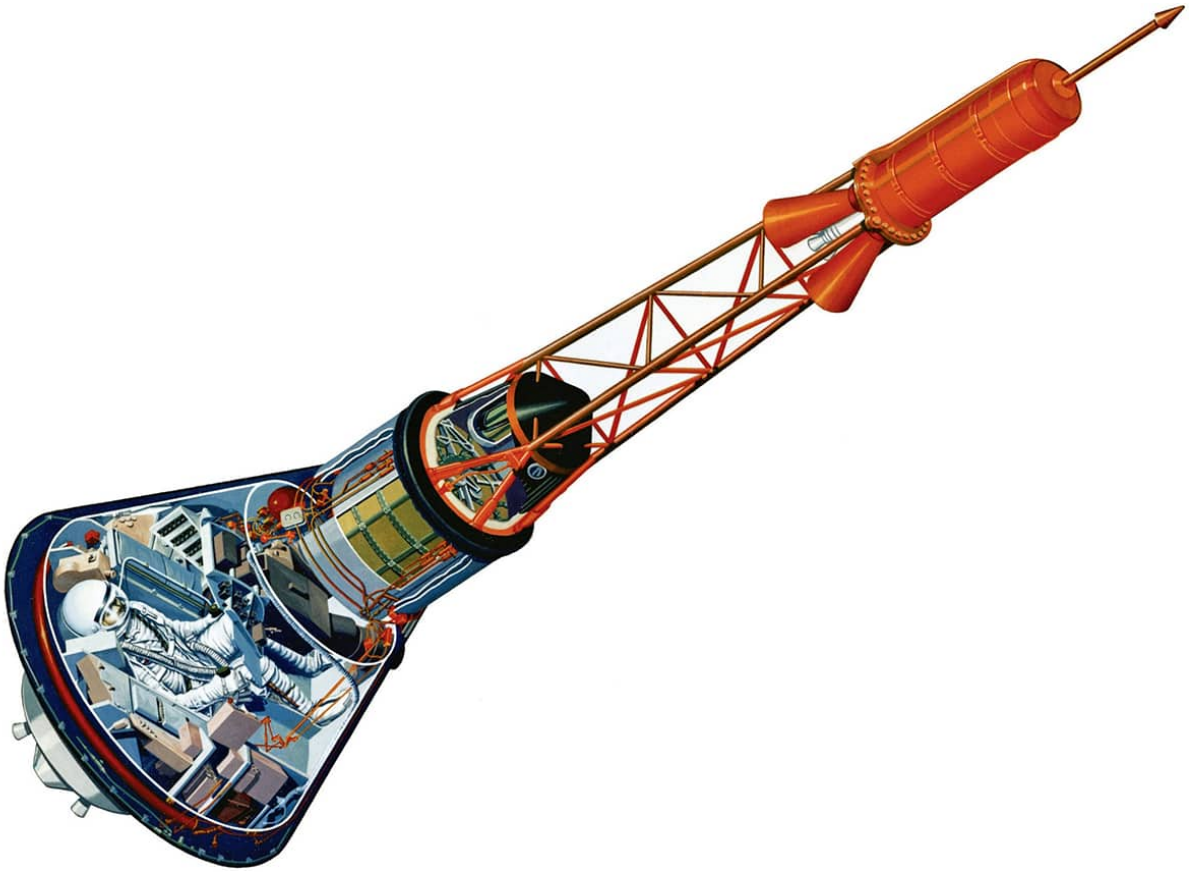
The Art of NASA

THE ILLUSTRATIONS THAT SOLD THE MISSIONS

PIERS BIZONY



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Additional research
MIKE ACS

Chariot for Apollo

Davis Meltzer was an important illustrator of space themes during the Apollo era. This is his 1967 conception of a Saturn V ascending from NASA's Kennedy Space Center in Florida.

Contents

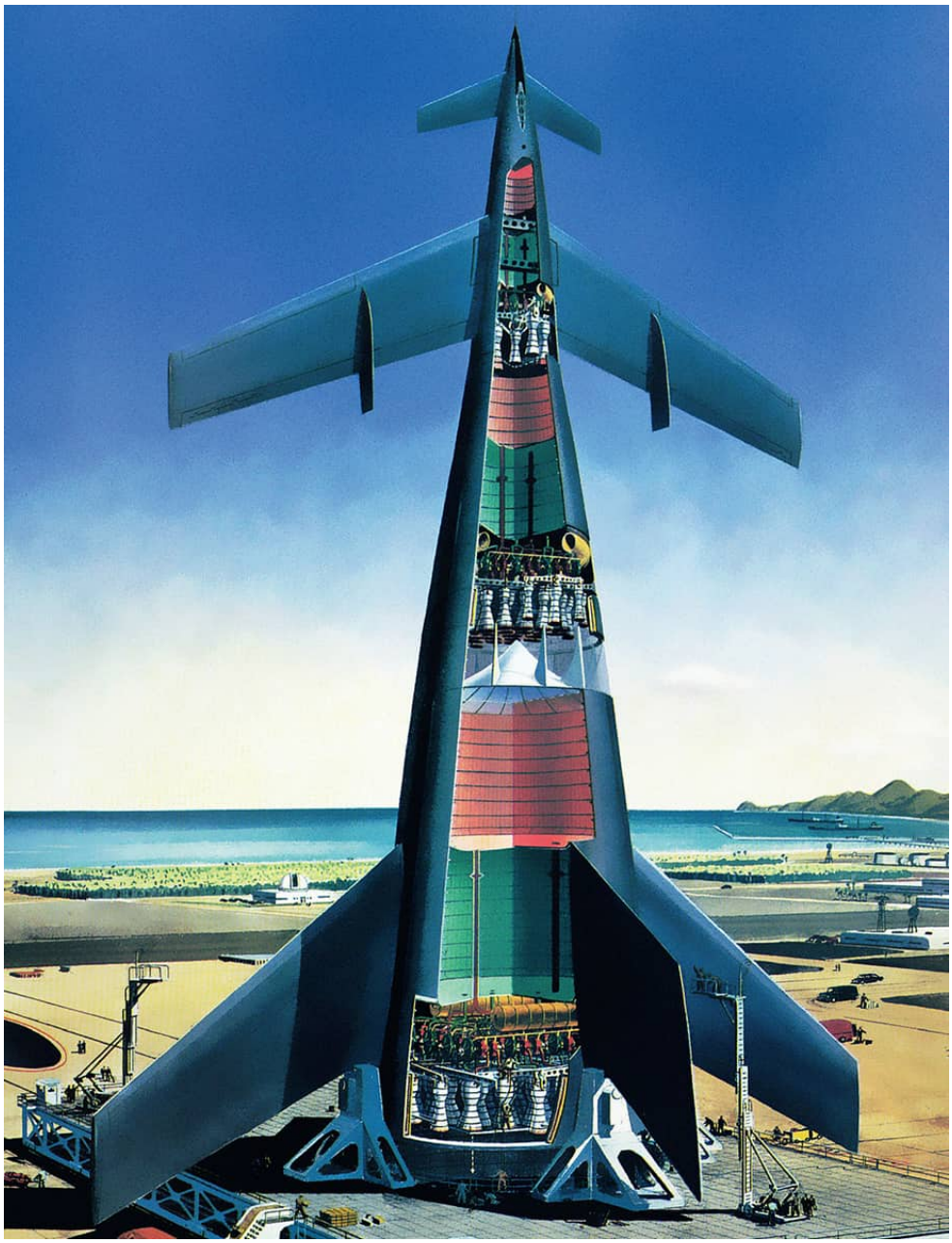
FIRST COMES THE DREAM

How Art Showed the Way to Space

In the early years of the American rocket program, explanatory graphics distributed by civilian space agency NASA were primitive by today's standards. The first press release depictions of the Mercury capsule, America's first human-carrying spacecraft, were quite literally sketchy on details. Simple black-and-white graphics for public relations purposes predominated in an age when newspaper photos and illustrations typically were not printed in color. Even most televisions that dominated living rooms were still monochrome throughout most of the 1960s, although several nationally prominent glossy magazines did carry color content. Among them, *LIFE* proved crucial in portraying the (albeit idealized) lives of NASA's new Mercury astronauts in vivid color, while *National Geographic* magazine commissioned brilliant artists, such as Pierre Mion and Davis Meltzer, to depict aspects of the emerging space adventure that no camera could ever hope to capture: godlike views of spacecraft and astronauts as if seen by a mysterious alien onlooker hovering some way outside the action.

Often the magazine materials and NASA press handouts overlapped because the same reliable corps of commercial artists with an eye for space subjects frequently made renderings for companies that were building the rocket hardware, as well as for the magazines presenting space-related stories for mass consumption. The first decent color cutaway of a Mercury capsule emerged not from NASA but from spacecraft fabricators McDonnell Douglas as part of its corporate literature, and then was widely disseminated to the press—usually in black-and-white. Promotion of the Gemini program also started out with rough visualizations, but by this point (the mid-1960s) in the so-called Moon Race, color was even more widely available on newsstands, and the media's appetite for handouts was insatiable. NASA's press departments, photo-processing labs, and graphics teams began operating on an industrial scale, making sure that American taxpayers were kept abreast of every tiny detail about the national space project. Partly this had to do with maintaining political support for a hugely

expensive enterprise, but just as important, it was a way to express how open NASA's effort was in comparison with the secretive Soviet rocket program, which seldom released photos of anything more informative than cosmonauts smiling for official portraits.

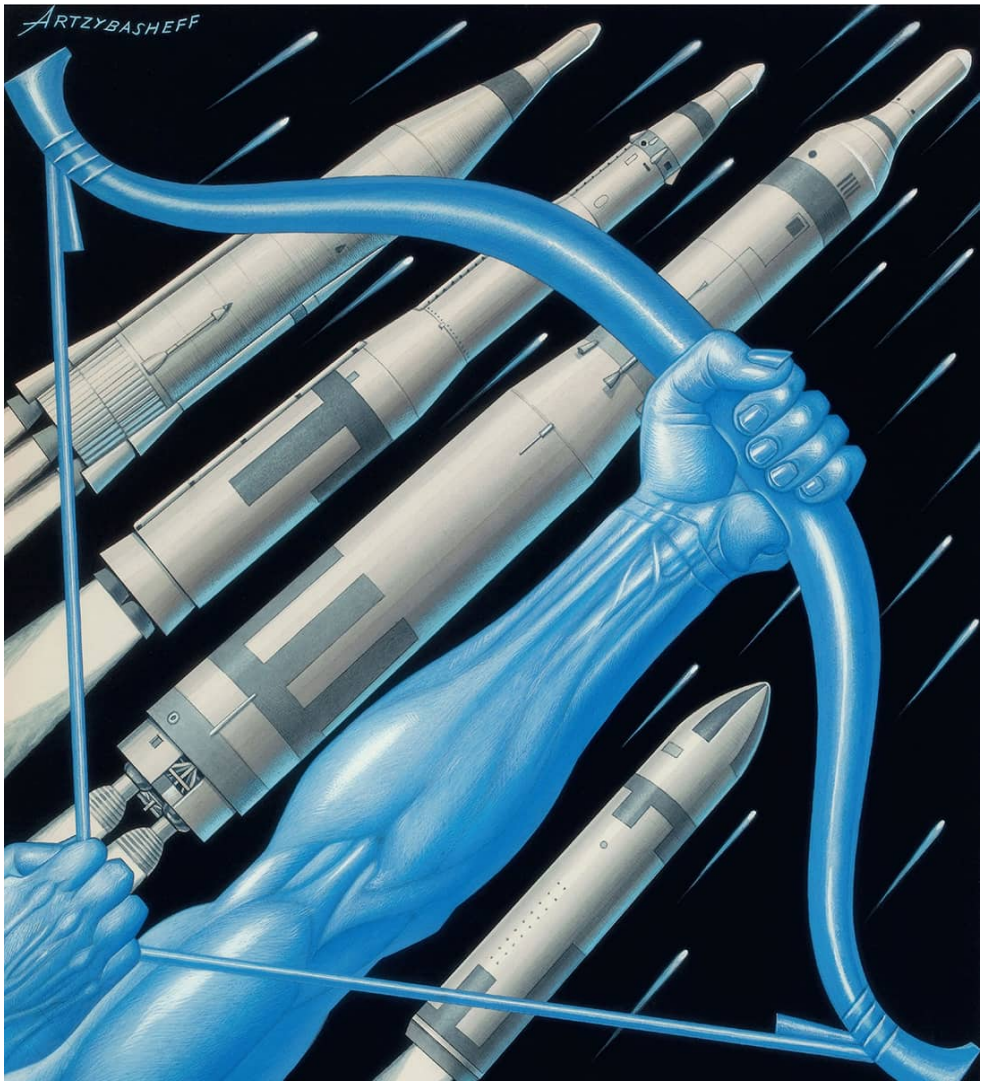


Wings of desire
Rolf Klep's 1954 illustration (left) for *Collier's* magazine of a reusable spaceplane atop a rocket designed by Wernher von Braun.

Apollo's complex and eventful mission profile of launches, dockings, undockings, landings and takeoffs, rendezvous maneuvers, jettisoned modules, and parachuted splashdowns brought illustrative storytelling from NASA and its contractors to new levels of sophistication. As ever, the many visuals showed the intricate space ballets from a perspective outside the vehicles, as if from a vantage point where no human observer could possibly exist. By 1968, just as the real Apollo lunar flights were on the verge of launching, artists' renderings had become highly detailed and technically accomplished. The Mercury days of explanatory labels glued unevenly onto photo prints of rough sketches were gone for good. Even when newspapers still demanded images that could be reproduced using just black ink, or "duotone" variations using shades of just one ink to create the illusion of greater color variation, some of the results, such as early Apollo ideas from the artist partnership of Ludwik Źiemba, and W. Collopy, or those created by *Los Angeles Times* art director Russ Arasmith to explain the lunar mission profiles, needed no full-color embellishments to stand out as timeless masterpieces in their own right. Art played a role in the NASA story beyond the technically illustrative alone. In 1962, NASA chief administrator James Webb and Hereward Cooke of the National Gallery of Art in Washington, D.C., wrote letters of invitation to prominent artists, inviting them to tour NASA and create works based on their impressions. They were eloquent about the need for both art and science in any space endeavor. "When a major rocket launch takes place, more than two hundred cameras record every split second of the activity," they wrote. "But the camera sees everything and understands nothing. It is the emotional impact, the interpretation and hidden significance of these events that lie within the scope of the artist's vision." Selected artists had a freedom of access to NASA's facilities that seems unthinkable in today's less trusting era.

Paul Calle, famous for his scenes of life in the Old West, took up the challenge, producing superb pencil drawings of astronauts and their capsules that served the needs of clear explanation and artistic interpretation alike. In similar vein, Pamela Lee brought a warm human touch to her portrayal of shuttle astronauts at work, keeping the human aspect in the forefront without compromising any background technical details. (Thank you, Pamela, for allowing us to use a fabulous example of your work in these pages.) Robert McCall, a well-known aerospace illustrator, made romantic yet technically accurate pictures to satisfy space hardware buffs,

while fine-art practitioners such as Lamar Dodd, Mitchell Jamieson, and James Wyeth captured a more impressionistic story of wires, switches, cables, and dials, silver-clad humans embedded into the machinery of their ships, and the eerie open landscapes around the launch pads. The resulting art collection, a major body of work, is now under the guardianship of the Smithsonian Institution's Air and Space Museum, in Washington, D.C.



Cold War Rocketry
Boris Artzybasheff's stylized 1963 portrayal of the United States' arsenal of missiles, *Sinews of Strength*, originally commissioned by the Avco Corporation. This artist made similarly dramatic covers for *Time* magazine during a period of anxiety about nuclear war and supposed Soviet missile superiority: a fear (based on exaggerated reports) that led to the opening of the U.S. space frontier using rockets based on adaptated missile hardware.

The importance of dreaming

Times have changed. In 2004, the singer and performance artist Laurie Anderson accepted a yearlong commission as artist-in-residence for NASA. With her penchant for dreamlike electronic experimentation and restless curiosity about modern technological culture, she was the perfect artist to take a quirky, sideways look at the space business. Sadly, by then Congress had forgotten the importance of art. When it got wind of Anderson's modest honorarium of $20,000 for a year's work, some lawmakers led a successful campaign to halt the project. "NASA should not be spending taxpayer dollars on a performance artist," they said. Such narrow-minded thinking could cost America its future in space, because, as the great Russian pioneer of theoretical rocket studies Konstantin Tsiolkovsky said in 1905, "First, inevitably, comes the idea, the fantasy, the fairy tale. Then, scientific calculation. Ultimately, fulfillment crowns the dream." Illustrations and art works are an essential aid to dreaming about future space projects, and ultimately, fulfilling at least some of those dreams.

When the dazzling NASA mission photos came back from the Hasselblad cameras carried by the Apollo astronauts, we saw what they saw: Earth from afar, rising above the lifeless lunar horizon; crewmates drifting weightless at the end of uncoiling umbilicals; white-suited figures with cyclopean golden visors kicking up lunar dust. We could imagine ourselves in an astronaut's place, photographing a colleague backdropped by the black of space, or the softly contoured mountains of the Moon. Those photos were priceless for their societal and psychic impact. Mainly it's the photos that we return to now, time and again. We can never be anything but stunned by their crisp, timeless beauty, but there's more than "just" the photos to the NASA story.

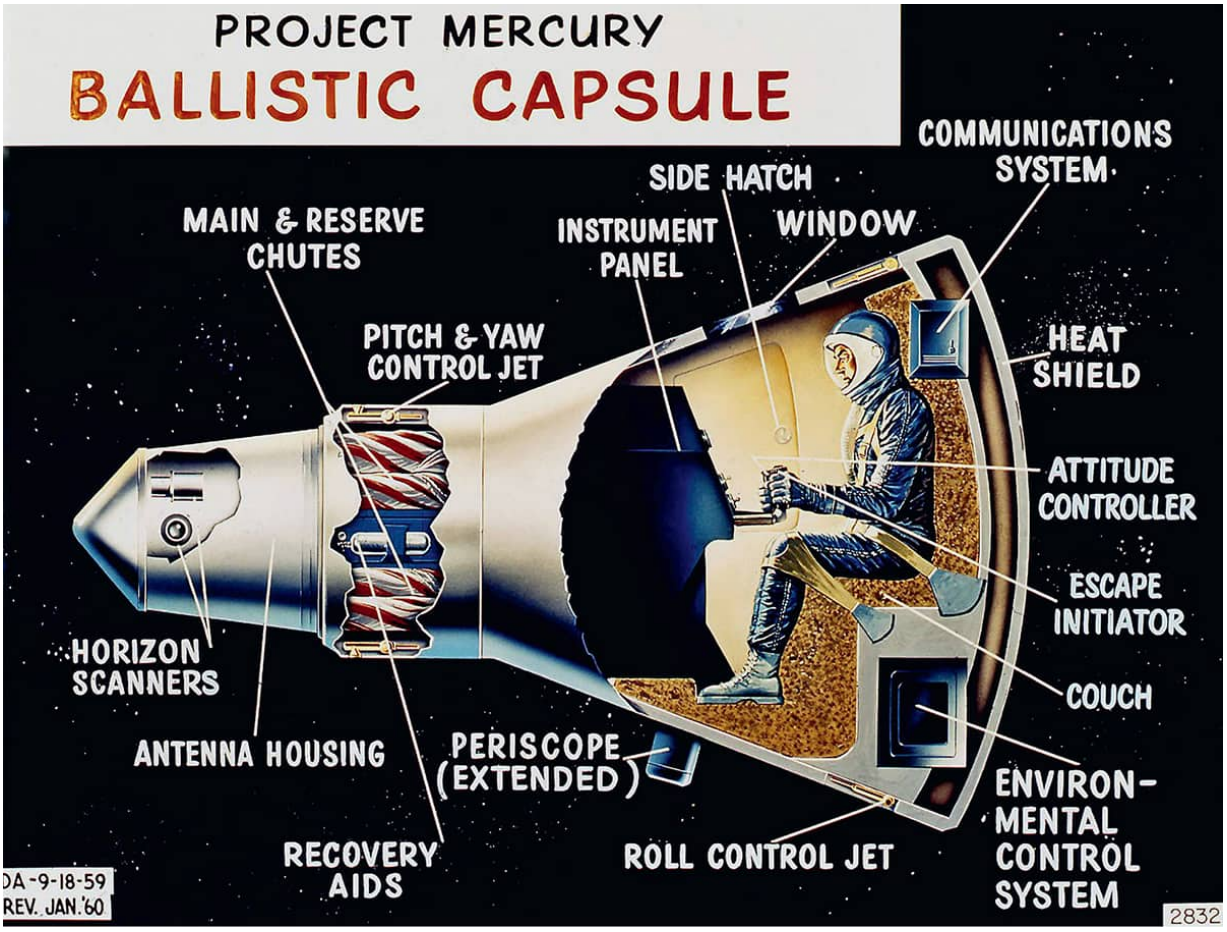
The challenges of archiving

Meanwhile the countless graphics, all the explanatory paintings and drawings made *before* the missions got underway in order to convey what was about to happen? Most of those have been relegated to the "no longer so important" part of our memories, and that's definitely a slight gap in the historical record. This book is an attempt to refill some of that gap, but there's a long way to go, because NASA is a space agency, not a museum, and far more historical materials have gone missing over half a century than can easily be retrieved.

The same applies to major space hardware contractors, such as Boeing, Lockheed Martin, North American Aviation, and so on. Again, these entities are businesses, not museums, so the allocation of costly real estate for unprofitable archives is limited. Company historians do what they can, while corporate takeovers keep changing the aerospace industry's restless configurations. All those clear-outs of weather-beaten hangars and outdated office buildings in the course of restructuring company hierarchies over the last five decades have condemned piles of "redundant" paper to dumpsters. In terms of pristine original physical materials, only NASA's photo film strips from the actual missions are held sacrosanct in special vaults. These first-generation physical artifacts are treated as national treasures. Too much else of the early American space story comes to us as hand-me-down reprints, or smudged copies of reprints.

Slipping the bonds of Earth

North American Aviation artist Robert Nicholson's 1960 depiction of the X-15 rocket plane, whose record-breaking ability to reach the edge of space helped win that company a major share of work on the Apollo lunar landing project during the subsequent decade.

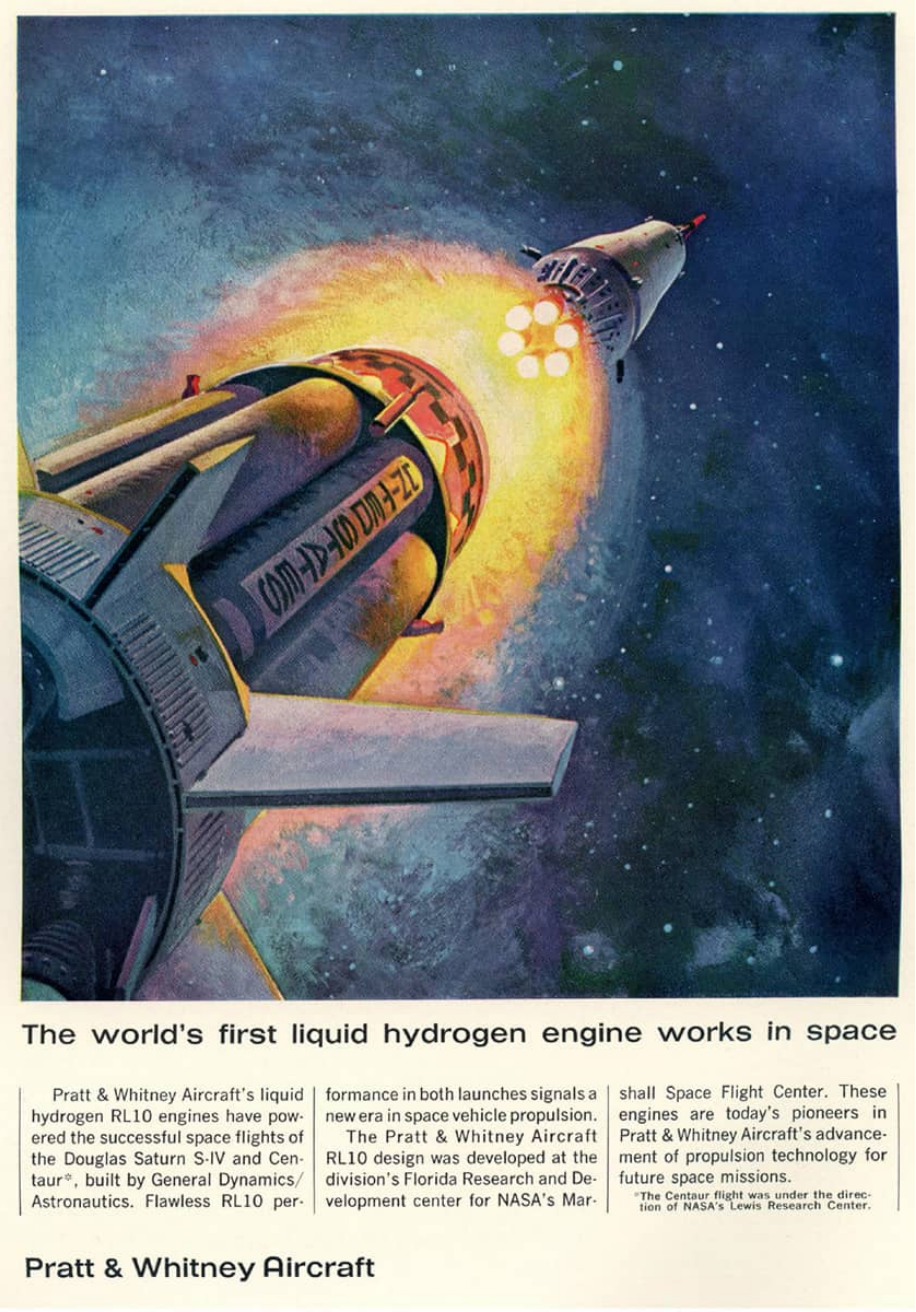


America's first piloted spacecraft
This may not be the finest technical illustration in aerospace history, but it is momentous all the same. This is the first rendition of a human-carrying spacecraft showing something that was destined actually to be built and flown. Note the date information at bottom left.

Tens of thousands of hand-inked hardware drawings adorned with rub-down letters and dot-screening textures were prepped on stiff white paper sheets for CRA (camera-ready artwork), which would be turned into negative film sheets and sent off for printing as positive photo handouts. Then the negative sheets were dispatched for acid etching onto metal plates for printing in technicians' instruction manuals. All too often, the original paper artworks were regarded as intermediate processes, and most were discarded once the photos and printing plates had been created. Even the printed technician's manuals are now collectible rarities.

Much the same fate lay in store for the countless gorgeous color paintings, all too many of which were discarded once the “important” business of turning them into glossy press handouts and glamorous lithograph special edition prints had been completed. Vintage space-related lithos are rare as hens’ teeth, these days. As for the actual artworks on which they were based, these are even harder to find. Happily, a generation of citizen space archivists is at work beyond the walls of NASA, tracking down and restoring whatever they can find, and often recreating passably good versions of important artworks by careful enhancement of photographic and print sources.

I am grateful to Paul Fjeld, Ed Hengeveld, Eric Jones, Scott Lowther, Ron Miller, and Kipp Teague, first-class historians of the Space Age with deep archival knowledge of NASA’s visual story. Look up the Internet shadows of any of these good people and you will not regret it. Most especially I should like to thank Mike Acs, a citizen archivist whose collection includes rarities not seen anywhere else—at least, not in the half-century and more since they were first created by NASA and its associated contractors. Mike’s substantial online presence is a marvel. His knowledge of individual artist biographies proved crucial to this project, as did many of his extremely rare images. Also seek out the digital doorways that lead you to J. L. Pickering, an important space historian, and one of the world’s leading archivists of vintage NASA imagery. J. L. also granted access to a wide range of fabulous images from his collection specially for this book. Thanks also to Patrick Short for unearthing rare works by Carl Zoschke, an early 1960s commercial illustrator whose name is hardly remembered these days, although it deserves to be.



The world's first liquid hydrogen engine works in space

Pratt & Whitney Aircraft's liquid hydrogen RL10 engines have powered the successful space flights of the Douglas Saturn S-IV and Centaur*, built by General Dynamics/Astronautics. Flawless RL10 performance in both launches signals a new era in space vehicle propulsion.

The Pratt & Whitney Aircraft RL10 design was developed at the division's Florida Research and Development center for NASA's Marshall Space Flight Center. These engines are today's pioneers in Pratt & Whitney Aircraft's advancement of propulsion technology for future space missions.

*The Centaur flight was under the direction of NASA's Lewis Research Center.

Pratt & Whitney Aircraft

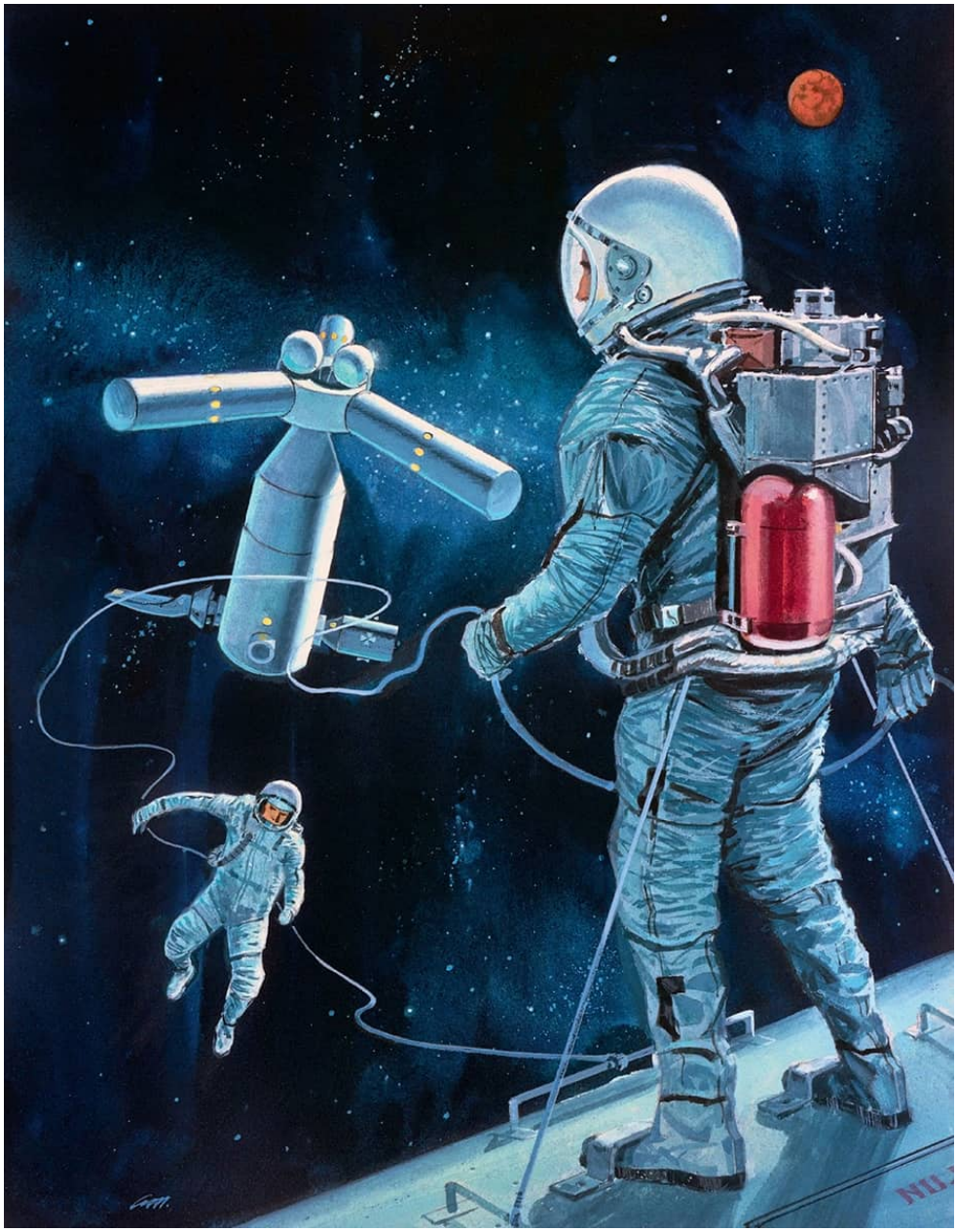
Selling the Space Age

Pratt & Whitney advertisements highlighting the company's contributions to space exploration. Some of the best artist's concepts were created for commercial uses, but because the hardware manufacturers had such a close relationship with NASA, many of their illustrations also found their way into the space agency's publicity files.

Despite the attrition of the "official record" over time, NASA of course does retain excellent copies of many key artworks, preserved on four-by-five-inch color film sheets. *The Art of NASA* benefited from the invaluable assistance of Bert Ulrich, multimedia liaison at NASA headquarters in Washington, D.C., and NASA senior photographicresearcher Connie Moore, who patiently unearthed and rescanned many treasures for me, often on the basis of vague hints of what I was searching for. In addition, veteran photo archivist and former NASA public affairs staffer Mike Gentry was a

staunch ally, often telling me what I did not know was out there, as well as helping to hunt down what I did.

