2

Giant launchers

SHOOT ‘EM UP

In ‘*From the Earth to the Moon*’ Jules Verne has three people shot into space with a truly enormous cannon, vertically installed in a 900-foot deep (270 m), 60-foot wide (18 m) hole in Stone’s Hill in Florida. Verne wrote his book in 1865, when the only way to get people into the air was by balloon. Rockets in those days were still small affairs, and not considered as a means of travelling through space. In Verne’s time, the heaviest things that flew any distance and at great speed were in fact artillery shells. Verne had an inkling that shooting people out of a gun might involve an uncomfortable acceleration, so in his story, he devised a means to cushion the shock by using an internal platform on a volume of water. Upon launch, the force of acceleration would squeeze the water out through holes in the base of the projectile, effectively spreading out the sudden increase in velocity over a longer time and thereby smoothing the kick felt by the intrepid Moon voyagers.

In 1903, Konstantin Tsiolkovsky, the Russian “Father of Astronautics,” pointed out that for Verne’s projectile to achieve sufficient velocity to reach the Moon, using the length of the barrel as described in the story, it would require an impossibly high acceleration of some 22,000 g. The passengers would thus suddenly experience a weight increase of a factor of 22 thousand. No amount of water dampening would have helped.

In fact, the highest ‘g’ number ever survived by a human is 46.2, by U.S. Air Force physician John Stapp, during a rocket sled deceleration experiment in 1954. A rocket launch is effectively a much longer drawn out explosion, subjecting astronauts to some 4 g in the case of a Soyuz launcher.

Still, the idea of launching satellites into space using giant cannons is not completely ridiculous, as sufficiently robust equipment can withstand staggering levels of acceleration while remaining functional. The electronics within modern artillery shells, for

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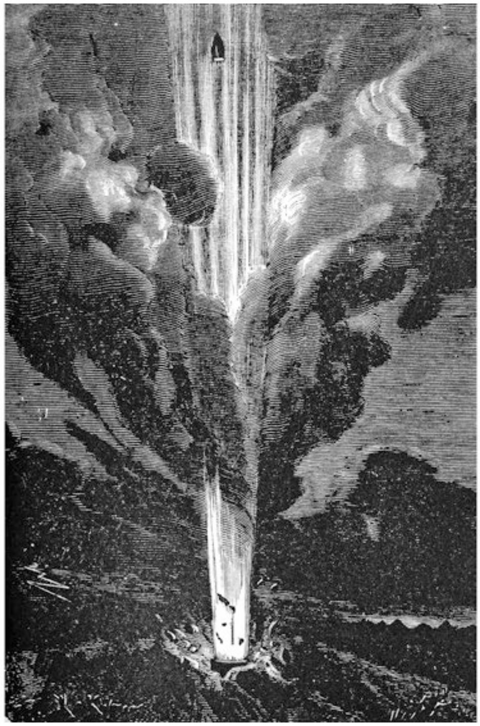


This engraving from an 1872 edition of Jules Verne's book '*From the Earth to the Moon*' depicts the firing of the lunar projectile out of the Columbiad cannon.

instance, are typically designed for 15 thousand g. And unlike old fashioned gun powder, today's more sophisticated explosives can accelerate projectiles up to orbital speeds, in principle, with much smaller cannons than the one envisioned by Jules Verne. In the mid-1960s, the Canadian engineer Gerald Bull shot relatively small Martlet projectiles to very high altitudes using a Navy gun with a 40-centimeter diameter barrel, in the U.S. Army's High Altitude Research Program (HARP). In 1966, Bull's team even fired an 85 kg Martlet 2C projectile into space, setting an altitude record of 180 km. The object did not have sufficient speed at that altitude to go into orbit, but in principle such a projectile could be equipped with a second rocket motor to achieve sufficient speed in an orbital direction and become a satellite. This was in fact planned for improved versions of the Martlet.

Unfortunately, the whole endeavor was cancelled when the Canadian government discontinued its support for the program, while more of the U.S. Army's attention and money was increasingly being diverted to the conflict in Vietnam. HARP also became the victim of a turf war, since weapons covering distances over 60 miles (96 km), including space launch vehicles, were supposed to be under the control of the U.S. Air Force, not the Army.

Some views of project HARP's supergun.

The useful payload of Martlet-type projectiles would in any case have been rather small, and the extreme accelerations, in the order of 1000 g, would have severely limited the type of equipment that could be flown. Most military missile electronics and sensors can handle only a few hundred g, while regular spacecraft are built to withstand far lower g-levels. Launching regular satellites with a supergun would thus be impossible. It may still be a viable method for putting raw materials, like water, fuel and metals into orbit, but there is no obvious reason to do so.

An alternative to using explosives could be the electromagnetic launch gun. Such a launch device would use powerful magnetic repulsion forces generated by strong electric currents to accelerate projectiles along a rail. Potentially, an electromagnetic rail gun can achieve higher velocities while subjecting its projectile to lower g-levels, because the acceleration is continuous. The longer the rail, the higher the velocity that can be achieved, or the lower the acceleration necessary to attain a given velocity. It could also be capable of launching heavier projectiles than traditional gun technology, as it is potentially easier to scale up. However, even a small electromagnetic launch system requires extremely high levels of electric power and impractically long rails. As with Bull's supergun, it would give its projectile a very high velocity at low altitude, resulting in significant loss of velocity due to aerodynamic drag in the dense atmosphere. In contrast, a conventional launch rocket takes off vertically to climb quickly through the densest part of the atmosphere at relatively low speed, then does most of its acceleration effectively in vacuum.

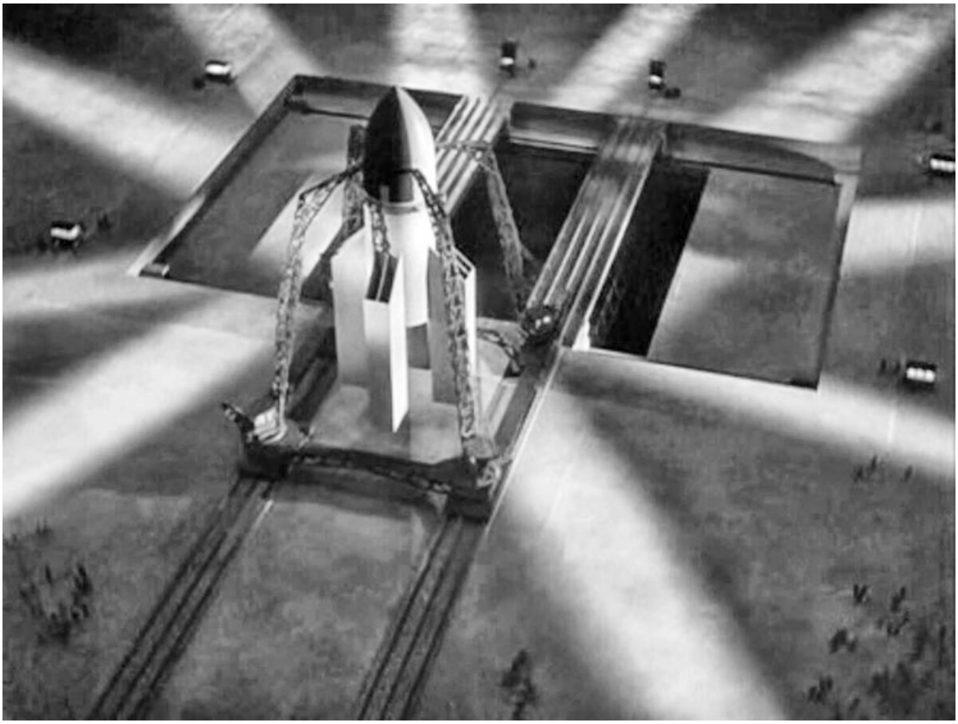
SUPER HEAVY-LIFT LAUNCHERS

So, while very small, very specialized spacecraft could potentially be launched using advanced types of cannons, launching large, heavy payloads into space means large, heavy rockets, at least for the foreseeable future.

The first reasonably realistic depiction of the kind of large rocket that would be needed to land people on the Moon can be found in the German movie *Frau im Mond* (*Woman in the Moon*) by the famous director Fritz Lang (also known for his cinematic science fiction milestone *Metropolis*). Released in 1929, *Frau im Mond* showed remarkable foresight for its time and left a lasting impression on young spaceflight enthusiasts like Wernher von Braun and Krafft Ehricke, who would grow to become leaders in German and then U.S. rocket development, as well as highly influential spaceflight visionaries of the early space age.

The movie depicts an enormous two-stage rocket, the *Friede* (*Peace*), exiting a gigantic assembly hall on a moveable platform on rails, very much like today's large launchers. It is seen suspended above its launch platform in four mechanical arms, similar to today's Soyuz rocket. The depiction is truly visionary for a time when the biggest rockets available were only a few meters long and could be mounted into their launch gantries by just a few men. The violent soundwaves produced by a Moon rocket were correctly foreseen to be an issue and in the movie, the *Friede* is therefore launched out of a massive tank filled with water. This method has never actually been applied in this way, but decades later, vast amounts of water were sprayed onto the launch platform of the Space Shuttle for the same reason.

