. (The two APS ullage engines are actually ignited a tenth of a second apart, and shut down a tenth of a second apart, so the net energy released from both engines is the same.) The APS engines have their own propellants, and do not depend on the liquid oxygen (now gone) and the liquid hydrogen (being rapidly vented) that are used by the main J-2 engine. On Apollo 12 -- the last lunar mission to use the lunar slingshot maneuver -- this maneuver also has the important purpose of putting some distance between the spacecraft and the S-IVB, ensuring that there is no risk of the combined CSM/LM and the S-IVB colliding at a later time. On Apollo 10 and 11, the CSM had already executed

	an engine burn to ensure that the CSM and S-IVB stayed away from each other (see +4h 40m 1s).
+5h 42m 48.8s	**Initiate maneuver to communications attitude.** The S-IVB maneuvers for best communication with Earth.
+75h 49m 50.4s	**Apollo 11 lunar orbit insertion.** Over 70 hours after abandoning the S-IVB, the two docked spacecraft reach their closest approach to the moon, almost 3 hours ahead of the S-IVB. At a point almost exactly on the opposite side of the moon from the Earth, the CSM's main engine (the Service Propulsion System) begins a 6-minute retrograde engine burn -- that is, a burn that slows the spacecraft -- that drops the spacecraft into an elliptical lunar orbit. Another burn at +80h 11m 36.8s circularizes the orbit. The timing was slightly different on other missions.
+78h 42m	**S-IVB closest approach to the moon.** On Apollo 11, the S-IVB makes its closest approach to the moon, 1,825 nautical miles above the lunar surface. The moon's gravity imparts additional speed to the S-IVB, sending it into a solar orbit with a 342-day period.

The Apollo 12 S-IVB was spotted by amateur astronomer Bill Yeung in 2002 and given the astronomical designation J002E3.

Lunar Impact

On the last five Apollo lunar landing missions -- Apollo 13 through 17 -- the S-IVB was intentionally crashed into the moon. Previous Apollo missions had left seismometers on the moon to measure seismic activity within the moon. By intentionally crashing objects into known locations on the moon and watching how the seismic waves traveled through the moon, scientists could uncover details about the moon's interior.

The S-IVB's job over the next few hours is to get on the proper path for lunar impact, and to vent all of the remaining hydrogen and oxygen. The J-2 engine is no longer needed, and the remaining hydrogen and oxygen are now a safety hazard for the S-IVB.

The following timeline is for **Apollo 17**.

+5h 3m 0s	**Start of Time Base 8** (T8). Time Base 8 begins the process of putting the S-IVB on a trajectory toward impact with the moon. It is the only Time Base that doesn't happen automatically within the LVDC -- it is initiated by ground command.
+5h 3m 1s	**S-IVB APS evasive maneuver.** The APS ullage engines burn for 80 seconds to make sure that the spacecraft and the S-IVB get some distance between them and do not accidentally collide.
+5h 12m 40s	**Maneuver to LOX dump attitude.** Using the APS, the S-IVB maneuvers into the proper attitude for beginning the H2 vent and the LOX dump -- see below.
+5h 19m 40s	**H2 continuous vent system opened.** The S-IVB's continuous vent system (CVS) begins venting liquid hydrogen. This venting imparts a small, continuous thrust to the S-IVB, and is the first step in adjusting the S-IVB's velocity so that it impacts the moon. The vent continues for 5 minutes, until +5h 24m 40s.

+5h 24m 20s	**LOX dump.** The liquid oxygen dump takes about 48 seconds and vents 2,564 pounds of LOX through the J-2 engine bell. The LOX escaping through the engine bell produces a thrust that changes the velocity of the vehicle by about 29 ft/sec.
+5h 29m 10s	**LOX non-propulsive vent opened and latched.** The LOX non-propulsive vent allows any remaining oxygen in the LOX tank to escape. Unlike the continuous vent system, the non-propulsive vent (NPV) is specifically designed with two vents that point in opposite directions, so that no net thrust is produced. The vent is latched open, so that all the oxygen will eventually escape.
+5h 53m 16s	**Helium dump.** Helium is used throughout the Saturn V -- and in most spacecraft, then and now -- to help pressurize propellant tanks. With the J-2 engine's job over, and the propellant being vented overboard, the helium is no longer needed. The small amount of helium onboard is vented through the LOX non-propulsive vent.
+6h 2m 15s	**Maneuver to attitude for 1st lunar impact burn.** The ground sends a command to the S-IVB to maneuver into the correct attitude for the first of two APS ullage engine burns. These burns will change the S-IVB's velocity so that it slows down, and instead of swinging around the moon, it hits the moon.
+6h 10m 0s	**First lunar impact burn.** The ground sends a command to ignite the APS ullage engines for 98 seconds. This burn attempts to change the S-IVB's velocity not only so that it hits the moon, but so that it hits a particular spot on the moon. This burn also has the important purpose of putting some additional distance between the spacecraft and the S-IVB, ensuring that there is no risk of the CSM/LM and the S-IVB colliding at a later time.
+6h 17m 44s	**Maneuver to S-IVB solar heating attitude.** With the first APS burn complete, the S-IVB executes a maneuver to minimize sunlight falling on the Instrument Unit. Before the burn, the IU's cooling system was temporarily turned off, because water venting from the cooling system made it hard to determine the S-IVB's trajectory after the burn.
+6h 40m 0s	**LOX pressure zero.** With most of the LOX having been dumped from the tank (+5h 24m 20s) and the rest vented, the pressure in the LOX tank is now effectively zero.
+6h 56m 40s	**H2 pressure zero.** The venting of hydrogen through the continuous vent system finally does the job -- the pressure reading in the liquid hydrogen tank is zero. It's estimated that 2,224 pounds of liquid hydrogen and 610 pounds of gaseous hydrogen were vented overboard on Apollo 17.
+11h 2m 40s	**Maneuver to attitude for 2nd lunar impact burn.** After the first APS impact burn and all the venting are complete, Mission Control uses ground tracking to determine the S-IVB's trajectory. The second lunar impact burn gives them one last opportunity to refine the S-IVB's trajectory, getting it closer to the desired target on the moon. The ground sends a command to the S-IVB to maneuver into the correct attitude for the second APS ullage engine burn.
+11h 15m 0s	**Second lunar impact burn.** The ground sends a command to ignite the APS ullage engines for a 102-second burn to refine the impact target on the moon.

+11h 31m 50s **S-IVB passive thermal control maneuver.** The APS maneuvering engines fire to place the S-IVB in a 3-axis tumble. This tumble spreads the sunlight evenly across the entire vehicle, preventing overheating in any particular area. The S-IVB now spins at a leisurely 5.2 revolutions per hour along each of its three axes.

Such maneuvers, known as PTC (passive thermal control) maneuvers, have been common throughout the history of spaceflight. During the 3-day flight to the moon the docked CSM/LM combination uses a similar but much simpler type of PTC maneuver: the spacecraft is slowly rolled around its longitudinal axis, over time exposing all sides of the spacecraft to the sun. This gentle roll of the spacecraft is nicknamed a "barbeque roll". On the 3-day flight back from the moon, the CSM does the same barbeque roll.

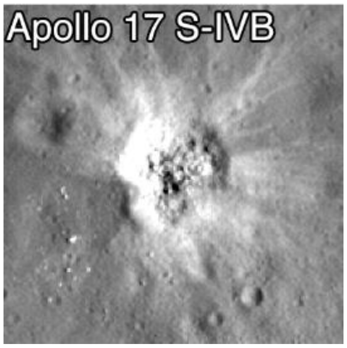
+11h 31m 59s **Flight control computer power off.** The S-IVB is now headed toward its target on the moon, and in a tumbling motion that it will maintain until impact. Any further maneuvering would be undesired. To ensure that the flight control computer does not mistakenly attempt to alter the S-IVB's condition, the ground now sends two commands to permanently shut down the flight control computer. The two shutdown commands are transmitted about 11 seconds apart.

+13h 47m 0s **Telemetry shut down.** The S-IVB is on the proper trajectory to meet its end (for the good of science!). Most of its propellants are gone, and the computer no longer has control over its trajectory or attitude. The LVDC's flight program now shuts off the telemetry subcarrier oscillator, ending telemetry from the S-IVB.

There is now nothing for the S-IVB to do except coast for the next 72+ hours toward a very abrupt meeting with the moon.

+86h 14m 23s **Apollo 17 lunar orbit insertion.** Almost 82 hours after discarding the S-IVB, the Apollo 17 spacecraft – the combined CSM and Lunar Module -- reaches its closest approach to the moon, about 45 minutes ahead of the S-IVB. At a point almost exactly on the opposite side of the moon from the Earth, the CSM's main engine (the Service Propulsion System) begins a 6-and-a-half-minute engine burn to drop the spacecraft into an elliptical lunar orbit.

+86h 59m 42s **S-IVB impact on the lunar surface. T**he S-IVB slams into the moon, blasting a small crater in the lunar surface. At impact the S-IVB weighs almost 15 tons (13,000 kg) and is traveling at 8,346 ft/sec (5,690 mph, 9,158 km/hr.). It hits the lunar surface at an angle of about 35° from vertical, and blasts a crater about 135 feet across.



On Apollo 17 the location of the impact is 4° 12' S. latitude, 12° 8' W. longitude. This location was about 155 km (84 nautical miles) from the target. On Apollo 17, the goal was to hit the moon within 350 km of the target, so the impact location easily met that goal.

The photo above shows the S-IVB impact crater. This photo was taken in 2010 by the Lunar Reconnaissance Orbiter.

Of the thirteen Saturn V launches, we mentioned that the S-IVBs for Apollo 8, 10, 11, and 12 did a slingshot around the moon, and that Apollo 13 through 17 impacted the moon. That's nine out of the thirteen Saturn V launches. What happened to the S-IVBs for the other four launches?

- The S-IVB for the unmanned Apollo 4 was placed in an orbit that intersected the Earth, and it wound up in the Pacific Ocean.

- The S-IVB for the unmanned Apollo 6 failed to restart, leaving the S-IVB in a low Earth orbit. The orbit eventually decayed and the S-IVB was destroyed on reentry into the Earth's atmosphere.

- The manned Apollo 9 mission was an Earth-orbital mission, and included the first manned flight of the LM. After the spacecraft separated from the S-IVB, the S-IVB's J-2 engine was burned to exhaustion, placing the S-IVB in a solar orbit. It is the only S-IVB that got into a solar orbit without doing a slingshot around the moon.

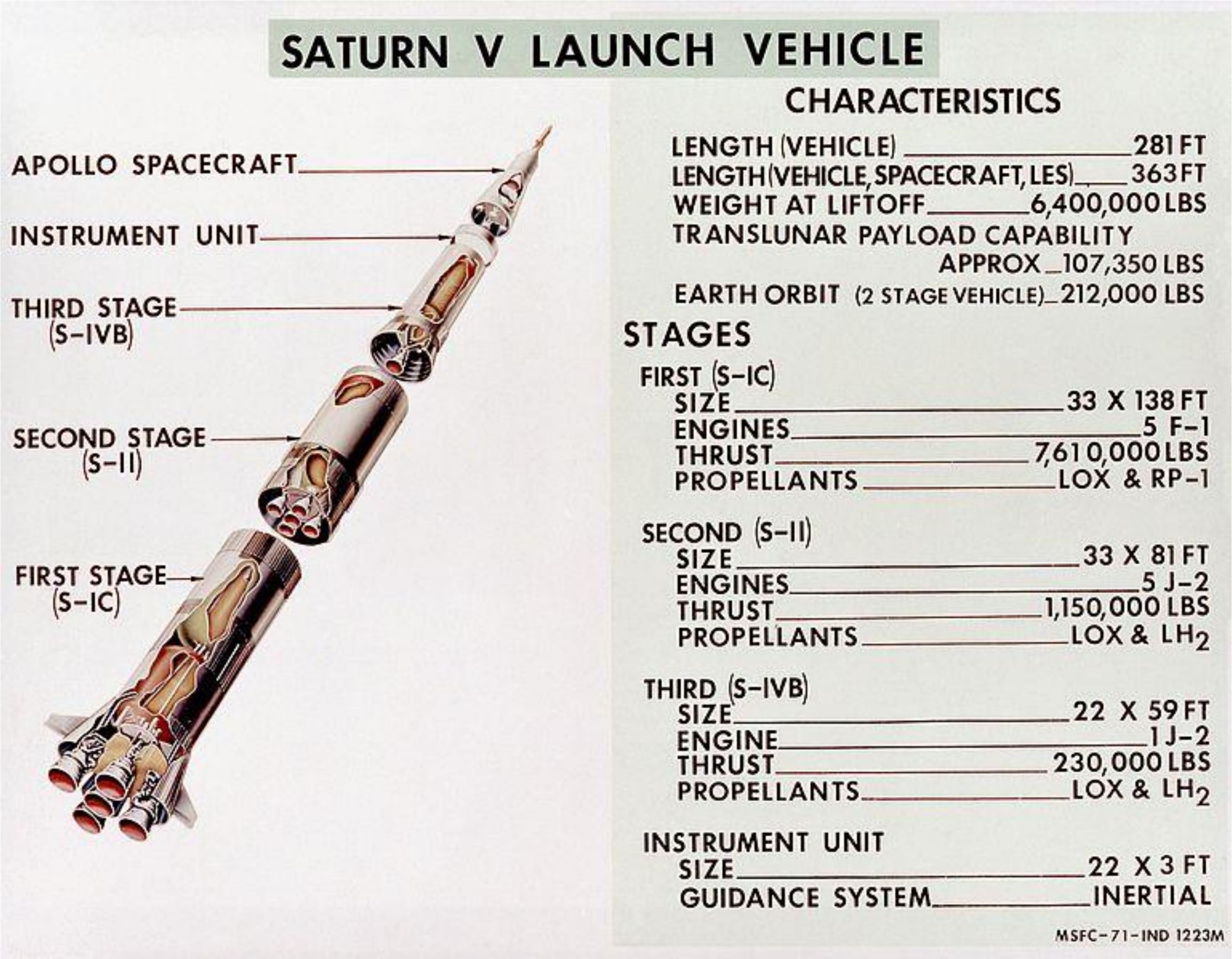
- The Saturn V that launched Skylab (the U.S.'s first orbital space station) did not have a third stage. This unmanned flight had the Skylab workshop -- which was actually a modified S-IVB -- where the S-IVB and the spacecraft had been on every other Saturn V launch.