Nevertheless, anyone familiar with NASA's history knows in their bones that despite all these surviving riches, too much has been lost, especially in the realm of original graphics and illustrations. There probably are more artistic wonders out there, in the homes of NASA veterans, retired aerospace workers, and the forgotten filing cabinets of press offices whose holdings haven't all been completely subsumed into digital libraries. Keep your eyes peeled and let me know if you find anything.



Heroes in shining armor

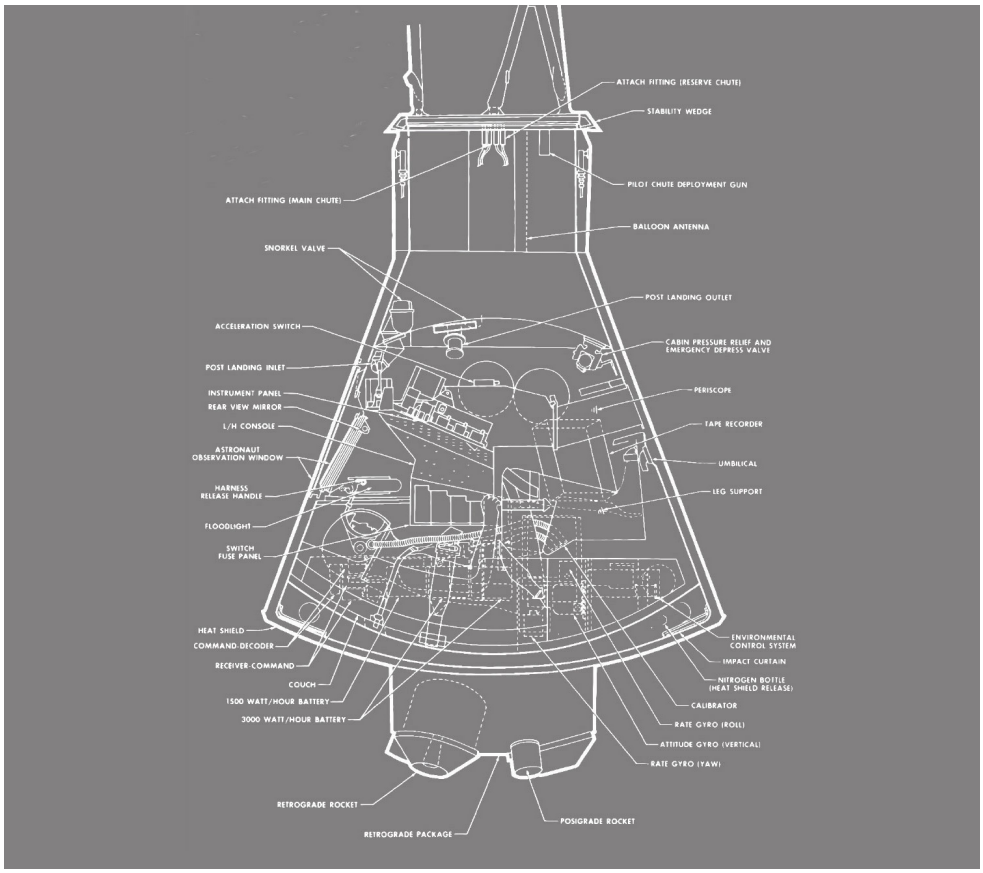
Just like many companies involved with NASA, Boeing hoped that the “Space Age” would continue indefinitely. This early 1960s concept for a space station is themed on extended versions of Apollo hardware, which Boeing hoped to build one day.

1

THIS NEW OCEAN

The Dawn of the American Space Age

In 1954 many experts predicted that we would build orbital space stations and undertake lunar missions by the early 21st century. None of them imagined that the first humans would venture into space just seven years later.

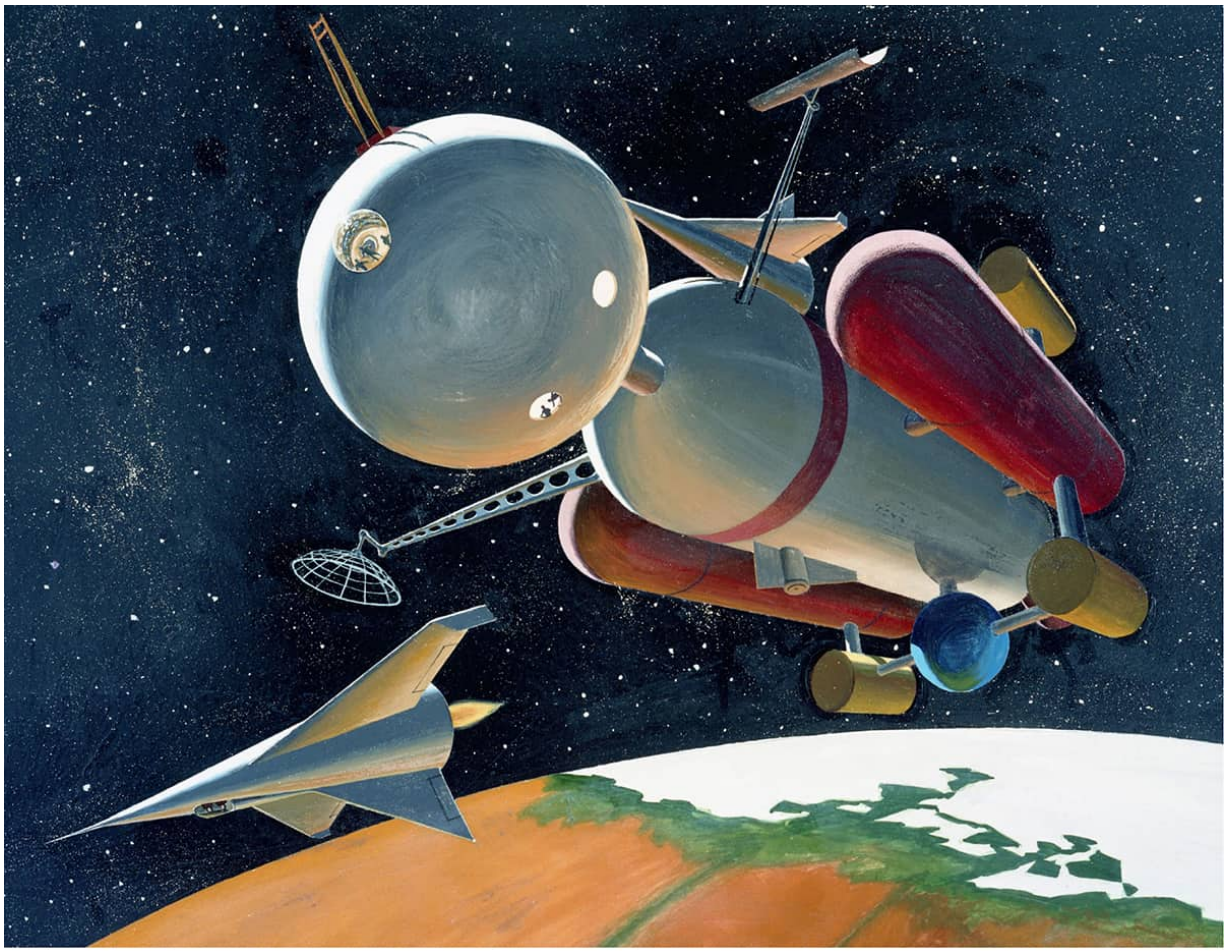


The “Dan Dare” Dream
This promotional fantasy from the Boeing company was just one of many such visions presented throughout the 1950s by corporations keen to play a role in turning space fiction into scientific and technological fact.

1: This New Ocean

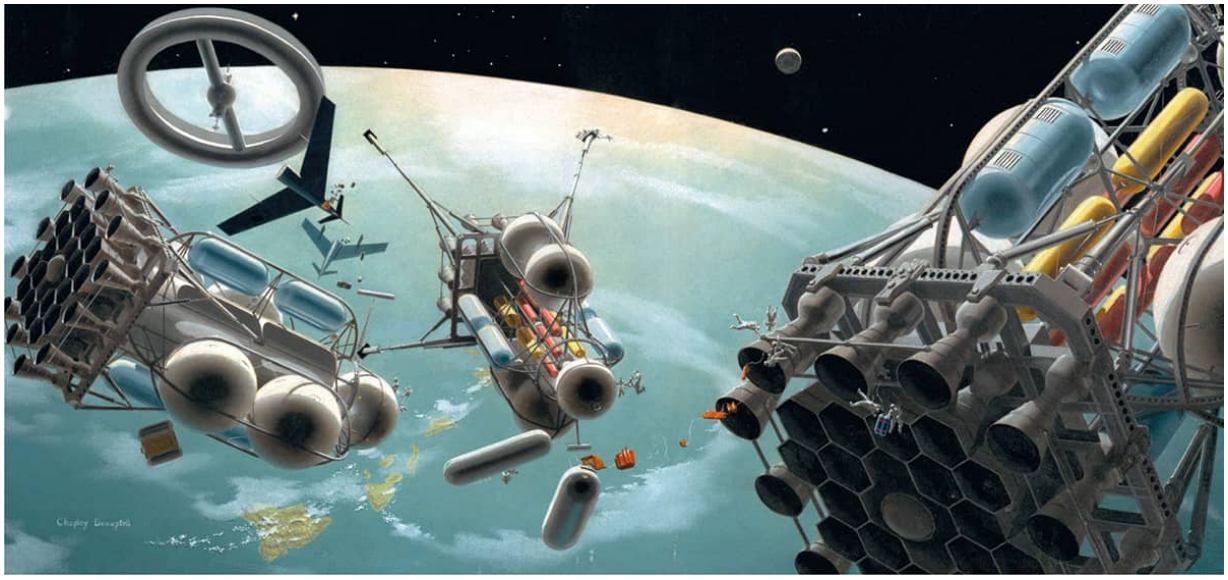
In 1954 the American public was informed that “scientists and engineers now know how to build a station in space that would circle the earth 1,075 miles up. The job would take 10 years and cost twice as much as the atom bomb. If we do it, we can preserve the peace and take a long step toward uniting mankind.” This vision was presented to a wide audience in a series of articles for *Collier’s*, a popular color illustrated magazine of the time. Between 1952 and 1954 seven major space articles were published, including descriptions of a lunar colony and a mission to Mars. Systems for potential future space missions, devised mainly by German-born rocket pioneer Wernher von Braun, were brought to life by illustrators Chesley Bonestell, Rolf Klep, and Fred Freeman. There was a giant wheel-shaped space station gently turning on its axis, its crew enjoying artificial gravity generated by the rotation. A painting by Bonestell shows the station attended by winged rocket planes, while in the foreground huge landing ships are prepared for missions to the Moon “within the next 25 years.”

Willy Ley, a successful space popularizer in his own right, was von Braun’s major partner in creating the articles, along with many followup books. Most of these dreams had been familiar to rocket visionaries and science fiction enthusiasts since the 1930s, but the *Collier’s* articles represented perhaps the first time the public had been invited to think about rocket ships, space stations, and trips to the Moon as serious elements of national policy. The magazine sold three million copies a month. As a family title it would have been read by perhaps fifteen million people. Space was no longer just a vague dream. It was something for taxpayers to consider in earnest.

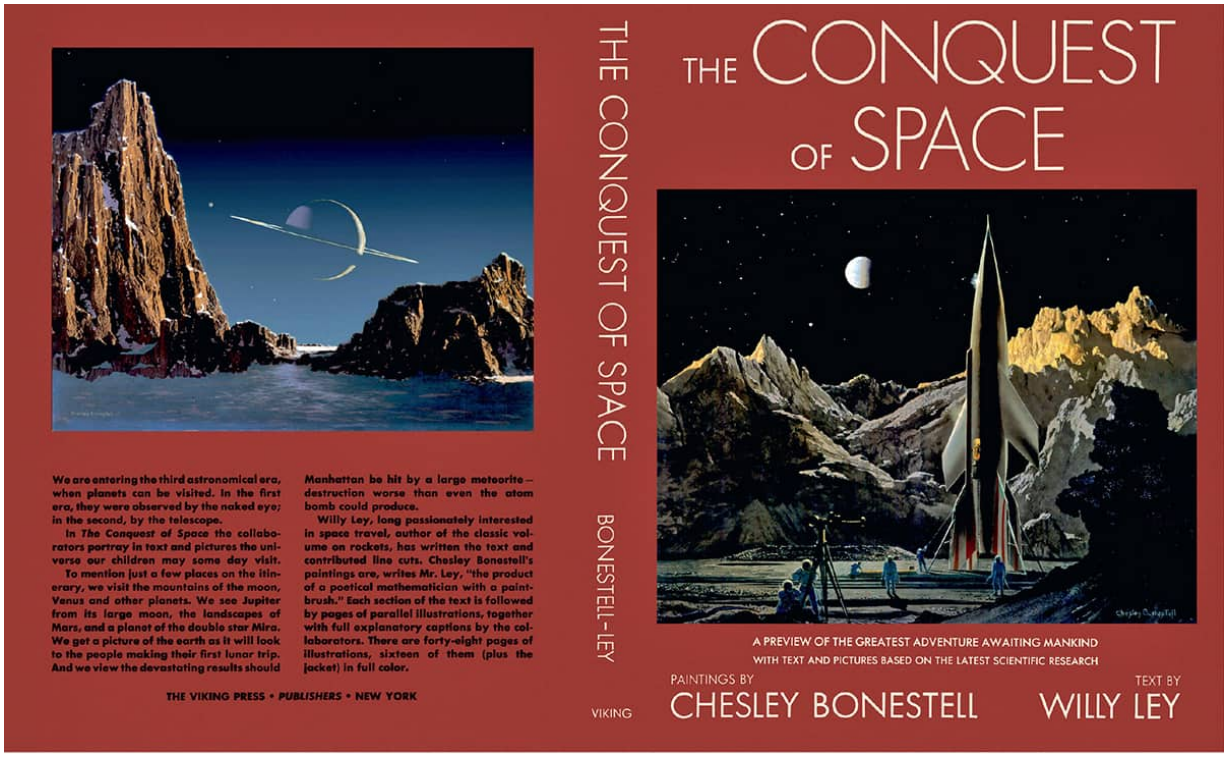


Aiming high

In the late 1950s, as America began to consider how to organize its space sector, major companies vied for the attention of Washington policymakers with enticing visions, such as this Boeing artwork of a rocket plane and a gigantic craft about to leave Earth on a great voyage of discovery.

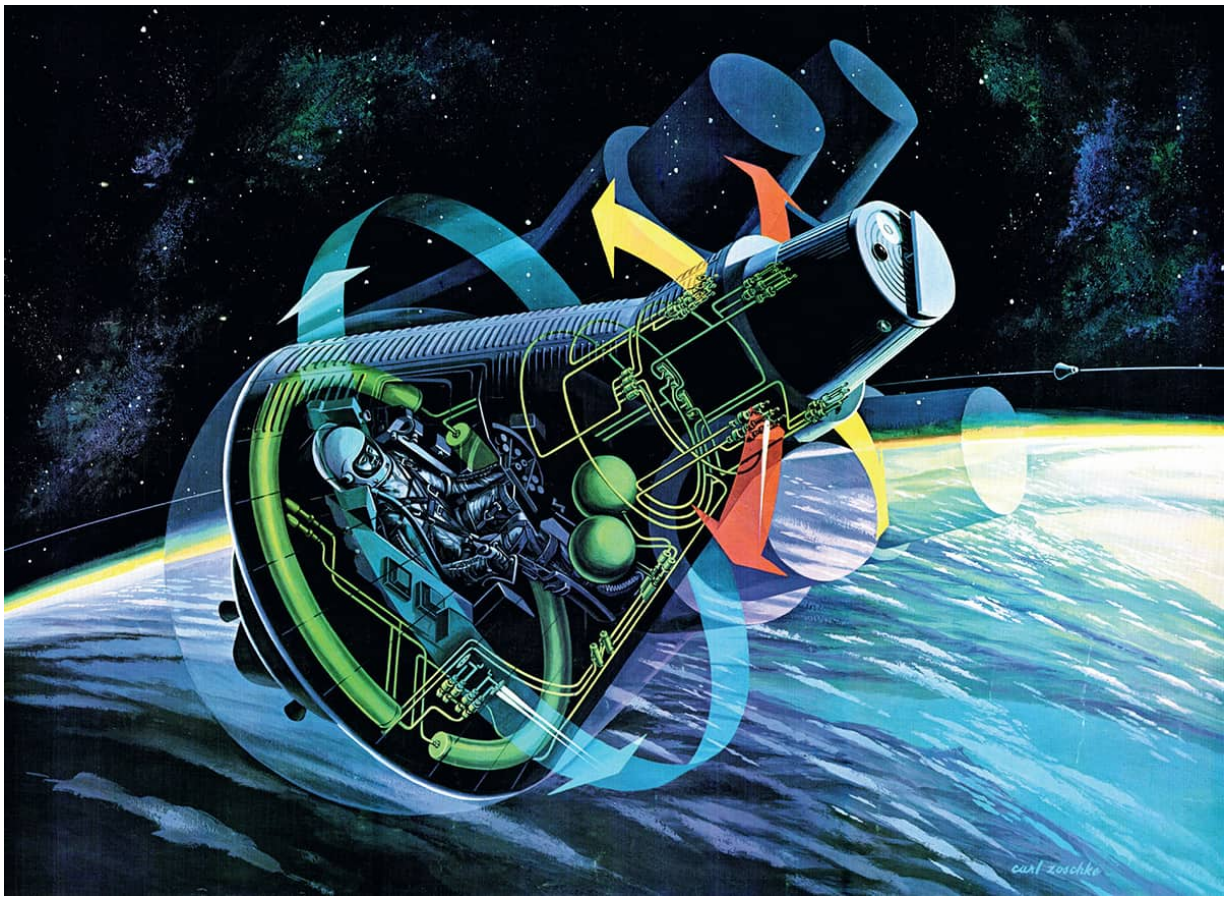


A vision for life in orbit
Chesley Bonestell's influential illustration for the *Collier's* space-themed articles of 1954. A fleet of moon landers is built from components delivered into Earth orbit by winged space planes.



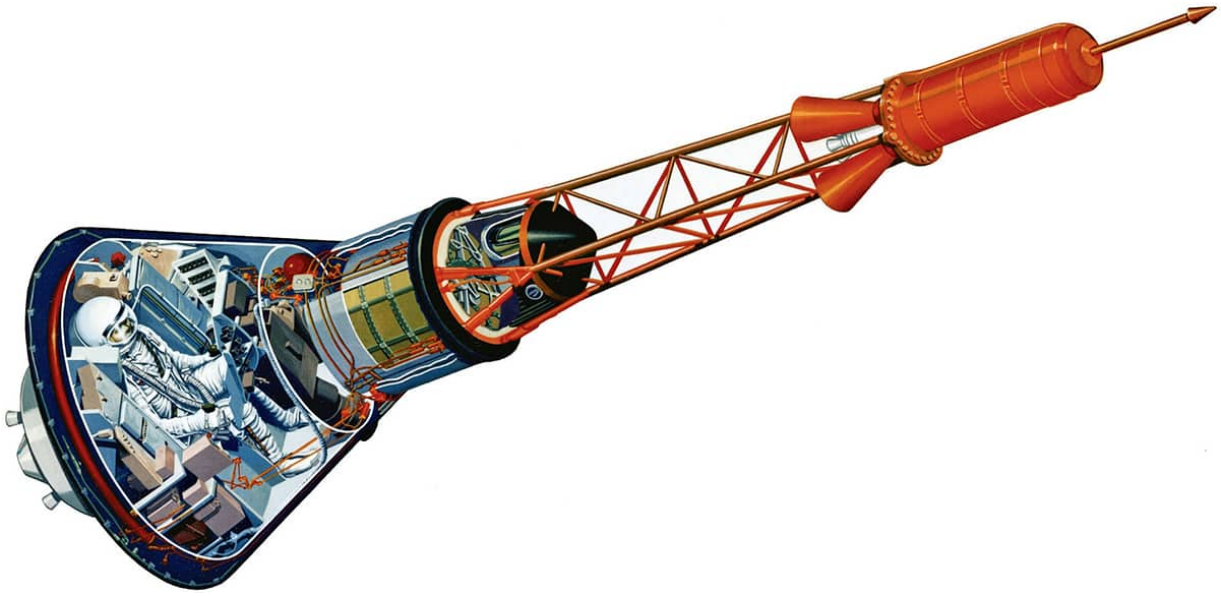
The literature of space
Hundreds of mid-20th century books, from cheap pulp editions to lavish art-quality volumes, helped sell the coming of the "Space Age." *The Conquest of Space*, first published in 1949, was among the most significant.

Just four years after the last of the *Collier's* space specials, the question of whether to turn any of those rocket visions into reality was becoming a matter of national importance. America had been planning low-key forays into space, but on October 4, 1957, the Soviet Union got there first, launching a tiny satellite, Sputnik. The National Aeronautics and Space Administration opened for business ten months later as an emergency response to Sputnik and the likelihood that the Soviets were planning to launch people into space in the near future. The fledgling space agency inherited some ideas for human space flight from various smaller aerospace research organizations across the United States, most of which were swiftly absorbed into NASA. The most developed project was called Mercury. A tiny cone-shaped capsule would ride on the top of a small battlefield missile, the Redstone, based closely on Wernher von Braun's notorious V2 rocket technology, which he had brought to fruition during World War II under the Nazi regime before escaping to America in the hope of pursuing his deepest ambition: the peaceful exploration of space.



Gaining control

Carl Zoschke's illustration of a Mercury spacecraft's reaction control system, manufactured by Bell Aerosystems. Color-coded arrows highlight pitch, roll, and yaw movements enabled by corresponding sets of thrusters.



Spam in a can

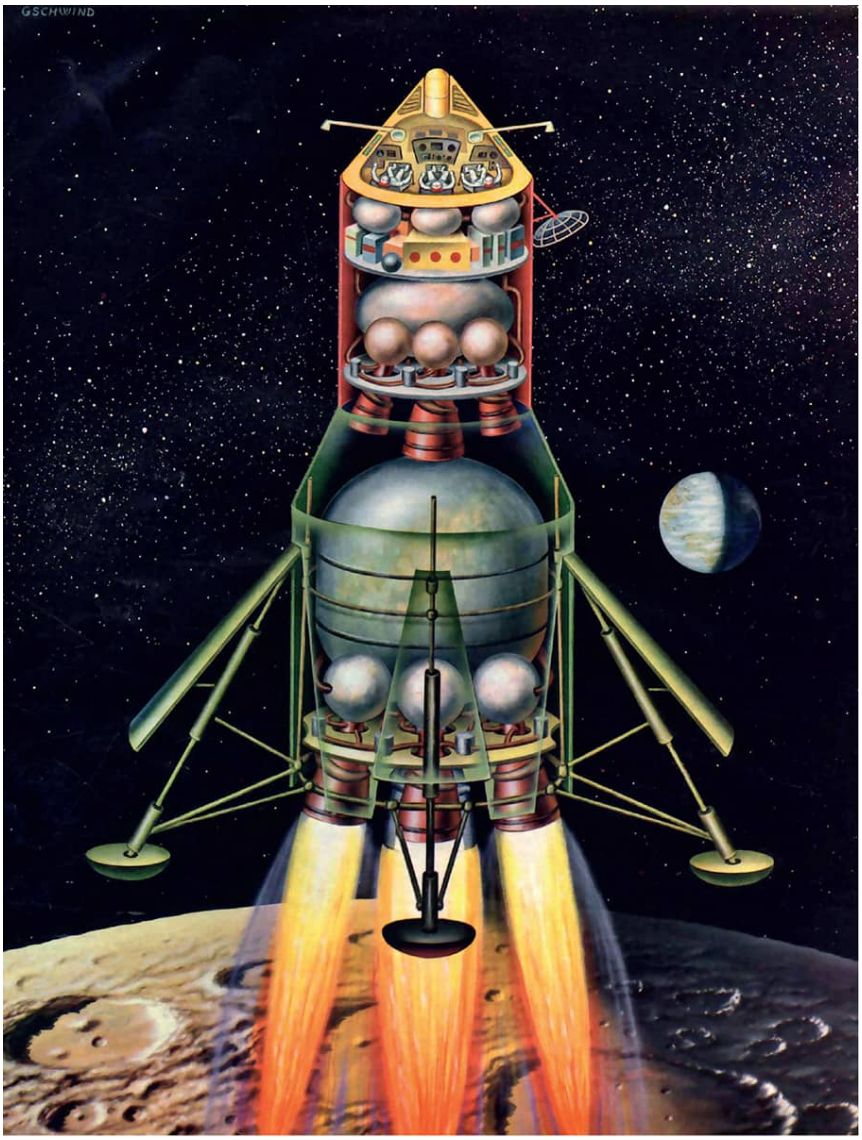
An accurate illustration by "A. Pierce" shows the equipment layout of the Mercury spacecraft manufactured by McDonnell Aircraft Corporation of St. Louis, Missouri, in conjunction with NASA's Space Task Group at Langley, Virginia. This painting dates from 1961, the final months before the Task Group's relocation to the much grander Manned Space Center in Houston.

Despite the Soviet threat, there were many doubts about the risks and vast expense of launching humans on temperamental rockets hastily converted out of prototype missiles, but in April 1959, NASA announced its selection of seven astronauts to participate in the Mercury program. Public excitement reached a peak when one of them, Alan Shepard, was chosen to be the world's first man in space. Unfortunately for NASA, the Soviet rocket team was ready with its own capsule, a spherical craft called Vostok. a young man named Yuri Gagarin beat Shepard into space by three weeks, orbiting the Earth on April 4, 1961.

Gagarin's flight was a tremendous blow to John F. Kennedy, the White House's newly elected occupant. He had not paid much attention to space affairs and was alarmed at the global response to the Soviet triumph. He paced the Oval Office, asking his advisors, "What can we do? How can we catch up?" Three days later, Kennedy suffered another serious defeat. A 1,300-strong force of exiled Cubans supported by the CIA landed at the Bay of Pigs, Cuba, with the intention of destroying Fidel Castro's regime.

Kennedy had approved the invasion, but Castro's troops learned of the operation ahead of time and were waiting on the beaches. The raid was an absolute disaster.

On May 5, 1961 Mercury astronaut Shepard was launched atop a Redstone. His flight was not a full orbit, merely a ballistic arc lasting about fifteen minutes. Gagarin's Vostok had circled the world, while Shepard's Mercury capsule splashed into the Atlantic just a few hundred miles from its launch site. But this cannonball flight was enough to prove NASA's capabilities. Kennedy now turned to space (which he termed "this new ocean") as a means of reviving national credibility. On May 25, 1961, he made his unforgettable speech pledging America to a land a man on the Moon and return him safely to the Earth "before this decade is out." By this point, Kennedy had placed NASA under the control of James Webb, a determined boss who made sure that disparate research teams put their weight behind Project Apollo, a unified approach for reaching the Moon.



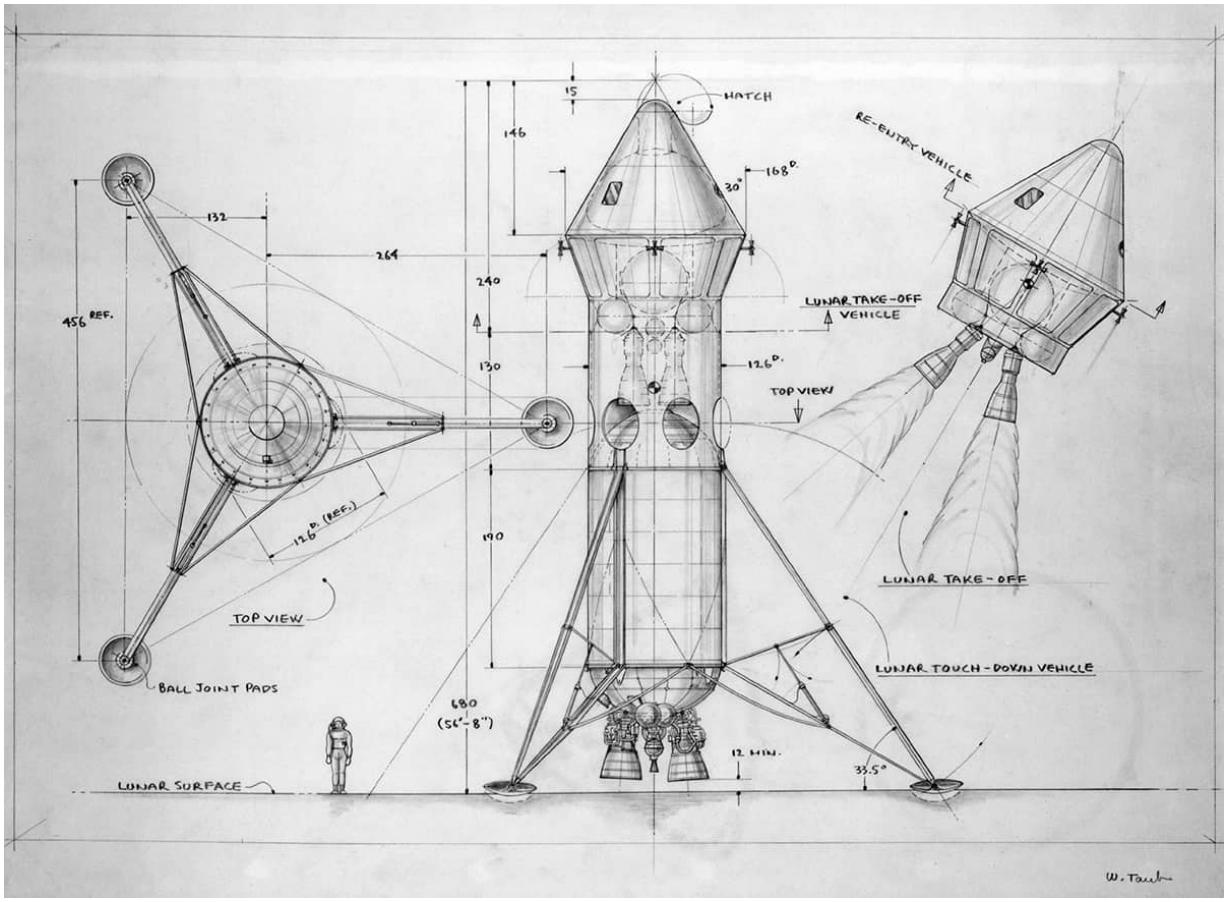
Oversized lunar lander

A Direct Ascent concept for the Apollo spacecraft. Sufficient fuel would be carried for landing on the Moon and taking off again for the return trip. A rocket larger than a Saturn V would have been needed to launch such a heavy ship from Earth.

Choosing a landing method

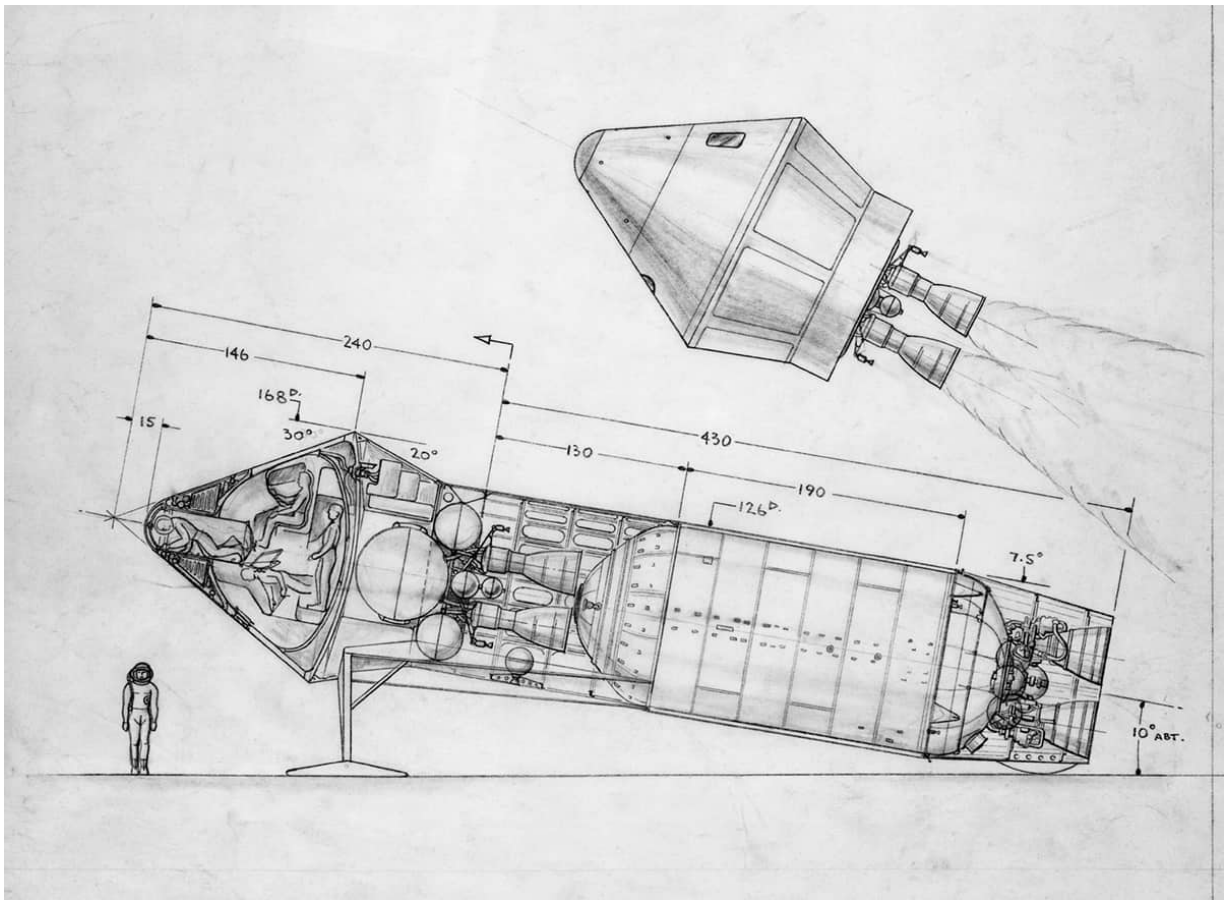
As NASA got down to serious work in response to Kennedy's challenge, the natural assumption was that a giant rocket would deposit astronauts on the lunar surface and bring them home again. This was known as the Direct Ascent method. Inspirational images from renowned astronomical artist Chelsey Bonestell dating from the late 1940s displayed a gorgeous silver rocket with sleek rear landing fins designed for the challenges of space and air alike. A few years later, *Collier's* depicted huge landing craft being

assembled piecemeal in Earth orbit before breaking away and heading for the Moon. NASA was worried that the Collier's scheme was too ambitious. It would take too long and cost too much. It seemed better and, above all, faster, to build one very large rocket that could get the job done in a single launch.