Movie poster of *Frau im Mond*. [UFA]



The *Friede* Moon rocket is transported out of its assembly building in the movie *Frau im Mond*. [UFA]

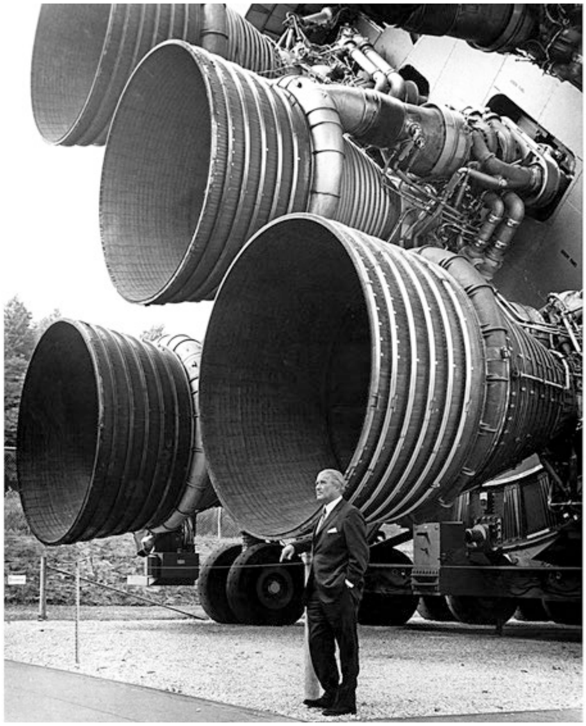
The upper stage of the behemoth launcher, carrying its integrated crewed spacecraft, is painted black on one side and white on the other, so that by rotating the stage with respect to the Sun, the interior temperature could be controlled. With the white side towards the Sun to reflect solar rays and the black side to empty space to radiate away heat, the spacecraft could be cooled down; and vice versa, with the black side to the Sun to heat up and the white side towards cold space to retain internal warmth. Decades later, this method was actually utilized for thermal control in a few early satellites.

All this clearly reflects the involvement of spaceflight pioneers Hermann Oberth and Willy Ley. Together with the director, these men had even planned to build and launch a small rocket for publicity, financed by the movie, but nothing ever came of this apart from some rocket engine tests on the ground.

The movie's most lasting influence on real spaceflight, however, must be the 'countdown'. Intended only to increase the dramatic impact of the launch in the movie, German rocketry pioneers like Wernher von Braun afterwards adopted the procedure for their actual launches, and imported the tradition to the U.S. after World War II. Today, no Western launcher takes off without the familiar, adrenaline enhancing, "10, 9, 8…"

The Space Race between the U.S. and the Soviet Union in the 1950s and 1960s was, for a large part, a race to build the largest, most powerful rocket. NASA developed the Saturn V, a 111-meter high monster capable of lifting 140 metric tons into a low Earth orbit, or to kick three astronauts, their spaceship and a two-person lunar lander to the Moon. The Saturn V had a launch mass of nearly three million kilograms, and each of its five F-1 first stage engines developed just under seven thousand kiloNewtons (kN) at lift off, burning 2.5 thousand liters of RP-1 (refined kerosene) and liquid oxygen per second. The F-1 remains the largest, most powerful single-combustion-chamber rocket engine ever developed. Only 13 of these monster rockets were ever launched, between 1967 and 1973: 2 unmanned test launches, 10 crewed Moon missions and one to put a space station into orbit.

A towering Saturn V launcher is driven out of the Vehicle Assembly Building at the Kennedy Space Center. [NASA]



Wernher von Braun, under whose lead the Saturn V was developed, standing before the F-1 engines at the lower end of a Saturn V test model. [NASA]

At about the same time as the Saturn V, the Soviet Union was developing its N1/L3 launcher, which was comparable in size and purpose but with lower performance, having a lift capability of close to 100 metric tons into LEO, compared to Saturn V's 140 metric tons. The N1/L3 would have launched two cosmonauts to the Moon, enabling only one of them to set foot on the lunar surface using a rather small lander that offered little hope of escape in the event something went wrong. Instead of a limited number of extremely powerful engines like the Saturn V F-1, the first stage of the N1 (which in fact developed a higher total thrust than the first stage of the Saturn V) depended on the use of no less than 30 NK-15 engines, fueled by highly refined kerosene and liquid oxygen. This meant simpler, easier to develop engines, but overly complicated first stage plumbing that proved prone to failure. All of the four (test) launches were failures, with none of them even making it to first stage separation. On the second launch attempt, the N1 rocket actually fell back onto the launch pad, resulting in the largest artificial non-nuclear explosion in human history.

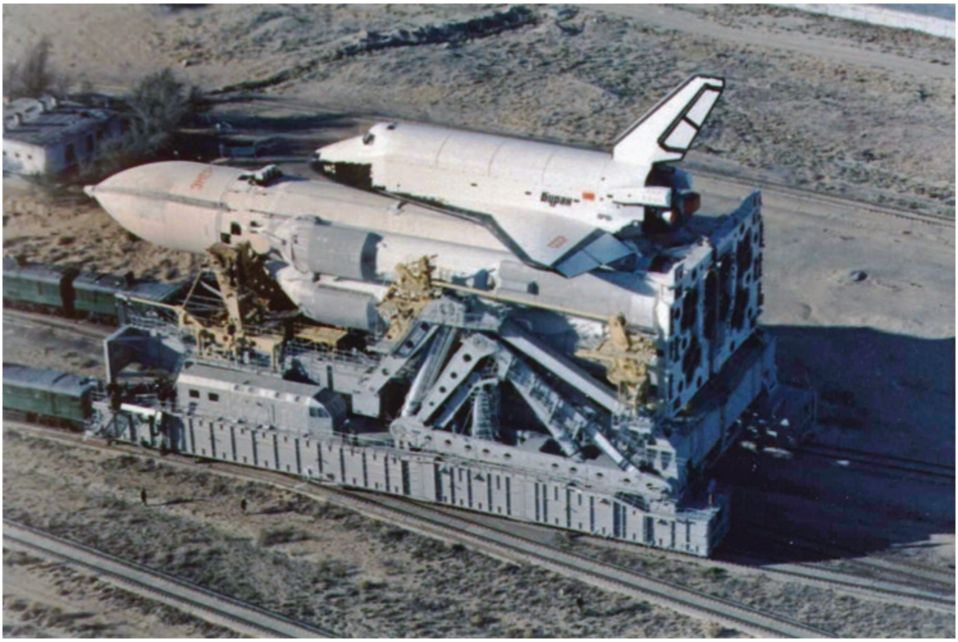
Development of the N1/L3 was suspended in 1974 and officially cancelled in 1976, effectively taking with it all Soviet manned lunar mission aspirations. The Soviets kept their giant launcher a secret almost until the very end. Only in 1989, a few years before the final collapse of the Soviet Union, was information about the rocket finally officially

Comparison of NASA's Saturn V and the Soviet N1/L3. [Wikipedia Creative Commons/Ebs08]

released (although U.S. spy satellites had already taken pictures of N1 rockets on the launch pad in the late 1960s).

After the N1 fiasco, the Soviet Union had another try at a 'super heavy' launcher (a launcher with a payload capability to low Earth orbit of over 50 metric tons) with the Energia. This new launcher was capable of putting 100,000 kg of payload into a low Earth orbit, just over two-thirds the capability of a Saturn V. It was primarily meant to launch the Russian Buran shuttle, a vehicle very similar to NASA's Space Shuttle Orbiter, apart from the lack of large rocket engines. For the U.S. Space Shuttle, the orbiter's main engines were an integral part of the launch system, whereas for the Soviet system, the Buran shuttle was basically only a static payload of the Energia rocket. The benefit of this was that the Energia booster could also be used without the Buran, as a stand-alone super heavy-lift launch vehicle.

Energia was launched only twice. The first was in 1987, without Buran and instead carrying a military prototype 'satellite killer' laser platform (which failed to reach orbit). The second launch was in 1988 with an unmanned Buran shuttle (which was a complete success). Within a short time, however, the Soviet Union fell apart and Russia was left in no condition to be able to afford expensive systems with disputable purposes like Energia/Buran.



An Energia rocket with Buran shuttle on its rail transporter/erector system.

After the Moon Race era ended in 1969, and certainly when the whole Cold War was effectively over in 1989, there was no longer any need for behemoths like the Saturn V. NASA flew its last one in 1973 to loft the Skylab space station into orbit, by which time the Saturn V production line had already been dismantled. The remaining flight hardware ended up in museums, and nearly 45 years later there is still no true successor available.