For information about all the stages of all the Saturn V's, see *Appendix E - All the Saturn V's*.

APPENDIX A - FIGURES

This appendix includes some useful diagrams, which are referenced in the timeline.

Saturn V Basic Information



CHARACTERISTICS

LENGTH (VEHICLE)	281 FT
LENGTH (VEHICLE, SPACECRAFT, LES)	363 FT
WEIGHT AT LIFTOFF	6,400,000 LBS
TRANSLUNAR PAYLOAD CAPABILITY APPROX	107,350 LBS
EARTH ORBIT (2 STAGE VEHICLE)	212,000 LBS

STAGES

FIRST (S-IC)	
SIZE	33 X 138 FT
ENGINES	5 F-1
THRUST	7,610,000 LBS
PROPELLANTS	LOX & RP-1
SECOND (S-II)	
SIZE	33 X 81 FT
ENGINES	5 J-2
THRUST	1,150,000 LBS
PROPELLANTS	LOX & LH_2
THIRD (S-IVB)	
SIZE	22 X 59 FT
ENGINE	1 J-2
THRUST	230,000 LBS
PROPELLANTS	LOX & LH_2
INSTRUMENT UNIT	
SIZE	22 X 3 FT
GUIDANCE SYSTEM	INERTIAL

Figure 1 - Saturn V Launch Vehicle

Apollo CSM, Lunar Module, and Launch Escape Tower

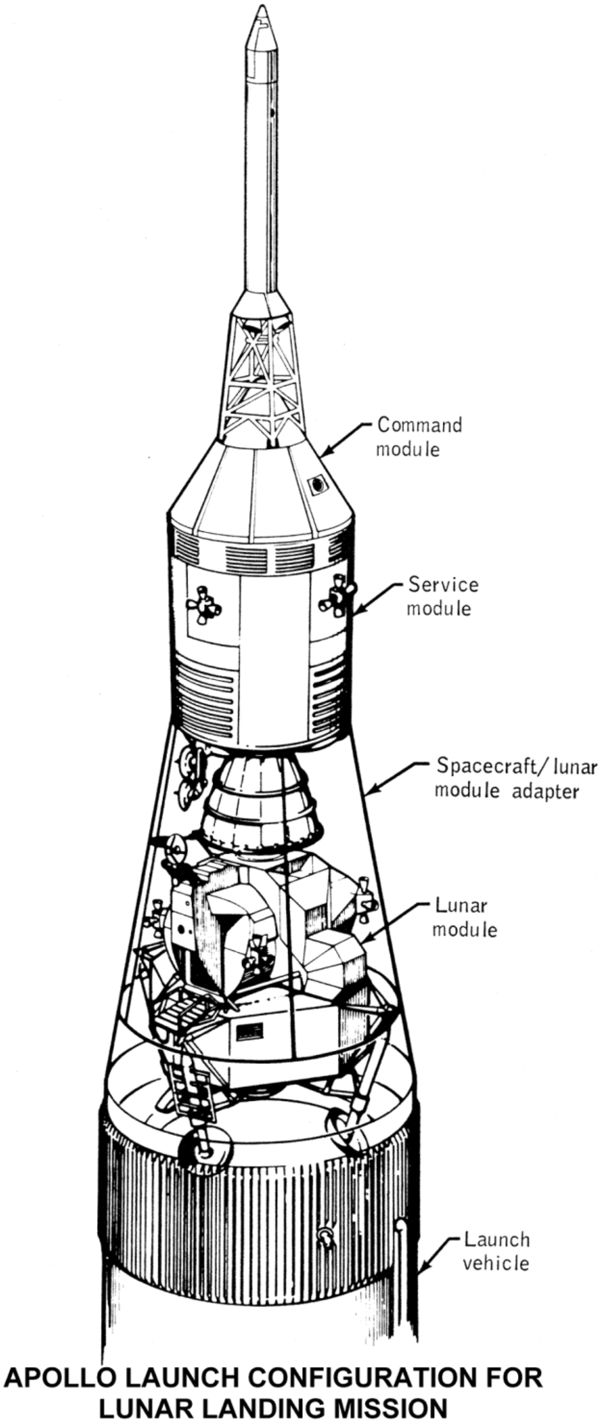


Figure 2 - Apollo CSM, Lunar Module, and Launch Escape Tower

Launch Escape System

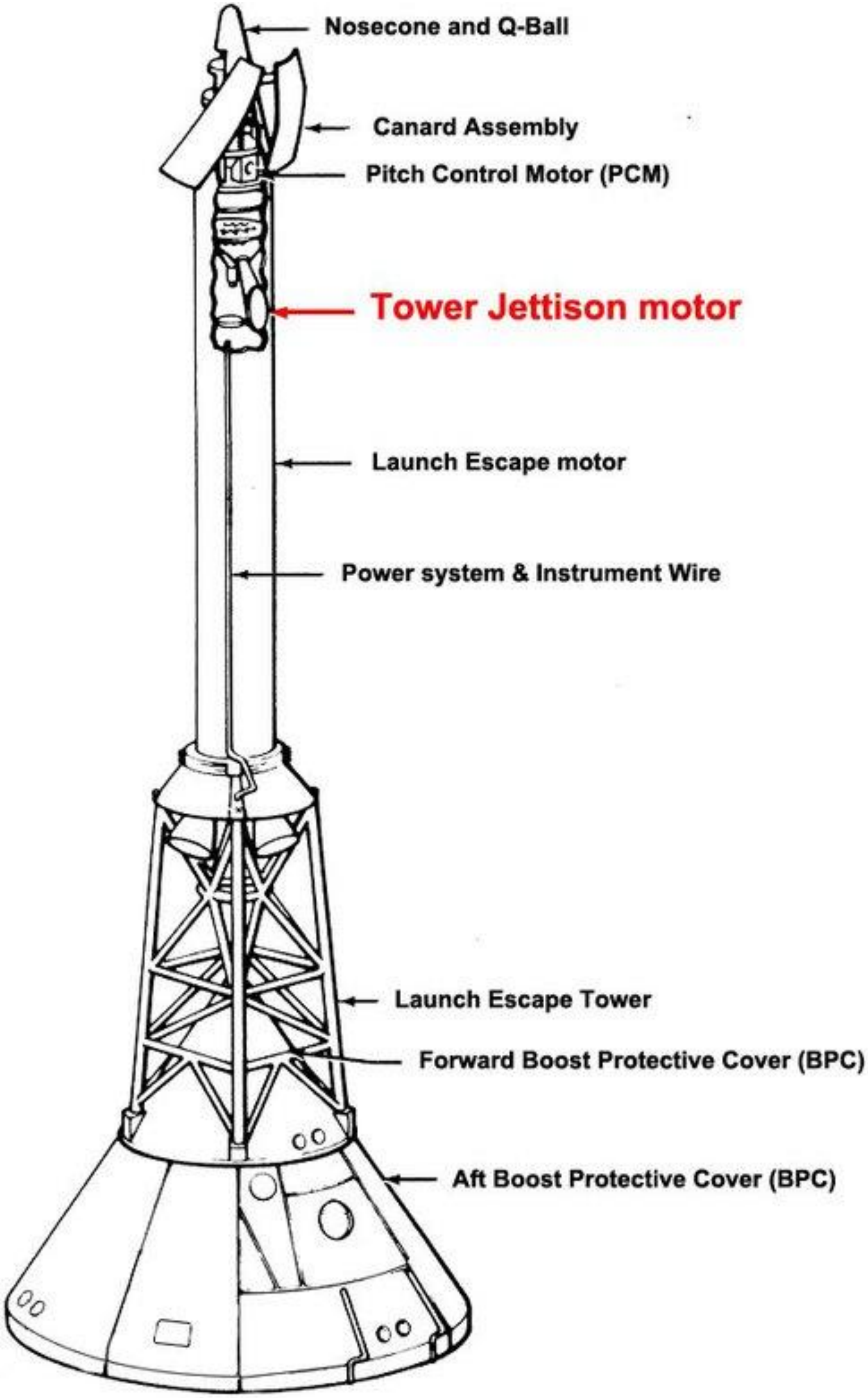


Figure 3 - Launch Escape System (LES)