Direct Ascent on the skids

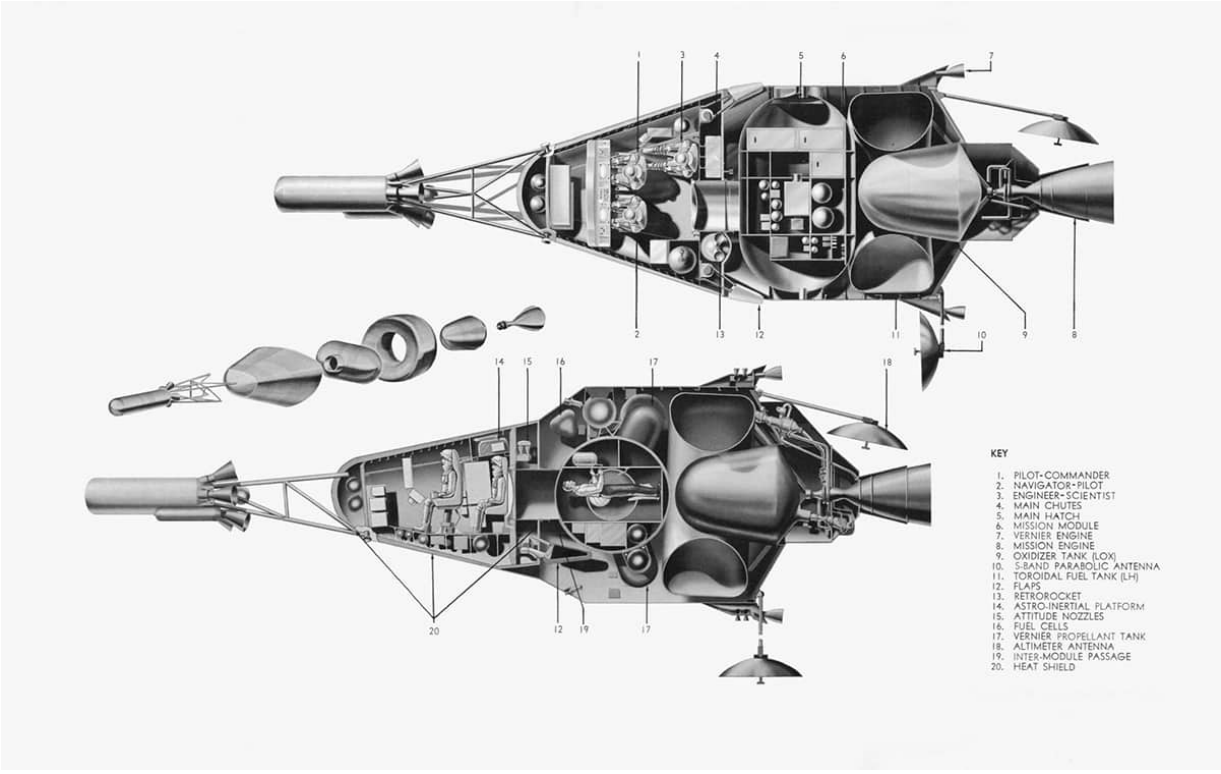
In these extremely rare 1961 diagrams by NASA engineer Willard Taub, two variants of a Direct Ascent lunar landing craft are depicted. One touches down tail first, using a tripod landing gear, and the other makes a semi-horizontal approach using skid pads, which settle the craft at a slight angle, supposedly ready for launching the return module back toward Earth.



Although everyone at NASA knew that such a rocket could reach the Moon, no one was sure how to get it safely to the surface. It would have to land on its stern and take off again without the benefit of a launch gantry and ground crew. It would also have to carry sufficient fuel and equipment for the return voyage, plus heat shielding to survive the punishing 25,000-mph reentry into Earth's atmosphere. If all these burdens went down to the lunar surface and had to be lifted off again, the rocket that carried them would have to be enormous. It was also quite a challenge to work out how the astronauts sitting on the top of this monster were supposed to pilot it safely to a touchdown when they couldn't see the landing zone through their windows. They would have to ease the ship down using periscopes and rear-pointing television cameras. Optimistic sketches showing an Apollo rocket landing on its side on skids and a return module launching back into space at a slant signaled the end for Direct Ascent.

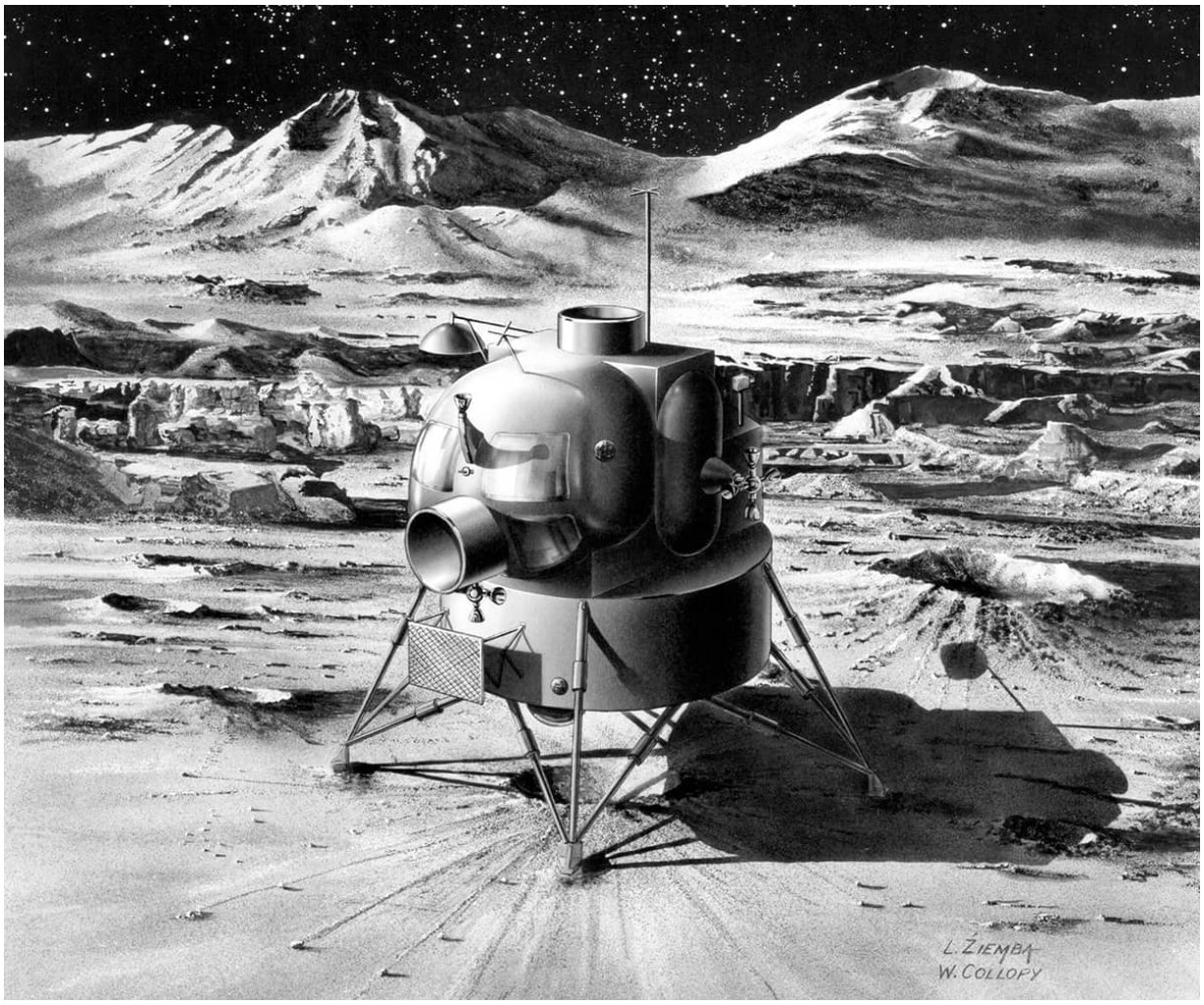
Instead, NASA engineer John Houbolt and a small group of colleagues within the space industry conceived the idea of a separate lander for Apollo,

built from ultralight components and carried inside the shell of the rocket. The main crew capsule and all the fuel and propulsion systems required for the return trip to Earth would be left in orbit above the Moon, while the lightweight lander descended to the lunar surface. After a suitable period of explorations conducted by moonwalking astronauts, the lander's upper ascent stage, a structure so light and fragile you could punch a hole in its skin with a screwdriver, would take off and rendezvous with the return ship, leaving behind the depleted landing stage. This scheme, known as Lunar Orbit Rendezvous (LOR), was a clever idea apart from the extreme hazard of getting the lander's ascent stage to find the return module and reunite with it: a task requiring far more navigational accuracy than locating the proverbial needle in a haystack.



Apollo as it could have been

A rare diagram of the Martin Company's "Model 410" Apollo proposal from 1961. Martin lost the bid, and North American Aviation was awarded the contract instead.

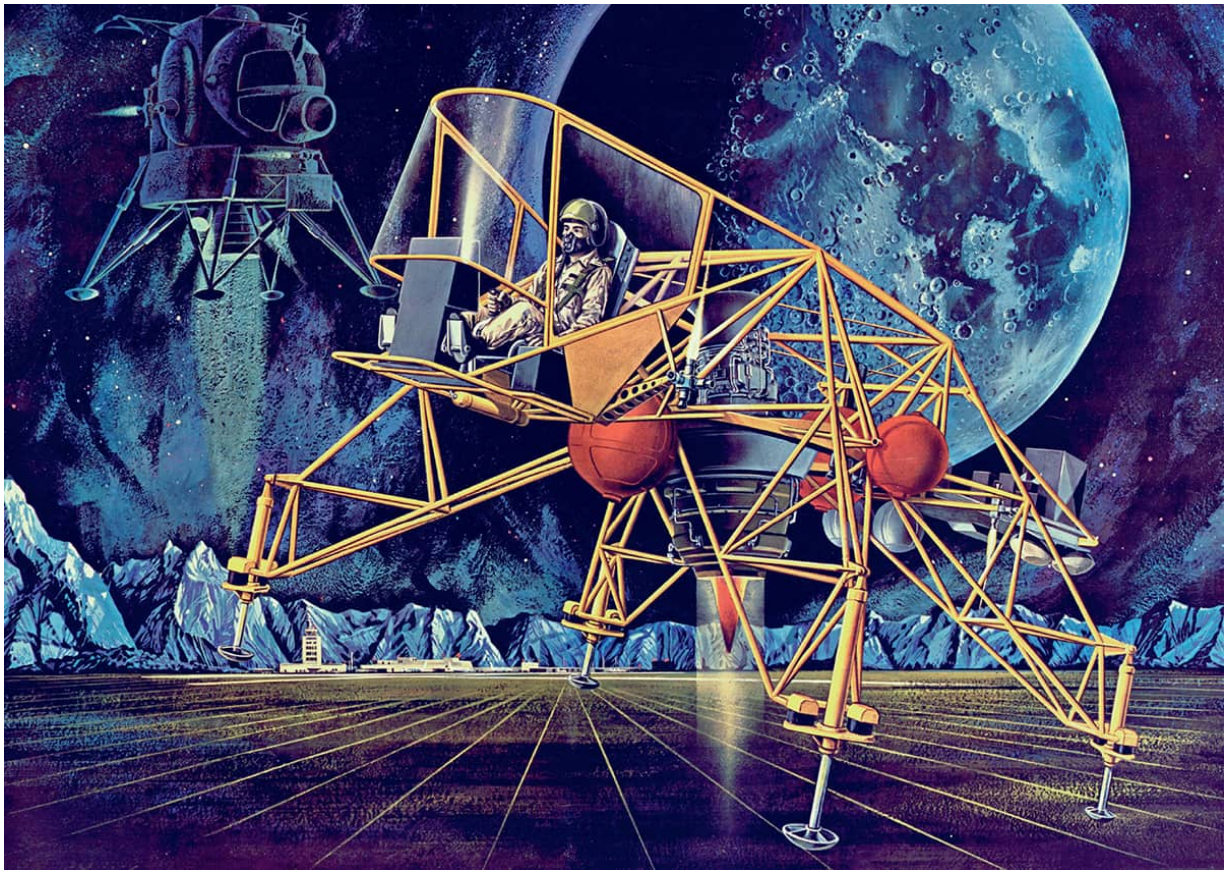


Closing in on the lander
Lockheed artist Ludwik Źiemba, and W. Collopy (from Grumman Aircraft) collaborated on this 1962 illustration of a Lunar Module (LM) with large windows, a combination forward hatch and docking port, and five landing legs. Grumman won the bid to build the LM. Its eventual shape owed much to this early design.

President Kennedy's science advisors worried that LOR was unreasonably dangerous, but Houbolt's team argued that all the astronaut activities in space as idealized in *Collier's* would depend on similar rendezvous procedures, whether near the Earth or the Moon, so why not just get on with them? Other critics included North American Aviation (NAA), the company selected in 1962 to build the Apollo moon ship. One moment they were the proud creators of the greatest vehicle in history; the next, they were assigned "just" the mothership component, known as the Command and Service Module (CSM). NASA won the argument, and another company, Grumman, was selected to build the Lunar Module (LM),

the spider-like machine that accomplished the landing. But when the first artists' renderings of the LM emerged from Grumman, many people found the concept utterly alien and hard to understand. Early versions showed a smoothly contoured craft with spindly grasshopper landing legs and large curving windows, but the need for extreme weight reduction caused a rethink. The windows became small, flat and triangular, the legs became foldable, and the craft's elegant rounded contours vanished in favor of polygonal surfaces (there was no need for sleekness on a lander designed purely for space).

By the mid-1960s the various modules and launch vehicles of Apollo as we have come to know them were more or less defined, although it wasn't until early 1969 that a painting by Grumman artist Craig Kavafes revealed that the LM would be a strange creature of gold and silver, rather than the white machine with intermittent black surfaces so often depicted before.



Dangerous training tool
An impressionistic view from 1963 of the Lunar Landing Research Vehicle (LLRV), an innovative but unforgiving vehicle that played an essential role in training Apollo astronauts for landing on the Moon. The artwork was made by Carl Zoschke for Bell Aerospace, manufacturer of the LLRV.

The first true spacecraft
The first public “reveal” by NASA of Grumman Aircraft’s Lunar Module No. 5, scheduled for Apollo 11, and rendered by company artist Craig Kavafes in early 1969. Shrouded in scaffolding and work platforms prior to flight in July that year, the actual LM was difficult for civilians to see.

Gemini as a teaching tool

Meanwhile, soon after the LOR decision for Apollo had been made, NASA set to work on a bigger and better version of Mercury: a two-seat craft known as Gemini, designed by Mercury’s builders, the McDonnell Douglas company. It would be launched atop a “man-rated” Titan missile. Apollo

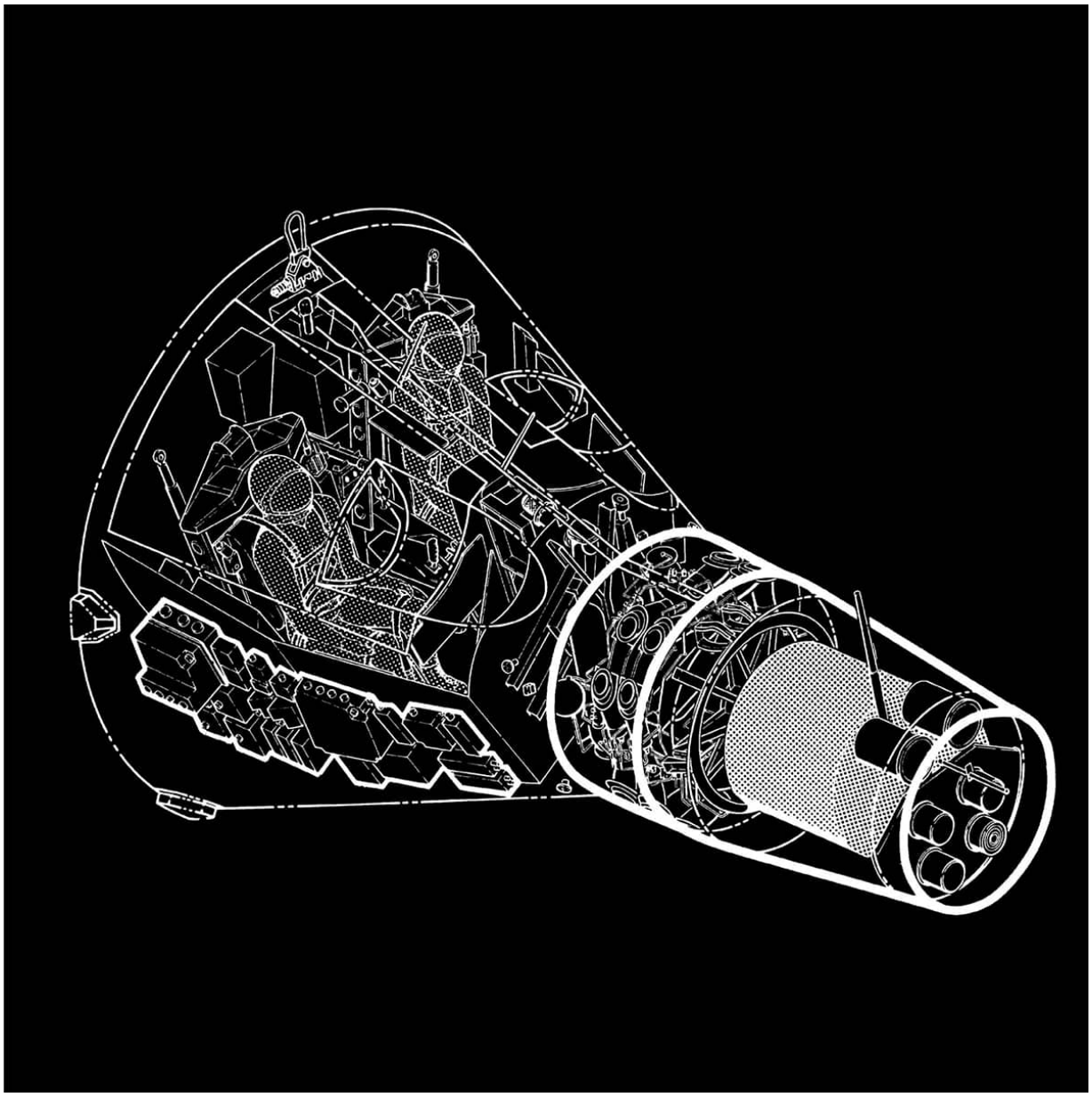
was still only paperwork in the early 1960s, and there was so much yet to learn. How could two spacecraft find each other in the depths of space and link in a docking? How would astronauts withstand missions lasting days or weeks rather than just a few hours? How could astronauts venture outside their craft and “walk” in airless, weightless space? All these routines needed to be practiced. NASA could not sit on its hands waiting for Apollo to be built. It needed an interim spaceship.

The two-seat Gemini was NASA’s sportiest spacecraft, with gull-wing doors for spacewalking (or emergency escape by ejection in the event of a problem during launch) and a complex array of thrusters. It was also the first crewed spacecraft with an onboard computer. Gemini could change orbit and rendezvous with other vehicles, using radar guidance and thrusters. Ten crewed Gemini missions were flown between March 1965 and November 1966, and each flight contributed to the task at hand: preparing NASA astronauts for the even more complex lunar adventure that lay ahead.

Major accomplishments included the first NASA spacewalk in June 1965, by Gemini 4 astronaut Edward White, and the first docking, in March 1966, between two spacecraft. Neil Armstrong was in command with David Scott in the copilot’s seat as Gemini VIII met nose to nose with its unmanned Agena target vehicle, launched earlier on another rocket and now patiently awaiting its Gemini companion. Moments after docking, Armstrong reported that the combined vehicles were spinning out of control. He reversed the Gemini out of the Agena, only to find that the tumbling accelerated because a thruster had jammed in the “on” position. Armstrong and Scott brought the Gemini back under control and prepared for an emergency return to Earth, which was accomplished safely. Gemini 9 astronauts Tom Stafford and Gene Cernan went aloft on June 3, 1966, only to find that their target vehicle’s protective launch shroud had not come away properly, blocking the docking ring. Cernan’s spacewalk to try and pick up a gas-powered backpack from the Gemini’s rear also did not go according to plan. NASA learned an essential lesson: astronauts cannot work outside a spacecraft without plenty of handholds and footrests.

On July 18, 1966, John Young and Michael Collins successfully docked Gemini 10 with another Agena and used its engine to boost their orbit to a record altitude 470 miles above Earth. Collins became the first person in history to make two spacewalks during the same mission. Two months later,

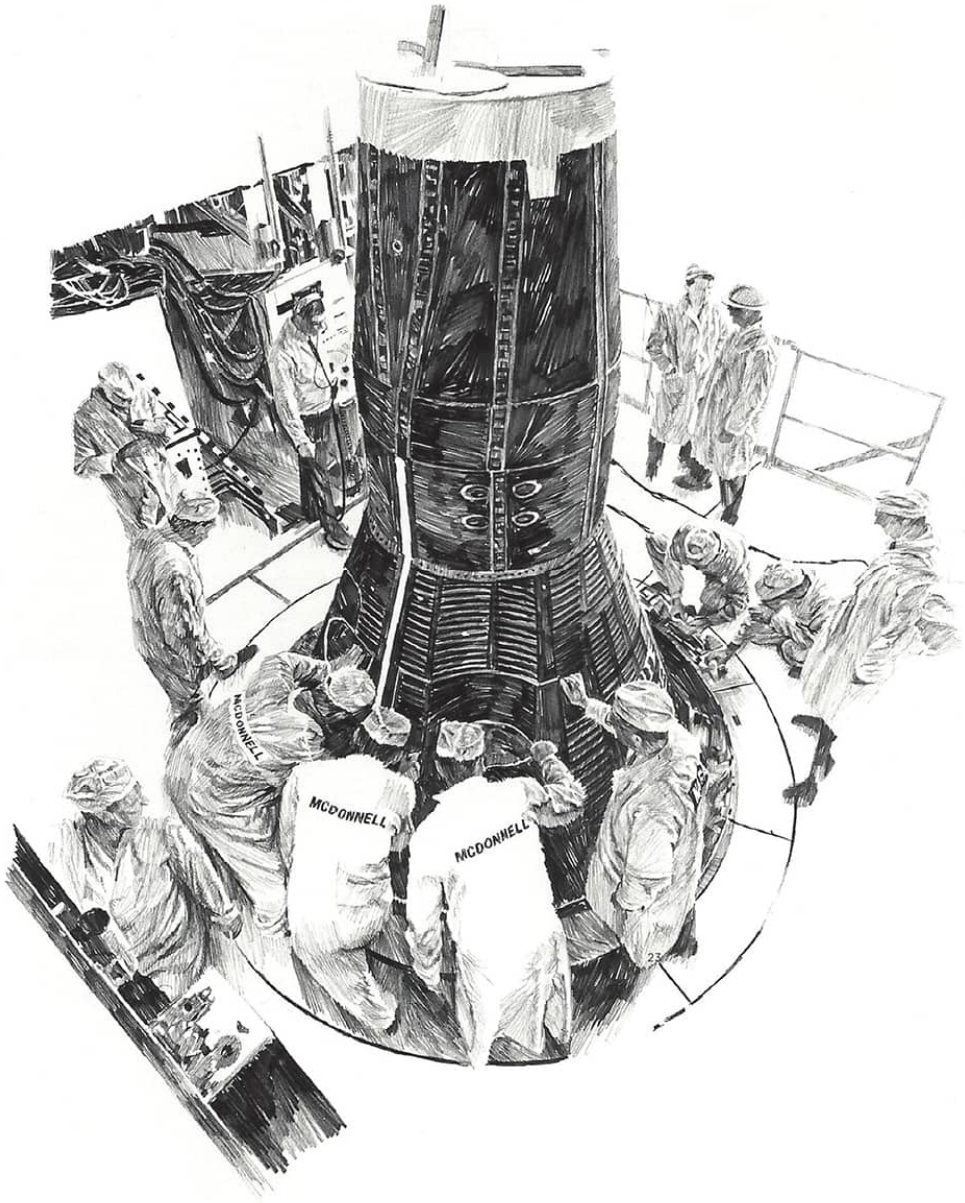
Gemini 11, with Pete Conrad and Dave Gordon aboard, docked with an Agena and boosted to an 800-miles-high orbit. Jim Lovell and Buzz Aldrin went up in Gemini 12 on November 11, 1966. Aldrin spent five hours spacewalking. Gemini pioneered all the techniques essential for Apollo.



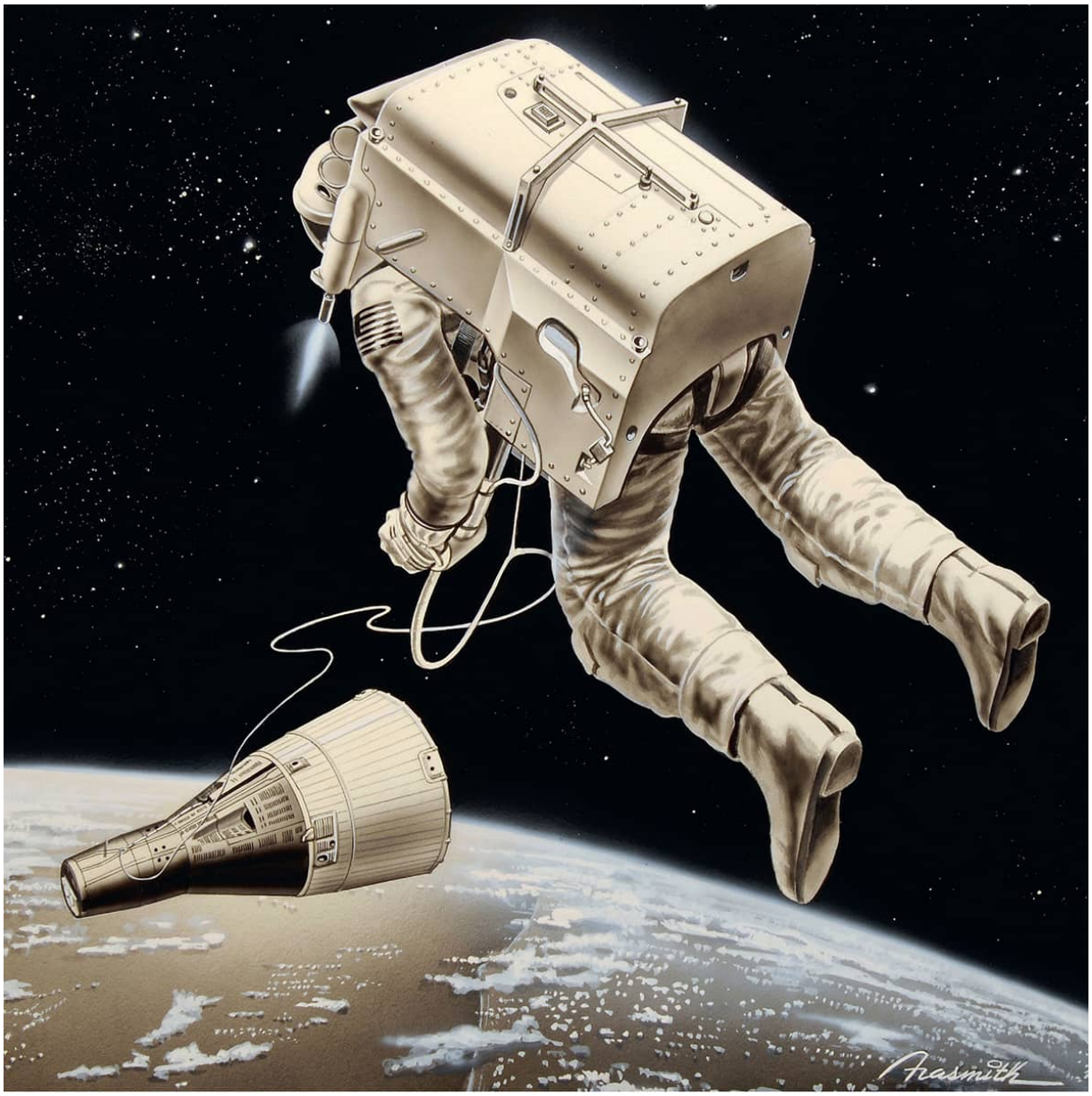
Lost work-in-progress
One of many thousands of film negatives derived from technical drawings made with ink and rub-down lettering and textures formed the basis for NASA's countless technical manuals and press pack diagrams. The negatives were the basis for the thousands of photo positives of diagrams distributed to the press and official space agency publishers. Most of these interim materials no longer exist. This was used in NASA's 1965 *Project Gemini Familiarization Manual*.

Ground crew commitment

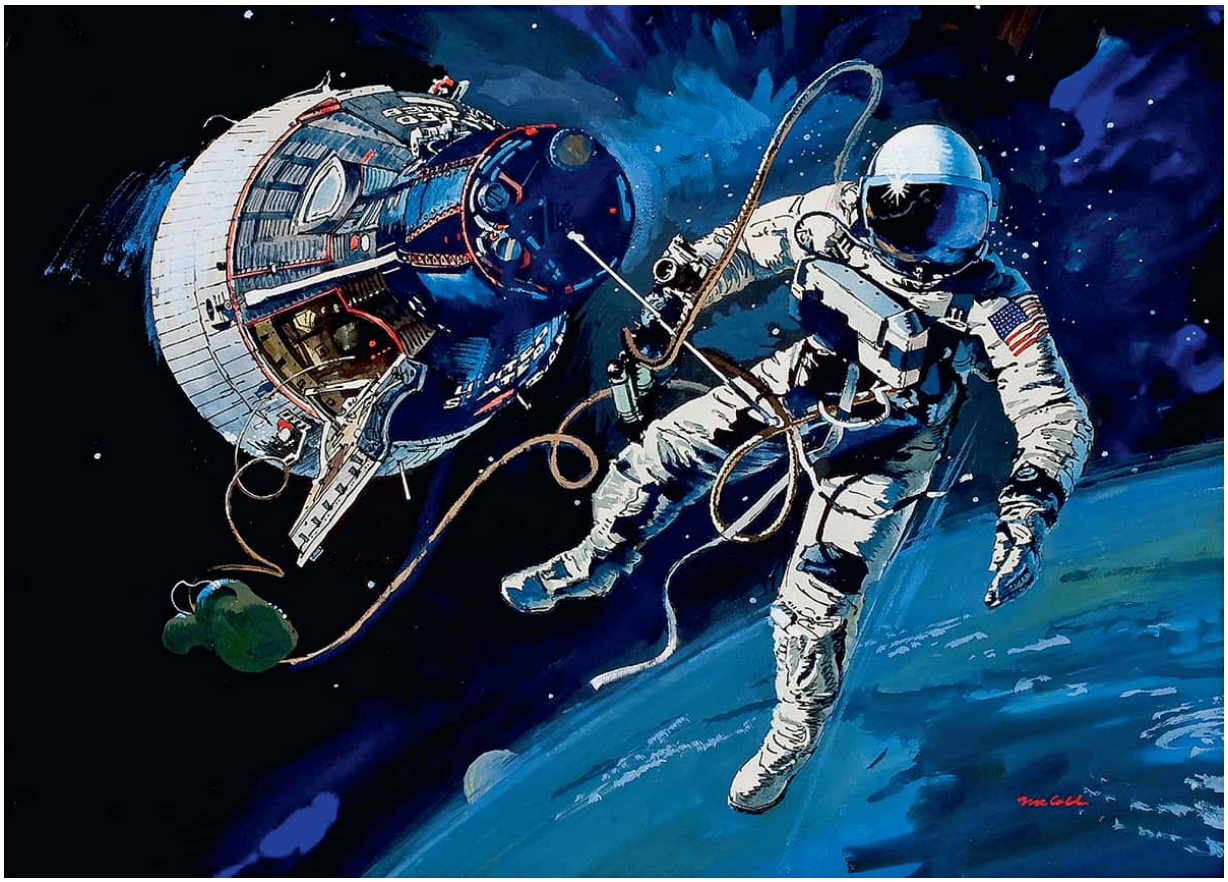
Aerojet-General artist George Mathis's 1965 depiction of a Gemini spacecraft being hoisted into position for mating with its Titan II launch vehicle. Aerojet built the Titan's first-stage engines. Artistic license has the two astronauts observing from a platform at the base of the rocket. Reproductions of this painting featured among NASA's press materials for Gemini VI.