You could argue that a Saturn V class launcher would be very useful for a large space-faring nation like the U.S. Consider for instance the International Space Station (ISS) that is currently circling our planet. Since its first module was launched in 1998, it has been continually growing and accumulating mass, to a total of about 420 thousand kilograms currently in orbit. The number of assembly flights (launches that brought up the 15 pressurized modules and other major elements), for what has been considered the completed station since 2011, adds up to a total of 31: 27 Space Shuttle missions, 2 Proton launches and 2 Soyuz flights.

In terms of mass, just three Saturn V rockets could have done the same job. Maybe more would have been required when taking payload volume limitations into consideration, but on the other hand, such a significantly smaller number of flights would have meant fewer interfaces; an equivalent space station could have been constructed from three very large modules rather than the 15 relatively small ones of the ISS.

This Saturn V can be visited at the Kennedy Space Center. Its first stage is a test stage, while the second and third stages were meant for the Apollo 19 mission that was cancelled. [Kennedy Space Center]

In terms of pressurized (and thus habitable) volume, the modules of the ISS add up to a total of just over 930 cubic meters, while the Skylab station had about 360 cubic meters. Launching three Skylab-sized "modules" on the Saturn V would therefore have created a space station roughly equivalent to the ISS. If the Saturn V had still been available in 1998, the number of assembly flights required to build the station could have been a factor of 10 fewer. This would have represented not only a huge saving in launch costs but also in assembly effort, connecting only the three modules instead of 15, plus assorted assemblies.

This logic could be extrapolated further. With an Ariane 5 ES rocket, it is possible to put a single 20 thousand kilogram satellite into low Earth orbit (the now-retired Space Shuttle could carry around 27,500 kg). A Saturn V could carry seven of those aloft in one shot, or a single, giant, 140 thousand kilogram satellite platform doing the job of seven Ariane 5-sized satellites.

So why don't we have a Saturn V launcher now, and come to think of it, why wasn't the Space Shuttle abandoned in the late 1990s in favor of a much higher performance Saturn V-class launcher? Quite simply, there is now little need for the very large payload capability of a rocket such as the Saturn V. Satellites for telecommunication, Earth observation and science do not, and need not, mass into the hundreds of thousands of kilograms. Such systems would be far too costly to develop, too complex and large to put together, and represent too high a risk. The value of the investment lost in case of a launch failure would be substantial.

Thus, it makes sense not to put all the eggs into a single (launcher) basket, but instead to build and launch a number of smaller, less complex satellites, with a smaller financial investment and reduced risk. In 2002, the European Space Agency (ESA) launched Envisat, the largest civilian Earth observation satellite ever. It had a mass of 8,200 kg and no less than 10 instruments, representing the combined efforts and hopes of hundreds of scientists. Although overall it is quite efficient to put so many instruments aboard a single spacecraft platform, many in ESA started to get a bit nervous when the launch date approached. A launch failure is always bad, but in the case of Envisat the impact would have been extraordinarily large. Ten expensive instruments all going into space at the same time could also mean ten instruments simultaneously ending up on the bottom of the ocean if something went wrong at launch.

The impact of failure can be considered to grow exponentially with the size of the mission: the larger the satellite, the greater the risk impact. ESA's latest major Earth observation satellites, the Sentinels, are quite a bit smaller than Envisat and each carries fewer instruments. Spreading the functional capabilities of a huge satellite like Envisat over a number of smaller, more specialized spacecraft like the Sentinels reduces the risk of losing it all and also gives more flexibility in terms of development and budget planning.

All this proves that a Saturn V-class launcher is now redundant. In truth, such a vehicle would only really be useful for launching large space stations and human interplanetary missions.

Still, if you were willing to accept the risks of an all-in-one launch, you could argue that a giant launcher could still be used to carry many smaller spacecraft all at the same time, potentially bringing down the launch price for each individual satellite. But that would also mean that the logistics of the launch schedule, and thus the development of many satellites from different organizations, would need to be closely aligned. Schedule slippage for one satellite could mean delaying the launch of all the others as well, or launching with fewer paying customers and therefore increasing the launch price for each of those who remained.

Moreover, such a combined launch would only work if all the satellites were targeted for compatible orbits, with similar orbital inclinations and altitudes. You could not, for instance, launch one satellite into an equatorial low Earth orbit, another into a polar orbit and yet another into a Geosynchronous Transfer Orbit (GTO). The very successful (up to now) Ariane 5 launcher provides a case in point. It was developed to launch two typical GTO satellites in one go for cost efficiency, but it has sometimes proven difficult to find compatible combinations of spacecraft to fulfill total mass and launch date requirements, so the Ariane 5 sometimes lifts off nearly half empty. A newer alternative, the highly cost-efficient and marketable Falcon 9 of SpaceX, is optimized for single-satellite GTO launches, as will be the light, two-strap-on-booster version of Ariane 6, the European successor to Ariane 5 that is currently being developed (although the version with four boosters will still be able to lift two satellites at a time).

If Ariane 5 has had problems launching just two compatible 5-ton satellites at the same time, then it's easy to see that getting ten or more of these ready to put onboard a Saturn V-class launcher all on the same date and bound for compatible orbits would be a substantial and difficult challenge.

All this means that barring the need to construct a new, large space station or other enormous orbital system, or a steady stream of crewed flights or outpost supply missions to the Moon or Mars, there would be little for a Saturn V to do these days. The development of such a huge launcher is highly expensive (for Saturn V, it would be around $55 billion in today's dollars), as is the maintenance of its ground infrastructure (launch pads, assembly buildings, control centers) and keeping the production infrastructure operational, making it a very uneconomical system if flown only once per year or less.

Even during the Apollo era for which they were built, NASA only launched a total of 13 Saturn V rockets from 1967 through 1973; an average of less than two per year. At that rate, a Saturn V launch would cost some $2.3 billion per flight in current-year dollars, without considering the development costs. In contrast, a successful modern medium class rocket like the Falcon 9v1.1 typically sees more than six launches per year, representing a far more economical use of a launch vehicle and its associated infrastructure. It may have only one-tenth the payload capacity of a Saturn V, but its launch price is nearly twenty times less, resulting in a considerably lower cost-per-kilogram in orbit.

The use of a lower-capacity launcher that is already available and can also be used for other missions thus clearly makes more sense than developing a dedicated Saturn V-class launch vehicle that will see only limited use. This was why the Soviet Union built up its Salyut and Mir space stations from modules put into orbit on medium class Proton rockets, rather than the problematic giant N1, and why the ISS was built from smaller pieces using the readily available Space Shuttle rather than a new Saturn V-class launcher.

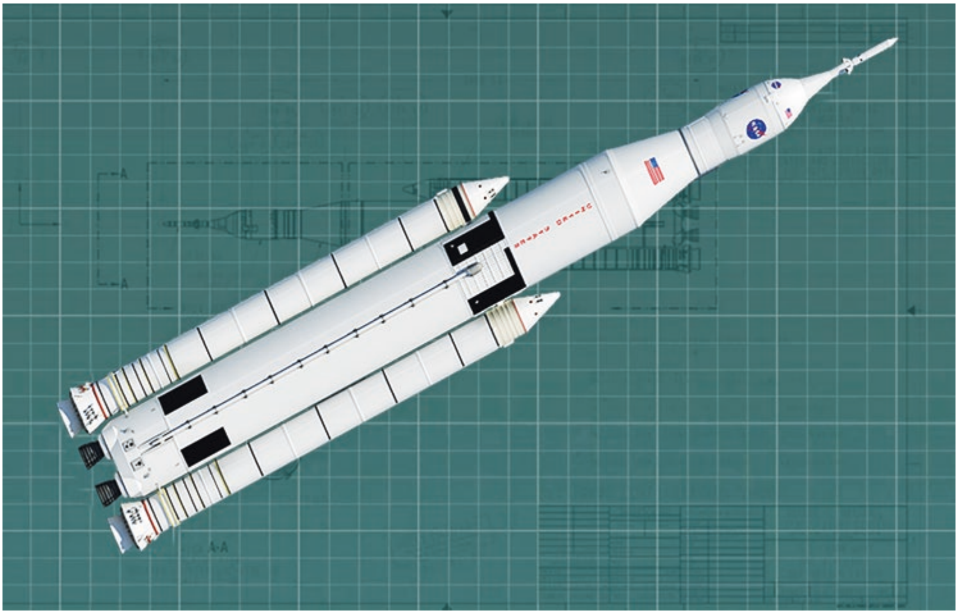
Although the cost-per-flight of the Shuttle was hardly less than that of a Saturn V, each ISS assembly flight also carried an astronaut crew and a handy robotic arm for in-orbit assembly activities, in addition to the space station's module or components. There is also the fact that the Shuttle's development was already paid for, while the development of a new super heavy launch vehicle would have taken considerable time and money. Construction of the ISS out of smaller modules over a longer time, rather than a few very large modules, also meant flexibility. It allowed the various countries and agencies (the U.S., Russia, Japan, ESA and Canada) to develop and built modules more or less independently and on their own schedule, and the station to grow slowly, spreading efforts and expenses over time. Moreover, if one module was not ready, another could be launched instead, offering a cost-conscious flexibility that would be much less viable with a station constructed out of three or four mega-modules.