Lunar Module

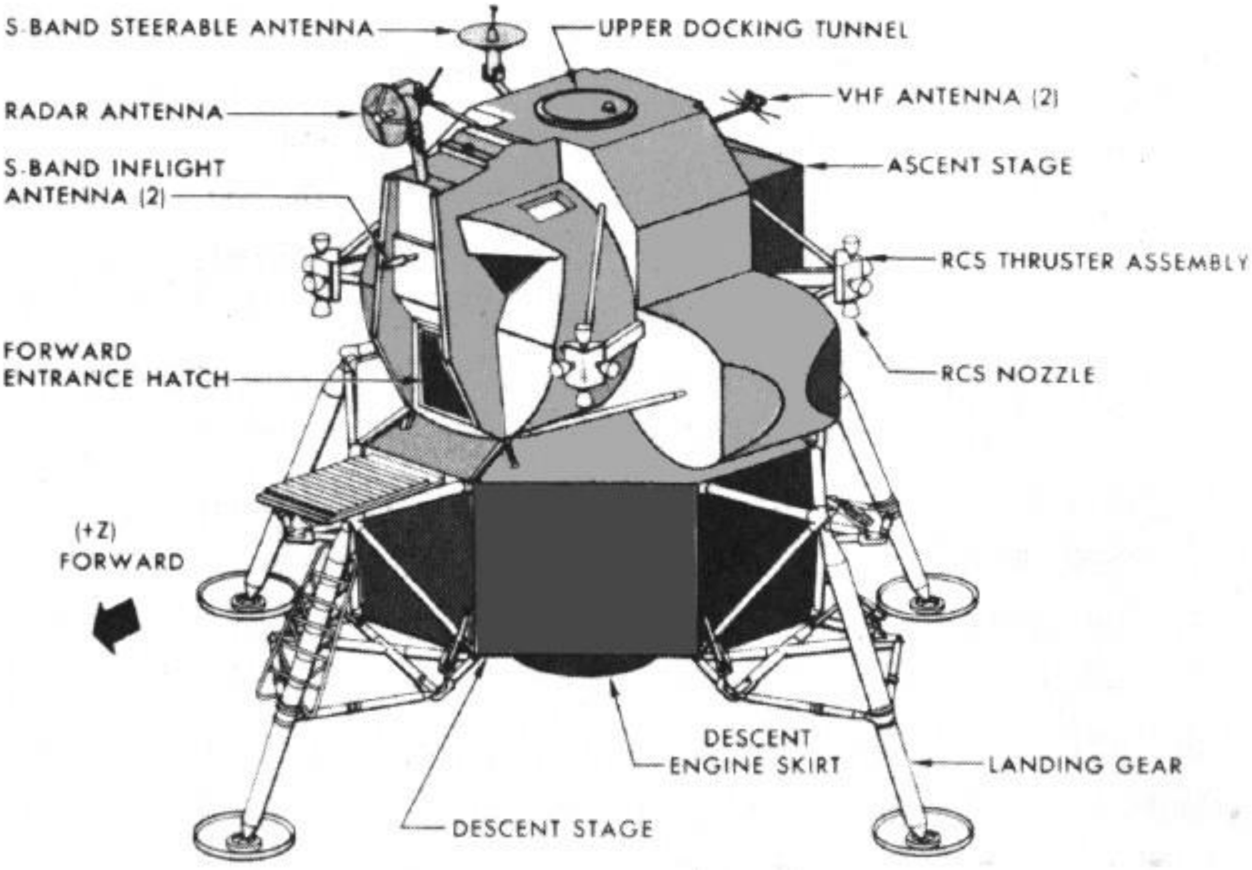
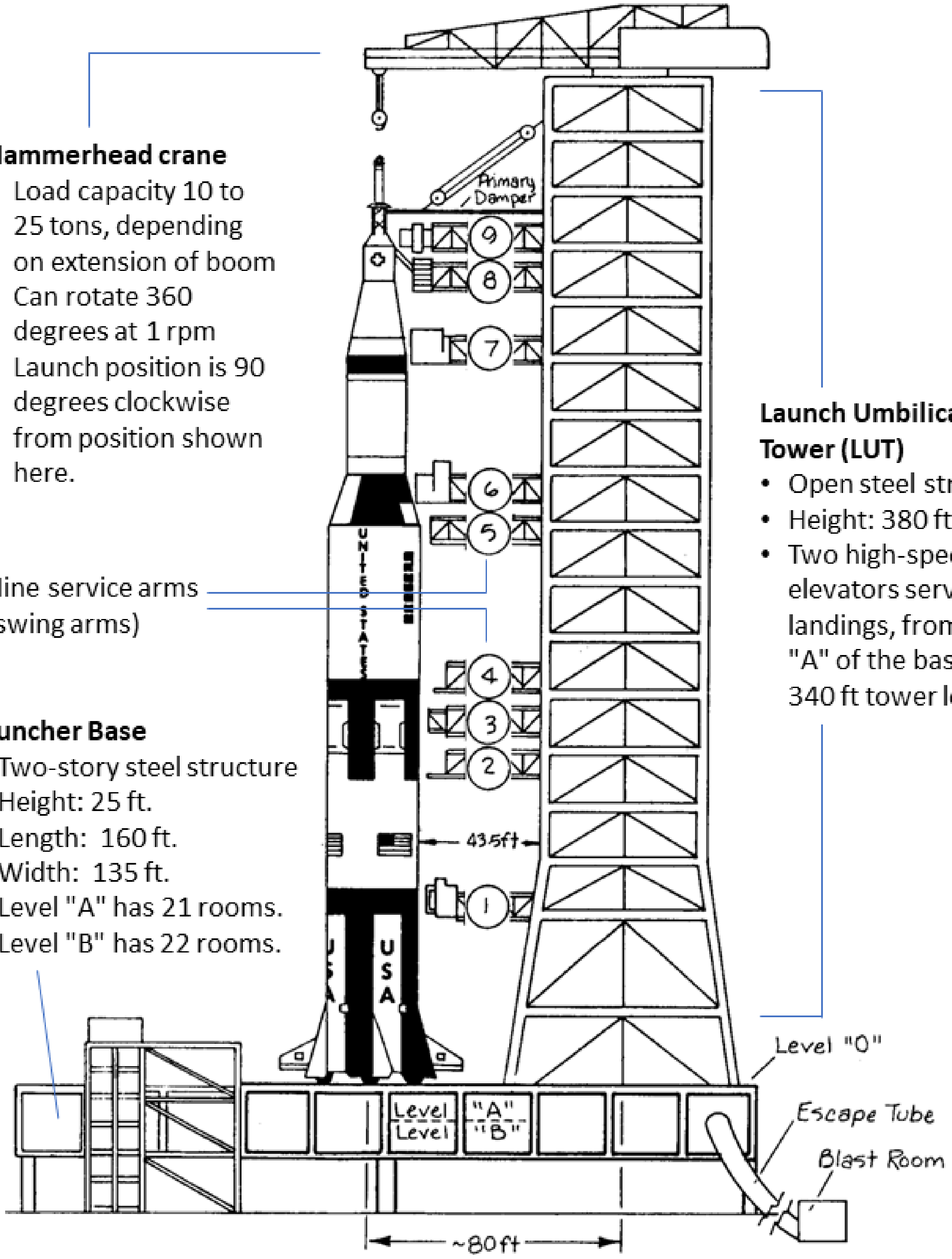


Figure 4 - Lunar Module

Mobile Launcher



Hammerhead crane

- Load capacity 10 to 25 tons, depending on extension of boom
- Can rotate 360 degrees at 1 rpm
- Launch position is 90 degrees clockwise from position shown here.

Nine service arms (swing arms)

Launcher Base

- Two-story steel structure
- Height: 25 ft.
- Length: 160 ft.
- Width: 135 ft.
- Level "A" has 21 rooms.
- Level "B" has 22 rooms.

Launch Umbilical Tower (LUT)

- Open steel structure
- Height: 380 ft.
- Two high-speed elevators service 18 landings, from level "A" of the base to the 340 ft tower level

Figure 5 - Mobile Launcher

See *Appendix D - Mobile Launcher Connections* for more information about the service arms.

Launch Complex 39

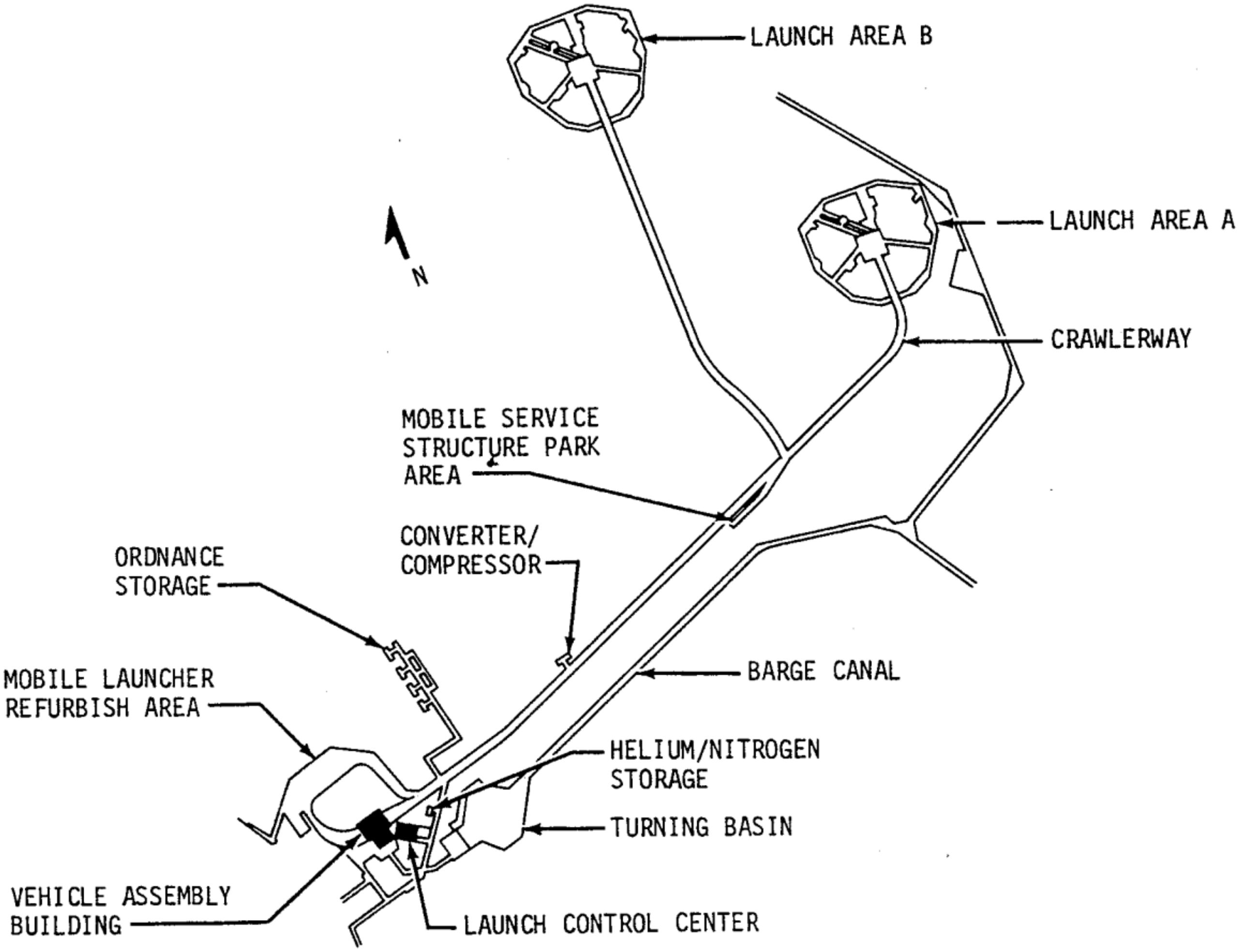


Figure 6 - Launch Complex 39

APPENDIX B - STARTING THE F-1 ENGINE

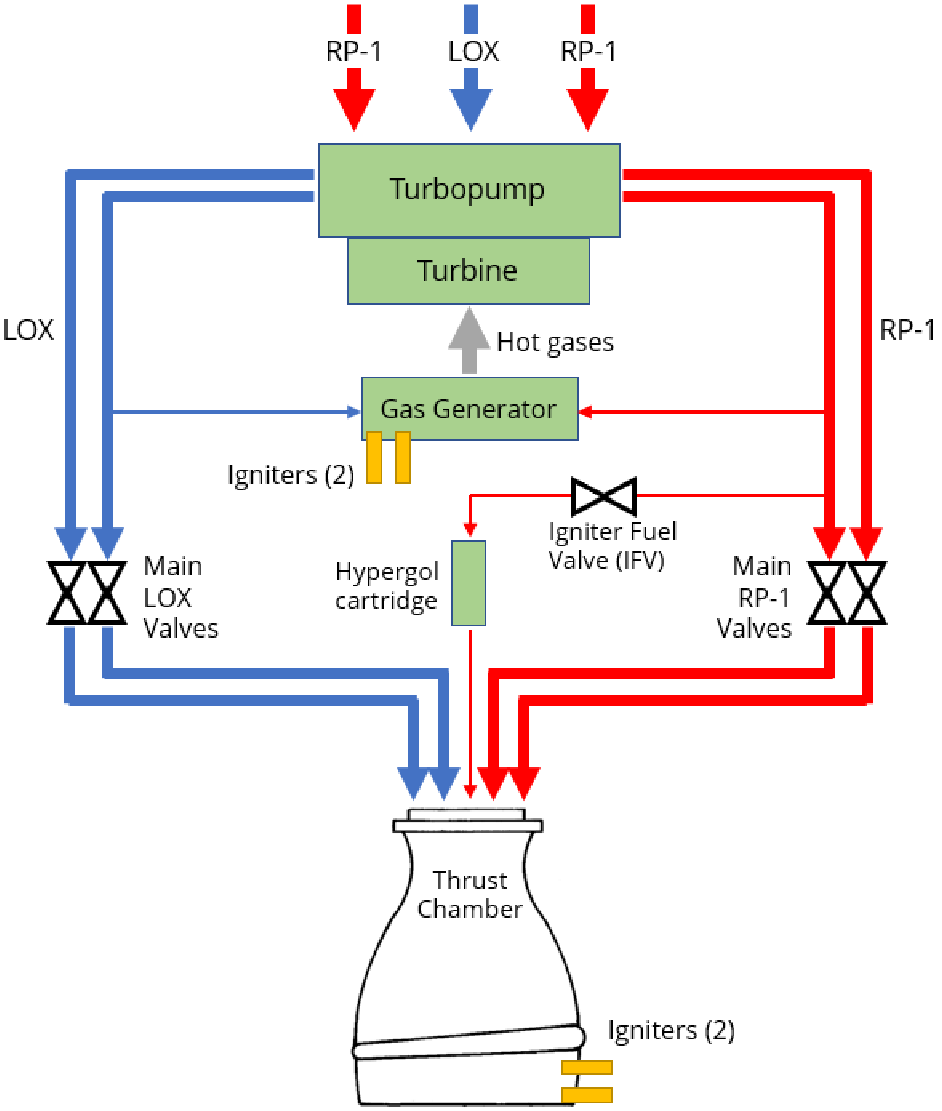
The Saturn V first stage (S-IC) was powered by five Rocketdyne F-1 engines.

Each engine contained a high-speed turbopump, which pumped fuel (RP-1) and oxidizer (liquid oxygen, or LOX) into the engine's thrust chamber (also known as a combustion chamber). The fuel and oxidizer are burned in the thrust chamber, producing the thrust that propels the rocket. The turbopump could deliver 15,471 gallons of fuel per minute, and 24,811 gallons of LOX per minute.

The turbopump was powered by a turbine, which was spun with hot gases. These hot gases were provided by a unit known as the *gas generator*. In addition to feeding huge amounts of fuel and LOX into the thrust chamber, the turbopump also pumped a relatively small amount of fuel and LOX into the gas generator. The propellants were burned in the gas generator, and produced a large amount of hot gases, which were fed into the turbine.