An onlooker on the pad
Paul Calle was one of several prominent artists granted direct access to NASA facilities. His pencil drawing of McDonnell Douglas technicians performing final inspections of a Gemini in the “white room” atop the launch tower was based on his direct observations at the time.

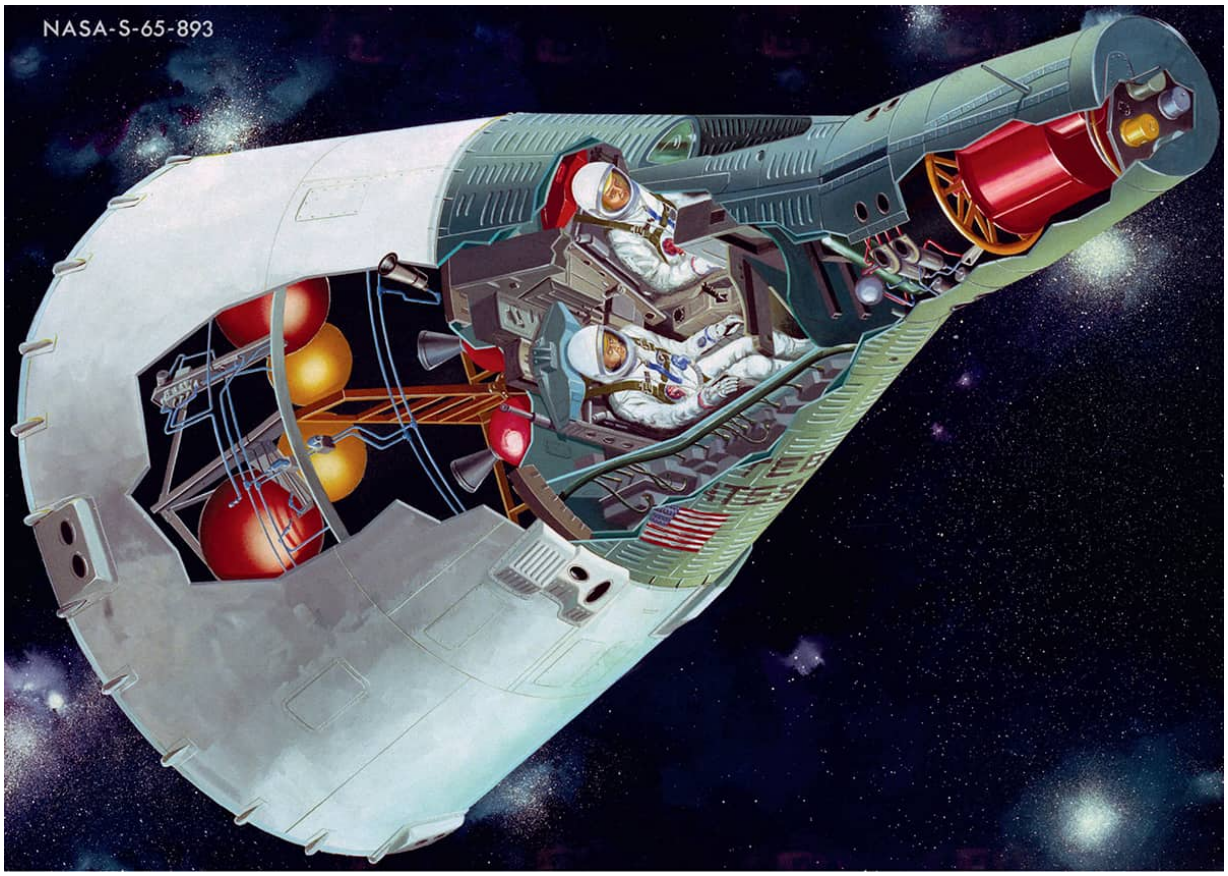


Unlucky backpack
Russ Arasmith was an art director for the *Los Angeles Times* from the early 1960s until 1992, and his space illustrations, syndicated to more than 300 news outlets, were among the most significant visualizations of key NASA events, most of which actually happened. This one didn't. An Astronaut Maneuvering Unit (AMU) was carried during Gemini IX in 1966, but space walker Eugene Cernan encountered problems, and did not get to "fly" his AMU backpack.



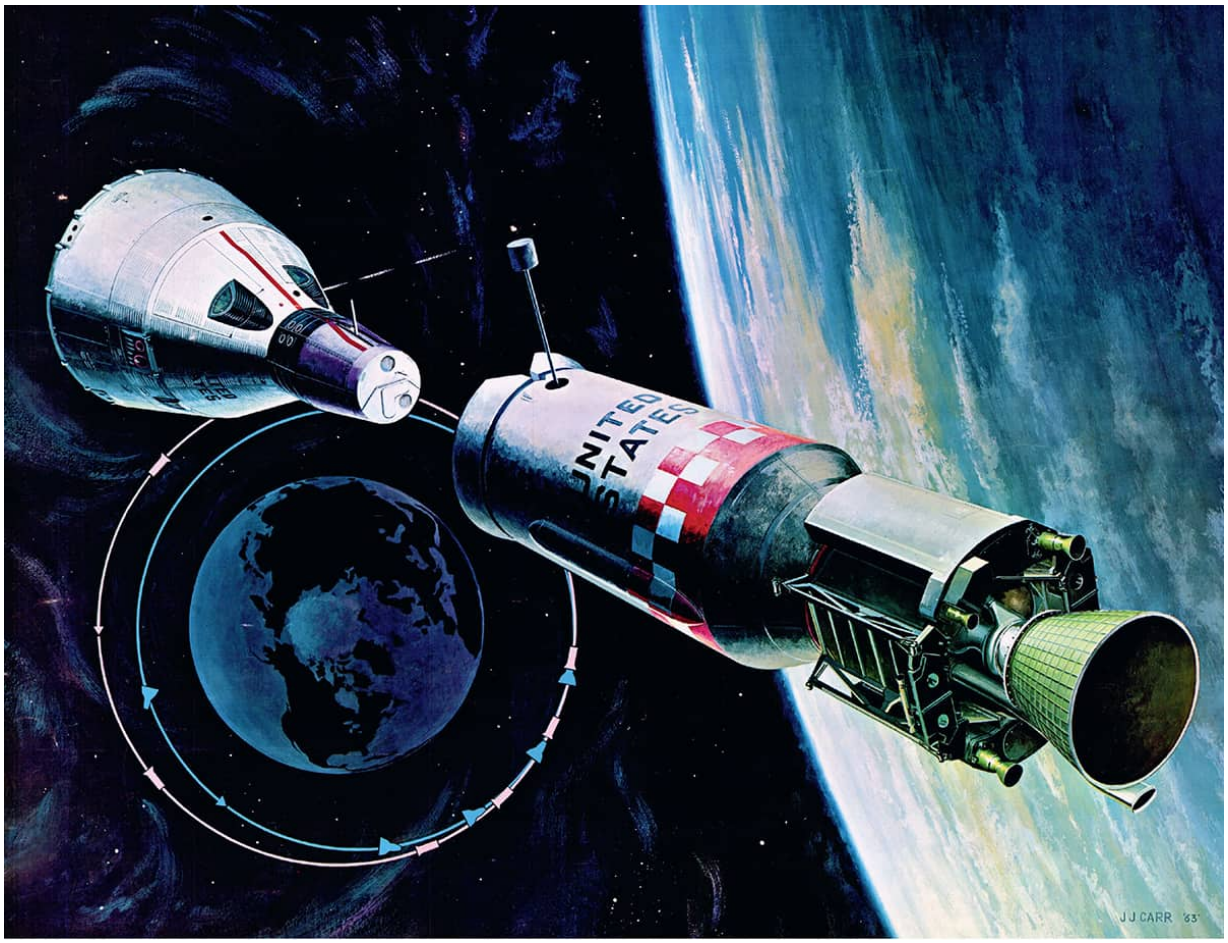
An American “first”

Robert McCall was one of the best-known space and aviation artists of the mid-20th century. His painting of Edward White’s historic spacewalk (the first conducted by an American astronaut) borrows a pose from a photograph taken by James McDivitt during the Gemini IV mission of June 1965.



Everything in its place

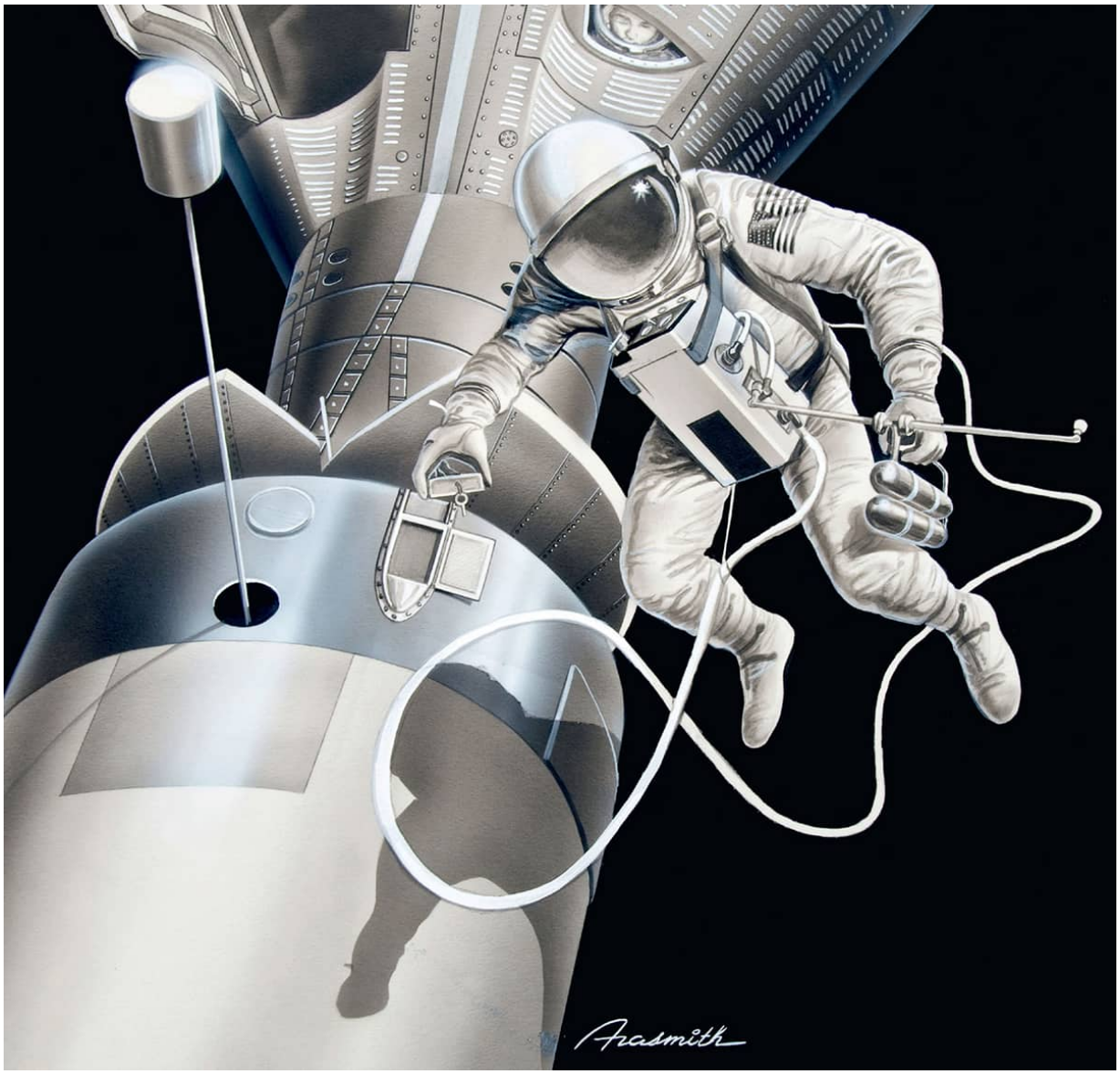
A widely distributed NASA cutaway of a Gemini spacecraft, made by an uncredited artist, revealing propellant tanks within the white adapter module, the astronauts in the crew compartment, the control thrusters, and the parachute container in the nose section.



Hooking up in orbit
Bell Aerosystems artist John J. Carr's 1963 depiction of rendezvous and docking of a Gemini spacecraft and an Agena Target Vehicle. The orbital tracks of both vehicles are depicted in the background. Bell's propulsion hardware is highlighted in green.

Rehearsal for the Moon

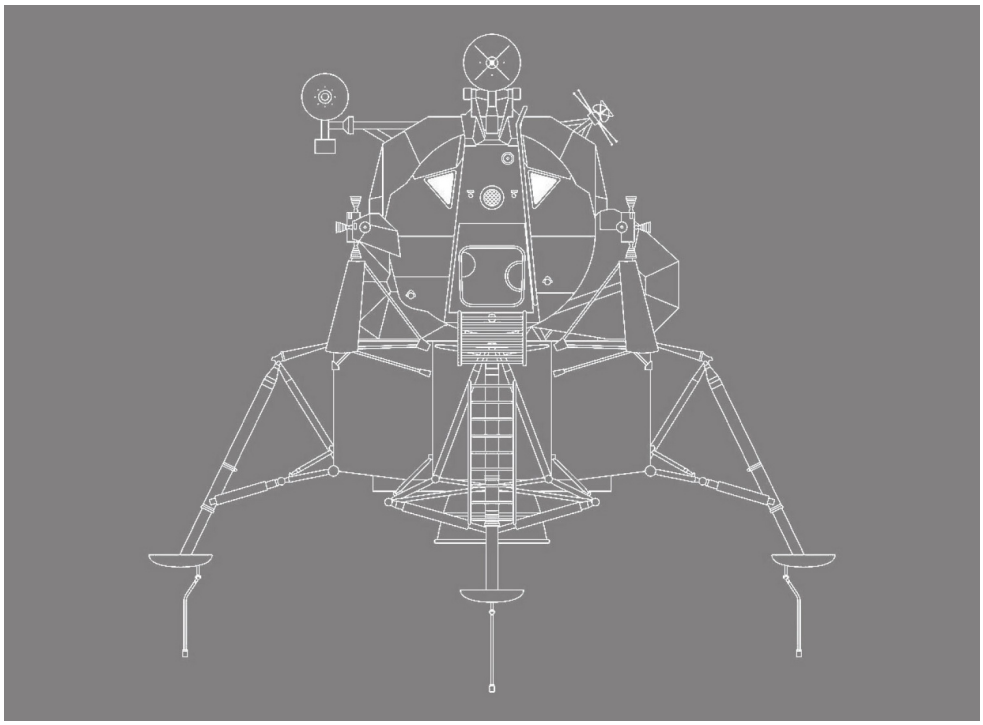
Russ Arasmith's portrayal (above) of a Gemini pursuing and docking with an Agena Target Vehicle, an essential practice procedure for the Apollo lunar adventure that lay ahead. Precise pitch, roll, and yaw adjustments during the reentry phase of a Gemini mission are highlighted by Arasmith (below). Fine adjustments steered the spacecraft into the proper orientation.

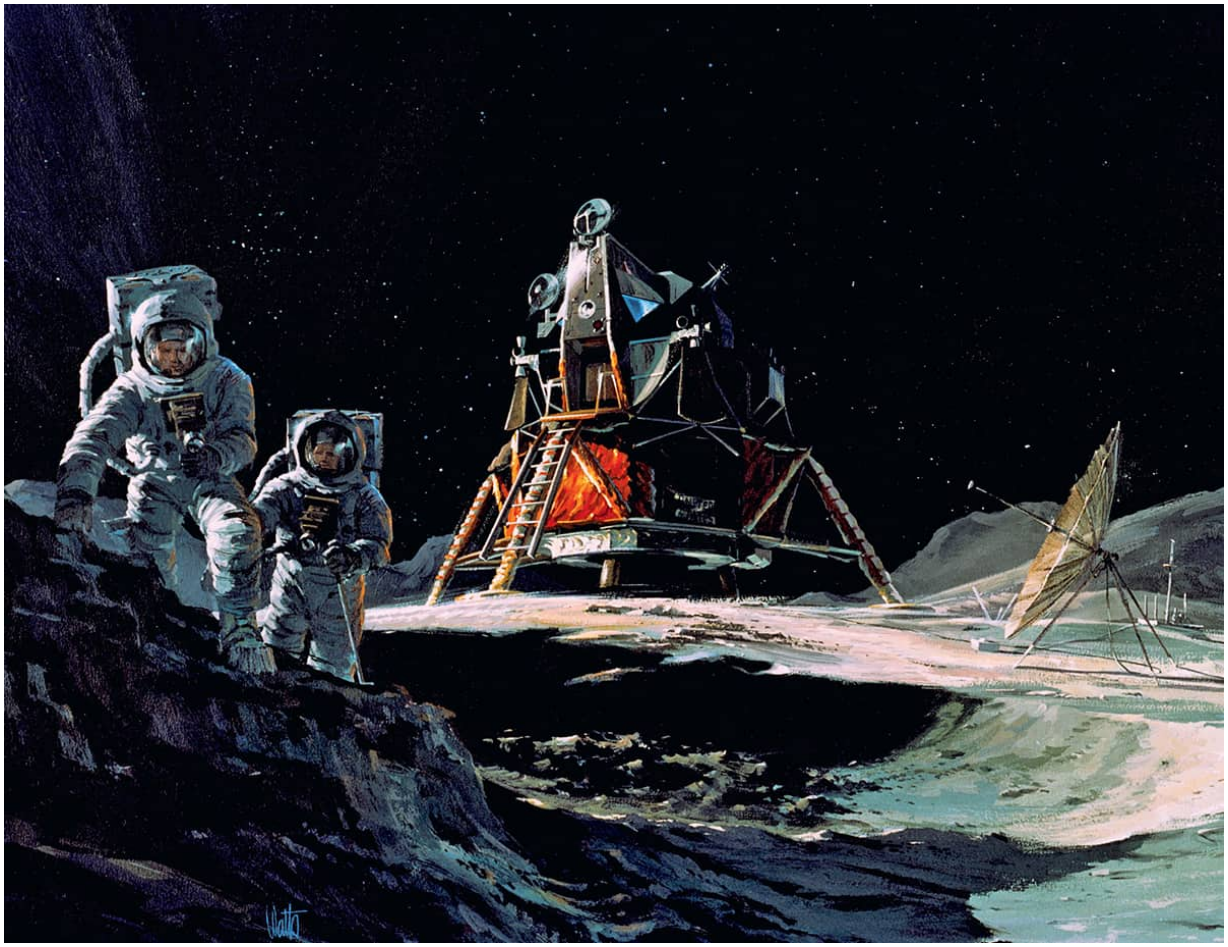


Hands-on operations
Arasmith's interpretation of a spacewalking Gemini astronaut grasping a maneuvering gas gun in one hand and a retrieved materials sample from the exterior of an Agena Target Vehicle in the other. His mission commander keeps an eye on him through the window of the docked Gemini.

2
ONE GIANT LEAP
The Voyages of Project Apollo

In 1972 the renowned futurist Arthur C. Clarke commented, “An age may come when Apollo is the only thing by which people remember the United States, or the world of their ancestors, the distant planet Earth.”





Never the two at once
Composed for the Apollo 13 mission of April 1970 and redistributed by NASA ahead of Apollo 14, Robert Watts' depiction of astronauts setting off to explore the lunar terrain shows something we never see in the mission photographs: two moonwalkers in the same scene.

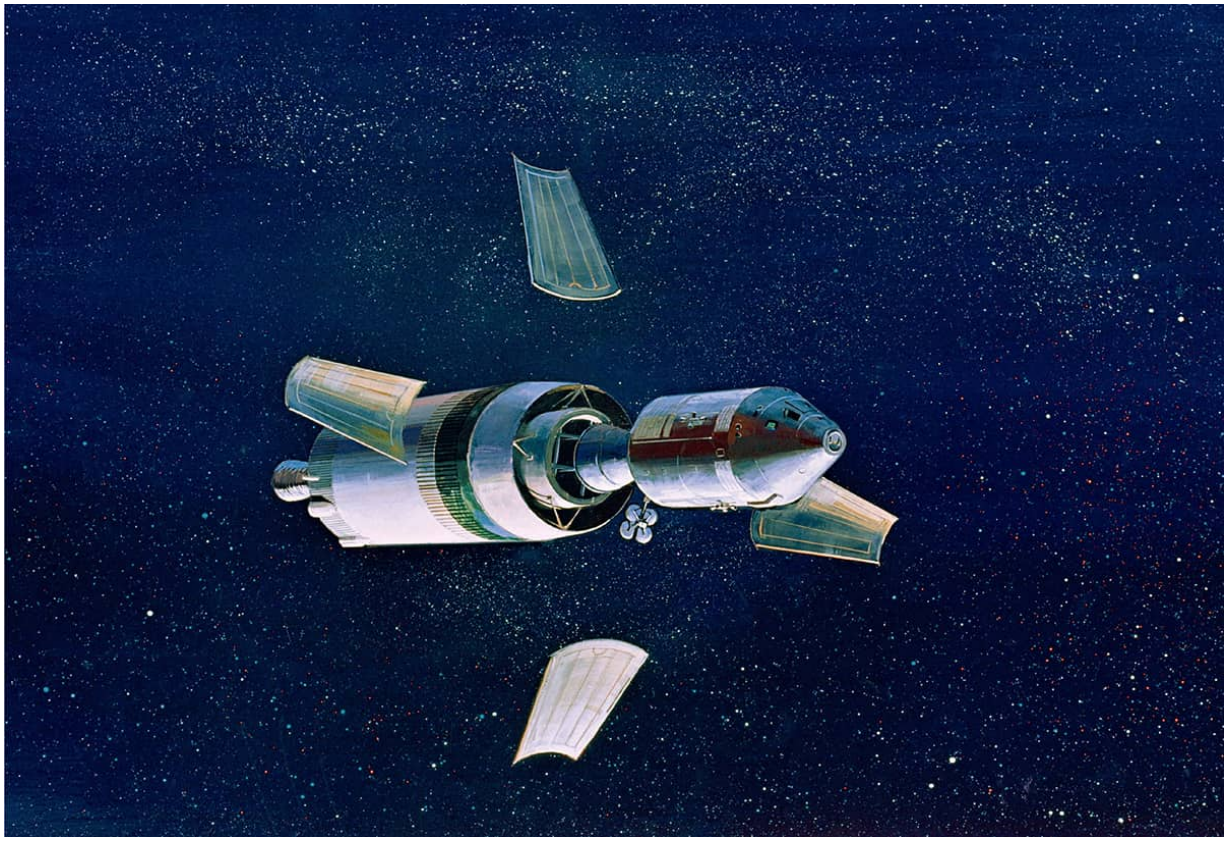
2: One Giant Leap

The literature on Apollo is vast, and in this book we shall only remind ourselves of two momentous dates. Sometimes we forget that the first human mission to the Moon happened before the famous touchdown of Apollo 11. On the morning of 21 December 1968, Apollo 8 took off, commanded by Frank Borman. His crew mates were Jim Lovell (later of Apollo 13 fame) and Bill Anders. Apollo 8 was the first crewed ship to leave Earth and travel toward another world. On Christmas day, almost all the world's television and radio stations carried a broadcast from the spacecraft, during which Frank Borman read paragraphs from the Bible. This didn't please aetheists, but most people welcomed Apollo's achievement at the end of a doom-laden year plagued by the assassinations of Martin Luther King and Bobby Kennedy, civil rights protests, the Soviet invasion of Prague, student riots, and of course, the seemingly endless agony of the Vietnam war.

Apollo 8 brought home something more precious than NASA had expected. Photographs of the Earth rising above the lifeless lunar horizon were printed in every major newspaper and magazine. We began to appreciate just how lonely and fragile our world is. Bill Anders observed later, "We went to explore the Moon, and the most important thing we discovered was the Earth."

Giddy heights
An unusual view from 1967, from North American Aviation's in-house artist Gary Meyer, looking down the length of Apollo's 364-foot tall Saturn V vehicle in position alongside its launch gantry.

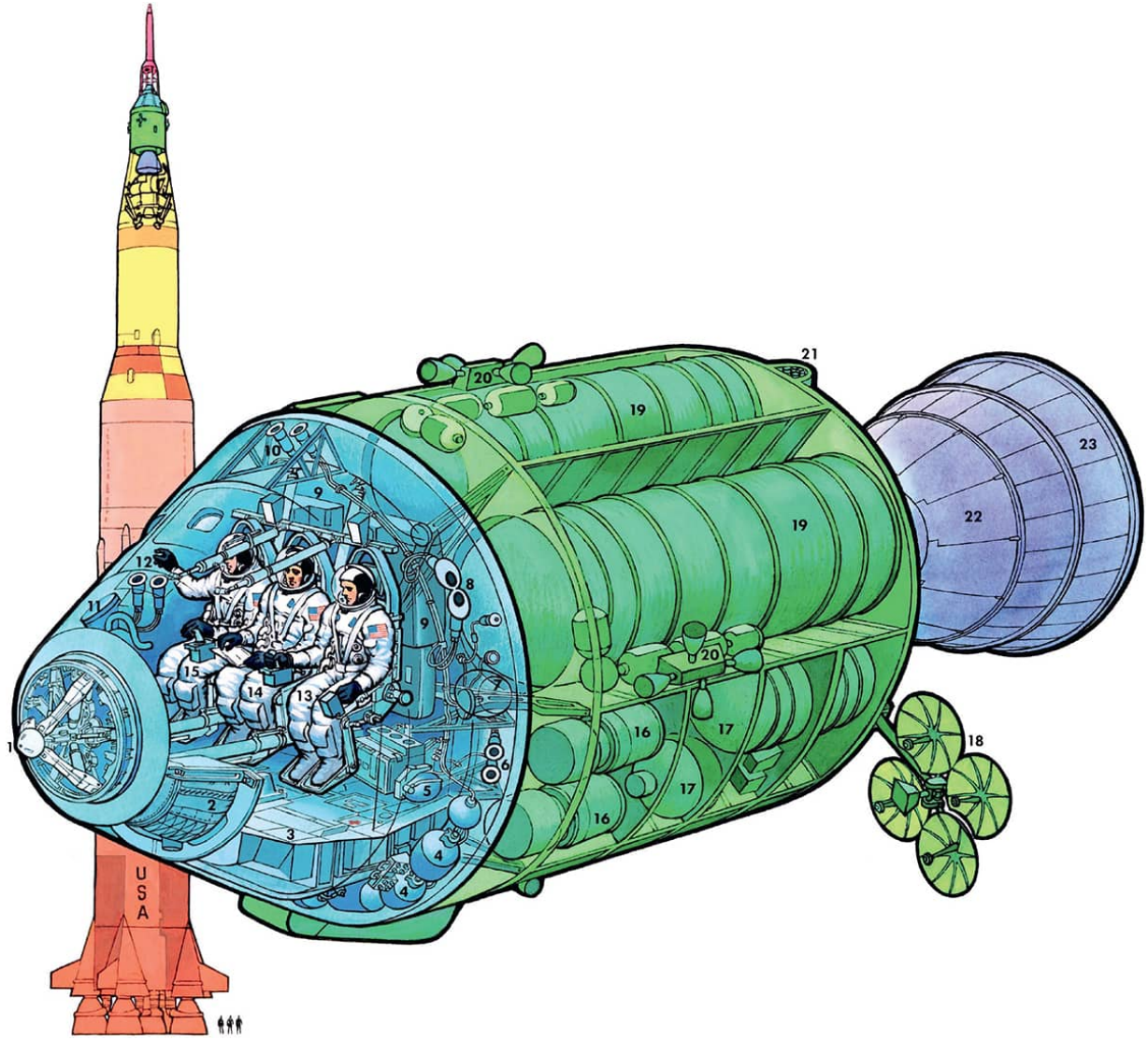
July 20, 1969 is *the* date that we all remember. That was when Apollo 11 astronauts Neil Armstrong and Buzz Aldrin, in the lunar module they named *Eagle*, hovered above the lunar surface for long, agonizing seconds, searching for a safe place to land after the onboard computer proposed to put them down in a boulder-strewn area. Adding to their difficulties, *Eagle*'s guidance computer flashed a series of alarm codes, warning of an impending overload. But they made it down safely, of course.



Breakaway from the ride
In this NASA image by an unacknowledged artist, Apollo 8 pulls away from the spent S-IVB stage of the Saturn V carrier rocket as it speeds toward an historic first crewed orbit of the Moon in December 1968.

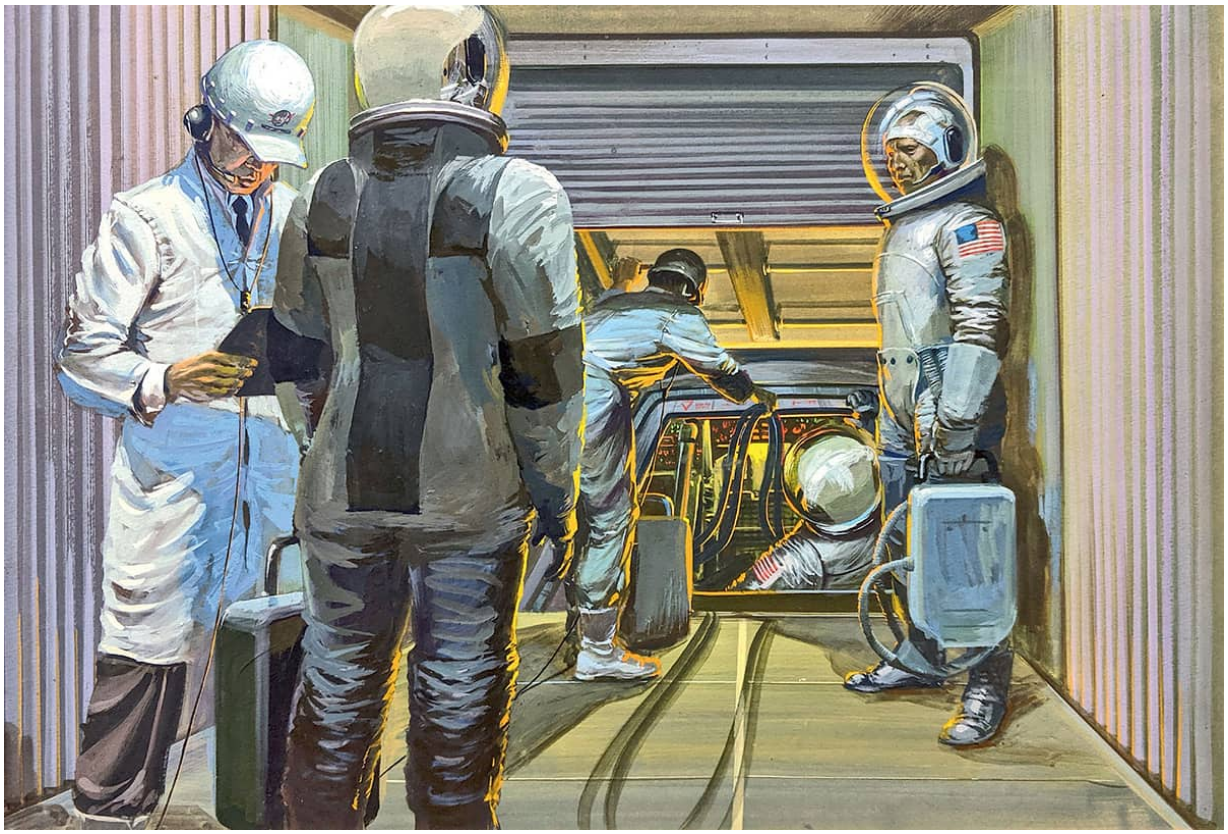
We all remember Neil's first words from the surface. "Houston, Tranquility Base here. The *Eagle* has landed." It's easy to forget what Mission Control Center said in reply: "We copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again." Houston knew that *Eagle* had just twenty seconds worth of propellant left in the tanks when it finally came to rest.