One possible way to combine the economy of high-launch-rate medium class launchers with the large payload capacity benefits of a heavy launcher in the future is the modular launcher concept, as represented by the Falcon Heavy of SpaceX. This new launcher is basically built up from Falcon 9 launcher elements: a complete Falcon 9 as the rocket core, and two Falcon 9 first stages as strap-on boosters. This would be able to carry a low Earth orbit (LEO) payload of up to about 53 metric tons, just over a third of the LEO capability of a Saturn V but approximately twice that of the Space Shuttle. Benefiting from the commonalities with the high-production-rate regular Falcon 9, the projected total launch price for the Falcon Heavy is somewhere between $90 and $150 million (at the time of writing, the SpaceX website is not clear on this, stating a cost of $90 million for a 6,400 kg payload to GTO, which is far less than its total GTO capacity). This is an order of magnitude less than the cost of a Space Shuttle flight, and equivalent to (or even less than) that of an Ariane 5, which has only a third of the LEO capacity. With three launches, the Falcon Heavy could carry aloft more than the equivalent payload mass of a Saturn V at around a third of the cost.

Artist's impression of a Falcon Heavy in flight. [SpaceX]

NASA is nevertheless developing a next-generation Saturn V in the form of the Space Launch System, or SLS. A significant part of this new launcher is based on existing Space Shuttle technology, using simplified (non-reusable) Space Shuttle Main Engines and longer Space Shuttle-type Solid Rocket Boosters. Apart from the obvious benefits of using heritage equipment and technology, in terms of both reducing cost and development risks, and reliability through familiarity, this also means that the SLS preserves jobs in areas and industries that would otherwise have been lost when the Space Shuttle was retired. The program's critics insist that this is the main reason for its existence and financial support from the government.

Opponents of the launcher highlight that NASA currently has no obvious need for it and that its job can be more economically performed by other, smaller launchers. The standing joke is that SLS really stands for "Senate Launch System."



Artist's concept of the Space Launch System (SLS) Block I heavy-lift launcher. [NASA/MSFC]

The Block I version of the SLS is designed to have an LEO payload capability of 70 metric tons, considerably more than the 53 metric tons of the Falcon Heavy. But it appears that the SLS will also be better suited for missions beyond LEO, having the capability to send its payload on the way to the Moon, for example. The SLS also has significant growth capability built in from the start: The subsequent Block 1B version will be able to put 105 metric tons into LEO, while the Block 2 version is anticipated to be capable of launching 130 metric tons, close to that of the Saturn V.

In the 1960s, when NASA was faced with the choice between a super heavy-lift launcher able to send an entire mission to the Moon with one launch, or to use two considerably smaller launchers to bring smaller elements up into Earth orbit which then had to rendezvous and dock, they choose to go for the single-launch Saturn V option. The dual-launch method would have required transferring propellant from an unmanned tanker module into the crewed spaceship and two successful launches within a very short period of time. The single-launch method simplified launch and flight operations, as well as the spacecraft's design. The Soviets followed a similar reasoning, leading them to develop the N1.

Large launchers typically have a better cost-per-kilogram to orbit performance than smaller launchers, but the problem is that you don't pay for a launch-per-kilogram payload; whether the fairing is full or half empty, the launch price remains the same. Super heavy-lifters like the Saturn V and SLS are thus only economical when flying at their maximum payload capacity, and it takes a lot of equipment to fill them up. If you plan to fly human missions or planetary base elements to the Moon or Mars on a regular basis, or need to launch extremely bulky things into Earth orbit in one go, then the development of a super heavy-lift launcher like Saturn V and the SLS makes sense. Without this need, considerably smaller launchers with a significantly lower development cost and price per launch, such as the Falcon Heavy, will suffice.

This appears to lead to an awkward 'chicken-and-egg' situation: without in-orbit factories, space colonies or large-scale crewed interplanetary missions, there is little need for a super heavy-lift launch vehicle; yet without such a launcher, such large-scale space projects are less likely to be viable. NASA's official selling point for the SLS is that it will be an enabler for the agency's beyond-LEO human spaceflight ambitions, a vital element on the path to crewed missions to Mars. It will, according to a NASA SLS fact sheet, "be the biggest, most capable rocket ever built for entirely new human exploration missions."

The SLS may also be useful for robotic space exploration, enabling larger probes with more payload instruments to reach distant destinations like Jupiter and Saturn in less time, by using more direct routes without requiring fly-bys of other planets to gain sufficient velocity. However, an SLS launch will cost a lot more than a flight with an alternative rocket like the Falcon 9 or Falcon Heavy, with their lesser, but likely still sufficient, capabilities. Moreover, space probes that are so large and massive that they need to launch on an SLS don't come cheap in themselves. SLS-based robotic exploration missions will thus be rather expensive and will not occur often, maybe only once per decade.

Taken together with the unofficial 'strong points' of the SLS program – maintaining Space Shuttle-era experience, jobs and industry – this reasoning seems to be sufficient for development of the SLS to continue. However, NASA currently has neither crewed lunar landing plans nor a definite schedule for human missions to Mars in the near future. In addition, there does not seem to be a queue of other potential customers, such as the military or the telecom satellites industry, that would really require super heavy-lift capabilities, and certainly not very often. This means that the SLS may find itself without much to do if and when it becomes operational.

Due to the high fixed costs for personnel and facilities, low launch rates for SLS would inevitably increase the cost per individual launch, and thus also payload launch cost per kilogram. Critics point out that keeping SLS operational, which may also involve using it for missions that could be flown more economically using smaller launchers, could become such a burden on NASA's human spaceflight budget that there would be little money left to do anything else, such as developing the other hardware needed for human missions to Mars. That would mean that the existence of the SLS would actually hamper the development of the very missions it is intended to launch.

Nevertheless, the first SLS is currently planned to fly by November 2018, so that 45 years after the last Saturn V rose from the pad, the U.S. may again have a super heavy-lift launcher at its disposal. Being a prerequisite for many of the other large "dreams" discussed in this book, it would at least open the door for such ambitious further plans.

Interestingly, in 2005, the Russian space company Khrunichev proposed to develop a super heavy launcher for NASA's 'Vision for Space Exploration' that was announced by U.S. president George W. Bush in January 2004 and which envisioned crewed human missions by 2020. Their Angara-100 would have been based on rocket engines derived from those used in the earlier Energia rocket, and was expected to have LEO payload capability in excess of 100 metric tons. Instead, NASA decided to develop its own super heavy, in the form of the Ares V. This evolved into the SLS after the next U.S. president, Barak Obama, replaced Bush's 'Vision for Space Exploration' in 2010 with his own space policy, aimed at putting astronauts in orbit around Mars by the mid-2030s.

In the late 2000s, under the designation Rus-M, Russia studied a number of heavy launchers of modular design, all based on a core stage with a number of liquid propellant strap-on boosters attached. The Rus-M50 version would have been able to put 50 metric tons into LEO, and the Rus-M100 over 100 metric tons. In 2011, however, the whole Rus-M development, even its more modest variants, was cancelled by the new chief of Russia's space agency, Roskosmos, citing both budget constraints and the lack of need for its capabilities.

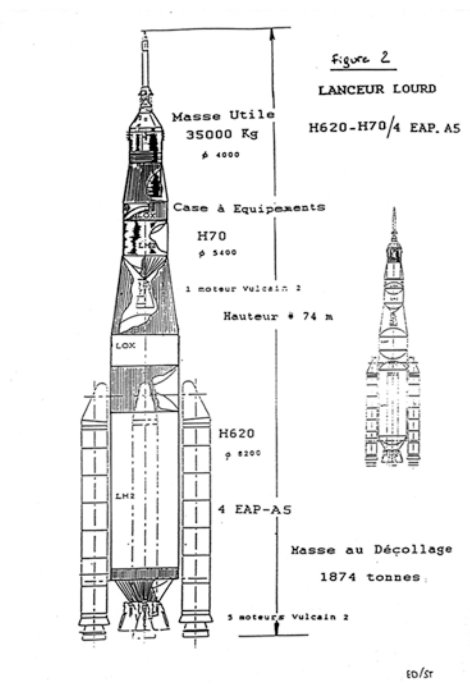
The Chinese also seem to be of the opinion that ambitious, large space projects will require super heavy-lift capabilities. China's Academy of Launch Vehicle Technologies, CALT, has preliminary designs for what they have already named the Long March 9, which may (according to one of the conceptual designs revealed) use first stage engines comparable to those of the Saturn V, and have LEO capability of 130 metric tons, the same goal as for the SLS Block 2. For China, this would represent a leap in launch capabilities, carrying some five times higher LEO payload mass than their recent Long March 5. According to CALT, the Long March 9 is expected to fly before 2031 and is intended to provide China with the capability to perform manned lunar missions.