The obvious question is how to get this process started. The gas generator depends on propellants pumped to it by the turbopump, but the turbopump can't operate until the gas generator begins spinning the turbine by burning propellants. It would appear to be a chicken-and-egg situation.

Here's a schematic of the F-1 engine ...



... and here is the process for starting this behemoth.

1. At ignition sequence start (T-8.9 seconds), a 500-volt electrical signal fires the four igniters, which burn for approximately 6 seconds. These igniters do **not** start the main combustion process in the thrust chamber.

    - Two igniters are in the gas generator, and will be used to start the gas generator.
    - Two igniters are in the thrust chamber nozzle extension, and will be used to ignite fuel-rich exhaust gases from the gas generator after these gases have run through the turbine.

    Each igniter has a wire that burns through once the igniter starts, and the burnt-through wire causes a signal to be sent to the terminal countdown sequencer (TCS), confirming that the igniter has fired. If the TCS does not receive signals from each igniter, it stops the engine-start process and aborts the launch.

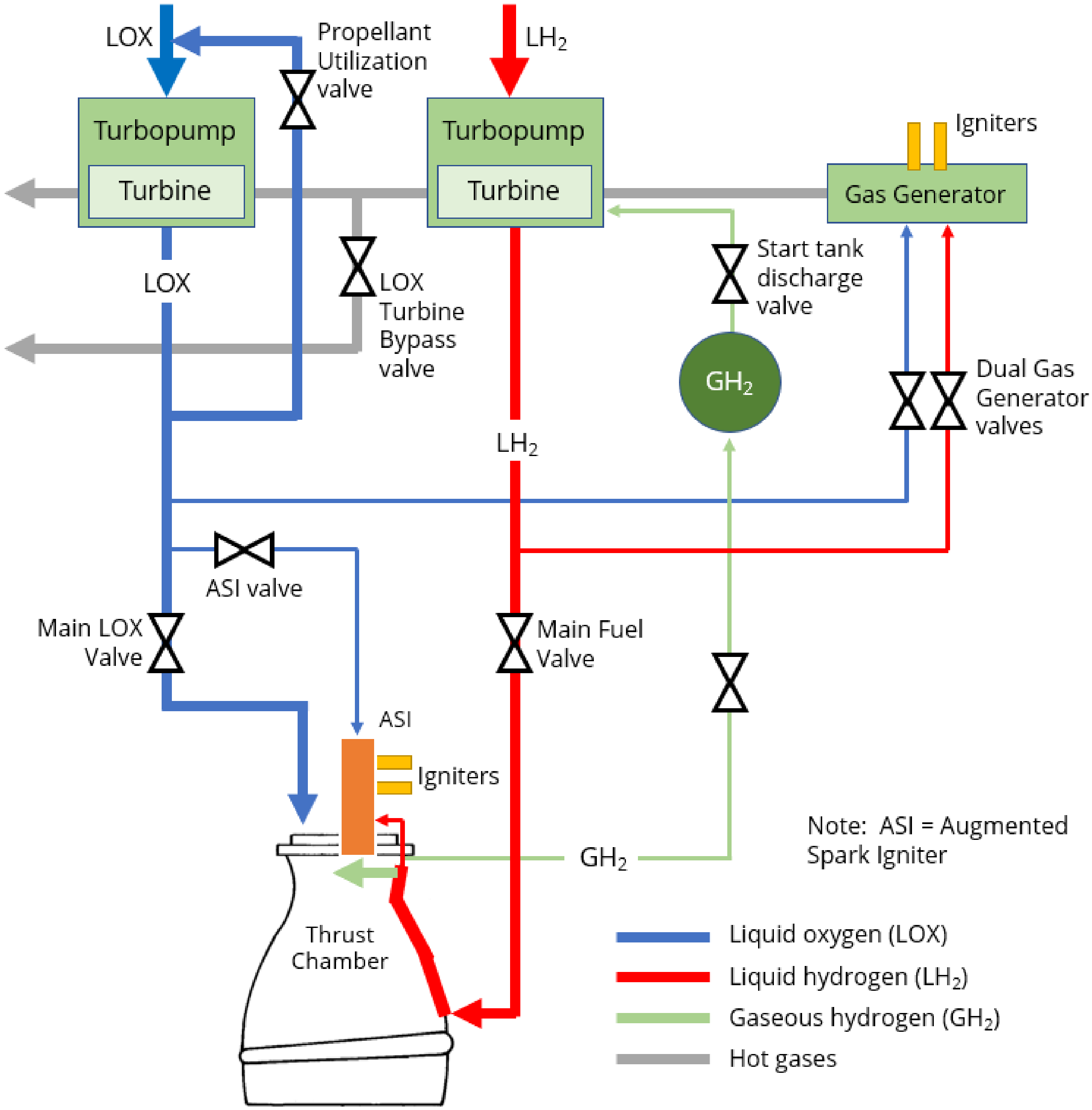
2. When all four signal wires have burned through, an electrical signal is sent to a 4-way control valve, which now directs hydraulic pressure to open the two main LOX valves. These valves allow LOX to flow to thrust chamber. (This process is clearly visible in videos of the F-1 engines taken

seconds before launch -- huge clouds of liquid come spilling out of the engine nozzles. This liquid is LOX.)

3. When both main LOX valves are open at least partially, hydraulic pressure opens the gas generator ball valve, allowing both fuel and LOX to be fed into the gas generator. These propellants are relatively low-pressure -- just a few atmospheres.
4. The propellants entering the gas generator are ignited by the igniters.
5. Combustion gas from the gas generator passes through the turbopump, and eventually is expelled through the engine nozzle. There is as yet no combustion taking place in the engine's thrust chamber, and no thrust is yet being produced.
6. Fuel-rich exhaust gases from the gas generator are ignited by the igniters in the exhaust manifold, preventing back-firing. This relatively cool gas (1,000° F) is the coolant for the nozzle extension. (This is the flaming gas that can be seen in videos falling from the nozzles before main engine ignition.)
7. The gas from the gas generator accelerates the turbopump, causing the turbopump's discharge pressure to increase. As the pressure in the gas generator increases, it is able to spin the turbine faster, pumping more fuel and oxidizer to the gas generator. The turbine quickly comes up to full speed, about 5,500 RPM.
8. With the LOX valves open, LOX is flowing freely into the thrust chamber, but the main fuel valves are still closed, so there is nothing to burn in the thrust chamber.
9. A small manifold -- known as the *hypergol manifold* -- feeds a small amount of fuel from the turbopump to a valve known as the *igniter fuel valve* (IFV), which is currently closed and blocks the flow of fuel. Beyond the IFV is the *hypergol cartridge*. The hypergol cartridge contains 85% triethylborane and 15% triethylaluminum, chemicals that spontaneously combust in the presence of oxygen. The hypergol cannister is connected to the thrust chamber, but a burst diaphragm on the front of the cartridge has so far prevented the cartridge's contents from entering the thrust chamber. As fuel pressure increases to approximately 375 psi, the pressure causes the IFV to open, allowing fuel to force its way into the hypergol canister. The fuel pressure on the cartridge causes that diaphragm to burst, pushing the cartridge's contents and a small amount of fuel into the thrust chamber. The thrust chamber is already full of LOX, and the chemicals from the hypergol cartridge burst into flame. A small amount of fuel continues to flow through the hypergol manifold and enters the thrust chamber, and the burning chemicals from the hypergol cartridge ignites the fuel.
10. A small amount of fuel continues to flow through the hypergol manifold and into the thrust chamber, and this fuel burns with the LOX, causing the thrust chamber pressure to climb. As pressure in the thrust chamber reaches 20 psi, the pressure opens a valve known as the *ignition monitor valve* (IMV). The valve sends hydraulic fluid to open the main fuel valves, feeding high-pressure fuel into the thrust chamber. The piping around the thrust chamber had been previously filled with ethylene glycol, and the fuel now flushes that ethylene glycol into the thrust chamber. The ethylene glycol dilutes the first rush of fuel, easing the initial stress on the engine as it comes up to full thrust.
11. With high-pressure fuel and LOX flowing into the thrust chamber, the engine is now running at full thrust, a condition known as *mainstage*.

12. When the pressure in the thrust chamber reaches approximately 1,060 psi, it triggers a set of pressure switches that send a THRUST OK signal to the LVDC, telling it that the engine is running at full thrust. When all five engines have reported THRUST OK, the process of starting the engines is complete. The LVDC reports ALL ENGINES RUNNING to the TCS, and the TCS begins the process of releasing the vehicle.

APPENDIX C - STARTING THE J-2 ENGINE



1. Four igniters (essentially spark plugs) fire -- two in the augmented spark igniters (ASI, explained below), and two in the gas generator.

2. The main fuel valve opens, allowing fuel (liquid hydrogen) to flow at tank pressure into the jacket that surrounds the engine bell. The liquid hydrogen warms enough to become gaseous, and flows into the engine thrust chamber. A small amount of fuel also flows into the augmented spark igniter

(ASI). At this point, the turbopumps are stationary, so only the pressure in the fuel tank is pushing fuel through the system.

3. The ASI valve opens, allowing a small amount of LOX to flow into the ASI. The igniters (spark plugs) in the ASI cause the fuel and LOX in the ASI to ignite, shooting a flame into the engine's thrust chamber.

4. The process stays at this point for a short time, allowing the supercold liquid hydrogen fuel to continue to circulate through the thrust chamber, conditioning it for engine start. For the second stage (S-II), this delay is 1 second. For the third stage's single engine, this delay is 3 seconds the first time the engine is started (during the climb to Earth orbit), and 8 seconds when the engine is restarted a few hours later for translunar injection (TLI).

5. The start tank discharge valve (STDV) opens for 0.450 seconds, feeding pressurized gaseous hydrogen into the turbines. The gas goes into the fuel turbine first, and then into the LOX turbine, causing them to spin. At the same time the LOX turbine bypass valve opens, so that some of the hydrogen gas bypasses the turbine. This decreases the amount of LOX pumped by the LOX turbopump, resulting in a gentler engine start.

6. The main LOX valve opens, allowing LOX to flow into the thrust chamber.

7. The dual gas generator valves open, allowing liquid hydrogen and LOX to flow into the gas generator, where they are ignited by the igniters. At the same time, the oxidizer turbine bypass valve is closed, allowing the LOX turbopump to come up to full speed.

8. As the gas generator produces gas, the speed of the turbopumps increases. The engine reaches full thrust, a condition known as *mainstage*. Two pressure switches in each engine send a THRUST OK signal to LVDC when the engine is producing full thrust.

9. With combustion in the thrust chamber and the gas generator now self-sustaining, the igniters (spark plugs) are no longer necessary. They are turned off by timers after a fixed amount of time.

Pressure in the fuel tank is maintained by tapping a small amount of gaseous hydrogen from the fuel injection manifold that feeds fuel into the thrust chamber.

Pressure in the LOX tank is maintained by heating a small amount of LOX using heat generated by the engine (through a heat exchanger). The heated LOX evaporates into gaseous oxygen, and this is fed back into the LOX tank to maintain pressure.

Interesting to note that the J-2 engine does not use any fluids other than the propellants (oxygen and hydrogen) and helium gas. The extremely low operating temperature of the engine does not allow the use of any other hydraulic fluids or lubricants. Gaseous helium is used as a hydraulic fluid to open and close valves.

APPENDIX D - MOBILE LAUNCHER CONNECTIONS

Service Arms (Swing Arms)

The Saturn V on the launch pad connects to ground equipment through 9 swing arms (also known as service arms) on the mobile launcher, and through three tail service masts (TSM) in the launcher base. Here are the nine swing arms:

9 **Command Module.** Provides access to the spacecraft. Partially retracted at T-43m, fully retracted at T-5m.

8 **Service Module.** Provides air conditioning, coolant, electrical, and pneumatic interfaces to the Service Module. Retracts at liftoff.

7 **S-IVB/IU forward.** Provides LH2 vent, electrical, pneumatic, and air conditioning interfaces to the third stage. Retracts at liftoff.

6 **S-IVB aft.** Provides LH2 and LOX transfer, electrical, pneumatic, and air conditioning interfaces for the third stage. Retracts at liftoff.