Six more lunar missions followed in the wake of Apollo 11, marred only by the onboard explosion that cancelled Apollo 13's chances of touchdown in April 1970, turning the mission into a dramatic (and in its own way, triumphant) rescue. Apollo 17 capped the landing series in December 1972. Half a century later we are still wondering what the legacy of Project Apollo should be…



Meticulous mechanical details

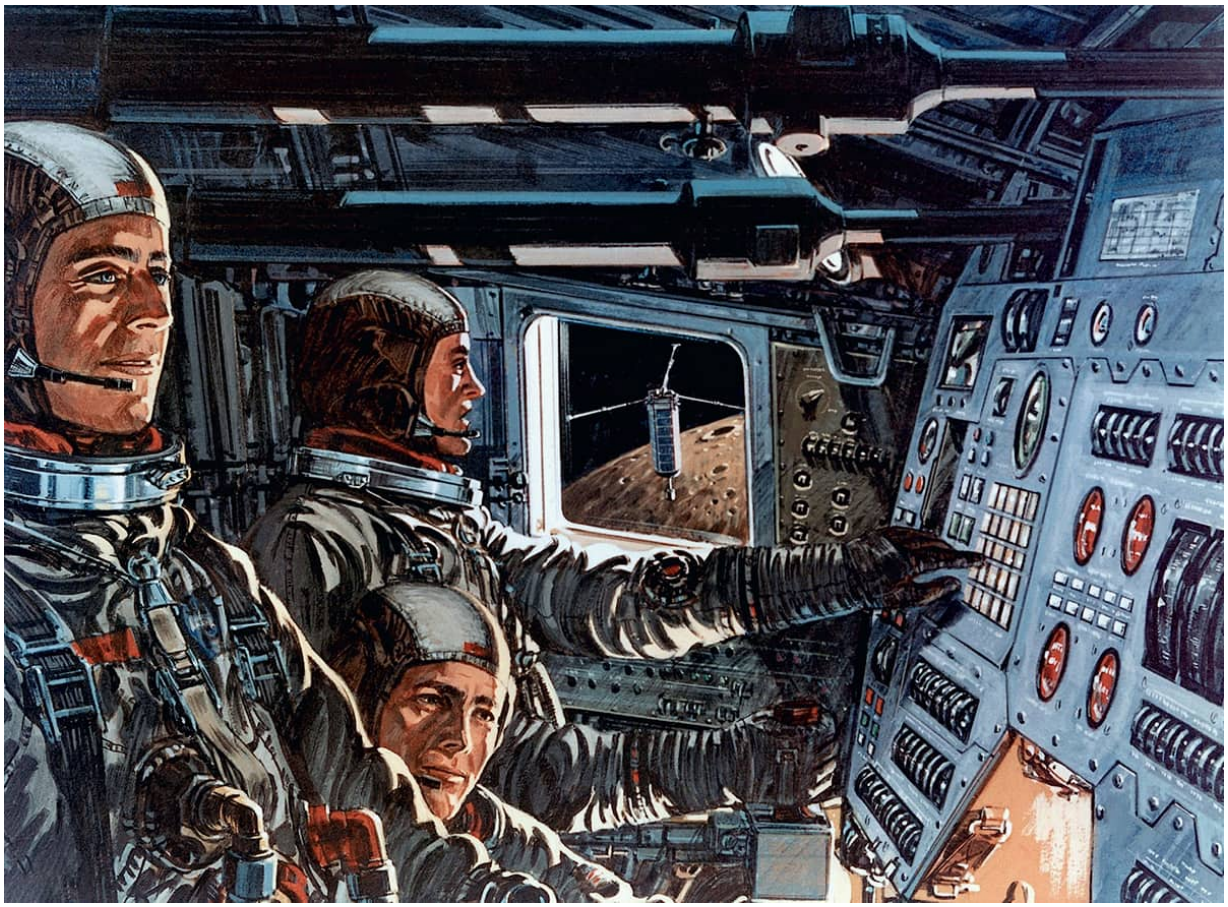
Davis Meltzer's cutaway of Apollo 8's Command and Service Module for *National Geographic* magazine was subsequently reused by NASA in its brochure celebrating the safe return of Apollo 13 in April 1970.



Lost Scenes from Apollo
Gary Meyer's mid-1960s scene of astronauts prior to insertion into a Command Module. Meyer created many illustrations for NASA, and Apollo manufacturers North American Aviation, but original versions are hard to find today.

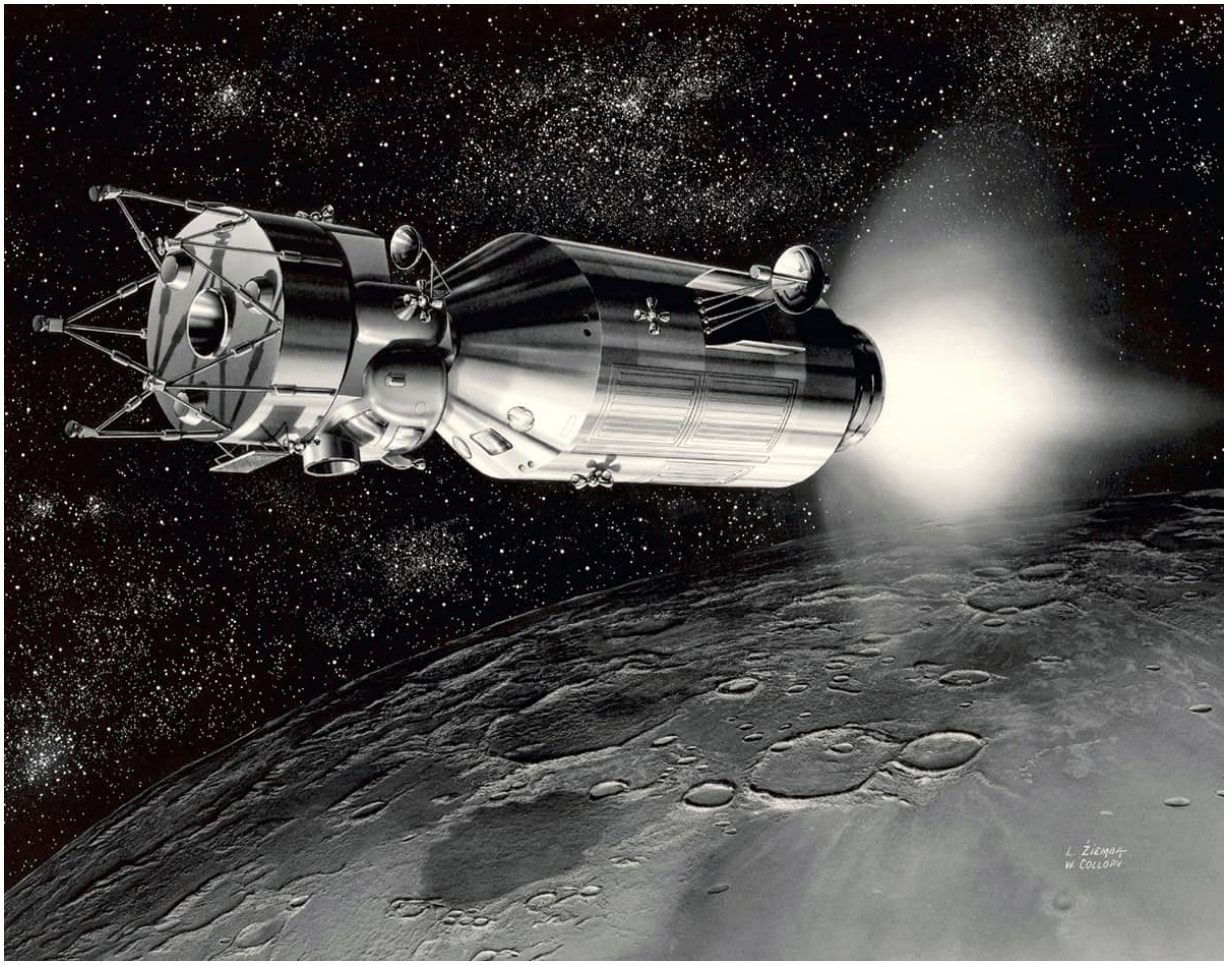
Reunion in lunar orbit

Apollo 12 Command Module pilot Richard Gordon maneuvers *Yankee Clipper* for docking with Lunar Module *Intrepid*'s ascent stage, after the exploration of the lunar surface by fellow crewmen Alan Bean and Pete Conrad in this pre-flight painting. The view through the window was changed for later Apollo mission press releases.



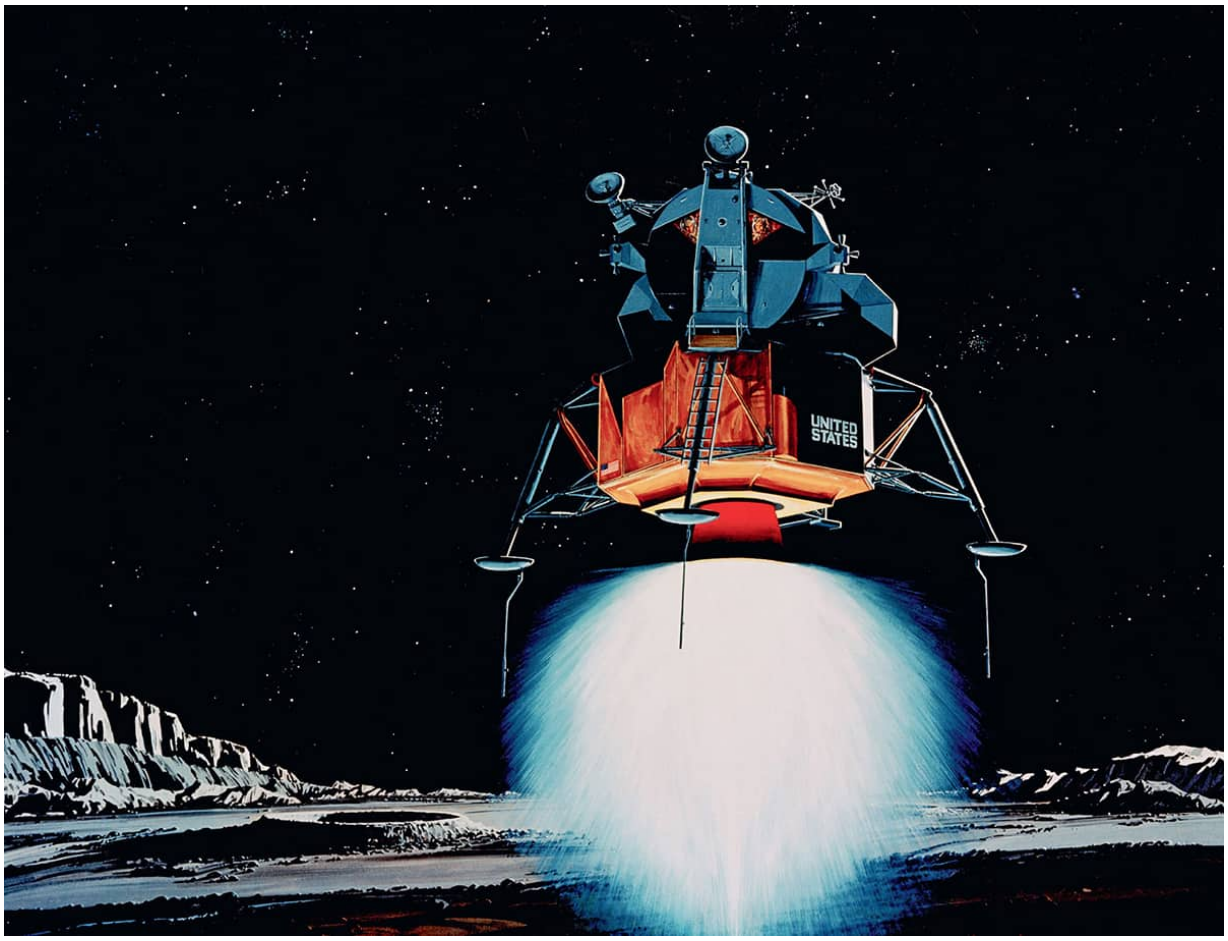
Sending out a satellite

Apollo 16's crew in their Command Module *Casper*, shortly after ejection of the "Particles and Fields Subsatellite," visible out the port window in this NASA image. A 1968 Smithsonian Institution exhibit entitled *Exploring Space: Paintings by John Desatoff* displayed similar works by this artist.



Slowing down for the Moon
The combined Apollo spacecraft makes a braking burn to achieve lunar orbit in this very striking Ludwik Źiemba and W. Collopy collaborative depiction, probably made in 1962.

Heading toward touchdown
In another early 1960s Źiemba and Collopy collaboration, a LM, undocked from the CM in the background, prepares for its descent to the Moon.

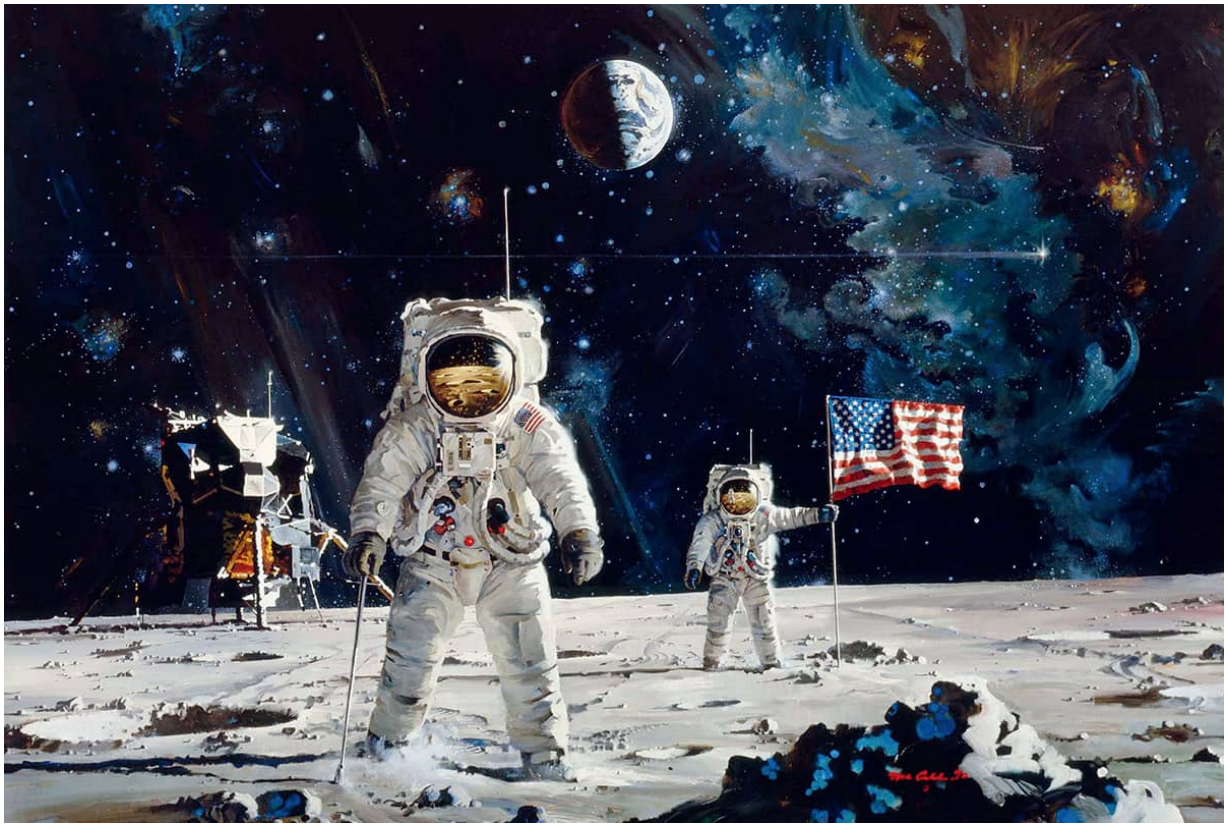


Glowing success
Apollo 11's LM *Eagle* about to touch down on the Moon, captured in detail by John Desatoff. The engine nozzle of the descent engine glows red from the intense heat of the exhaust plume.

An illustrative icon

One of the most-reproduced artist's concepts of an Apollo 11 mission highlight is this 1969 scene by Craig Kavafes, for Grumman and NASA, of the final fraction of a second before the first human boot print is implanted in lunar soil.

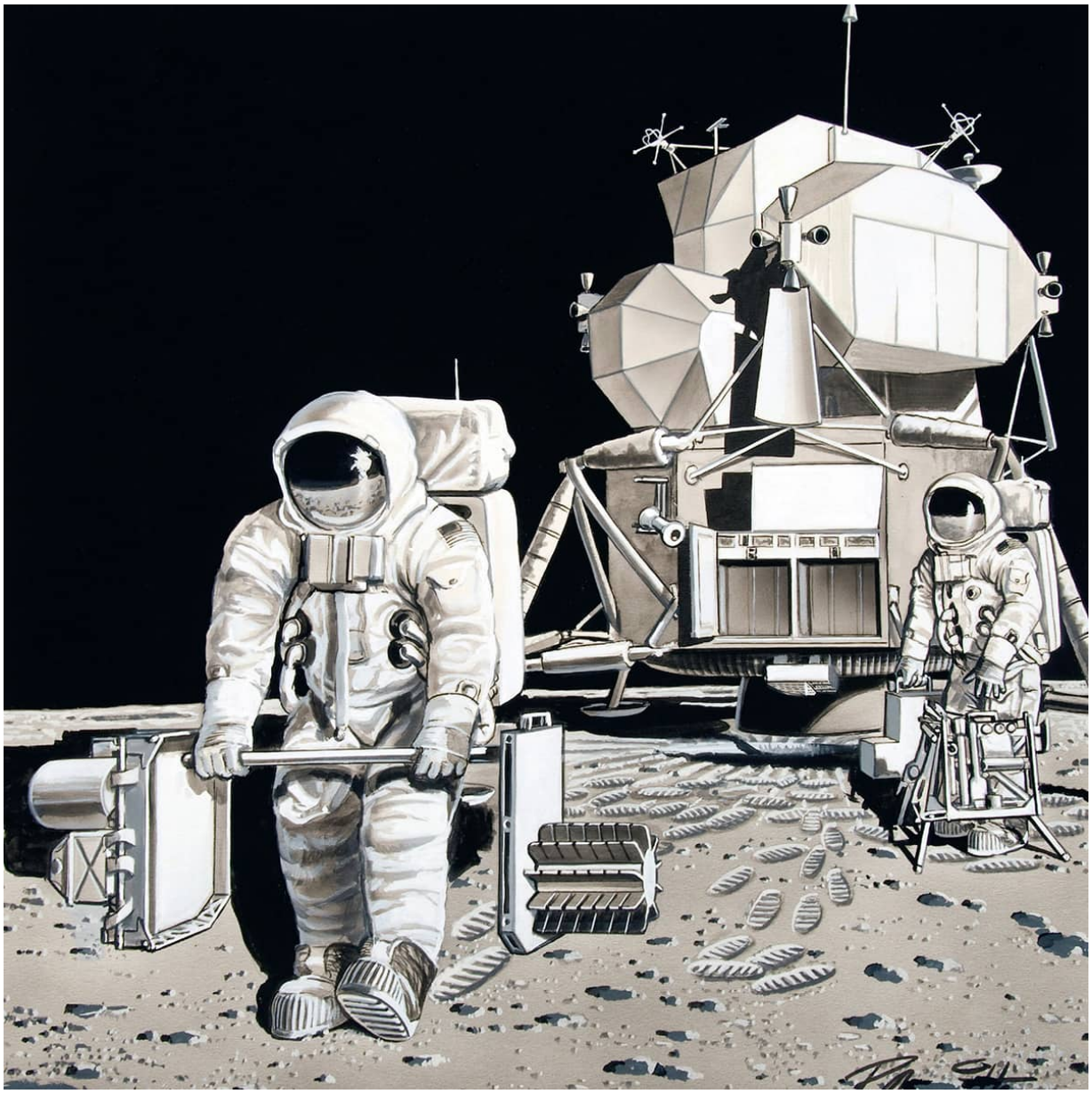
Many layers of a lunar explorer
The inner secrets of the A7L space suit worn by Apollo lunar astronauts, revealed by Paul Calle, and derived from a series of photos showing a technician wearing various layers of the suit.

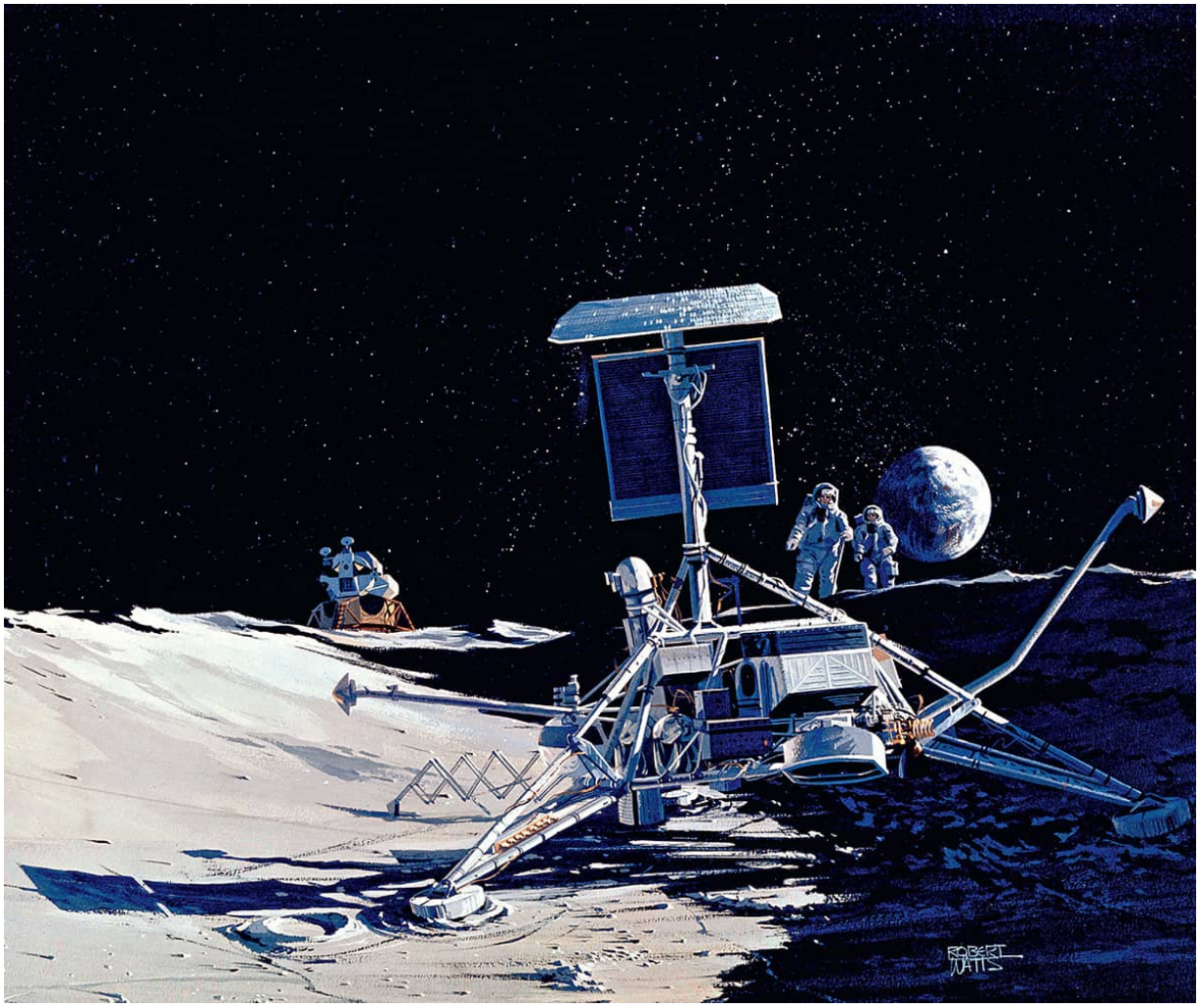


NASA's greatest moment?
Robert McCall's 1970 *First Men on the Moon* was displayed in the visitor centre at NASA's Johnson Space Center (JSC) for many years before passing to a private collection in JSC's home state of Texas.

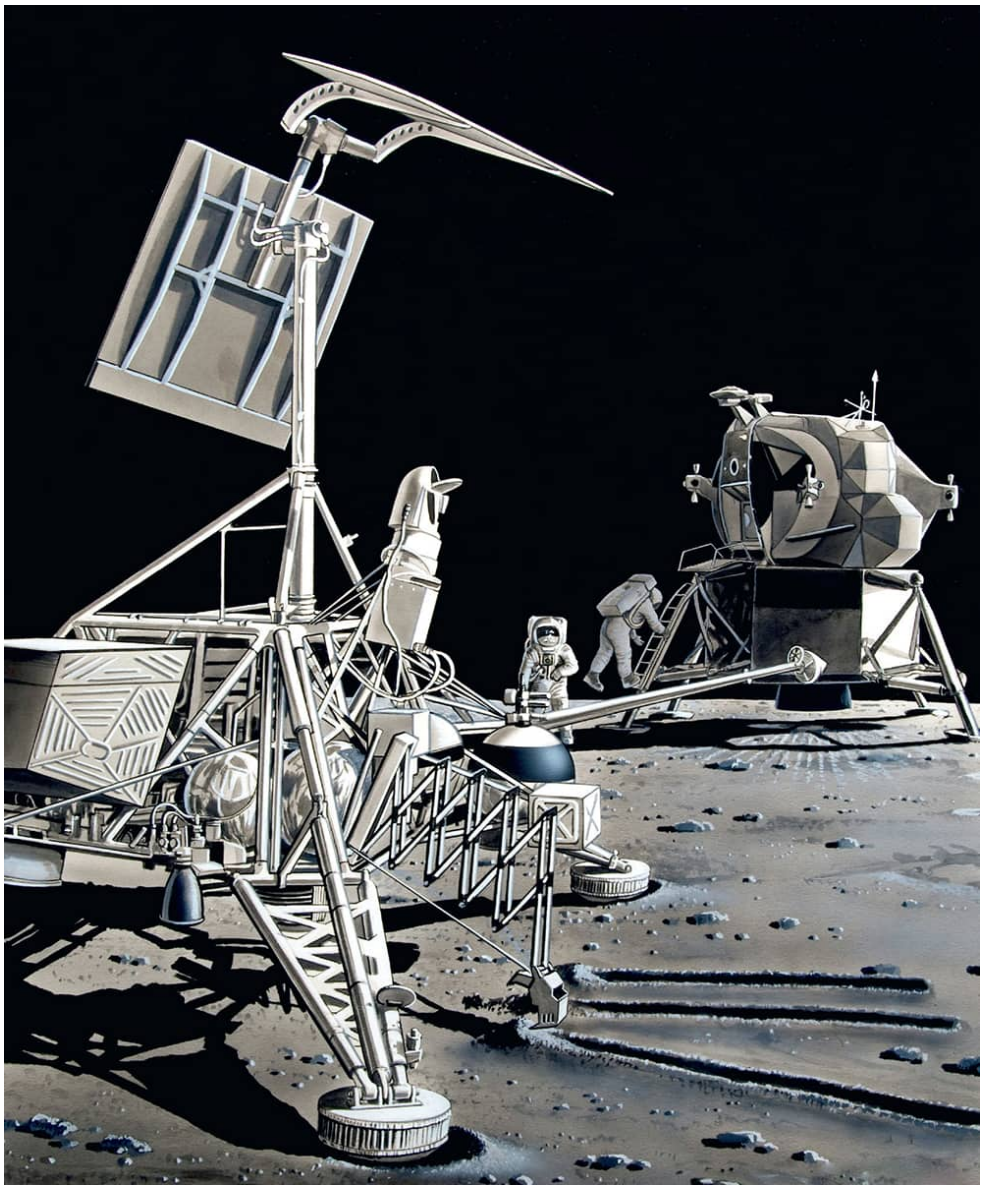
Science on the Moon

Russ Arasmith's depiction of Apollo 16's commander John Young with the Far Ultraviolet Camera/Spectrometer in the shadow of LM *Orion* (above) and Pete Conrad and Alan Bean deploying the Apollo Lunar Surface Experiments Package (ALSEP) during Apollo 12 (below).



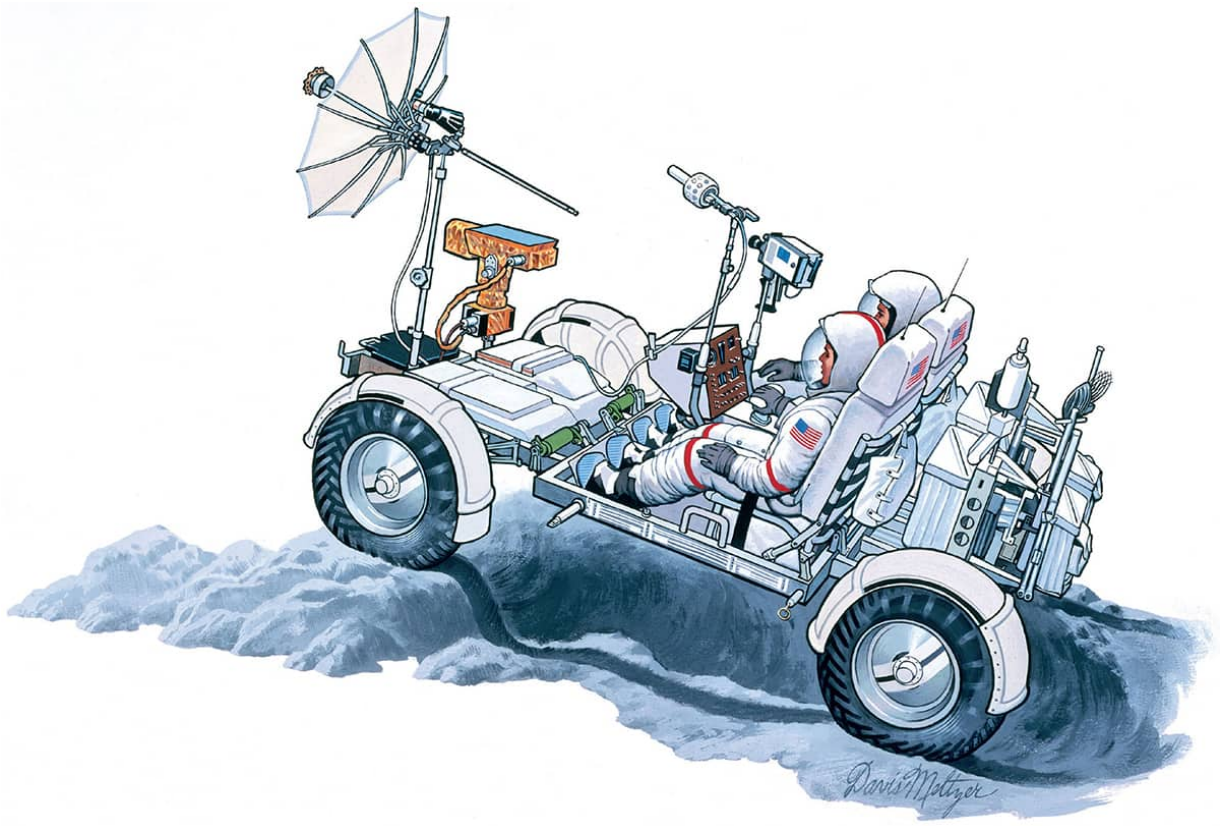


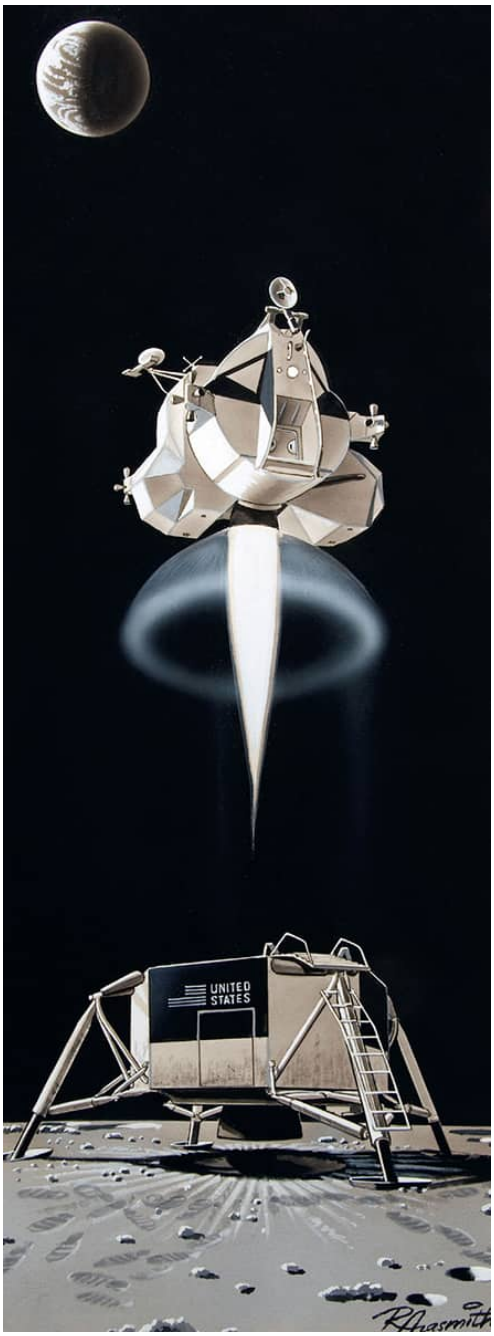
Robotic precursor
Astronauts Pete Conrad and Alan Bean feature in this 1969 Robert Watts artwork showing Apollo 12's encounter with the robotic lander Surveyor III, which touched down in 1967. The astronauts retrieved a TV camera and brought it back home.



Not quite realistic
A similar scene by Russ Arasmith deploys a certain amount of artistic license, because safety constraints prohibited Apollo 12’s LM from touching down so close to the Surveyor.