One of the concepts for China's Long March 9 super heavy launcher. [CALT]

The Chinese launcher concept is not only impressive, it also hints at ambitious spacefaring goals. As already mentioned, such a launcher really only makes sense in combination with large space stations or crewed interplanetary missions, and CALT officials have already mentioned manned lunar missions. The decision to go ahead with the full development of the Long March 9 is expected to be made by 2020, so the launcher could be flying by the middle of that decade and the Chinese could be landing on the Moon by 2030, thus fulfilling their goal to be on a par with the U.S. and Russia as a major spacefaring nation.

In Europe, the French space agency, CNES, studied the feasibility of a super heavy-lift launcher based on Ariane 5 elements in the early 1990s. Their concept was based on a large first stage, using five Vulcain-2 main engines (Ariane 5 uses only one), four P230 solid rocket boosters (Ariane 5 uses two) and an upper stage using a single modified Vulcain-2. The philosophy of reusing existing hardware and technology was similar to that currently employed in the SLS, which, as previously indicated, will incorporate main engines and boosters derived from those used in the Space Shuttle. The 'Ariane Super Lourd' ('Ariane Super Heavy'), or ASL rocket was expected to be able to launch 35 metric tons to the Moon, or put 90 metric tons into LEO. Even more powerful versions were deliberated, of which the ultimate concept consisted of even larger first and second stages combined with two Ariane 5 boosters and four Space Shuttle-type solid rocket boosters. That would have increased the LEO capability to 140 metric tons, the same as a Saturn V.

The study was initiated in 1991, some five years before the first flight of Ariane 5, and seems to have been more an exploration of possible further developments and uses of Ariane 5 equipment rather than an answer to a specific need. Europe had no manned lunar missions planned at the time, nor any need to put such large masses into LEO.



The Ariane Super Heavy, studied by the French in 1991. [CNES]

Interest in a European Heavy Launcher briefly re-emerged in the mid-2000s, when the European Space Agency (ESA) studied the possibilities for short-duration human missions to the Moon and found that the existing Ariane launchers and their planned enhanced versions would not have the capabilities to fulfil the mission requirements. Simply put, if Europe wanted to be able to fly manned lunar missions independently, it would need a super heavy-lift launcher. In 2005, the agency performed an in-house study on such a vehicle (simply called HLLV, for Heavy-Lift Launch Vehicle), with the constraint that all development and production would need to be performed within Europe.

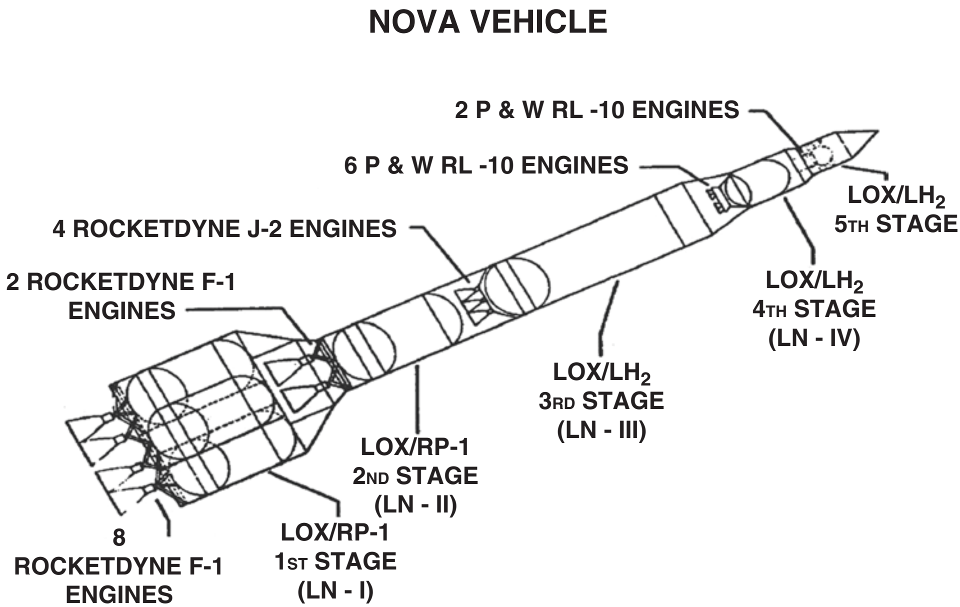
The result was a rocket that had a lot in common with the earlier CNES 'Ariane Super Heavy'. It incorporated five new, to-be-developed, high-thrust rocket engines (each with a thrust of about a third of a Saturn V F-1; still double that of the Ariane 5 Vulcain) in the first stage, four Ariane 5 solid rocket boosters, a second stage with three new engines, plus a third stage with two engines of yet another type. The rocket would have been able to launch 80 metric tons into LEO and send 35 metric tons to the Moon. Its maiden flight would have been around 2020, and it was assumed that 50 flights would be required over 10 years; a rather ambitious number. Developing and flying independent crewed lunar landing missions together with such a super heavy-lift launcher would have required a hefty increase in ESA's annual budget.

Although the current ESA General Director is arguing the case for developing an international 'Moon village', there have been no suggestions that Europe would again contemplate the development of a super heavy-lift launcher. With its member states currently recovering from a financial crisis, the large increase in ESA's budget that such a launcher would require is highly unlikely to materialize anytime soon.

EXTREMELY HEAVY-LIFT LAUNCHERS

While the Saturn V was a giant, a considerably larger launcher had originally been contemplated, to land astronauts and their entire spacecraft on the Moon directly without requiring any spacecraft rendezvous and docking activities in either Earth orbit or lunar orbit. In NASA's first long range plan, delivered to President Dwight D. Eisenhower early in 1959, this launcher was identified as Nova.

Not long afterwards, the supposed launcher technology 'gap' with the Soviets was made into a major issue in the election campaign by presidential candidate John F. Kennedy. When he took up office in 1961 and the Soviets launched Yuri Gagarin as the first human in space, the political environment for developing Nova could scarcely have been better. At the time, NASA's baseline Nova launcher was a five-stage monster, with no less than eight F-1 engines in the first stage (Saturn V had 'only' five) and another two in the second stage. The third stage would have had four J-2 engines (five of these were eventually incorporated into Saturn V's second stage).

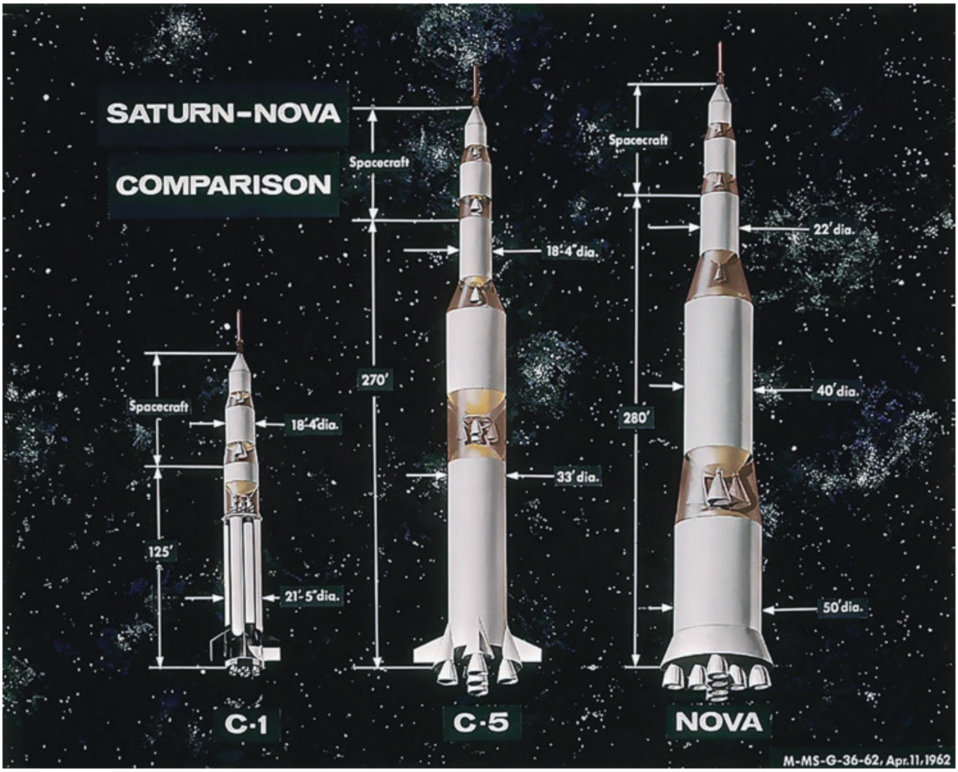


Nova baseline concept of 1961. [NASA/MSFC]

Nova was never one specific launcher design, but rather a number of different concepts. The early ones were based on clusters of modular units using the F-1 and J-2 rocket engines that were under development at the time, and which would eventually power the various stages of the Saturn V. The simplest Nova design at this time used four F-1 engines in its first stage and had a much lower launch capability than the eventual Saturn V. It was proposed as an intermediate step towards a true Moon rocket. But other concepts featured up to ten of these engines, while some designs meant for follow-on developments later in the decade even had nuclear upper stages, with nuclear reactors heating propellant up to temperatures not attainable by normal chemical (burn) reactions, and thus reaching much increased propulsion efficiencies.