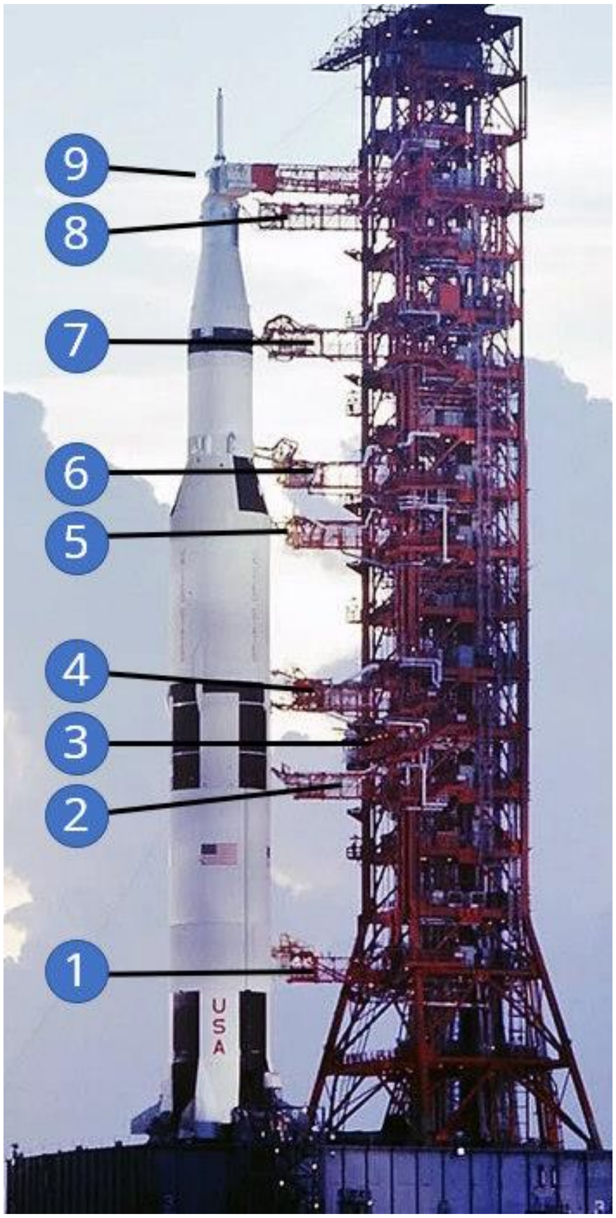
5 **S-II forward.** Provides gaseous hydrogen vent, electrical, and pneumatic interfaces for the second stage. Retracts at liftoff.

4 **S-II intermediate.** Provides LH2 and LOX fill and drain, pneumatic, instrument cooling, electrical, and air conditioning interfaces for the second stage. Retracts at liftoff.

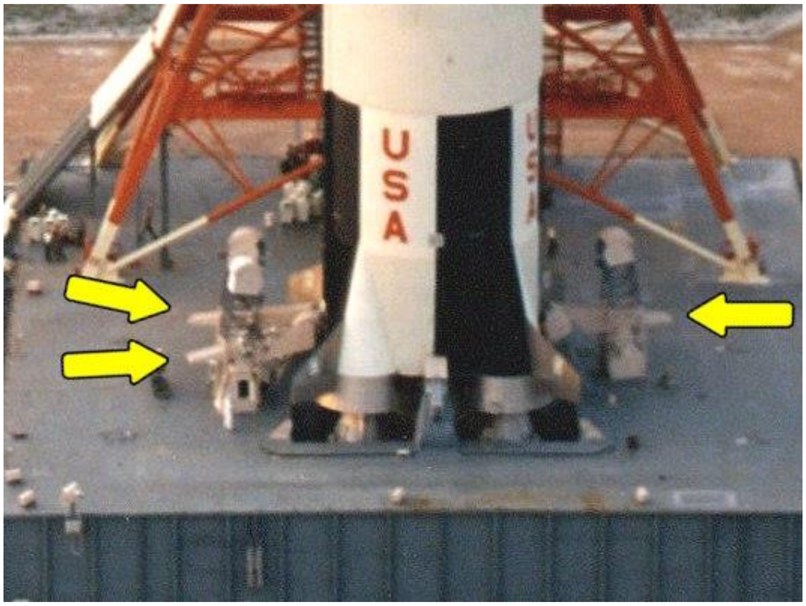
3 **S-II aft.** Provides worker access to the bottom of the second stage. Does not contain any electrical or fluid connections. Retracts well before launch, when workers no longer need access to the aft end of the second stage. On Apollo 11, retracted at T-12h. The arm is in the retracted position in the photo at right.

2 **S-IC forward.** Provides pneumatic, electrical, and air conditioning interfaces to the first stage. Retracts 16.2 seconds before launch.

1 **S-IC intertank.** Provides LOX fill and drain. Retracts 30 seconds before launch.



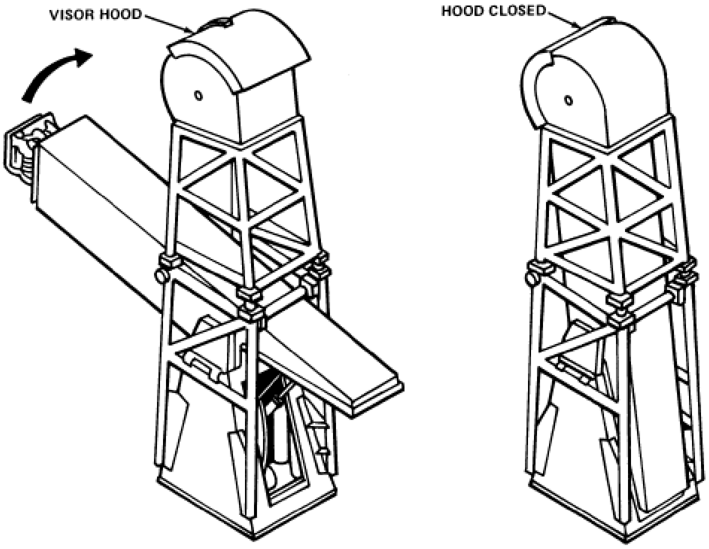
Tail Service Masts



In addition to swing arms #1 and #2, the Saturn V first stage (S-IC) had three additional connections through three tail service masts (TSM). These structures were mounted directly on the launcher base, and connected at three places around the base of the S-IC. The umbilicals in the tail service masts contained electrical connections, and provided propellant loading lines, hydraulic lines, and other connections.

The umbilicals in each TSM were connected to the S-IC through a mostly-horizontal arm. At liftoff the arm swung up until the umbilical connectors were covered by a hood, in an attempt to protect the relatively fragile connectors from the intense engine blast that was about to hit it as the Saturn V rose into the air.

The tail service masts were built by American Machine & Foundry Company.



APPENDIX E - ALL THE SATURN V'S

Four Saturn V test vehicles and 15 flight vehicles were built, or partially built.

				WHAT BECAME OF THEM?		
SERIAL#	**FLIGHT**	**LAUNCH**	**COMMENTS**	**FIRST STAGE**	**SECOND STAGE**	**THIRD STAGE**
SA-500-S	Not intended to fly	None	Structural test vehicle, built with non-functional systems to test the structural integrity of each complete stage under simulated critical load conditions. All three stages were built.	Location is unknown -- probably scrapped.	Destroyed on the test stand September 29, 1965.	Previously on display at the Alabama Welcome Center in Ardmore, but scrapped in 2024 due to deterioration.
SA-500-T	Not intended to fly	None	Test stages built with functional systems for captive test firing. The first and second stages (S-IC-T and S-II-T) were built. The third stage (S-IVB-T) was never built.	On display at the Kennedy Space Center.	Destroyed by accident during pressure testing May 28, 1966.	Never built - canceled during assembly. Tanks were transferred to S-IVB-F.
SA-500-D	Not intended to fly	None	Dynamic test vehicle. Built with functional systems to test the vehicle structure during flight conditions. The first and third stages (S-IC-D and S-IVB-D) were built; the second stage (S-II-D) was canceled.	On display at US Space & Rocket Center in Huntsville, Alabama.	Never built.	On display at the US Space & Rocket Center in Huntsville, Alabama.
SA-500-F	Not intended to fly	None	Facilities integration vehicle. Used to test launch facilities and ground support equipment at the Kennedy Space Center.	Location is unknown -- probably scrapped.	Used as a Dynamic Test Stage replacement after the destruction of S-II-S/D and S-II-T. On display at the US Space & Rocket Center in	Turned into the Skylab Dynamic Test vehicle, and eventually scrapped.

					Huntsville, Alabama.	
SA-501	Apollo 4	11/9/1967	First all-up test mission, unmanned.	Impacted the Atlantic Ocean.	Impacted the Atlantic Ocean at 32°12′N 39°40′W	Impacted Pacific Ocean at 23.435N, 161.207E.
SA-502	Apollo 6	4/4/1968	Second unmanned Saturn V test flight, intended to be the first translunar injection. TLI burn failed, leaving the vehicle in low earth orbit.	Impacted the Atlantic Ocean.	Impacted the Atlantic Ocean	J-2 restart failed due to damage from pogo oscillation of previous stages; decayed from low earth orbit.
SA-503	Apollo 8	12/21/1968	First manned circumlunar mission, and first manned flight of the Saturn V.	Impacted the Atlantic Ocean at 30°12′N 74°7′W	Impacted the Atlantic Ocean at 31°50′N 38°0′W	The original S-IVB intended for this vehicle never flew. A replacement was flown, and entered solar orbit after sending Apollo 8 to the moon.
SA-504	Apollo 9	3/3/1969	First manned flight of the lunar module.	Impacted the Atlantic Ocean at 30°11′N 74°14′W	Impacted the Atlantic Ocean at 31°28′N 34°2′W	Engine burn in Earth orbit caused it to reach escape velocity and enter solar orbit.
SA-505	Apollo 10	5/18/1969	Dress rehearsal for the first lunar landing. The only Saturn V launch from pad 39B.	Impacted the Atlantic Ocean at 30°11′N 74°12′W	Impacted the Atlantic Ocean at 31°31′N 34°31′W	Entered solar orbit.
SA-506	Apollo 11	7/16/1969	The first humans on the moon, landed at the Sea of Tranquility.	Impacted the Atlantic Ocean at 30°13′N 74°2′W	Impacted the Atlantic Ocean at 31°32′N 34°51′W	Entered solar orbit.
SA-507	Apollo 12	11/14/1969	Manned lunar mission, landed at the Ocean of Storms.	Impacted the Atlantic Ocean at 30°16′N 74°54′W	Impacted the Atlantic Ocean at 31°28′N 34°13′W	Intended to be placed in solar orbit, but because of a bad state vector in the Saturn V’s IU, entered a wonky Earth orbit. Eventually made it into solar orbit. It was

						discovered by amateur astronomer Bill Yeung in 2002 and given the designation J002E3.
SA-508	Apollo 13	4/11/1970	Unsuccessful lunar mission, returned to Earth when an oxygen tank in the Service Module ruptured.	Impacted the Atlantic Ocean at 30°11′N 74°4′W	Impacted the Atlantic Ocean at 32°19′N 33°17′W	Impacted the moon 4/14/1970.
SA-509	Apollo 14	1/31/1971	Manned lunar mission, landed at Fra Mauro highlands.	Impacted the Atlantic Ocean at 29°50′N 74°3′W	Impacted the Atlantic Ocean at 29°3’N, 33°34’W.	Impacted the moon 2/4/1971.
SA-510	Apollo 15	7/26/1971	Manned lunar mission, first mission to use the lunar rover, first of the so-called "J" missions that used the extended LM. Landed at Hadley-Apennine.	Impacted the Atlantic Ocean at 29°42′N 73°39′W	Impacted the Atlantic Ocean at 26°59’N, 37°5’W.	Impacted the moon 7/29/1971.
SA-511	Apollo 16	4/16/1972	Manned lunar mission, landed at Descartes highlands.	Impacted the Atlantic Ocean at 30°12′N 74°9′W	Impacted the Atlantic Ocean at 31°44’N, 35°59’W.	Impacted the moon 4/19/1972.
SA-512	Apollo 17	12/7/1972	The last mission to put humans on the moon, landed at Taurus-Littrow.	Impacted the Atlantic Ocean at 28°13′N 73°53′W	Impacted the Atlantic Ocean at 20°03’N, 39°36’W.	Impacted the moon 12/10/1972.
SA-513	Skylab 1	5/14/1973	Delivered the Skylab space station to orbit. Originally intended for Apollo 18. The third stage for this vehicle was built but never flew – Skylab flew where the third stage and the spacecraft would normally be.	Impacted the Atlantic Ocean.	Only S-II to enter earth orbit. Made an uncontrolled reentry on January 11, 1975 and impacted the Atlantic Ocean at 34°00′N 19°00′W.	Never flew -- on display at Johnson Space Center.

SA-514		n/a	Intended for Apollo 19. Never flown.	On display at Johnson Space Center in Houston.	On display at Kennedy Space Center.	On display at Kennedy Space Center.
SA-515		n/a	Intended for Apollo 20. Used as a backup for Skylab. Never flown.	On display at Michoud Assembly Facility until June 2016, then preserved at INFINITY Space Center in Mississippi.	On display at the Johnson Space Center in Houston.	Converted to a backup Skylab, never flew. On display at the National Air and Space Museum.

Notes:

- **SA-500-F first stage**: Destacked on October 21, 1966, and then shipped to Michoud aboard the barge Poseidon on October 10, 1966. From there it went to Marshall on the Poseidon on September 29, 1969. What happened to it after that is unknown, but it was supposedly scrapped.