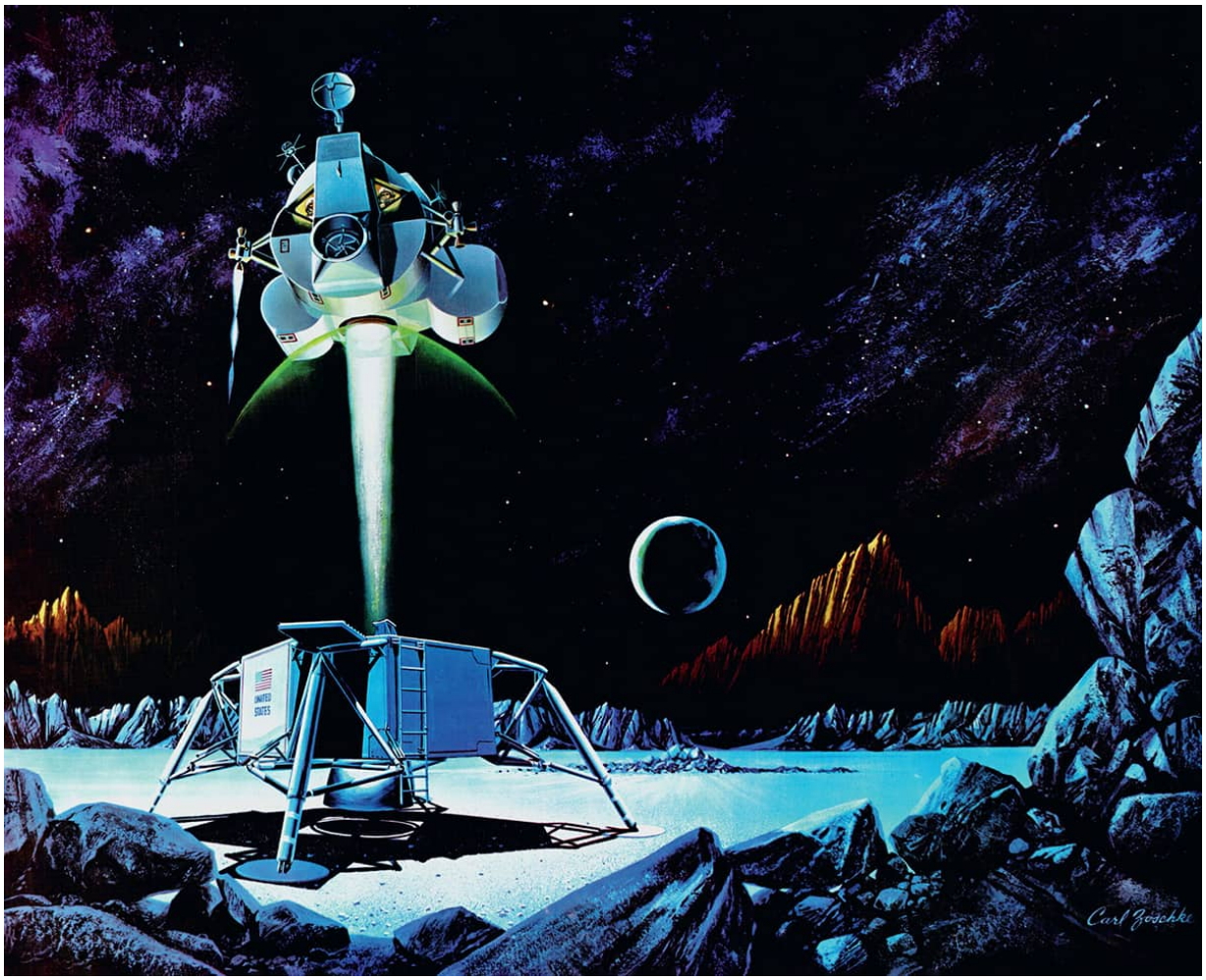
First Car in Space
Robert Watts' 1971 pre-mission painting (above) of Apollo 15 mission commander David Scott (in the left seat) and LM pilot James Irwin aboard the Lunar Roving Vehicle (LRV), manufactured by the Boeing Company, and (below) a typically detailed depiction of the LRV made for *National Geographic* magazine that same year by Davis Meltzer.


Davis Meltzer



Three versions of a take-off

Russ Arasmith's view of the liftoff of a LM's ascent stage (above). The color TV camera on the LRV partially caught this moment live during Apollo 15 and 16, and captured the action in full for Apollo 17. Carl Zoschke's 1964 version of the same scene (next image) depicts a moonscape more colourful than the real thing, while Pierre Mion's rendering for *National Geographic* (second following image) shows something closer to reality.


UNITED
STATES
Carl Roschke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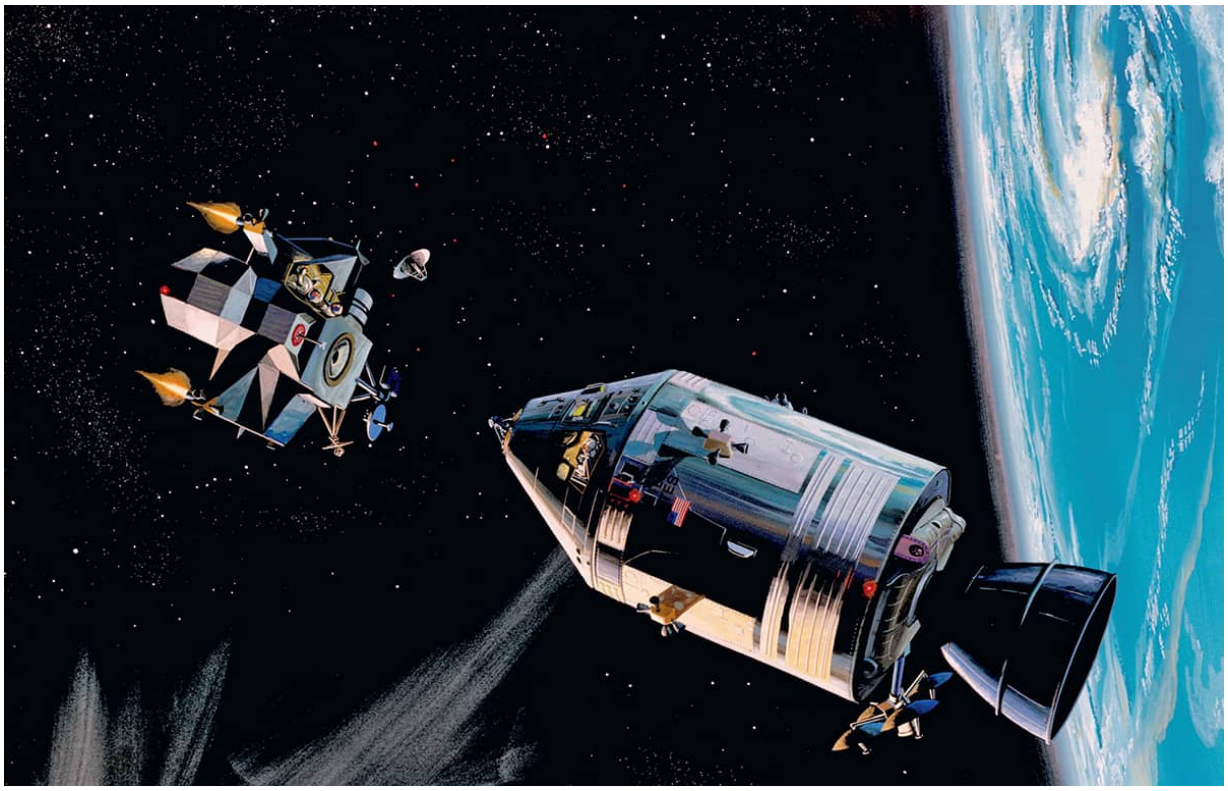
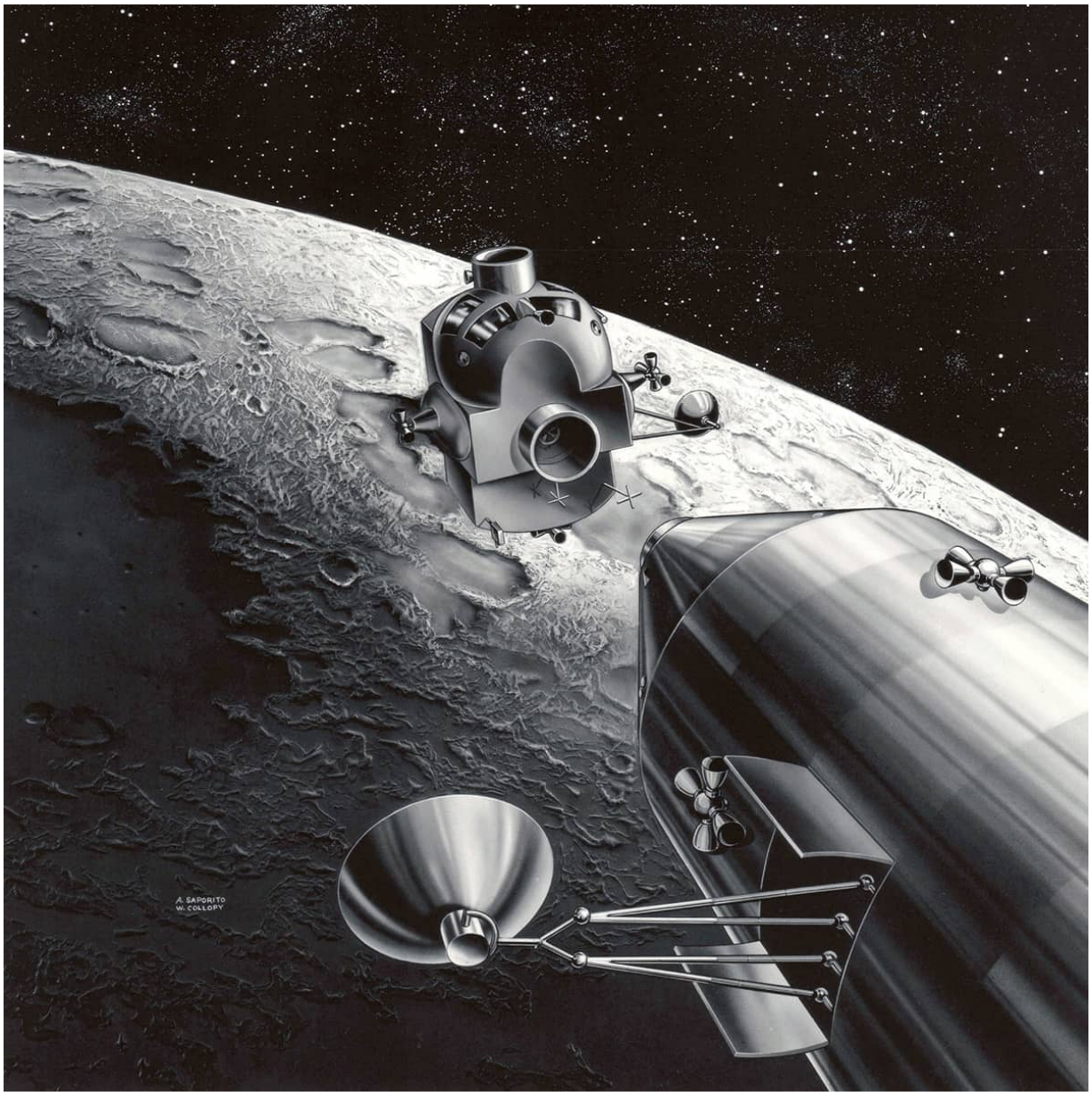


Testing the lander
In a significant work for NASA by an unknown artist, LM ascent stage *Spider* and CM *Gumdrop* prepare to redock during the critical rehearsal flight of Apollo 9, conducted in the relative safety of Earth orbit in March 1969. This was the first crewed flight of a LM.



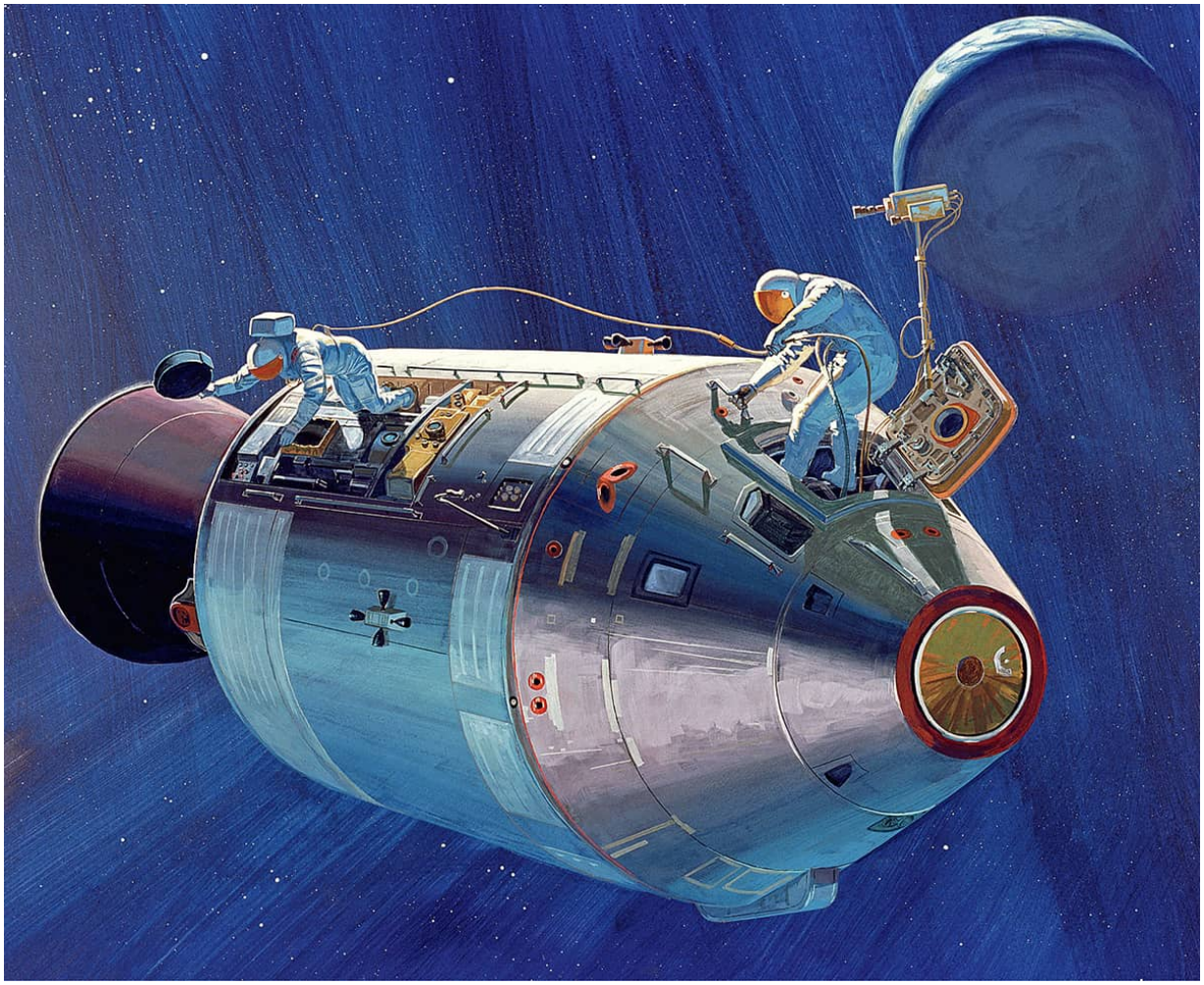
Two versions of a homecoming
Artists A. Saporito and W. Collopy made this early 1960s interpretation of a LM's ascent stage coming up from the Moon to rejoin the CM (above). By 1965 the Apollo hardware was more closely defined, as seen in this slightly dramatised Davis Meltzer version of the reunion (below).

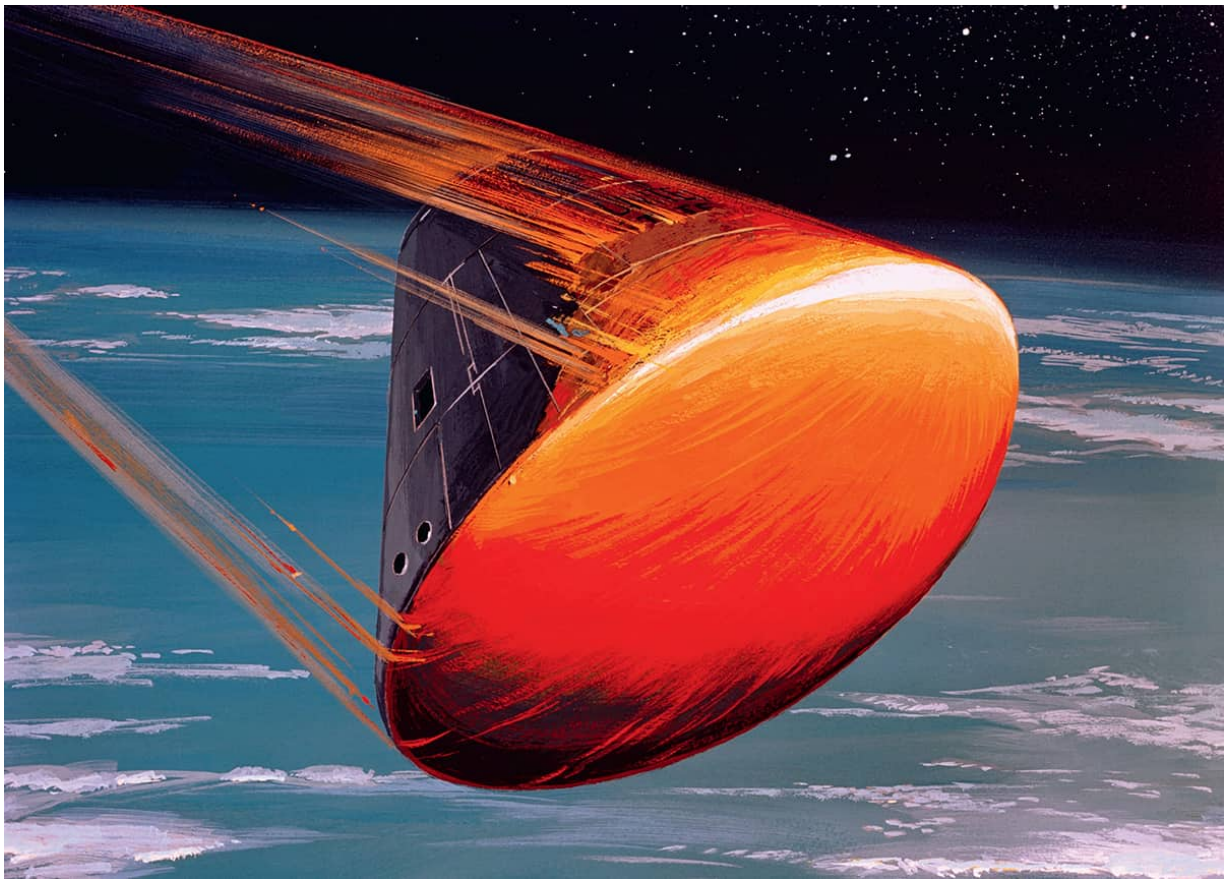

UNITED STATES

High altitude dance
The LM's critical homecoming rendezvous high above the stark lunar landscape is just one scene from Robert McCall's *Apollo Story* lithograph series, originally created in 1973 for the College of Fine Arts at the University of New Mexico, and gifted by the McCall family to NASA.

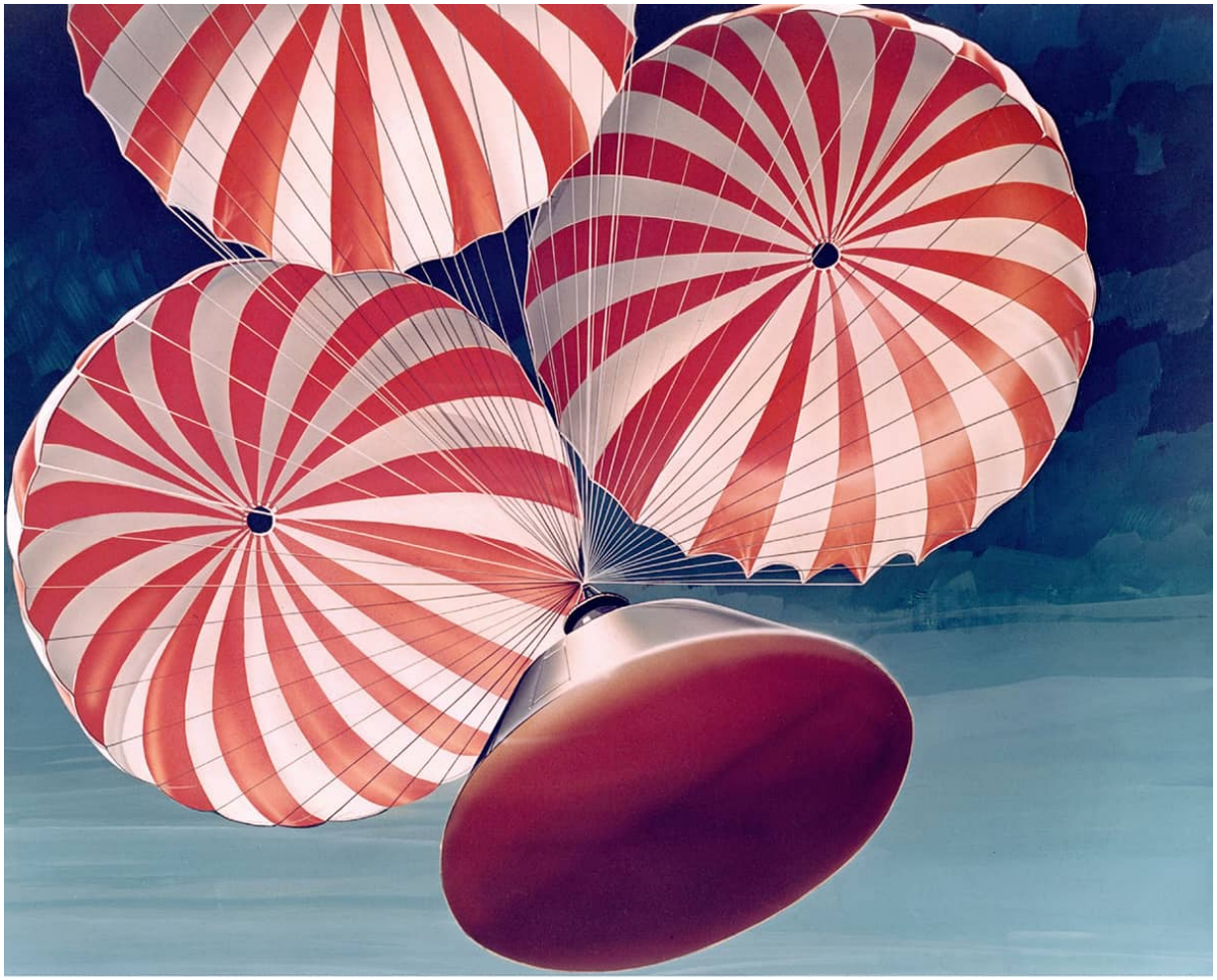
Making an escape
Unknown NASA artist's concept from 1968 depicts Apollo 8's critical engine burn while on the far side of the Moon in December that year: a procedure essential for returning home.

A “walk” in deep space
Apollo 15 LM pilot Jim Irwin watches CM pilot Alfred Worden as he retrieves lunar mapping film cassettes from the flank of Apollo 15’s Service Module in this 1971 painting by Pierre Mion (above). A different perspective is captured (below) by an uncredited NASA artist.





Made it in one piece
A classic NASA image, an unknown artist's 1966 concept of an Apollo CM reentering the Earth's atmosphere on returning from a lunar mission.



Finally over

These were the moments when everyone could breathe a sigh of relief: the smooth opening of an Apollo CM's parachutes, which essentially guaranteed the crew's safety. The splashdown is depicted by Gary Meyer.

Skylab and Apollo-Soyuz

After the lunar landings were completed, NASA hoped to begin a phase of operations known as the Apollo Applications Program. It would use the vast power of the Saturn V rocket to launch space stations and other very large payloads into Earth orbit. Budget cuts forced mission planners to scale down the program, but one project survived. The Skylab Orbital Workshop, launched in 1973, still holds the record as the largest spacecraft ever launched on a single rocket. The big factor in Skylab's favor was its economy. It was already half-built even before it was formally approved as a new project in 1969. The third, uppermost stage of a Saturn V rocket was adapted as the station's main compartment. This stage normally carried fuel for an Apollo spacecraft's trip out of Earth orbit and to the moon, but NASA realized that if this stage remained in Earth orbit, the propellants and rocket engines for the lunar journey would not be needed, and the huge fuel

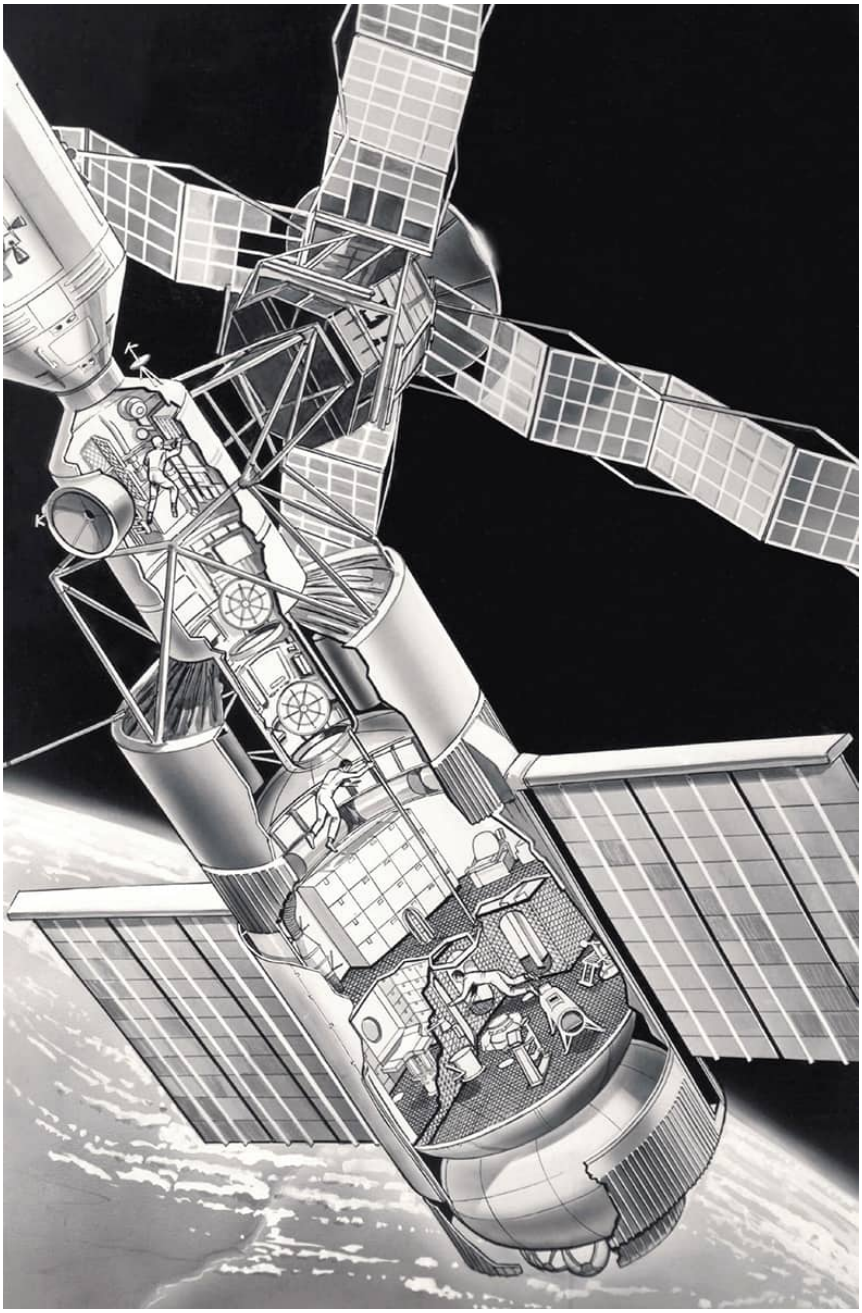
tanks could be filled with air instead of fuel. They could be split into cabins and work areas using lightweight floor and wall dividers.

Apollo lunar landing missions 18, 19, and 20 were canceled in 1970 because the public no longer felt the need for further lunar missions, and the political establishment gave priority to matters other than space. However, most of the hardware was already prepared. A spare Saturn V became available, along with three Apollo CSMs to serve as crew ferries. Skylab assembly was completed in thirty-six months and the station was blasted aloft on May 14, 1973, on the last Saturn V booster to fly.

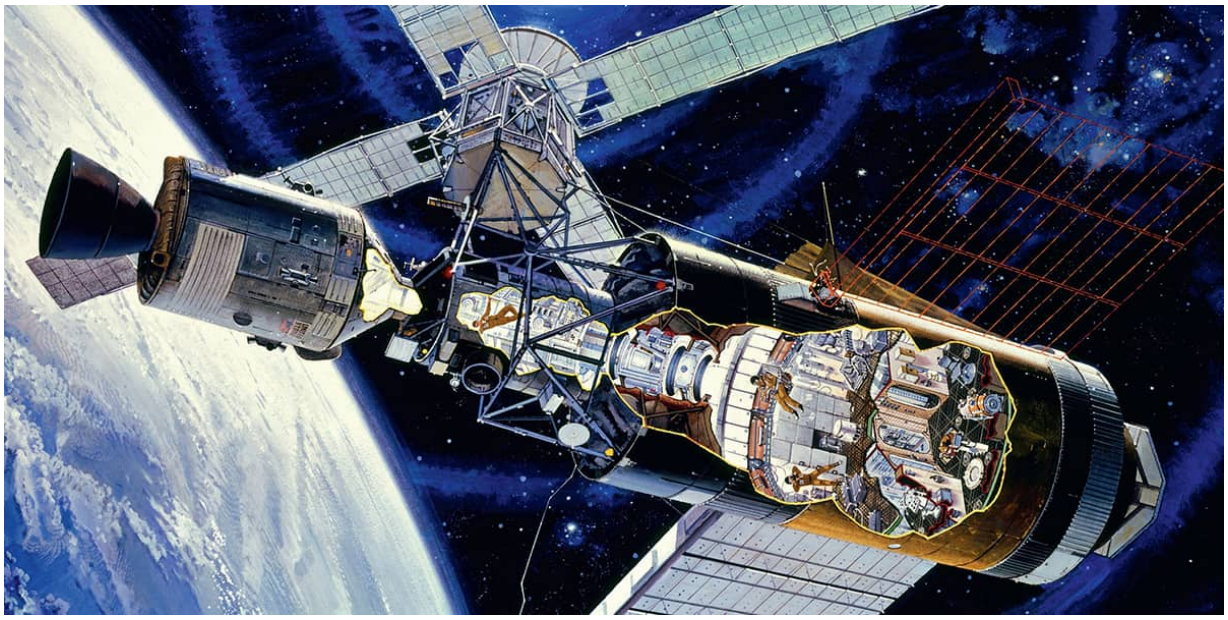
The liftoff appeared flawless. Skylab climbed to a perfect orbit, circling earth at an altitude of 270 miles. But it later transpired that shielding on the lab's outer skin had been badly damaged during the flight. One of the two solar panels was jammed shut in its launch position and the second panel had torn away like a bird's wing ripped off at the shoulder. Skylab's electrical systems were all but crippled. There was no choice but to postpone the launch of the first three-man crew on a separate, smaller rocket (a Saturn 1B) by ten days while NASA considered its next move. Astronauts Joe Kerwin and Paul Weitz, along with their commander, Pete Conrad, began training for an emergency spacewalk, testing out repairs for Skylab in a giant water tank, using a full-scale mockup of the station. Conrad and his crew docked with Skylab on May 25, 1973, although the nose of their command module ferry had initially seemed reluctant to mate properly with the station. Then they began their epic spacewalk. They freed the surviving solar panel so that it could open properly and then deployed a shield of metal foil to protect the lab's main compartment against the Sun's heat. They had to push the shade, folded in a tight bundle, through the airlock of the command module, unwrap it and tie it down against the station using thin straps. Conrad and his crew saved the Skylab project from disaster in a dramatic rescue that made headline news. Two subsequent crews also lived aboard the station, conducting intensive medical experiments and making intensive studies of the Sun using Skylab's specially designed solar observatory instruments.