However, in 1962, the Lunar Orbit Rendezvous (LOR) method, using a separate lunar lander that would rendezvous with a mothership in lunar orbit upon return from the surface of the Moon, was chosen for the Apollo program. With LOR as the preferred method, the requirement to place a complete spaceship on the lunar surface disappeared, and with it the need for such monster rockets.

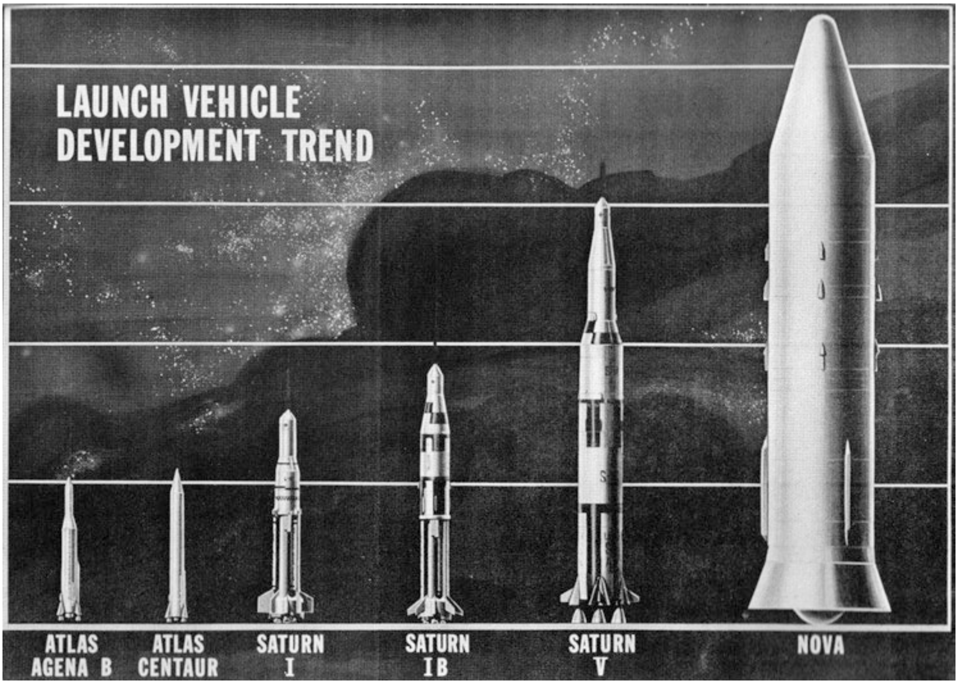
Instead, a member of the Saturn family of launchers, whose relatively small Saturn I version was already operational, was selected to achieve Kennedy's challenge of "landing a man on the Moon and returning him safely to the Earth" before the end of the decade, a national goal the young president had announced in 1961. It is quite staggering to contemplate that, at a time when the largest rockets didn't have even a tenth of the launch capability needed for the lunar missions, the giant Saturn V moon rocket was considered to be of relatively modest size and capability.



Comparison of the Nova C8 concept with its Saturn V rival and the smaller Saturn I. [NASA/MSFC]

This was by no means the end of Nova, however. With the Saturn V selected for NASA's near-term needs, new Nova concepts were optimistically contemplated as its successors for the 1970s and beyond. The goal was a million-pound (450 metric ton) LEO payload, three times as much as a Saturn V could muster. Over 1962 and 1963, two large rocket companies not involved in Saturn V activities, Convair and Martin Marietta, received NASA study contracts, while Douglas Aircraft also decided to do a study of their own. The concepts that resulted from their work were staggeringly colossal. Imagine launchers the size of three Saturn Vs strapped together, some with engines considerably larger than Saturn V's F-1 and some with solid rocket boosters the size of the Saturn V first and second stages combined.

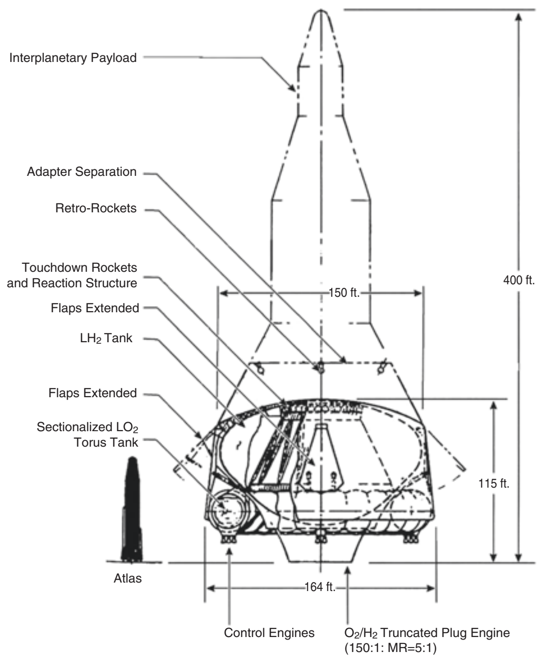
Launchers of this size raised all the issues being addressed for the Saturn V to a whole new level. Where could the massive Nova stages be built? How could these monsters be transported? Where could they be launched from? NASA had already purchased land for Nova launch sites north of the Saturn V launch pads, but engineers quickly came to realize that the incredible soundwaves produced by a Nova launch would preclude doing so from



One of the advanced Nova concepts from the study by Martin Marietta, featuring an innovative 'plug-nozzle'. [NASA/MSFC]

the Kennedy Space Center. The damage that would be caused to the area by a launch failure would also be devastating. The Nova rockets would require floating launch platforms off the Florida coast, or sites that were even more remote.

The early 1960s saw other gigantic launcher concepts beside Nova given serious consideration. The ever-ambitious Krafft Ehricke at Convair, for instance, advocated a concept called NEXUS, for a launch vehicle capable of carrying up to eight times more payload than a Saturn V. As if this was not impressive enough, the vehicle was conceived as a fully reusable, single-stage-to-orbit (SSTO) launch vehicle, meaning it would go up and come back as one single vehicle to improve economy. It was designed to descend with the help of parachutes, which would have been of colossal size, and then use rocket engines to slow down further, just before landing in the ocean. Standing at 122 meters tall, including the orbital payload section, and with a diameter of 50 meters, it is the largest conventionally-powered (i.e. non-nuclear) launch vehicle ever conceived. It would have been like flying an office block.

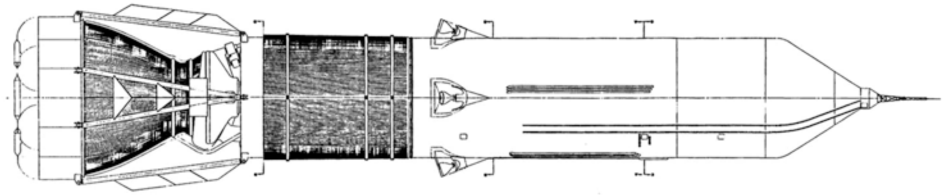


The Nexus reusable launcher, designed by Krafft Ehricke, next to an Atlas rocket of the type used for NASA's orbital Mercury missions. [Convair]

A similar, but smaller design was ROMBUS – Reusable Orbital Module-Booster and Utility Shuttle – by Philip Bono of Douglas Aircraft, who had also headed his company's Nova study team. Like NEXUS, his proposal involved a very big SSTO super heavy-lift reusable launcher (although it would have dropped its empty propellant tanks on the way up). It would use its large, actively cooled base plug-nozzle area as a re-entry shield, before deploying parachutes and using braking rockets for a soft landing on land. The plug-nozzle consisted of a ring of 36 individual rocket engines, potentially a very problematic set-up, as the Soviet N1 would soon prove. Take-off mass was expected to be 6,350 metric tons, of which 450 metric tons would consist of orbital payload.

The idea was that this monster would be developed in the mid-1980s, would be able to make at least 20 flights per individual vehicle, and would have a turn-around time between landing and relaunch of three months. The development cost was estimated to be $4.1 billion and the initial cost per flight about $22.4 million, both in 1964 dollars, which today (2017) would be some $31.5 billion and $170 million, respectively. Considering the costs for launchers that actually flew, modern estimates for much smaller reusable launchers and lessons learned from the far smaller Space Shuttle project (with a typical turn-around time of 3 months), all of these expectations and estimates can now be regarded as highly optimistic.