APPENDIX F - SATURN V'S ON DISPLAY

Three complete Saturn V vehicles are on display at these locations:

- Johnson Space Center, Houston, Texas. The stages for this display arrived between 1977 and 1979, and were displayed outdoors until its 2005 restoration, when a structure was built around it for protection. This is the only Saturn V on display that consists entirely of flight-rated stages.
- Kennedy Space Center, Apollo/Saturn V Center, Merritt Island, Florida. This vehicle was displayed outdoors, until it was enclosed in 1996 in the Apollo/Saturn V Center.
- U.S. Space & Rocket Center, Davidson Center for Space Exploration, Huntsville, Alabama. The stages in Huntsville were all test stages not meant for flight. This vehicle was displayed outdoors from 1969 to 2007, was restored, and is now displayed in the Davidson Center for Space Exploration.

	Johnson Space Center	**Kennedy Space Center**	**U.S. Space & Rocket Center**
First stage	S-IC-14 from SA-514 (Apollo 19)	S-IC-T (ground-test replica). Paint scheme meant to mimic S-IC-6. (See Note 3.)	S-IC-D (a.k.a. SA-500D), part of the Saturn V Dynamic Test Vehicle
Second stage	S-II-15 from SA-515 (Skylab backup vehicle). Originally intended for Apollo 20.	S-II from SA-514 (Apollo 19) (See Note 1.)	S-II-F/D, second stage of the Saturn V Facilities Integration Vehicle, which was used to test the launch facilities at the Kennedy Space Center.
Third stage	S IV-513, originally part of SA-513 (Skylab), re-designated for Apollo 18.	S-IVB from SA-514	S-IVB-D, part of the Saturn V Dynamic Test Vehicle.
CSM	Either CM-115 or CM-115A. May have been intended for Apollo 20.	CSM-119, Skylab Rescue and ASTP backup.	SM-010 and BP-23A (See Note 2)

Note 1 Lack of documentation makes it difficult to confirm that the second stage at Kennedy is from SA-514.

Note 2 BP-23 was launched for A-002 to test the launch escape system and recovery parachutes on December 8, 1964. It was refurbished, designated BP-23A, and exercised the launch escape system again in Launch Pad Abort Test 2, June 29, 1965. It is now part of the Saturn V display in Huntsville.

Note 3 The first stage booster (S-IC-T) on display at the Kennedy Space Center is a ground-test replica of an actual Saturn V booster. It was manufactured at the Marshall Center in 1963. Although this S-IC-T stage was described in official documents as the "All Systems Test Stage," it came to be known by those inside NASA as the "T-Bird."

GLOSSARY

This glossary contains terms particularly applicable to the launch phase of an Apollo mission.

AGC	**Apollo Guidance Computer.** The computer used for guidance and navigation in spacecraft during the Apollo program. Every Apollo lunar landing mission used two AGCs – one in the Command Module and one in the Lunar Module. The two computers used essentially identical hardware, but the software was different, reflecting the very different purposes of the two spacecraft. The AGC in the Command Module was referred to as the CMC (Command Module Computer) and the AGC in the LM was referred to as the LGC (LM Guidance Computer). During launch, the computer in the Command Module (the CMC) monitors the vehicle's flight path, but under normal operation has no part in steering the vehicle -- that job is handled by the LVDC (see below), a separate computer which resides in the Saturn V's Instrument Unit. If the LVDC were to fail, the AGC can take over guidance of the launch vehicle, a contingency that was never actually necessary. The AGC has 2K words of working memory (known as *erasable memory*) and 36K of read-only memory (known as *fixed memory*). Each word of memory is 15 bits. The processor has a clock speed of about 2 MHz. The computer weighs about 70 pounds. The computer communicates with the crew through flight instruments and through a display/keyboard known as the DSKY (pronounced DISS-key, see DSKY below). The computer also accepts inputs through various controls. Most importantly, the computer is able to fly the spacecraft by firing engines and RCS thrusters. The AGC was designed by the MIT Instrumentation Lab (now the Charles Stark Draper Laboratory) and built by Raytheon.
ALSEP	**Apollo Lunar Surface Experiments Package.** ALSEP was a package of experiments deployed on Apollo lunar missions. The package contained various experiments, all powered by a SNAP-27 radioisotope thermoelectric generator (RTG, a device which used the heat produced by a radioactive material to generate electricity). Apollo 11 used a simpler variation of ALSEP, known as EASEP (see EASEP below).

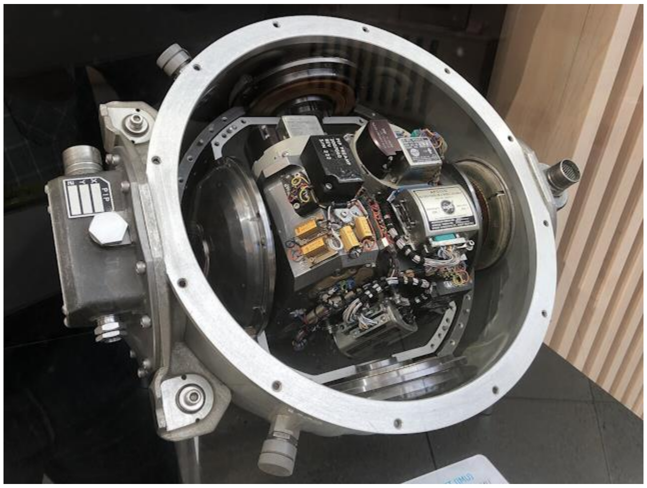
APS	**Auxiliary propulsion system.** Two sets of rocket motors mounted on the sides of the third stage (S-IVB), near the bottom of the stage, used to control the S-IVB's attitude and to provide a small amount of thrust during some maneuvers.  Each APS unit contains four rocket motors. The motors pointing left, right, and outward are 150-pound thrusters; the motor pointing aft (downward), known as the ullage motors, are 70-pound thrusters. The APS units have their own supply of propellants, which are nitrogen tetroxide (N_2O_4), the oxidizer, and monomethyl hydrazine (MMH), the fuel. (Note that the abbreviation "APS" also stands for "Ascent Propulsion System", the ascent engine on the Lunar Module. Since the Saturn V third stage and the LM ascent engine are used at very different points in an Apollo mission, there is usually no confusion.)
ASI	**Augmented Spark Igniter.** In the J-2 engine, used on the Saturn V second stage (S-II) and third stage (S-IVB), essentially a small flame thrower that shoots a flame into the engine's thrust chamber, igniting the fuel and oxidizer and initiating combustion. (See *Appendix C - Starting the J-2 Engine*.)
BEF	**Blunt-end forward.** Describes the Command Module when traveling with the heat shield (i.e., the "blunt end") facing the direction of travel. The Command Module is in this attitude during reentry.
BMAG	**Body-Mounted Attitude Gyros.** A backup set of gyroscopes, used if the primary system, the IMU (Inertial Measuring Unit), fails. The BMAG is a simpler system, but less-accurate than the IMU. The BMAGs send information about changes in the spacecraft's attitude to a device known as the GDC (Gyro Display Coupler), which sends the information to the spacecraft computer (the CMC). Because the IMU normally has a more accurate take on the spacecraft's attitude, a push-button in the Command Module, labeled GDC ALIGN, enables the GDC to take information from the IMU to replace the GDC's less-accurate information. The crew's last action before launch is pressing GDC ALIGN, ensuring that the GDC starts the flight with the more-accurate attitude information from the IMU. Note that the spacecraft navigation systems have nothing to do with steering the Saturn V -- the equipment in the Instrument Unit does that -- but the spacecraft's navigation system enables to the crew to check that the LVDC is steering the vehicle correctly.
BOOSTER	**Booster Systems Engineer.** One of the flight controller positions in Mission Control. BOOSTER monitored the launch vehicle during prelaunch and ascent. During Apollo there were three Booster positions, one for each stage of the Saturn V, who worked only until TLI. All Booster technicians were employed at Marshall Space Flight Center and reported

	to JSC for launches. After the Saturn V had done its job, the BOOSTER consoles were used by scientific technicians.
BPC	**Boost protective cover.** A conical cover that is part of the Launch Escape System (LES). The BPC fits over the Command Module, and in the event of an abort, protects the Command Module from the powerful blast of the launch escape motors. The BPS is jettisoned along with the rest of the Launch Escape System about 3-and-a-quarter minutes into flight. (See +3m 17.9s, and see *Appendix A, Figure 3 - Launch Escape System (LES)*).
CDR	**Commander.** One of three crew positions on an Apollo lunar mission. The Commander had overall responsibility for the progress of the mission. The Commander, along with the LMP, were the crew who landed on the moon on lunar landing missions, and it was the Commander who had hands on the controls during the final phase of lunar landing.
CECO	**Center-engine cutoff.** CECO occurs when the center engine on the first or second stage is shut down. These stages have five engines, and the center engine is intentionally shut down before the other four engines. The first stage center engine is shut down early (see +2m 15.2) to lessen the g forces on the crew. The second stage center engine is shut down early to avoid an engine condition known as *pogo* (see +7m 40.6s for a discussion of pogo). The other four engines are shut down a short time later (+2m 41.6s for the first stage, +9m 8.2s for the second stage) when the stage's fuel is exhausted, an event known as **outboard engine cutoff** (OECO).
CM	**Command Module.** The conical portion of the Apollo CSM, containing the crew compartment. During launch, reentry, and maneuvers all three crew members sit in couches in the CM. At launch the CM is covered by the boost protective cover (BPC), which protects it from the blast of the Launch Escape motors in the event of an abort. See *Appendix A, Figure 2*. The CM is the only portion of the entire Saturn V stack that returns to Earth and is recovered. (See *Appendix A, Figure 2 - Apollo CSM, Lunar Module, and Launch Escape Tower*.)  ***Apollo 14 Command Module, on display at the Kennedy Space Center*** The Command Module was part of the Command and Service Module (CSM), which was manufactured by North American Aviation in Downey, California. (A note about North American: The contract for the CSM was originally awarded to North American Aviation. In 1967, North American merged with Rockwell-Standard, becoming North American Rockwell, and that was the name of the company when all of the Apollo lunar landing missions flew. North American Rockwell later became Rockwell International, and is now part of Boeing.)
CMC	**Command Module Computer.** The Apollo Guidance Computer (AGC) as installed in the Command Module. (See AGC above.) Every Apollo lunar mission had two AGCs, one in the Command Module and one in the Lunar Module. (The computer in the Lunar Module was known as the LGC.)

CMP	**Command Module Pilot.** One of three crew positions on an Apollo lunar mission. On lunar landing flights, the CMP was the sole crew member who remained in the Command Module while the CDR and LMP took the LM down to the lunar surface.
CSM	**Command and Service Module.** The combined Command Module (CM) and Service Module (SM). The CM and SM are combined for almost the entire mission, and are collectively known as the CSM. The Service Module is jettisoned about half an hour before splashdown, about 15 minutes before reentry into the Earth's atmosphere, and it is only during this short time that the Command Module is flying by itself. (See *Appendix A,* Figure 2 - *Apollo CSM, Lunar Module, and Launch Escape Tower.*)  ***Apollo 15 Command and Service Module*** The CSM was manufactured by North American Aviation (now part of Boeing) in Downey, California.
C-T	**Crawler-transporter.** Either of two vehicles used to carry a mobile launcher with a Saturn V stacked on it from the VAB to one of the LC-39 launch pads. It was also used to carry the Mobile Service Structure (MSS) between its parking spot and the launch pads.  The crawler-transporters were built in 1965 by Marion Power Shovel Company. The crawler-transporters have been upgraded since the Apollo era and were used on the Space Shuttle program. They are still in use at the Kennedy Space Center today.
DSKY	**Display/Keyboard.** The unit which provides a user interface to the spacecraft computer. Pronounced "DISS-key". There are two DSKYs in the Command Module -- one on the main control panel and one in the lower equipment bay, next to the sextant (see AOT). There is a single DSKY in the Lunar Module. 
EASEP	**Early Apollo Surface Experiment Package.** Because of limited time on the lunar surface, Apollo 11 carried a simplified version of the ALSEP experiment package, known as EASEP. This package contained only two experiments, a set of four seismometers and a lunar dust detector. Apollo 11 also carried two experiments which were not part of EASEP: a retroreflector and a device to gather particles from the solar wind.