The magnificent Saturn V had the power to hurl ships to the Moon and to send huge space stations into Earth orbit, but this mighty rocket had an unresolvable Achilles heel: it could launch only once before being discarded. The last Apollo mission took off on July 15, 1975, on board Saturn V's little cousin, the Saturn 1-B. Tom Stafford, Deke Slayton, and

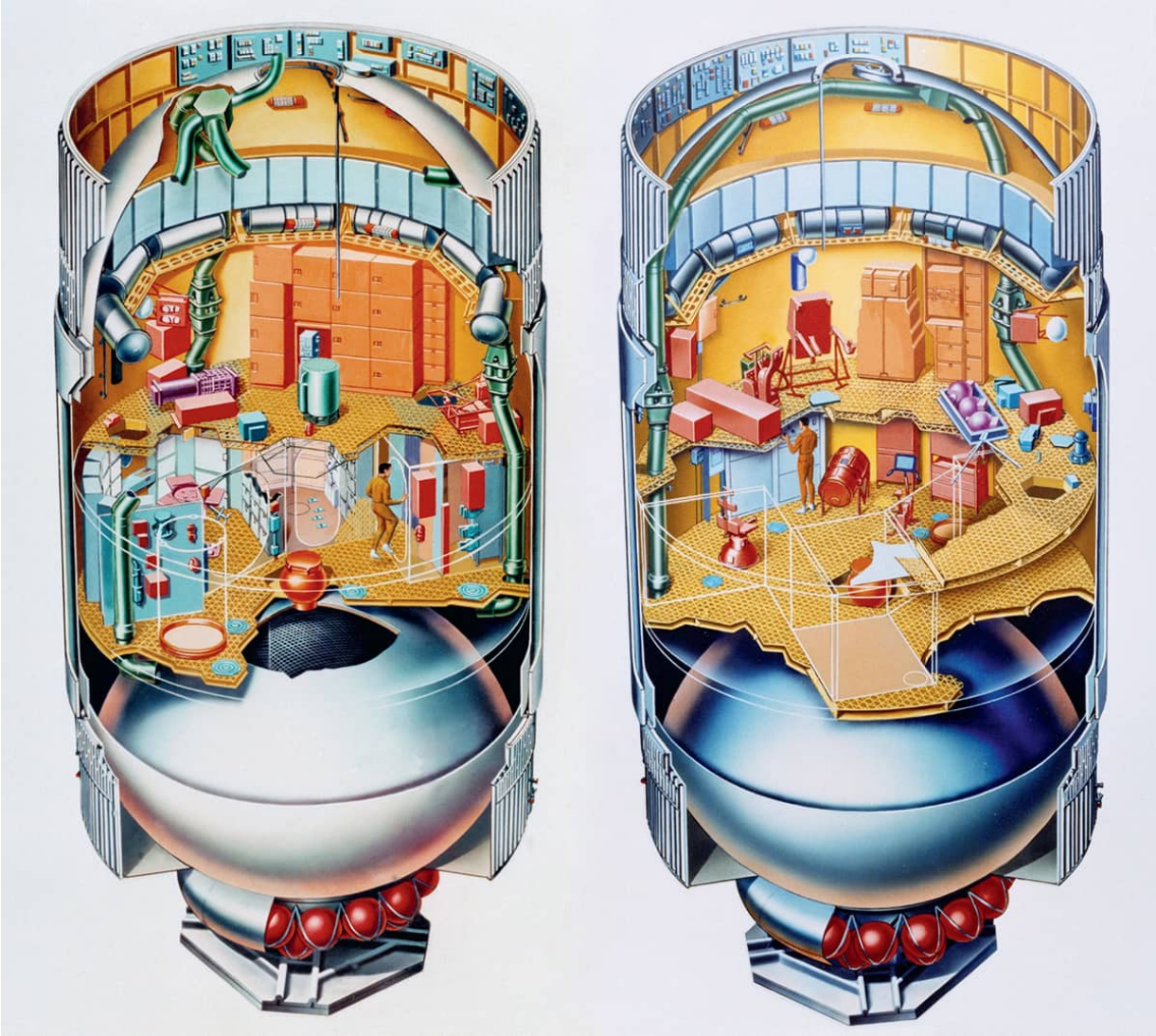
Vance Brand were headed for the first international crewed space mission, a peaceful orbital hookup with a Soviet Soyuz spacecraft crewed by the world's first spacewalker, Alexei Leonov, and fellow cosmonaut Valeri Kubasov. This joint mission, known as the Apollo-Soyuz Test Project (ASTP), had been approved back in 1972 by the Nixon administration just before that president's fall from grace. It was a positive forerunner of larger-scaled orbital international collaborations still ahead. It was also the end of the Apollo-Saturn era.



Repurposing Apollo
An early 1970s Russ Arasmith cutaway of the Skylab Orbital Workshop, America's first space station. The hardware was derived from "spare" Saturn V components that became available when planned Apollo lunar landing missions 18, 19 and 20 were cancelled because of budget constraints and a general sense that NASA had completed the task of reaching the Moon and now had to look beyond that goal.

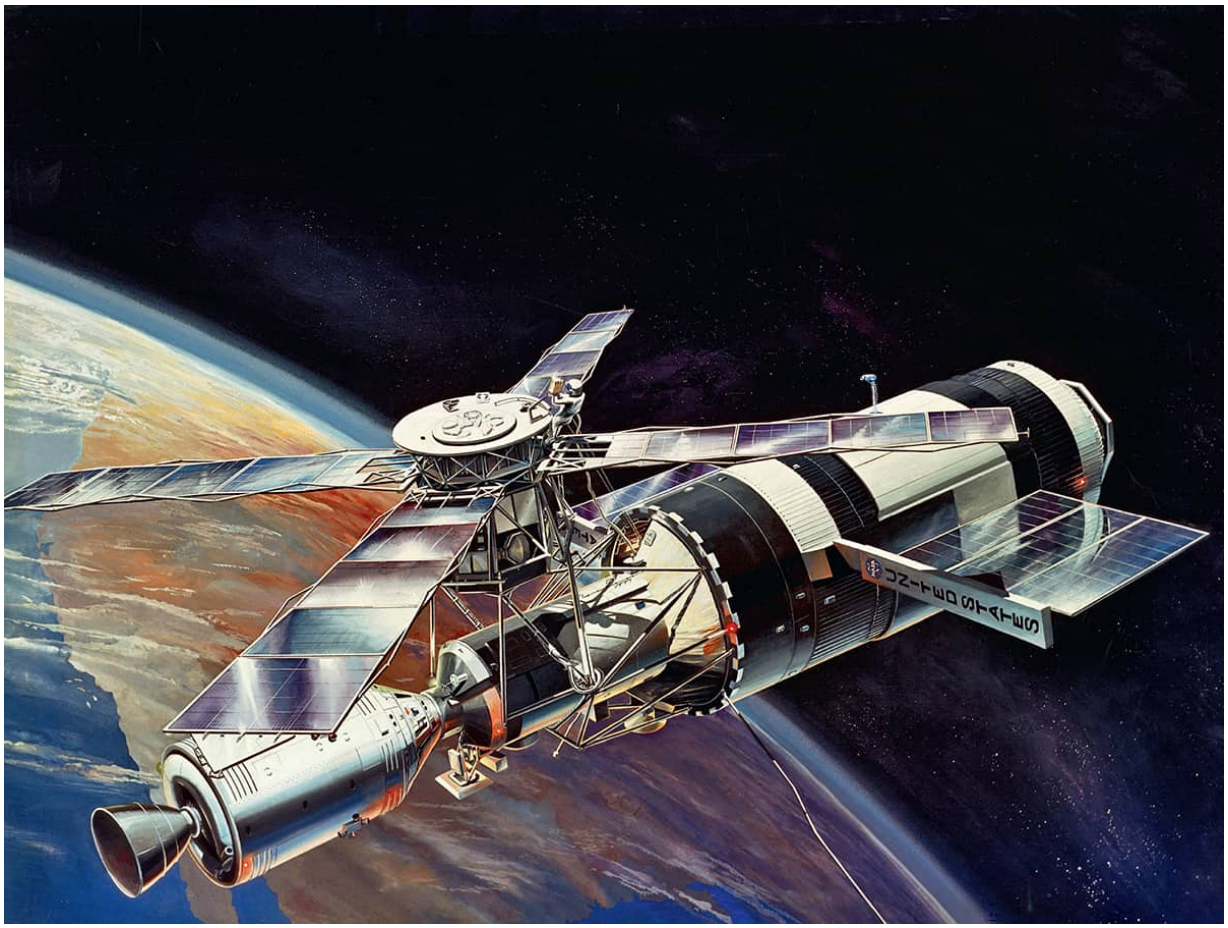


Plenty of room to work
An accurately detailed cutaway view of Skylab made by Robert McCall in 1973. An astronaut is seen testing an Astronaut Maneuvering Unit similar to the one abandoned during the Gemini project, and which subsequently evolved into the Manned Maneuvering Unit briefly employed during the Space Shuttle era. The outline of Skylab's missing solar array, along with the emergency sunshields deployed by Skylab astronauts, are visible along the top edge of the huge spacecraft.



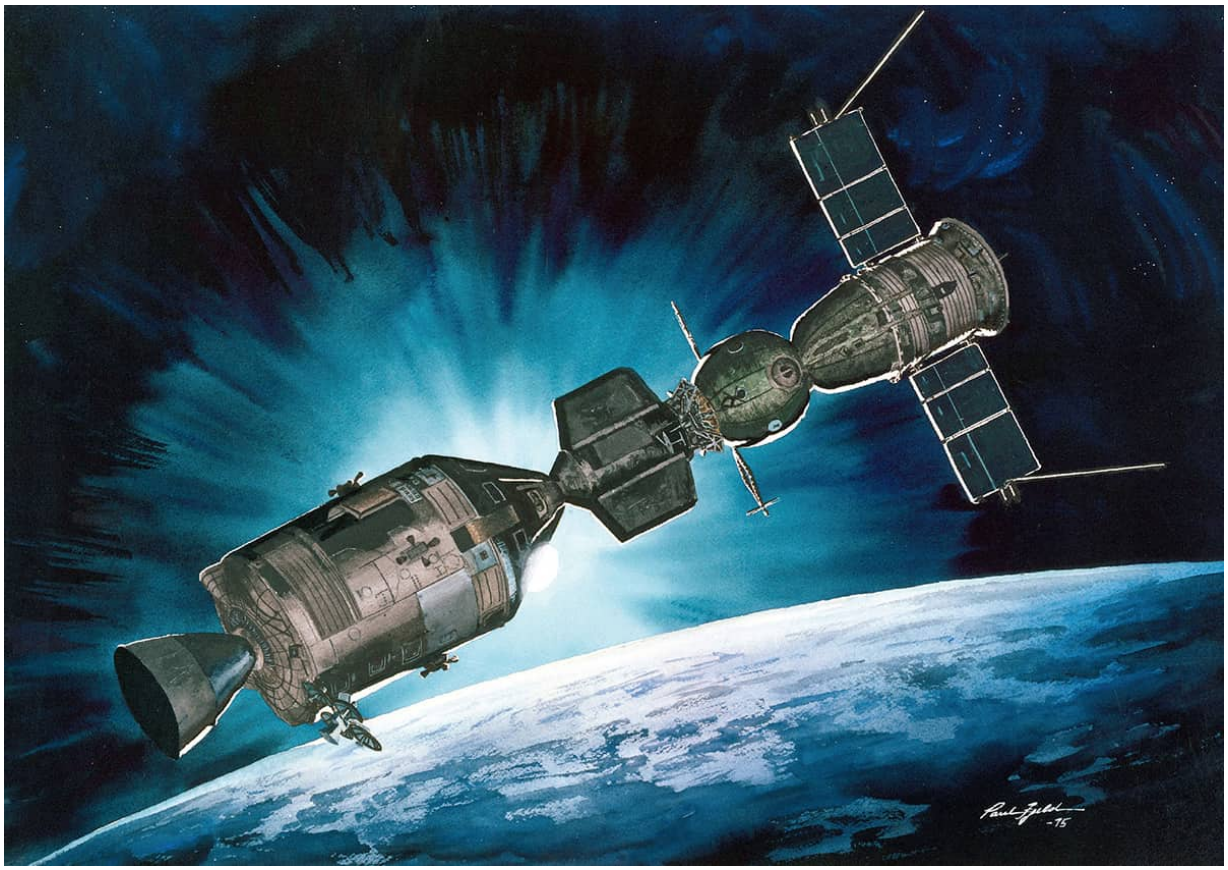
A machine for living

Views from 1973 of Skylab's internal layout. The large tank beneath the "lower" floor is for waste. A flight-ready duplicate of this section is on display at the Air and Space Museum in Washington, D.C.



Engineer and artist

Martin Marietta was one of the contractors involved in Skylab. Company engineer Charles Bennett also had a talent for painting. This is his 1972 pre-mission view of Skylab.

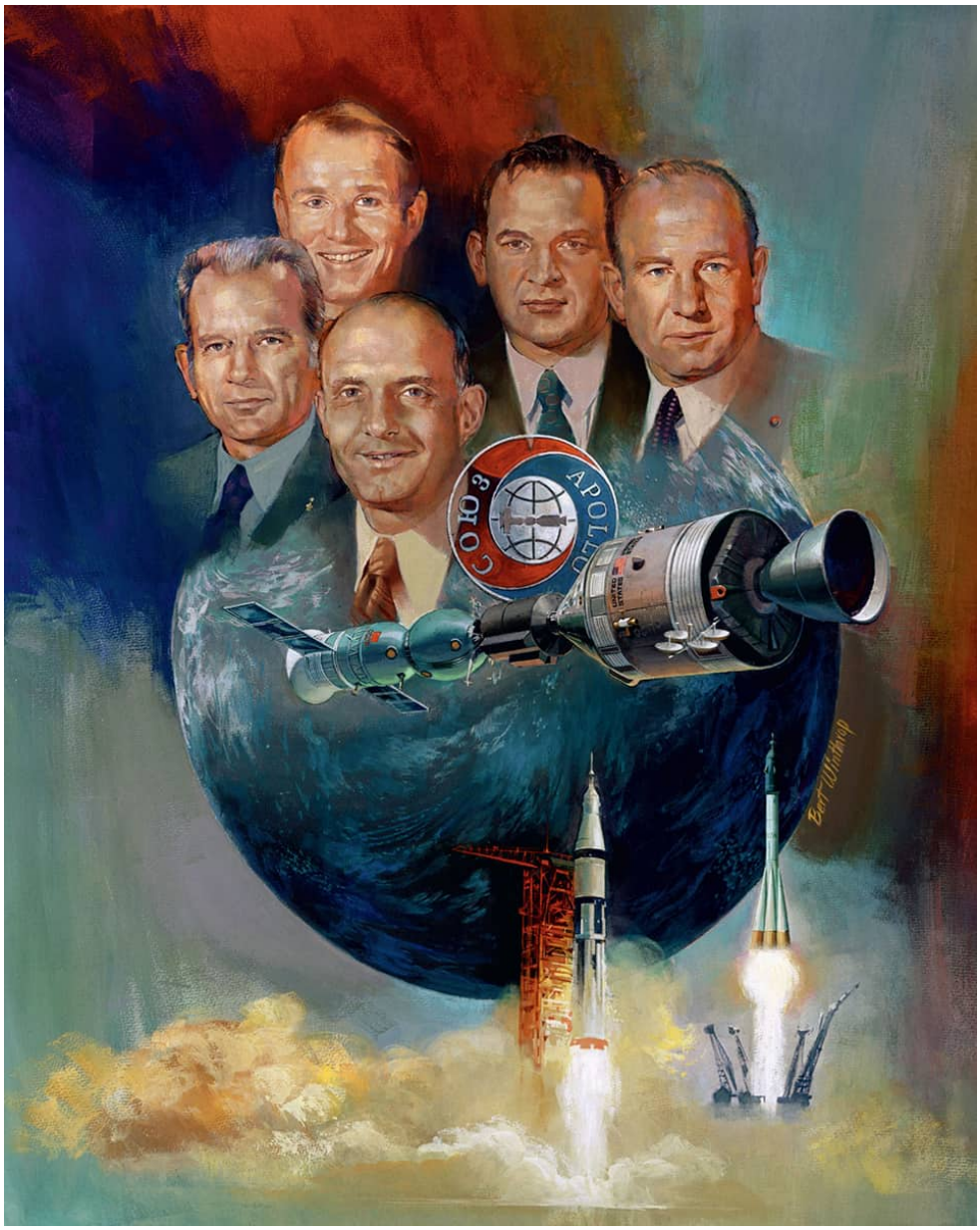


Peaceful get-together

Paul Fjeld's 1975 perspective on the Apollo-Soyuz Test Project (ASTP) of July 1975, the first collaboration between NASA and its erstwhile Russian rivals. Fjeld's achievements have ranged from the design of official mission patches to the preservation of an unflown LM at the Cradle of Aviation Museum in Long Island, NY.

Causing no offense

Davis Meltzer's 1975 view of the Apollo and Soyuz spacecraft depicts the moment when the two crews greeted each other in space for the first time. The two commanders, Tom Stafford and Alexei Leonov, are shaking hands. The docking module had an "androgynous" collar so that the Soviets would not be upset by having their craft "penetrated" by Apollo's arrowlike probe.



Diplomacy in space
Apollo-Soyuz Test Project (ASTP) symbolism from Bert Winthrop for Rockwell International (the company that absorbed what used to be known as North American Aviation). The launches of NASA's Saturn IB carrying the Apollo, and the Soyuz lifting off from Baikonur in Kazakhstan, are also shown.

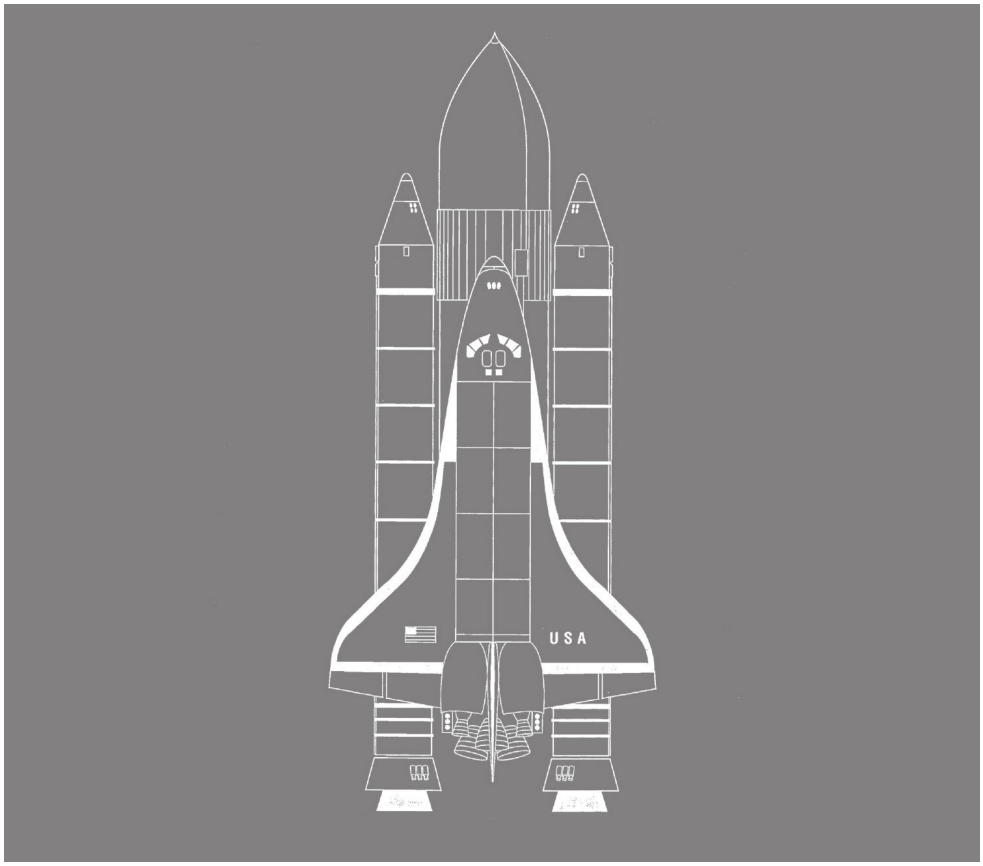
The ideal of peace
Robert McCall's pre-flight depiction of the link-up captures the political optimism of the moment, at a time when Cold War tensions persisted.

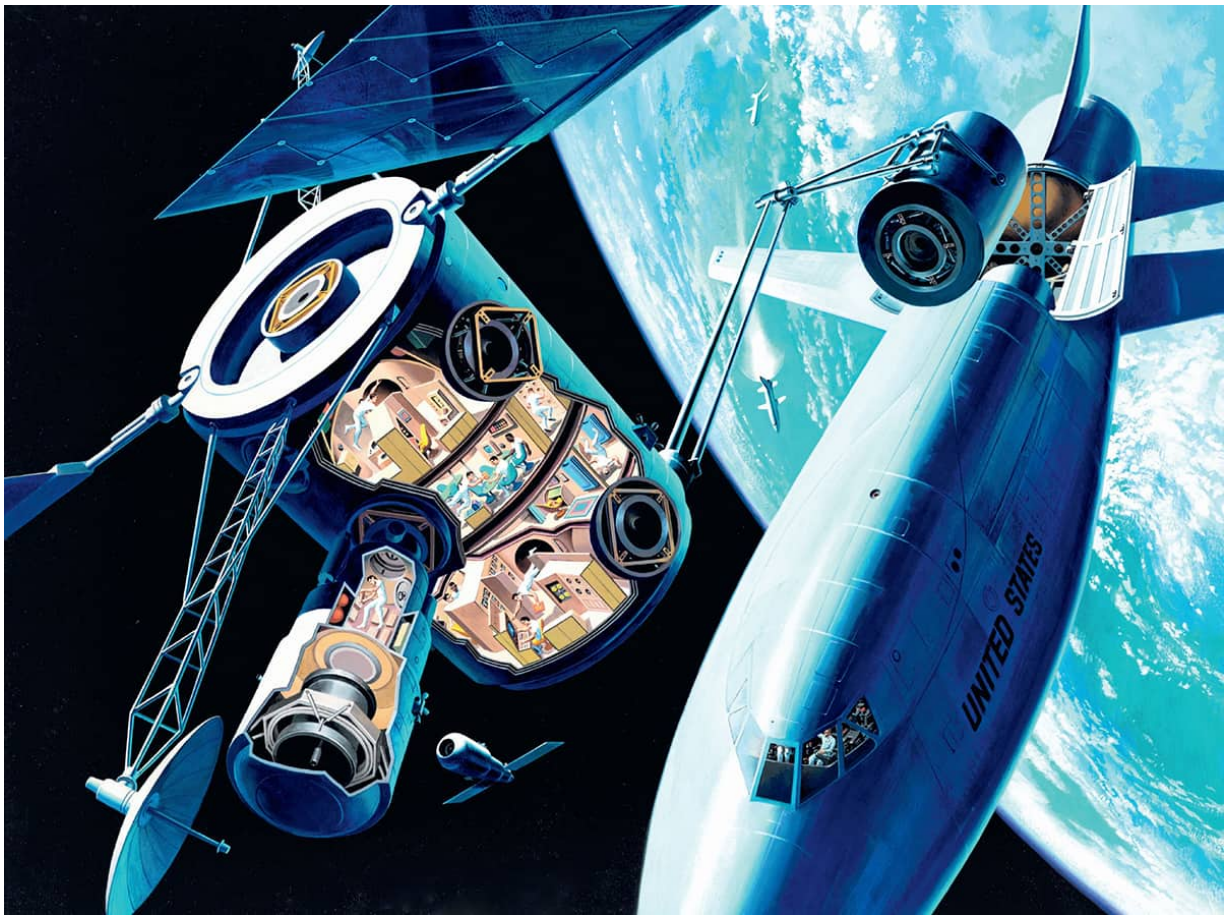
3

ISLANDS IN THE SKY

Inhabiting the Realm of Earth Orbit

As the first lunar landing era drew to a close, space planners retired the Saturn V and looked for a cheaper, reusable launch system that could provide regular access to space.





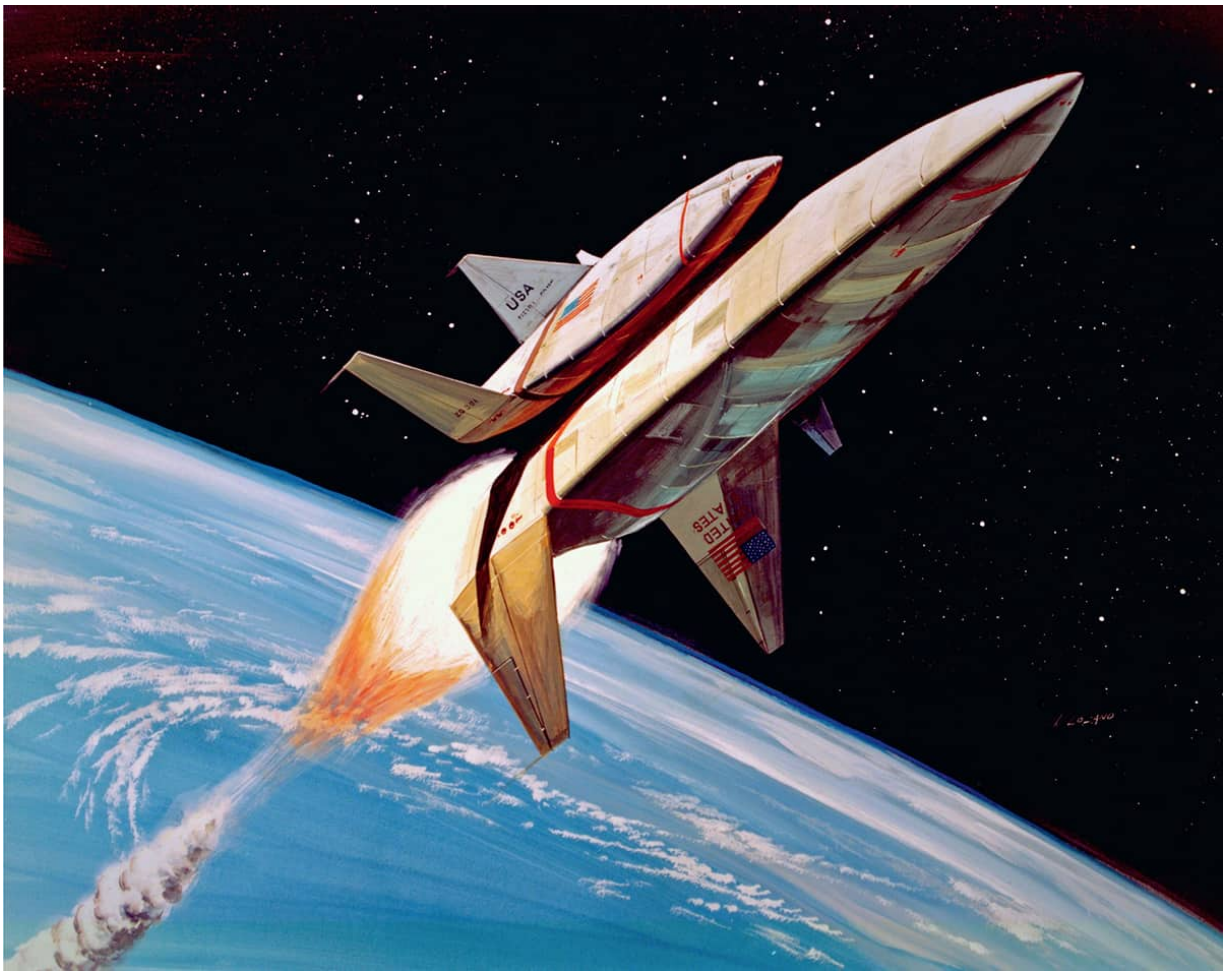
Toward the shuttle era
Davis Meltzer's *A Space Station*, commissioned by *National Geographic* and featured in the August 1970 issue. This kind of image became the new baseline for visions of life in orbit, enabled by winged space shuttles.

3: Islands in the Sky

Even before the Apollo missions drew to a close, NASA looked afresh at all the data from the X-15 and Lifting Body programs and began development of the world's first reusable spacecraft, known as the Space Shuttle. On April 12, 1981, NASA launched shuttle Columbia, commanded by Apollo veteran John Young and copiloted by Bob Crippen. So many of America's successes in space over the subsequent three decades were made possible by the shuttle's multi-mission capabilities. Accommodating up to seven astronauts and featuring a sixty-foot-long cargo bay, it served the needs of both human and cargo transportation.

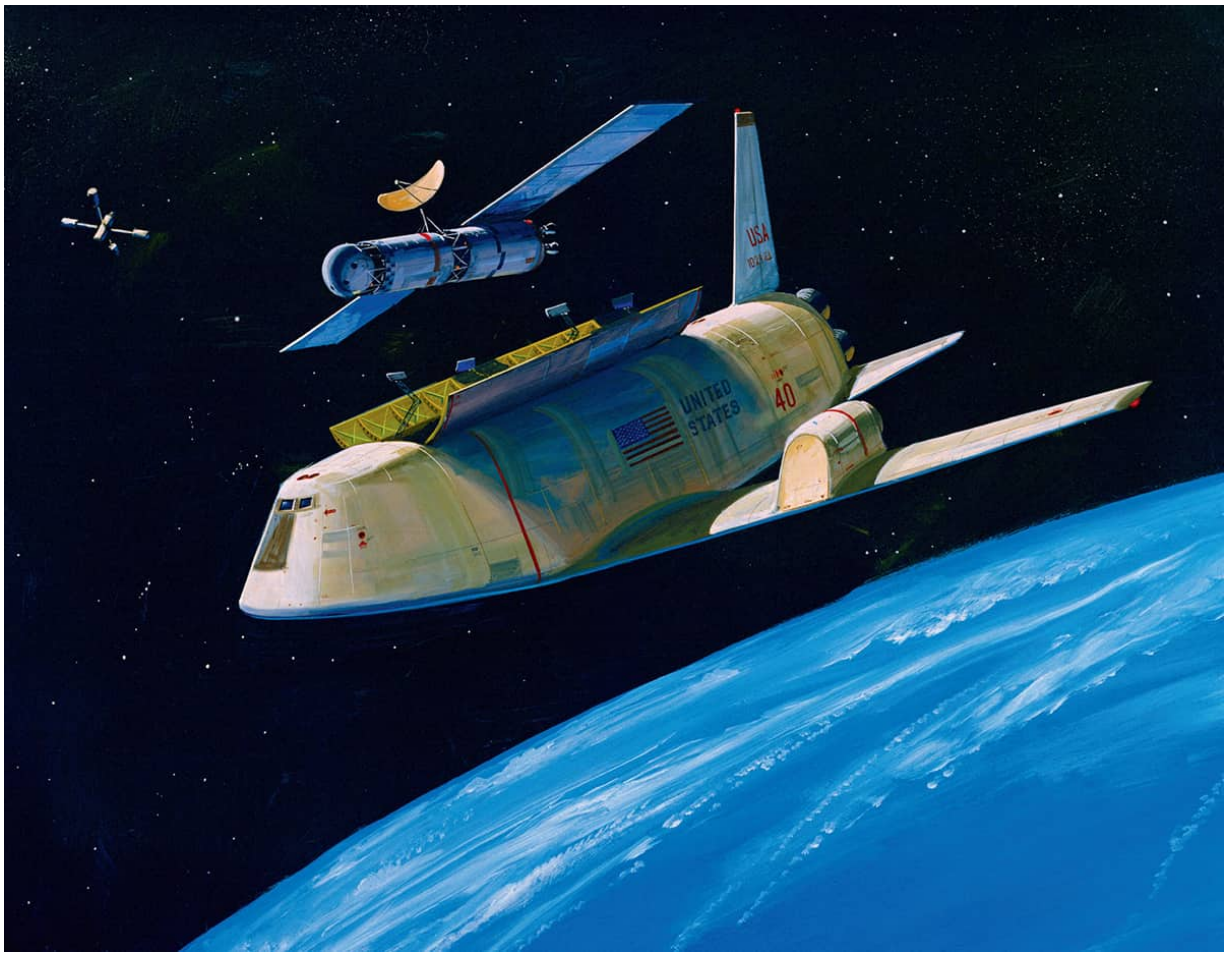
Not yet this big
In this 1964 Robert McCall painting, a delta-winged space shuttle is refueled inside a massive spherical space port orbiting the Earth. This was typical of many grand-scale visions for our future in space that have not yet been realised.

Over the course of the thirty-year Space Shuttle Program, NASA flew 133 successful missions, its fleet accomplishing marvels that were once science fiction dreams. The shuttle story also encompassed two tragedies. In January 1986 Challenger exploded less than two minutes after launch, and killing the entire crew of seven. In February 2003, sister ship Columbia disintegrated during reentry. Another crew was lost. They had no clue, while enjoying what had seemed like a smooth mission, that a suitcase-sized piece of thermal insulation foam had peeled off the huge external fuel tank shortly after launch, hitting the shuttle's left wing and making a small but ultimately catastrophic hole. A fortnight later, as Columbia hurtled through the atmosphere at the end of its mission, hot gases rushed into that hole, destroying the vehicle. Both disasters perhaps could have been avoided if NASA managers had heeded the many internal warnings they received about serious flaws in operational procedures. There was a tendency among mission managers and the public alike to think of a system powered by five furious infernos of hydrogen, oxygen, and ammonium perchlorate so well-tamed that its launches were barely worth remarking upon anymore. It is not possible to underestimate the human tragedy in the shuttle story. Fourteen astronauts lost their lives during the program. However, it would be wrong not to add another salient fact. Flying at a rate of once every two or three months, the shuttle asserted American leadership in space for three decades prior to the system's retirement in 2011.



Piggy-back ride to space
One of many proposals for a shuttle with fully reusable fly-back components. NASA's plans kept changing in response to shifting signals from the political establishment.

Delta dreams
This elegant version of the shuttle, with a fully reusable human-piloted winged booster, proved too expensive for NASA to develop.