At Aerojet, Robert Truax came up with a ‘low-cost’ gargantuan two-stage launcher called Sea Dragon, designed to have LEO payload capability of 550 metric tons. This concept would launch straight out of the ocean. In order to do so, it would first be towed to its launch location horizontally, after which a ballast tank module attached to the first stage engine nozzle (a nozzle that would have been the width of about two Saturn V first stages) would be filled with water to pull the launcher upright. Being heavy with rocket propellant, the Sea Dragon would then mostly disappear under water, with only its cargo area remaining easily accessible above the water line. The Sea Dragon would require no complex launch infrastructure – apart from a nuclear aircraft carrier to power a floating propellant factory, in order to turn sea water into liquid oxygen and hydrogen through electrolysis to fuel the Sea Dragon on-site. To lower costs further, Truax envisioned that his design would be built out of inexpensive steel sheets, using shipbuilding techniques rather than aerospace materials and procedures.



The Sea Dragon with an Apollo capsule on top, as normally fitted on a Saturn V, to give an idea of its scale. [Aerojet]

By the end of 1963, however, NASA had lost interest in Nova and similar concepts, as other studies had shown that the Saturn V had plenty of upgrade possibilities (through improved rocket engines, a larger first stage, strap-on boosters, etc.) that could give it Nova-like capabilities. In fact, in NASA’s *Summary of Nova Studies* of May 1963, the main conclusion read: “A new large launch vehicle in the 500-ton orbital payload class cannot be justified, unless one or more of the following requirements materialize: a. A large lunar base, b. manned planetary flight, c. military orbital [requirements], or d. global cargo missions.”

Of these four, only the first two would still warrant a super heavy-lift launcher today. There is no use for military space stations, as unmanned reconnaissance satellites can do their job better for far less money, and with plenty of efficient air and sea transport options available, nobody in their right mind would nowadays propose gigantic launch vehicles merely for transporting heavy cargo around the world.

Even the more conservative Saturn V upgrades turned out to be surplus to requirements by the end of the 1960s, when it became clear that the Apollo Moon missions were not going to be followed up by ambitious human space exploration projects with million-pound payload needs. The Apollo program was being cut back, the war in Vietnam was becoming an ever-increasing burden on the U.S. budget, and the political will to support further human expansion into the solar system was non-existent. NASA dissolved its Future Projects Branch in the mid-60s, ending nearly all of its activities on lunar base design and manned Mars missions.

The Apollo program would end with Skylab (and the largely symbolic joint ASTP mission with the Soviet Union in 1975), a space station that was reasonably large but could nevertheless still be put into orbit on a Saturn V without major upgrades. By the time Skylab was launched, in 1973, NASA was already contemplating a reusable winged shuttle as its next generation launcher, with a much lower payload capability but a much higher economic efficiency. Large structures like space stations would be brought up to orbit one piece or module at a time at low cost, rather than being shot up in one go on expensive, non-reusable monster rockets. Which brings us back to the issues discussed at the start of this chapter.

The only major aerospace company in the U.S. still looking at Nova-class launchers by the end of the 1960s was Boeing, which performed studies under NASA contract on a single-stage-to-orbit plug-nozzle liquid oxygen/hydrogen launcher, with optional solid propellant rockets for increased payload capabilities. The main purpose of the studies, however, was not to lead directly to the development of the actual launcher, but instead to gain an understanding of which 'enabling' launcher technologies would need to be developed.

In the mid-1970s, interest in Space Solar Power systems, or satellites with gigantic solar arrays beaming energy down to Earth (see Chapter 5), briefly rekindled the interest in extremely heavy-lift, cost-effective launchers. Among other ideas, it led to the Boeing concept resurfacing, in a somewhat different and more modest form, as the subject of a study conducted for NASA on launchers with LEO performance of over 200 metric tons. In the revived study, the reusable Apollo capsule-shaped vehicle would use its engines to slow down after re-entry, then gently splash down in a five-kilometer-wide fresh water pond next to its launch pad. (Landing in fresh water was considered a better idea than landing in the ocean, as previous concepts proposed, because it was much less corrosive than salt water.) Two-stage alternatives would be able to carry 450 to 900 metric tons and this latter version was a monster, with a lift-off mass of 14 thousand metric tons, close to five times that of a Saturn V.

A very different looking concept favored at the time by NASA for launching Space Solar Power satellites was a Boeing design for a two-stage tandem winged vehicle with LEO capability of 424 metric tons; imagine two oversized Space Shuttle orbiters, one on top of the other, towering to a combined height of 164 meters (whereas a Saturn V stood 'only' 111 meters). The winged second stage would employ 14 Lox/LH2 engines (liquid oxygen as oxidizer and liquid hydrogen for fuel) similar to those of the later Space Shuttle orbiter, while the first stage vehicle would use 16 rocket engines fed with liquid oxygen and liquid methane fuel, and jet engines to help it fly back (the first stage would only glide, not ending up too far from the launch site at burn-out).

Quite reasonably, some in NASA thought this vehicle would be too big, leading the agency to request the company Rockwell to design a smaller version. Their concept had the two winged shuttles mated belly-to-belly, both downsized so that the LEO capability was 'only' 126 metric tons; similar to a Saturn V, but fully reusable, at least in theory.

Launcher developments in the Soviet Union also included plans for Nova-class rockets in the early 1960s. As an interesting aside to the N1 Soviet Moon rocket story, we now know that it's developers were not only in a race with the Saturn V in the U.S., but initially also with a national rival, an even larger and more powerful design in the Soviet Union itself.

The N1 was the brainchild of Sergei Korolev, the chief designer behind all the early Soviet space spectaculars such as Sputnik and the flight of Gagarin. His successes depended in no small way on Valentin Glushko, whose design bureau (the Soviet version of an aerospace company) had provided all Korolev's launchers with rocket engines up to the N1.

For the N1, Glushko had offered to develop extremely powerful engines, with similar thrust to Saturn's F-1, using propellants that would self-ignite upon contact and that would not need to be cooled to very low temperatures. This would avoid the need for igniters and would mean that the rocket could be kept fueled for a very long time without the propellant boiling off, thereby simplifying the rocket's design and operation. His choice of propellants had one disadvantage, however, in that they were highly toxic. Korolev preferred non-toxic propellants with a higher efficiency, a combination of kerosene and cryogenic (extremely cold) liquid oxygen.

Things got personal, and Glushko refused to collaborate further on the N1. Korolev turned instead to an aviation engine design bureau, which could offer engines running on Korolev's choice of propellant but had relatively low thrust; hence the need for 30 engines in the first stage.

Glushko, meanwhile, found another rocket manufacturer, Korolev's big national rival, Vladimir Chelomei, and came up with an alternative heavy-lift rocket concept based on his choice of propellants, the UR-700. Unlike the N1, the UR-700 was a modular design based on a cluster of separate booster stages, which would simplify testing and transportation. Bigger, wider, but less tall than both the N1 and Saturn V, the fully assembled UR-700 would beat the performance of the Saturn V and be capable of lifting some 150 metric tons into LEO.

Unlike the U.S., the Soviets made no early final decision on which launcher to develop. Instead, the N1 and UR-700 projects were largely developed in parallel, resulting in a very inefficient use of available expertise, resources and government funding. In 1969, when the first N1 was launched (but failed), the UR-700 was still in development. Glushko was in fact carrying out an extensive test program for the UR-700's RD-270 main engines, even though it was clear by then that the Soviet Union's only hope for beating the Americans to the Moon lay with the N1/L3.

Glushko and Chelomei, however, saw the UR-700 not only as a competitor to the N1, but also as the starting point for even more powerful derivatives. Development of a nuclear rocket engine to power new third and fourth stages was initiated, which was expected to raise the LEO capability to 250 metric tons. This nuclear UR-700A would enable the Soviets to land a complete manned spacecraft directly onto the lunar surface, similar to what was foreseen for the early Nova concepts in the U.S. There would be no need for separate orbiting and landing spacecraft, as with the schemes adopted for Apollo and Korolev's N1/L3. Later, during the 1970s, the UR-700A could be used for launching lunar base modules, large assemblies for in-orbit construction of a manned Mars landing mission, or even complete manned spacecraft for fly-bys of Venus and Mars.

But Glushko and Chelomei's ambition reached even further with the ultimate follow-on concept, the truly colossal, 16 thousand metric ton UR-700M, whose envisioned LEO capability was a spectacular 750 metric tons, more than five times that of a Saturn V. How it would have looked is still a mystery, but with this monster at their disposal, the Soviets hoped to beat the U.S. to Mars, if that had turned out to be the next goal in the Space Race. As late as 1971, engineers were working on launch pad designs for this monster, but it all ended when it became clear that the Space Race was over and there would be no manned missions to Mars by 1980. Instead, the focus in the U.S. and the Soviet Union shifted to more modest projects closer to home, in the form of reusable shuttles and Earth-orbiting space stations.

The engineers who envisioned colossal launchers like the various Novas or the UR-700M, seem to have had a mindset that is somewhat difficult to understand today. These people regarded the powerful Saturn V as only a relatively modest rocket, a step on the way towards more capable systems. Did they really think their supersized creations would ever have turned out to be technically and financially feasible? For an equivalent to their bold way of thinking, their fearlessly creative proposals for launchers so large that they defy the imagination even (or especially) today, I think we have to look at the world of architecture, where plans for kilometer-high skyscrapers are not deemed beyond credible. Buildings, however, do not need to be able to fly.