ECO	**Engine cutoff.** This term is most often used in reference to the third stage, which has only a single engine, and denotes the moment when the engine is shut down.
EDS	**Emergency Detection System.** During a Saturn V launch, the Emergency Detection System watches for deviations in the first two minutes of flight. During these first minutes, catastrophic situations can develop faster than humans can respond. The EDS detects critical problems and can abort the launch very quickly. Note that EDS also stands for **Explosive Devices Subsystems**, one of the Lunar Module's systems. There is generally no confusion between the two meanings of EDS, since the Emergency Detection System and the Explosive Devices Subsystem are used during very different parts of the mission.
EMR	**Engine Mixture Ratio.** In the Saturn V, mixture ratio of fuel to oxidizer. On the second and third stages, the LVDC can command the engine to change the amount of LOX fed to the engine, while the amount of fuel (liquid hydrogen) remains constant, thus changing the mixture ratio. For example, the second stage (S-II) uses a 5:1 ratio on startup, which causes the mixture to be fuel-rich and eases the stress on the engine as it starts. The amount of LOX is then increased within seconds to a 5.5:1 ratio, which produces the maximum amount of thrust. Near cutoff, the ratio is dropped significantly (to 4.34:1 on Apollo 11) to ensure that LOX and fuel run out at the same time.
EPO	**Earth Parking Orbit.** On an Apollo lunar mission, the launch places the vehicle (consisting of the combined S-IVB third stage, Instrument Unit, Lunar Module, and Command & Service Module) in a roughly-circular 100-nautical-mile orbit, known as earth parking orbit. The vehicle spends about one and a half orbits (about 2.5 hours) in this orbit, checking spacecraft systems and preparing for translunar injection (TLI). The vehicle was able to spend an additional orbit (90 minutes) in EPO and still perform the translunar injection burn, but this was never necessary. See the introduction to *Translunar Injection*.
F-1	The engine used in the Saturn V first stage. The engine burned RP-1 as a fuel, and liquid oxygen as an oxidizer. Each of the engines used in the first stage produce approximately 1.5 million pounds of thrust. The engine was built by the Rocketdyne Division of North American Aviation. (The company is now Aerojet Rocketdyne.)  ***S-IC with its five F-1 engines***
FDO or FIDO	**Flight Dynamics Officer.** Pronounced "fido". One of the flight controller positions in Mission Control. Responsible for orbital and atmospheric flight path, and lunar trajectory on lunar flights. FDO monitors vehicle performance during powered flight, assesses abort modes, calculates orbital maneuvers and trajectories, and monitored vehicle energy during re-entry. FDO is notable in that during Apollo, it was the only station other than the flight director which could directly call for a mission abort during launch, using a dedicated set of toggle switches. This heavy responsibility stemmed from FDO's role of watching over

	the vehicle's path; deviations from the preplanned launch trajectory could signal potentially catastrophic problems and would require swift and immediate action to make sure the crew was kept alive.
Feet wet	A naval term meaning that a flight is over water. Used on Apollo 17 by CapCom Robert Overmyer to indicate that the launch vehicle had crossed the Florida coastline and was over water.
FLIGHT	**Flight Director.** One of the flight control positions in Mission Control. FLIGHT has ultimate authority to do anything necessary to ensure the crew's safety and the mission's success, in that order of priority. The concept of a central unimpeachable authority presiding over the mission came directly from an incident during the Mercury program where NASA management overruled Chris Kraft on a decision; during Gemini and Apollo, the only way for NASA management to countermand a flight director's orders was to fire him.
GCC	**Ground Control Computer.** A pair of linked RCA-110A computers, one in the base of the mobile launcher and one in the Launch Control Center. The computers are used for testing the Saturn V, beginning in the VAB and continuing on the launch pad. It is the GCC that starts the terminal countdown sequencer (TCS), which controls the last 3+ minutes of the countdown and actually performs the launch of the Saturn V.
GDC	**Gyro Display Coupler.** In the Command Module, the device which reads information from the BMAGs (see **BMAG**) and provides backup navigational information.
GSE	**Ground support equipment.** The wide variety of equipment which supports the launch vehicle and the spacecraft before liftoff.
IGM	**Iterative Guidance Mode.** (Also known as “polynomial” guidance, “closed-loop” guidance, or "path adaptive" guidance). Iterative guidance mode describes the type of guidance in effect from +3m 24s onward. In IGM, the LVDC is constantly checking the trajectory of the vehicle, comparing it to the desired trajectory, and steering the vehicle as necessary to keep it on the desired trajectory. From liftoff until +3m 24s, the computer uses what is known as “open-loop” guidance, during which it follows a predetermined sequence of maneuvers. The maneuvers are designed to keep the vehicle approximately on track without placing undue aerodynamic forces on the vehicle. The LVDC does not check to see if the vehicle gets a little off-course. IGM begins shortly after second stage ignition when the vehicle is above the vast bulk of the atmosphere, and the focus shifts from avoiding aerodynamic stress on the vehicle to finding the most efficient path to keep the vehicle on its desired trajectory.

IMU	**Inertial Measuring Unit.** The primary device that the Saturn V and the spacecraft use for navigation. The IMU is a stable platform which contains gyroscopes and accelerometers. The CM and the LM each have an identical IMU, and the Saturn V's Instrument Unit contained a similar IMU. It can detect changes to the spacecraft's attitude and motion, and send these changes to the computer (the CMC in the Command Module, the LGC in the LM, or the LVDC in the Saturn V).  ***Internals of an IMU for a Command Module or Lunar Module*** In the CM and LM, the IMU was manufactured by the Delco Division of General Motors. In the Saturn V, the IMU was manufactured by Bendix Corporation.
IU	**Instrument Unit.** The ring of equipment at the very top of the Saturn V, and just below the Lunar Module. The IU contains the brains of the Saturn V, including the computer, the LVDC. (See LVDC below, and see *Appendix A, Figure 1 - Saturn V Launch Vehicle.*) IU is sometimes written I/U, but IU is preferred.  The Instrument Unit was designed at NASA's Marshall Space Flight Center and was manufactured by IBM.

J-2	The engine used in the Saturn V second and third stages. The engine burns liquid hydrogen as a fuel, and liquid oxygen as an oxidizer. Each engine produces approximately 232,000 pounds of thrust. The second stage has five J-2 engines; the third stage has a single J-2 engine. The engine was built by the Rocketdyne Division of North American Aviation. (The company is now Aerojet Rocketdyne.) At right: A Saturn V third stage (S-IVB) and its single J-2 engine. 
JSC	**Johnson Space Center** (full name: Lyndon B. Johnson Space Center) See MSC (Manned Spacecraft Center).
KSC	**Kennedy Space Center.** NASA facility on Merritt Island, Florida. Formed in 1962, it was originally the Launch Operations Center until 1963, when U.S. President Lyndon Johnson renamed it as the Kennedy Space Center. All Apollo lunar missions were launched from one of the two launch pads that make up KSC's Launch Complex 39.
lb.	Pound. This symbol can represent a unit of mass, weight, or force in the U.S. customary system of measurement, but as used during the Apollo program, it usually refers to mass if not otherwise qualified. See **lbm** below.
lbf	Pound-force. A unit of force in the U.S. customary system of measurement. During Apollo, it was most commonly used to measure the thrust of an engine, with the units often described as "pounds of thrust" (e.g., the F-1 engine produced 1.5 million pounds of thrust, or 1.5 million lbf). The pound-force is the force of gravity at the Earth's surface on one avoirdupois pound of mass, and is equivalent to a force of about 4.448 newtons in the metric system.
lbm	Pound-mass, also referred to as simply a "pound". The term refers to the avoirdupois pound, a unit of mass in the U.S. customary system of measurement. It is defined as equal to exactly 0.45359237 kg.

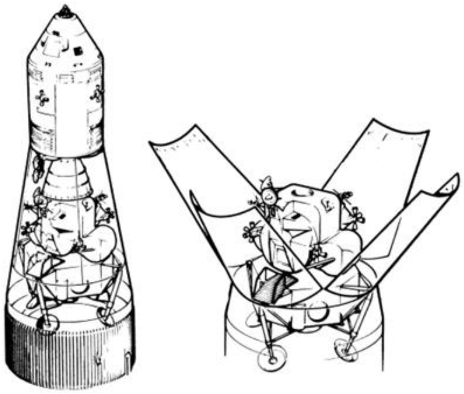
LCC	**Launch Control Center.** Building at the Kennedy Space Center from which the launch team manages a launch. The LCC had responsibility for an Apollo mission until about 4 seconds after liftoff, when the vehicle clears the launch tower, after which responsibility is transferred to the Mission Control Center (MCC) in Houston, Texas. (Photo: Recent photo of LCC)	
LES	**Launch Escape System.** The upper-most component on a Saturn V launch vehicle, containing a powerful solid-fuel rocket motor that can pull the Command Module and its crew away from the Saturn V in the event of a launch emergency. The LES includes the boost protective cover (BPC), which protects the Command Module from potential damage from the LES's rocket motor. No LES was ever needed during a manned flight, and on each mission was jettisoned about 3m 18s into flight. The launch escape and pitch control motors were built by Lockheed Propulsion Company.	
LET	**Launch Escape Tower.** See LES.	
LGC	**LM Guidance Computer.** The Apollo Guidance Computer in the Lunar Module. (See AGC above.) (The computer in the Command Module was known as the CMC.)	
LH2	**Liquid hydrogen.** LH2 was the fuel used for the second and third stages of the Saturn V. LH2 is *cryogenic* (supercold) and must be stored at a temperature of -423° F / -253° C.	
LM	**Lunar Module.** The second of the two spacecraft on every Apollo lunar landing mission. (Apollo 9, a manned Earth-orbital mission, also included a LM.) The LM was the spacecraft that took two astronauts to the lunar surface. The LM was composed of two sections, the ascent stage and the descent stage. The LM begins its mission with the two stages attached as a single spacecraft. The ascent stage contains the crew compartment; the descent stage contains the engine used during landing, and contains oxygen, water, and batteries that the crew will use	

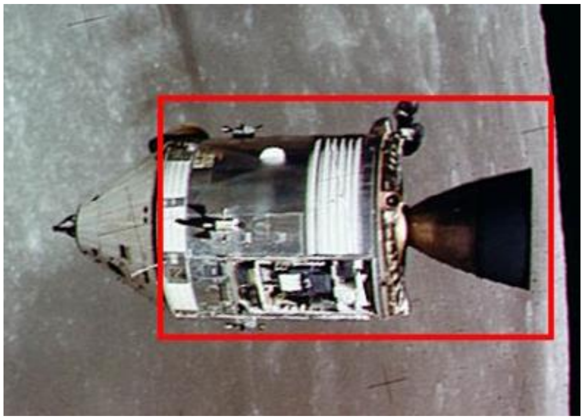
	during their stay on the lunar surface. At the end of the lunar stay, the ascent stage lifts off from the lunar surface and docks with the CSM in lunar orbit. (See *Appendix A, Figure 4 - Lunar Module.*) The Lunar Module was manufactured by the Grumman Aircraft Corporation in Bethpage, New York.
LMP	**Lunar Module Pilot.** One of three crew positions on an Apollo lunar mission. The LMP and the Commander were the two crew members who piloted the LM to the lunar surface on Apollo 11, 12, 14, 15, 16, and 17. Despite the name, the LMP was not the crew member with hands on the controls during a lunar landing -- that was the Commander's job. The LMP monitored LM systems. During the final phase of a lunar landing, the LMP called out vital numbers to the Commander, so that the Commander could keep his focus outside the LM. **Fun fact:** Early in the Apollo program, the position of LMP was called Systems Engineer (SE), but eventually changed to LMP before the first manned Apollo flight. However, some remnants of the old title persisted throughout the program -- for example, the circuit breaker which controlled power to the LMP's audio equipment was labeled SE AUDIO throughout the Apollo program.
LOX	**Liquid oxygen.** LOX is used as oxidizer in the main engines of all three Saturn V stages. LOX is also stored in tanks aboard the Command Module and the Lunar Module, and converted to gaseous oxygen to provide a breathable atmosphere for the crew. In the Command and Service Module, it is also used in the fuel cells to generate electricity. Unlike the Saturn V's engines, LOX is not used as an oxidizer in any of the engines on the Command Module or Lunar Module. Those engines instead use nitrogen tetroxide as an oxidizer.
LUT	**Launch Umbilical Tower.** The 380-foot service tower which provides umbilical connections between the ground and the Saturn V, and provides worker access to the Saturn V while on the launch pad. The launch umbilical tower containers two high-speed elevators as well as test equipment. Also known as the *launch tower*. The launch umbilical tower and the launcher base make up the mobile launcher. See *Appendix A, Figure 5 - Mobile Launcher*, and *Appendix D - Mobile Launcher Connections*.
LV	**Launch Vehicle.** The Saturn V's components (three stages and the Instrument Unit), along with the spacecraft (the LM, the CSM, and the launch escape system).
LVDC	**Launch Vehicle Digital Computer.** The underappreciated hero of the Saturn V is the Launch Vehicle Digital Computer, or LVDC. The LVDC is responsible for almost everything that happens aboard the Saturn V during flight. It sits inside a ring of equipment known as the Instrument Unit (IU). The IU sits at the very top of the Saturn V, above the third stage, and below the Lunar Module. For the entire ascent -- from launch to Earth orbit -- the LVDC has almost complete autonomy, and flies the vehicle without any help from humans. The LVDC is not the only computer onboard each flight, and should not be confused with the more well-known computer, the Apollo Guidance Computer, onboard the Apollo spacecraft. The LVDC was built by IBM.