Since the 1970s, the lack of projects necessitating their extreme performance levels and warranting the huge investments required has meant that no plans for extremely heavy-lift launchers worth mentioning have been developed. Debates about the need for super heavy-lift launchers like the SLS still rage on, but the overall consensus appears to be that Nova-class monsters are definitely unrealistic in terms of the required investments, technical complexity and 'customer' needs.

THE FUTURE OF HEAVY LIFT

By the late 1970s, the Saturn V had been decommissioned, the Soviets had given up on their N1, and concepts for even larger Nova-type launchers were largely forgotten. This is linked to the increasing air of pessimism in spaceflight developments at the time, because with the end of the Space Race, it was no longer obvious that Moon bases and human Mars missions would follow on from the Apollo lunar landing missions. There seemed little need for the related super heavy-lift, let alone extremely heavy-lift, launchers.

At this point, the emphasis of launcher development, at least in the U.S., shifted to the reusable Space Shuttle, which promised such low operational costs and such frequent flight rates that putting bulky things into LEO piecemeal using a series of Shuttle flights seemed to make more economic sense than flying it all up on a few Saturn V-type launchers. The Shuttle was incapable of sending crewed spacecraft on their way to the Moon or Mars, lacking the ability to fly beyond LEO, but its short-term tasks were foreseen to include putting satellites into orbit, flying astronaut repair missions when these satellites malfunctioned or needed upgrades, and assembling a large modular space station (initially Space Station *Freedom*, which eventually evolved into the ISS), followed by microgravity factories where new metal alloys could be mixed, perfect crystals could be grown and spacecraft could be assembled and repaired. Any crewed Moon- or Mars-bound spaceships further into the future could then likewise be flown up one module at a time, to be assembled and fueled up in orbit. The time of the expendable heavy-lift launchers seemed to be over.

When the Space Shuttle turned out not to fulfill its promises of low costs, frequent launch rate and reliability, interest in old fashioned expendable launchers returned. As an aside, when the Shuttle became operational, it was expected to make all expendable U.S. launchers obsolete, which left the country with a serious lack of alternatives when the Shuttle was temporarily grounded in 1986, after the *Challenger* accident. Human spaceflight has now returned to using more conventional capsules sitting on top of relatively traditional launchers without wings. Those nations able to launch their own astronauts, the U.S., Russia and China, currently all follow this approach and are likely to do so until at least well into the next decade.

Unfortunately, no technologically transformative breakthroughs have taken place in the area of super heavy-lift launchers, or in fact launchers in general, in the decades since the birth of the space age. The technology and performance levels have improved over the past 50 years, but not by orders of magnitude, and the propellants used in operational launch systems have not changed over the past half-century, because the advantages of various alternatives did not turn out to compensate for their serious disadvantages. As mentioned, the Saturn V's F-1 rocket engine, developed in the late 1950s, is still the most powerful single-combustion-chamber, liquid-propellant rocket engine ever produced.

To bring the cost-per-kilogram to orbit figure down, the approach currently adopted by major launcher industries is to simplify the design of their launchers, streamline the production and furthermore aim for reusability (all exemplified by SpaceX), rather than go for massive, unproven launch vehicle concepts.

Nevertheless, for putting large and heavy elements into orbit and sending them beyond LEO, the interest in super heavy launchers has returned, exemplified by the SLS in the United States and the Long March 9 in China. These would enable crewed missions to the Moon with the use of one, or at most two launches. Concepts for crewed Mars missions now typically rely on super heavy-lift capabilities, such as those envisioned for the SLS, accepting that in-orbit assembly of the spacecraft will be necessary. The feasibility of this operation has been proven with the assembly of the modular International Space Station.

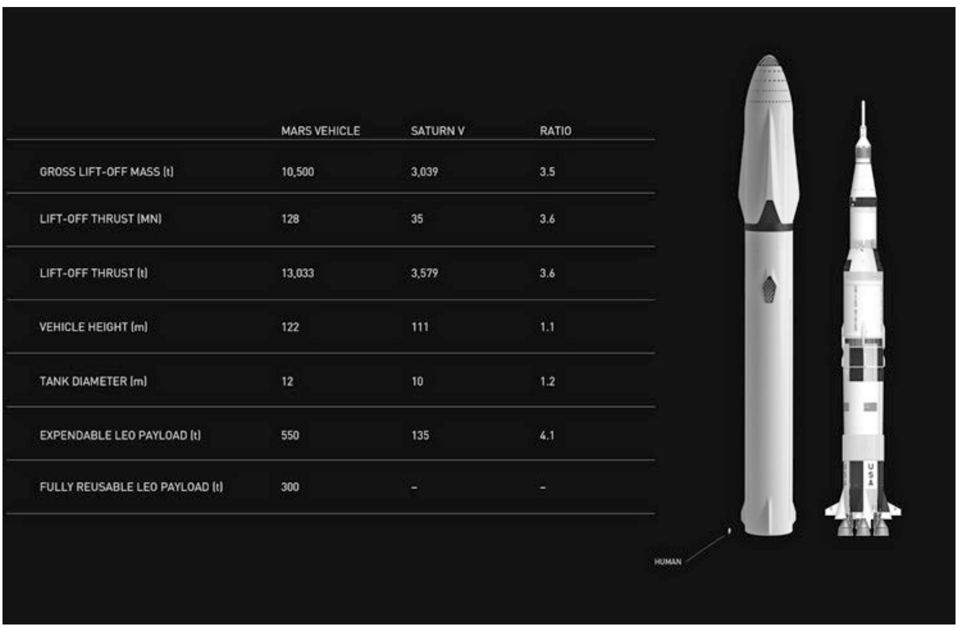
However, even with this new interest in super heavy launchers, there are currently no advanced plans for extremely heavy-lift launchers of the Nova class. Even bearing in mind the all-pervading optimism of the 1960s, as well as the technological developments and the seemingly limitless government space budgets, when looking back at concepts like NEXUS and Sea Dragon from a modern point of view, they do appear to be quite a bit over-the-top. This is particularly true given the lack of fast-paced human expansion into the solar system or at least a thriving business for very large LEO satellites and space stations.

It would certainly be spectacular to witness something with the size, thrust and sonic onslaught equivalent of four Saturn V rockets lifting off. Unfortunately, with the lessons learned from the Space Shuttle in mind, the assembly, transportation, operation and reuse logistics of these gigantic launchers now appears to be unfeasible and, more importantly, unnecessary.

In today's world, it would also be unthinkable to incorporate the live nuclear rocket stages that were part of many of these old U.S. and Soviet concepts. A launch failure of such a rocket could radioactively contaminate the entire launch complex for decades, similar to the area around the Chernobyl nuclear power plant that blew up in 1986.

It therefore seems unlikely that we will see any Nova-class launchers going up in the near future. That being said, the Mars colonization plans that Elon Musk, founder and CEO of the successful launch company SpaceX, presented at the International Astronautical Congress in September 2016 are based on a massive reusable launcher that would have 3.5 times the lift-off mass, 3.7 times the lift-off thrust and 4.1 times the LEO payload of a Saturn V. It would still fit on Kennedy Space Center's launch Pad 39A, from which Saturn Vs and Space Shuttles used to take off, because that pad was originally oversized for Saturn V and because the Space X 'Mars Vehicle' is only slightly higher and thicker than the Apollo Moon rocket (more on Musk's Mars plans in Chapter 7; see '*On Mars in 2030+*').

Musk's design is based on clustering large numbers of rocket engines, similar to the concept of the Soviet Union's ill-fated N1 moon rocket, with 42 Raptor rocket engines in the first stage. The N1 suffered all sorts of problems with this clustering concept, but SpaceX has experience with it, as their Falcon 9 first stage uses nine engines and their new Falcon Heavy uses three Falcon 9-derived core boosters for a total of 27 engines.



	MARS VEHICLE	SATURN V	RATIO
GROSS LIFT-OFF MASS (t)	10,500	3,039	3.5
LIFT-OFF THRUST (MN)	128	35	3.6
LIFT-OFF THRUST (t)	13,033	3,579	3.6
VEHICLE HEIGHT (m)	122	111	1.1
TANK DIAMETER (m)	12	10	1.2
EXPENDABLE LEO PAYLOAD (t)	550	135	4.1
FULLY REUSABLE LEO PAYLOAD (t)	300	-	-

SpaceX concept for a Mars colonist transporter on top of its reusable launcher, compared to a Saturn V. [SpaceX]

This latest giant launcher design, which is planned to incorporate the most up-to-date materials and rocket engine technology, is for now only a concept, although SpaceX has done considerable design work already. Huge (government) investments would be needed to have it developed, and currently the U.S. government does not seem ready for a huge Mars settlement undertaking. Moreover, the context in which this launcher was presented emphasizes the point that Nova-class launchers only make sense as part of a large-scale space settlement program.

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