mainstage	**Mainstage** is the phase of a rocket engine’s operation in which the engine has completed its startup phase and is in stable operation, producing thrust.
Max Q	**Maximum dynamic pressure.** The point in a rocket’s ascent in which it experiences the maximum aerodynamic stress. See +1m 23s for more information.
MCC	**Mission Control Center.** For Apollo, responsibility for managing the mission after liftoff resided with NASA's Mission Control Center at the Lyndon B. Johnson Space Center in Houston, Texas.
ML	**Mobile launcher.** The platform on which the Saturn V sits from the time it was stacked until launch.  Three mobile launchers were built, and all were used for the Apollo lunar missions. One of them -- ML-1 -- was modified for use with the Saturn V’s smaller cousin, the Saturn IB, which was used for the manned Skylab flights in 1973 and for the Apollo/Soyuz Test Project (ASTP) in 1975. (Note that Apollo 7 was also launched atop a Saturn IB, but it went through a different launch process than the other manned Saturn IB launches. Rather than being assembled in the VAB, Apollo 7 was stacked and launched from Launch Complex 34, and did not involve a mobile launcher.) See also *Appendix A, Figure 5 - Mobile Launcher.* The Mobile Launchers were built by Ingalls Iron Works, and the swing arms were built by Hayes International.
MR	**Mixture Ratio.** See EMR (engine mixture ratio).
MSC	**Manned Spacecraft Center. The** NASA center responsible for manned space flight, and location of Mission Control. The facility was formed in 1961, and is located in the Clear Lake Area of Houston, Texas. Throughout the Apollo lunar missions, the facility was known as the Manned Spacecraft Center. In February, 1973, the site was renamed the Lyndon B. Johnson Space Center, and is usually referred to as the Johnson Space Center.
MSFC	**Marshall Space Flight Center.** NASA facility near Huntsville, Alabama. During the Apollo program, the facility was responsible for the development of the Saturn series of launch vehicles. Founded in 1960, MSFC is the largest NASA facility.
MSFN	**Manned Space Flight Network.** (Pronounced "miss-fin"). Communications network that provides reliable, (usually) continuous radio communications with the astronauts, launch vehicle, and spacecraft from lift-off to splashdown.

MSOB	**Manned Spacecraft Operations Building.** During Apollo, this was the building where spacecraft were taken for testing and final assembly, before being taken to the VAB to be stacked atop the Saturn V. The MSOB also contained quarters for the astronauts to stay before their flight, and the facilities in which astronauts “suited up” before a flight. This building was originally known as Operations & Checkout (O&C), and that name appeared on many documents during the Apollo era. In 2014 the building was renamed to the Neil Armstrong Operations and Checkout Building.
MSS	**Mobile service structure.** Large scaffolding structure placed around the Saturn V on the launch pad during checkout to provide technicians with access to the vehicle, and to provide connections to ground equipment. The MSS was moved to a dedicated parking location over a mile from the pad shortly before launch. 
MTF	**Mississippi Test Facility.** A NASA facility for testing engines. All Saturn V first and second stages were sent there to undergo engine tests before being shipped to the Kennedy Space Center. In 1974 the facility was renamed National Space Technology Laboratories, and in 1988 received its current name, the John C Stennis Space Center.
NM	**Nautical mile.** A common unit of distance used during the early U.S. space program, including the Apollo program. A nautical mile is defined as 1,852 meters, and is approximately equal to 6,076 feet or 1.151 statute miles.
O&C	**Operations and Checkout.** See MSOB (Manned Spacecraft Operations Building).
O2/H2 burner	**Oxygen/hydrogen burner.** The third stage O2/H2 burner burns a small amount of liquid hydrogen and liquid oxygen to generate heat. The heat is used to warm supercold helium (-410°F / -245°C), which is used to pressurize the third stage liquid hydrogen and liquid oxygen tanks in preparation for the TLI engine burn. The O2/H2 burner produces a small amount of thrust (less than 30 lbf), and this thrust helps settle the propellants in the third stage tanks.
OECO	**Outboard Engine Cutoff.** During the first and second stage burns, the moment when the four outboard engines are shut down. See **CECO**.

open loop guidance	The guidance mode used during the first stage burn, in which the LVDC issues preprogrammed steering commands without regard to how closely the vehicle follows the desired trajectory. Open loop guidance is used early in the flight when the goal is to make sure that aerodynamic stresses on the vehicle are minimized, rather than attempting to follow an exact trajectory.
PAO	**Public Affairs Officer.** NASA employee who provides information and commentary to the public during space missions.
PDS	**Propellant dispersal system.** The PDS was the Saturn V's self-destruct system. In the event of a dire emergency, the propellant dispersal system could be triggered by an Air Force controller, known as the Range Safety Officer (RSO). Explosives would rupture the propellant tanks on each stage, allowing the propellants to mix and ignite, destroying the vehicle. Such a command would hopefully be sent only after the Command Module was safely away from the vehicle. (For more information, see the glossary entry for RSO, as well as the timeline at -109h, -63h 15m, and -40m.)
pogo	Pogo is a type of potentially-catastrophic oscillation in which the rocket surges forward and then slows down in a rapidly-repeating cycle. The effect is named after the bouncing child's toy, the "pogo stick". For more information, see +7m 40.6s in the timeline.
polynomial guidance	Another name for iterative guidance mode. See IGM.
PTCS	**Propellant tanking computer system.** The PTCS monitors propellant levels in the cryogenic tanks between the time that the tanks are filled and the time that the tanks are pressurized just before launch. After the tanks are filled, a small amount of the supercold propellant is constantly boiling off. The PTCS adds propellant as necessary to maintain the proper level in the tanks.
PU	**Propellant Utilization.** The system that controls the mixture ratio of propellants fed into the engine on the second and third stages of the Saturn V. See EMR for more information.
RCS	**Reaction Control System.** Collections of small rocket engines on the Command Module, Service Module, and Lunar Module ascent stage, used for maneuvering. 
RP-1	**Rocket Propellant-1.** A highly-refined form of kerosene, used as fuel in the Saturn V's first stage.
RSO	**Range Safety Officer.** US Air Force personnel responsible for destroying the vehicle in the event that the rocket goes off-course during launch. In the event of a failure during flight, the RSO would transmit a pair of signals to shut down the engines and trigger the propellant dispersal system (PDS), which would split open the tanks on each stage, causing the propellants to ignite and destroy the rocket. (See -109h, -63h 15m, and -40m for more information about the propellant dispersal system.) This role is not unique to the Saturn V or to manned launches.
Saturn I	The first rocket in the family of Saturn launch vehicles, first flown in 1961. The two-stage Saturn I could launch 20,000 pounds into low Earth orbit. The Saturn I was launched 10

	times, all successful. It was never used for manned launches. The Saturn I last flew in 1965.
Saturn IB	An uprated version of the Saturn I rocket, first flown in 1966. The two-stage Saturn IB could launch 46,000 pounds into low Earth orbit, more than double its Saturn I predecessor. The Saturn IB's second stage was the S-IVB, essentially the same stage used as the Saturn V's third stage. The Saturn IB was launched 9 times, all successful. It carried five manned missions: Apollo 7 (the first successful manned Apollo flight), the three crews to the Skylab orbital workshop, and the American crew of the Apollo-Soyuz Test Project (ASTP, a joint U.S./Soviet project). The Saturn IB last flew in 1975.
Saturn V	The largest of the Saturn family of rockets, the three-stage Saturn V could launch 311,000 pounds to low Earth orbit, or send 52,700 pounds on a trajectory to the moon. By the end of the Apollo program, improvements allowed it to send about 96,000 pounds to the moon. It first flew in 1967. It was launched a total of 13 times, 12 of which were fully successful, and one of which was partially successful (the unmanned Apollo 6). Three flights were unmanned (Apollo 4, 6, and Skylab) and ten flights were manned. Nine of the manned flights carried people to the moon (Apollo 8, and 10 through 17). The Saturn V last flew in 1973, when it carried the Skylab orbital workshop into Earth orbit.
S-IC	The first stage of the Saturn V. The S-IC was manufactured by the Boeing Company at NASA's Michoud Assembly Facility in Louisiana.
S-II	The second stage of the Saturn V. The S-II was manufactured by North American Aviation in Seal Beach, California.
S-IVB	The third stage of the Saturn V. The S-IVB was manufactured by McDonnell Douglas in Huntington Beach, California. (The S-IVB was also the second stage of the Saturn IB launch vehicle.)
SLA	**Spacecraft LM adapter.** The cradle and protective cover which attached to the top of the Instrument Unit, in which the LM (Lunar Module) sits during launch. The LM is surrounded by four panels, and the CSM sits on top of these four panels. Once the spacecraft is on the way to the moon, the CSM separates from the SLA, the SLA panels open, and the CSM docks with the LM and extracts it from the SLA. (See TD&E.) 

SM	**Service Module.** This is the cylindrical bottom portion of the Apollo CSM spacecraft. The SM contains a large engine (the Service Propulsion System), RCS thrusters, fuel and oxidizer tanks for the engine, oxygen tanks, hydrogen tanks, and fuel cells to generate electricity. About 15 minutes before the CM begins its reentry into the Earth's atmosphere, the crew jettisons the SM, which burns up in the atmosphere a few minutes later. The Service Module is outlined in red in the photograph at the right. 
ST124-M	The model number of the IMU used in the Saturn V. See IMU.
Super Guppy	Large cargo aircraft manufactured by Aero Spacelines which could carry components too large to be carried by any other cargo aircraft. Most of the Saturn V's third stages (S-IVB) were transported by the Super Guppy. (The first and second stages were too big even for the Super Guppy, and had to be transported by barge.) Five Super Guppy aircraft were built, one of which remains in service today. 
T&D	**Transposition and docking.** See TD&E.
TCS	**Terminal Countdown Sequencer.** The piece of equipment that automatically handles the events of the final countdown. The TCS is located in the mobile launcher, and is started a little over 3 minutes before liftoff (-3m 6s). It issues the commands that trigger all the events required during the last phase of the countdown and verifies that each event takes place successfully at the proper time. It is the TCS that issues the commands to start the Saturn V's first stage engines (-8.9s) and releases the Saturn V at the proper instant.
TD&E	Transposition, docking, and extraction. The process of separating the CSM from the third stage, turning the CSM around (transposition), docking with the LM, and extracting the LM from the third stage. See +3h 5m 3.9s through +4h 16m 59s on the timeline for a complete explanation.
Time Base	Within the Saturn V's computer (the LVDC -- see above), the time bases are nine important milestones from which crucial events are timed. The first time base -- T0 -- occurred at T-16.97 seconds. Each time base is identified and explained in the timeline.
TLI	**Translunar injection.** The engine burn that boosts the S-IVB, the LM, and the CSM out of low Earth orbit and places them on a trajectory which intercepts the moon. On the Apollo 11 timeline, TLI preparation began at +2h 34m 38.2s and the actual engine burn began at +2h 44m 16.2s.
ullage	The space in a rocket's propellant tanks which does not contain propellant. When the rocket is sitting on the ground before launch, or when the rocket is in powered flight, the ullage space is typically filled with air or some other gas and is at the top of the tank.

By contrast, when a rocket is in space and not burning its engine, the propellant in the tanks is floating in the tank, and the ullage space can be anywhere in the tank.

An issue arises because the fuel lines that carry propellant from a tank to an engine are typically at the bottom of the tank. If the propellant is not at the bottom of the tank, it is not available to be fed to an engine.

An **ullage motor** is a small rocket motor -- usually, but not always a solid-fuel engine -- that provides enough thrust to cause the propellant in a tank to settle to the bottom of the tank. Ullage motors are usually fired a few seconds before igniting main engines.

VAB

Vehicle Assembly Building. An enormous building at the Kennedy Space Center, originally designed to assemble Saturn V launch vehicles. Construction of the VAB was completed in 1966.

During Apollo, the VAB provided space in which the individual components that made up a Saturn V -- the three stages, the Instrument Unit, and the spacecraft -- could be stacked to form a complete Saturn V. The components were stacked atop a Mobile Launcher (ML), and the entire structure -- the mobile launcher and the completed Saturn V -- was transported to the launch pad atop a crawler-transporter.

The VAB consists of two major areas: High Bay and Low Bay. The eight Low Bay areas, 210 feet high, provided space to receive Saturn V upper stages and perform checkout functions. The four High Bay areas, 525 feet high, provided facilities in which the components for a Saturn V could be stacked atop a mobile launcher. The VAB thus had the capacity to have four Saturn Vs in the process of assembly at one time. After the Apollo program, the VAB was used to assemble the Space Shuttles and the SLS launch vehicles.

The primary contractor for the VAB was Morrison-Knudsen.

Source: Existing self-created glossary, and https://history.nasa.gov/afj/ap14fj/acron.html

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DOCUMENT HISTORY

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November, 2024	Version 1.1	Addition TCS and interstage information, readability changes.
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