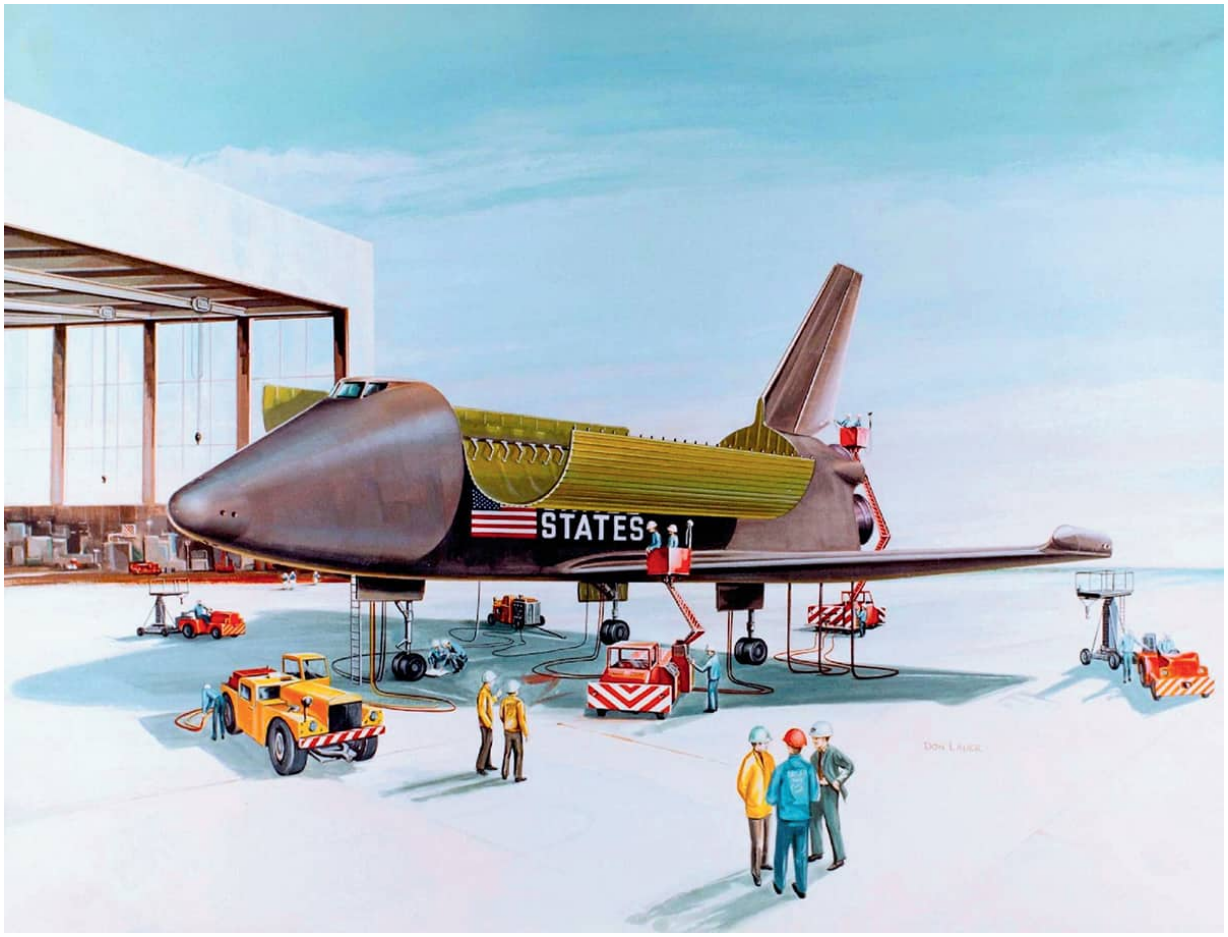
Additional engines
Another idea that never reached fruition was to incorporate small jet engines in a shuttle's wings in order to give the vehicle greater flexibility in its choice of landing sites.

Shuttles achieved joint scientific missions with European Spacelab modules, a succession of dockings with Russia's Mir space station, and dozens of orbital science flights. The fleet deployed more than fifty satellites for military, governmental, and commercial clients, and launched three interplanetary craft: Magellan to Venus, Galileo to Jupiter, and Ulysses to study the Sun. Shuttles also launched major astronomical observatories, including the Hubble Space Telescope, the Gamma Ray Observatory, the Diffuse X-Ray Spectrometer, and the Chandra X-Ray Observatory. Shuttles carried more than 3.5 million pounds of cargo to orbit, filled 833 crew seats, and logged nearly 200,000 hours of accumulated astronaut time. And, of course, the shuttle made possible the world's most ambitious space program, the International Space Station.

Island in the Sky

The common public perception is that the so-called “Space Race” came to an abrupt end with the lunar touchdown of Apollo 11 in July 1969. In fact, a competitive tension persisted for another two decades, until the fall of the Berlin Wall and the end of the Soviet era. While NASA worked throughout the 1970s on shuttle development, the Soviet Union answered with a steady expansion of its space station fleet, starting with the Salyut orbiting platforms and culminating in the multi-module Mir complex. When Ronald Reagan came to the White House in 1981, some of his advisors expressed concern about Soviet dominance in orbit. It seemed natural for NASA to build a new space station in response. On January 25, 1984, Reagan announced that a station called Freedom would be assembled in orbit by an international partnership of agencies from Europe, Canada, and Japan, led by NASA. But the road to Reagan’s station was long and bumpy, and often so muddled in costly paperwork over the next two decades that Washington lawmakers several times threatened to cancel the entire program. Compare and contrast Shuttle- and Station-era NASA, assailed from all sides by political infighting, with the days of Apollo when, once the dust had settled in the design process, almost everyone agreed on what the lunar program was about and how it should be accomplished. In all the renditions of Apollo, at least there was a certain consistency once the Lunar Orbit Rendezvous business had been decided upon. However, when it came to designing the space station, no such consistencies were apparent in the design process. Artists’ concepts ranged from gigantic webs of metal struts supporting solar-power arrays the size of football stadiums to vast hangars servicing Mars ships, tight bundles of cylinders housing just a few astronauts, and all points between. NASA spent billions of dollars redesigning the station because no one could agree what it was for. When we use the term “NASA” it’s easy to forget that the agency is really a scattered collection of specialist centers. The Kennedy Space Center (KSC) in Florida launches most of the rockets. The Johnson Space Center (JSC) in Houston controls crewed flights. The Jet Propulsion Laboratory (JPL) in Pasadena handles robotic missions beyond Earth. Goddard in Maryland deals with most of the Earth science and astronomy missions. Capping it all, NASA headquarters in Washington tries to get all the centers to work in harmony. But because each is in a different US state, political rivalries often come into play. After the space station idea was approved by Reagan, the

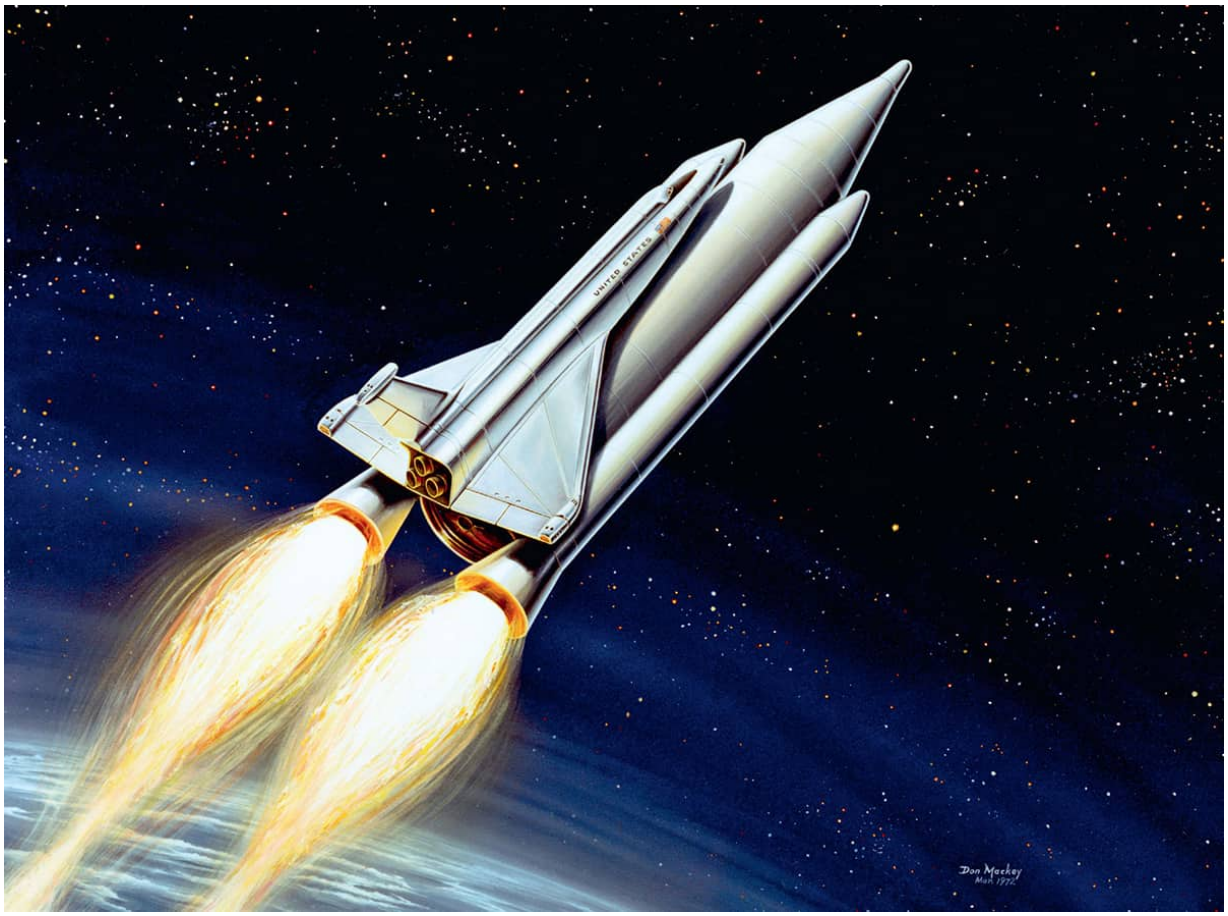
various centers argued vehemently about how to proceed. No surprise, then, that artist's concepts of the space station are the most varied among all of NASA's program visualizations. Perhaps more of a surprise is how hard it is to find high-resolution versions, let alone original artworks, of the thousand-and-one iterations prior to actual construction of the first real station hardware. One could almost imagine that NASA is embarrassed by the early, expensive years of design chaos and prefers now to focus on the crisp and comfortingly "this is what we actually came up with" version that actually was built.



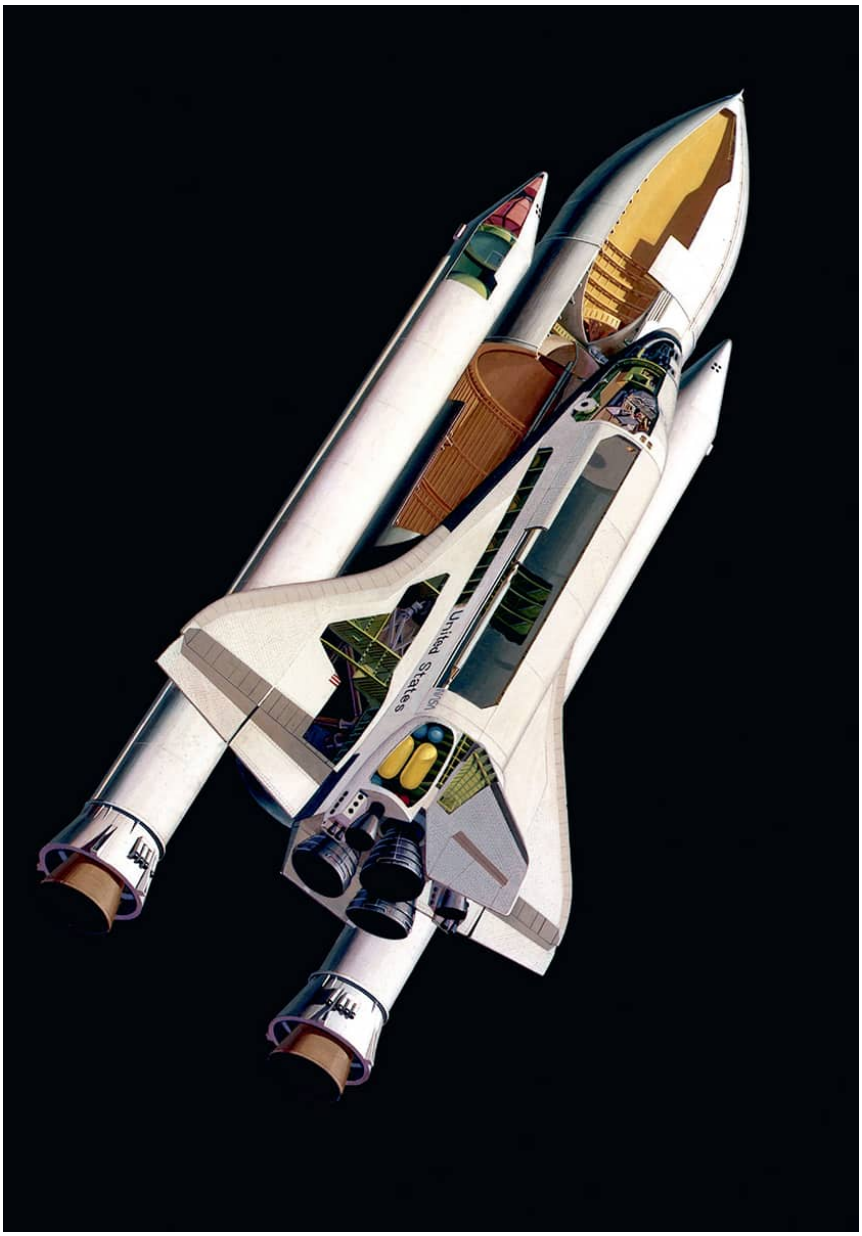
Not so simple
A somewhat naive illustration from the mid-1970s suggested that space shuttles would be as easy to service, land, and fly as any normal aircraft. This turned out not to be true.

Smaller cargo capacity

Billion-dollar space programs need wide political support. The Pentagon did not like this version of NASA's shuttle concept because it deemed the payload bay too small for carrying spy satellites.



The winning scheme
This is the concept for the space shuttle system from Rockwell International, the company that won approval from NASA in July 1972 and also obtained the backing of the White House.

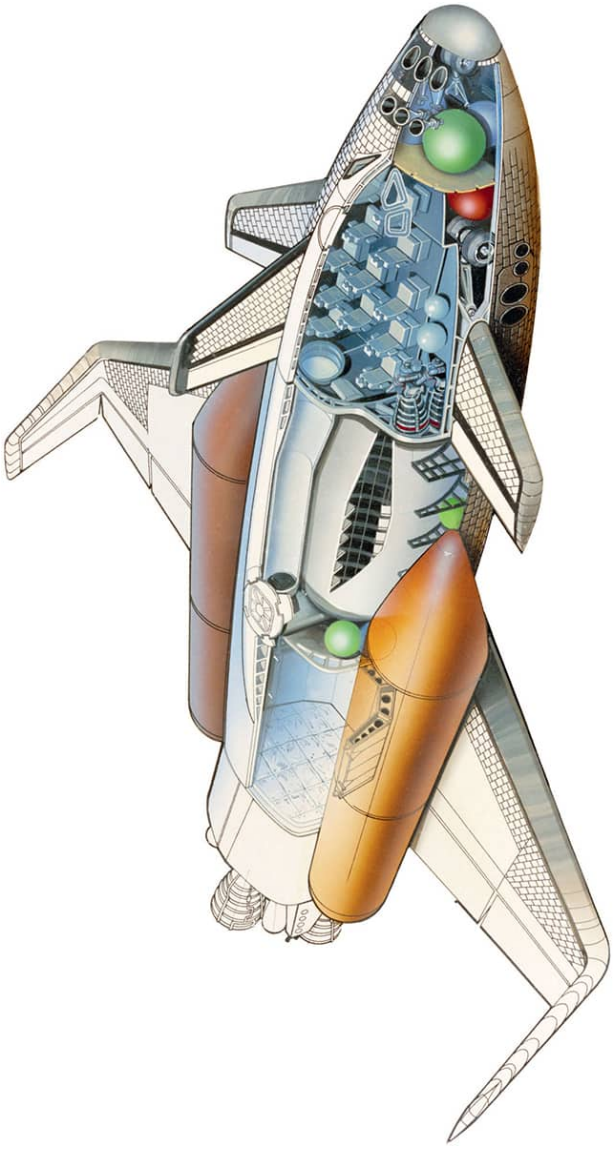


Final configuration
This late 1970s cutaway of the Space Shuttle shows how it finally looked, with the semi-reusable Solid Rocket Boosters (SRBs) at the sides of the huge expendable External Fuel Tank.

Close to reality

A 1974 Robert McCall contribution to *Our World In Space*, a book by science fiction author Isaac Asimov. The shuttle design is close to what was finally constructed and ready for flight by the end of the 1970s, apart from thruster pods on the wing tips, which were relocated to the base of the tail plane.

Ascent of a winged space plane
Rockwell International won the coveted award to build the winged Space Shuttle orbiter component for NASA. Company artist M. Alvarez created this dynamic 1975 overhead view of a shuttle launch. The first mission actually flew in 1981.

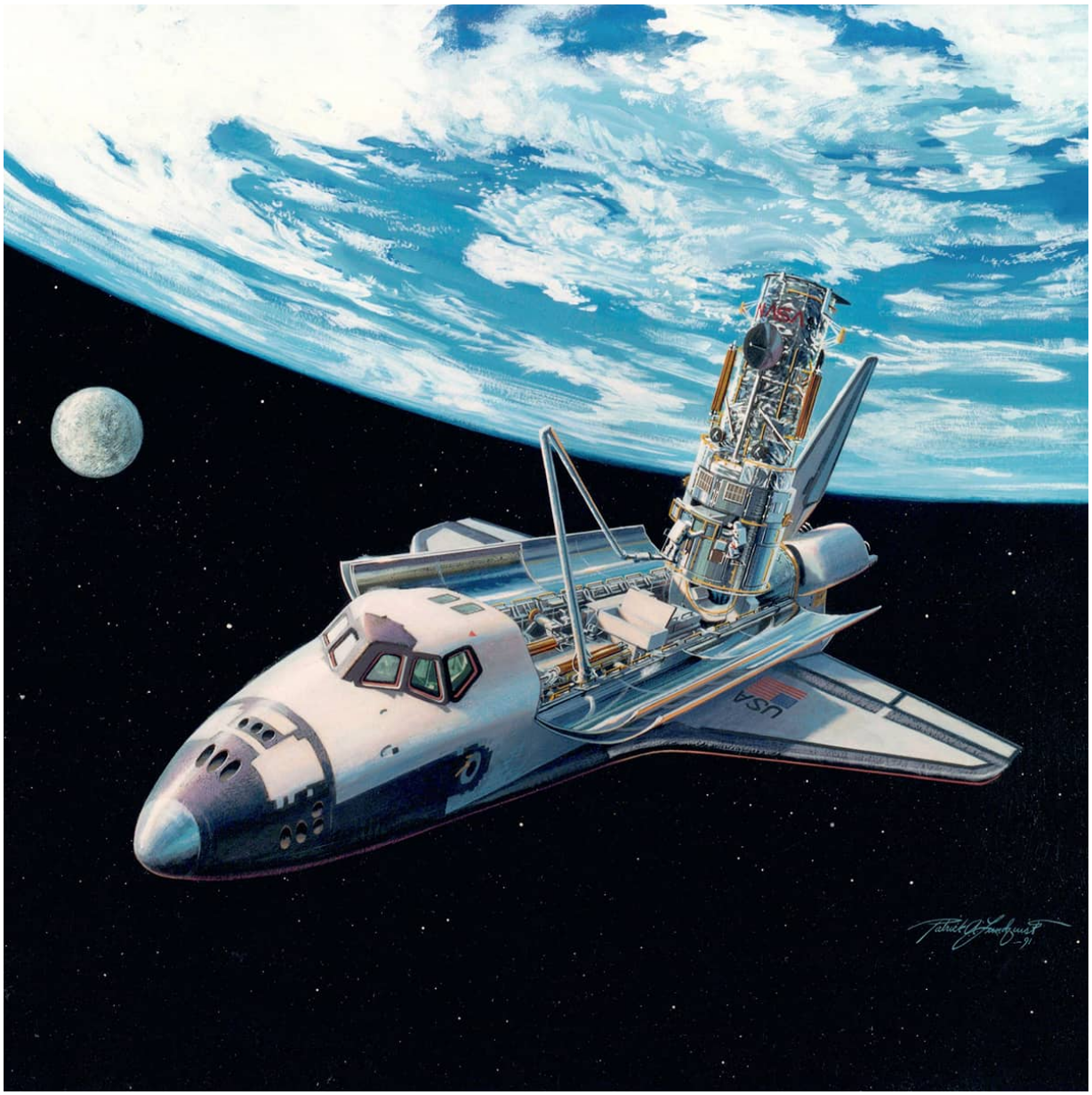


Extending the shuttle story
John Frassanito's work featured often in NASA presentations from the 1980s and into the early 21st century. This is an optimistic depiction of an upgraded space shuttle with capacity for a dozen astronauts.

In the 1990s, a seismic shift in history resulted in a new bias to the station's political justification. In June 1992, NASA chiefs met with their Russian counterparts. The subject under discussion was epic: could Russia and the US, those bitter Cold War enemies, find common cause in space now that the Soviet era had ended? Over the next two years, NASA negotiated for joint missions aboard Mir, the last of the Soviet-era space stations, prior to securing Russia's peaceful partnership in Earth orbit. The proposed architecture was redesigned one last time to include Russian

modules, and the project finally became known as the International Space Station (ISS).

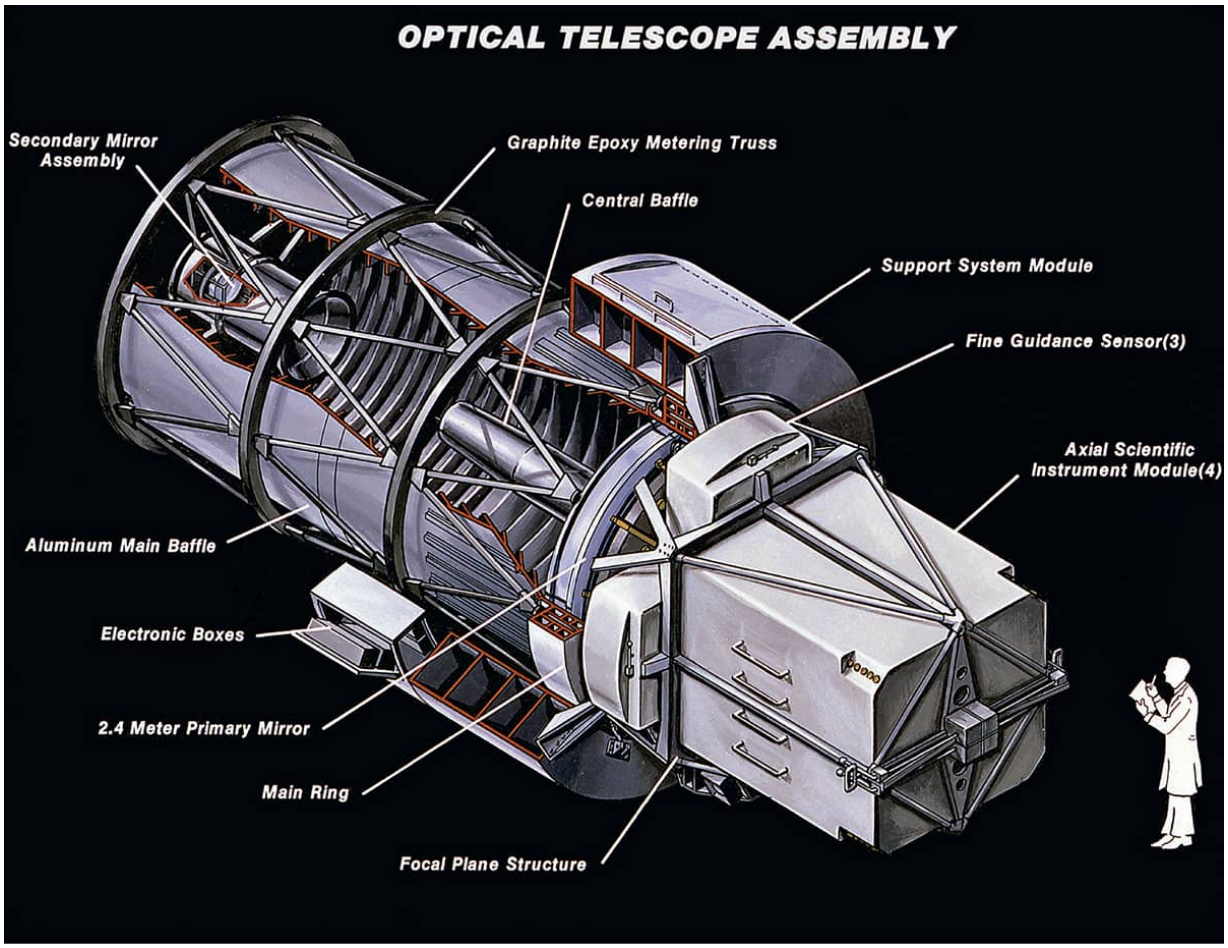
The first component of ISS, the Russian-built control module Zarya, was sent into orbit by a Russian Proton rocket launched from Baikonur in Kazakhstan, on November 20, 1998. Then came the US-built Unity docking node and the Russian Zvezda Service Module, just the first three in a series of ISS components. This project became the largest international scientific and technological collaboration in peacetime history. America and Russia, for so long the main protagonists in a global Cold War, were working closely, alongside Canada, Japan, and eleven other nations represented by the European Space Agency ESA.



Delivering the telescope
Patrick Lundquist's 1993 interpretation of the Hubble Space Telescope (HST) and its planned repair in Earth orbit by astronauts working from the payload bay of a shuttle (above), and artist John Solie's view of the "clean room" facilities at Lockheed Martin (below), where HST underwent final checks that failed to catch an error in the main mirror.


NASA
esa

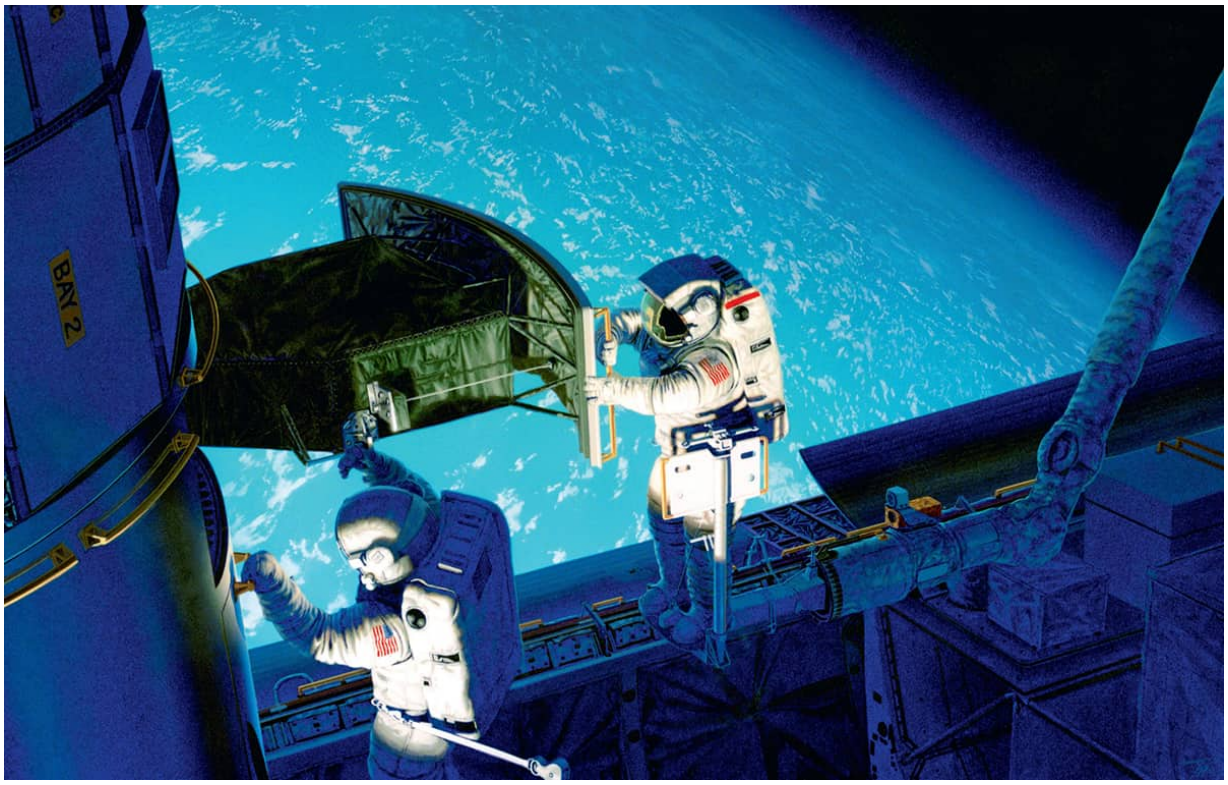
World-famous instrument
An unidentified artist made this 1990 painting of the Hubble Space Telescope for NASA's Marshall Space Flight Center (MSFC) in Hunstville, Alabama.



The business end

Hubble's Optical Telescope Assembly (OTA), consisting of two mirrors, a primary and a secondary, support trusses, and the focal plane structure. The system detects objects 25 times fainter than anything that can be seen from Earth.

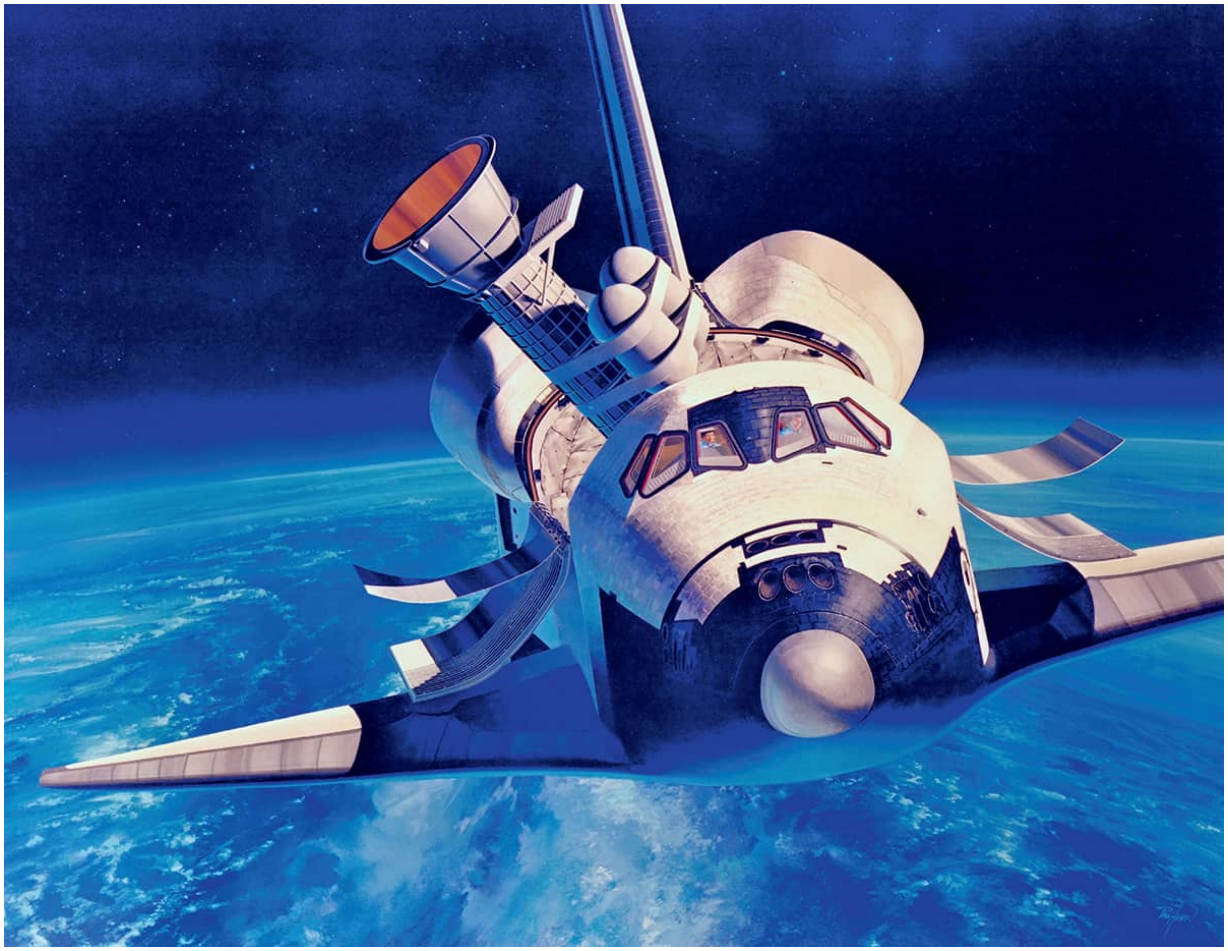
Successful “fix-it” flight
Paul Hudson’s 1990 painting (above) of the Hubble Space Telescope’s launch into space from the payload bay of shuttle *Discovery* in April 1990, and his subsequent rendition (below) for NASA’s Jet Propulsion Laboratory (JPL) of the critical first Hubble Servicing Mission in December 1993, during which astronauts installed instruments with corrective optics to compensate for Hubble’s flawed primary mirror. The mission was a triumph, and helped keep Hubble fully operational for more than two decades.


BAY 2

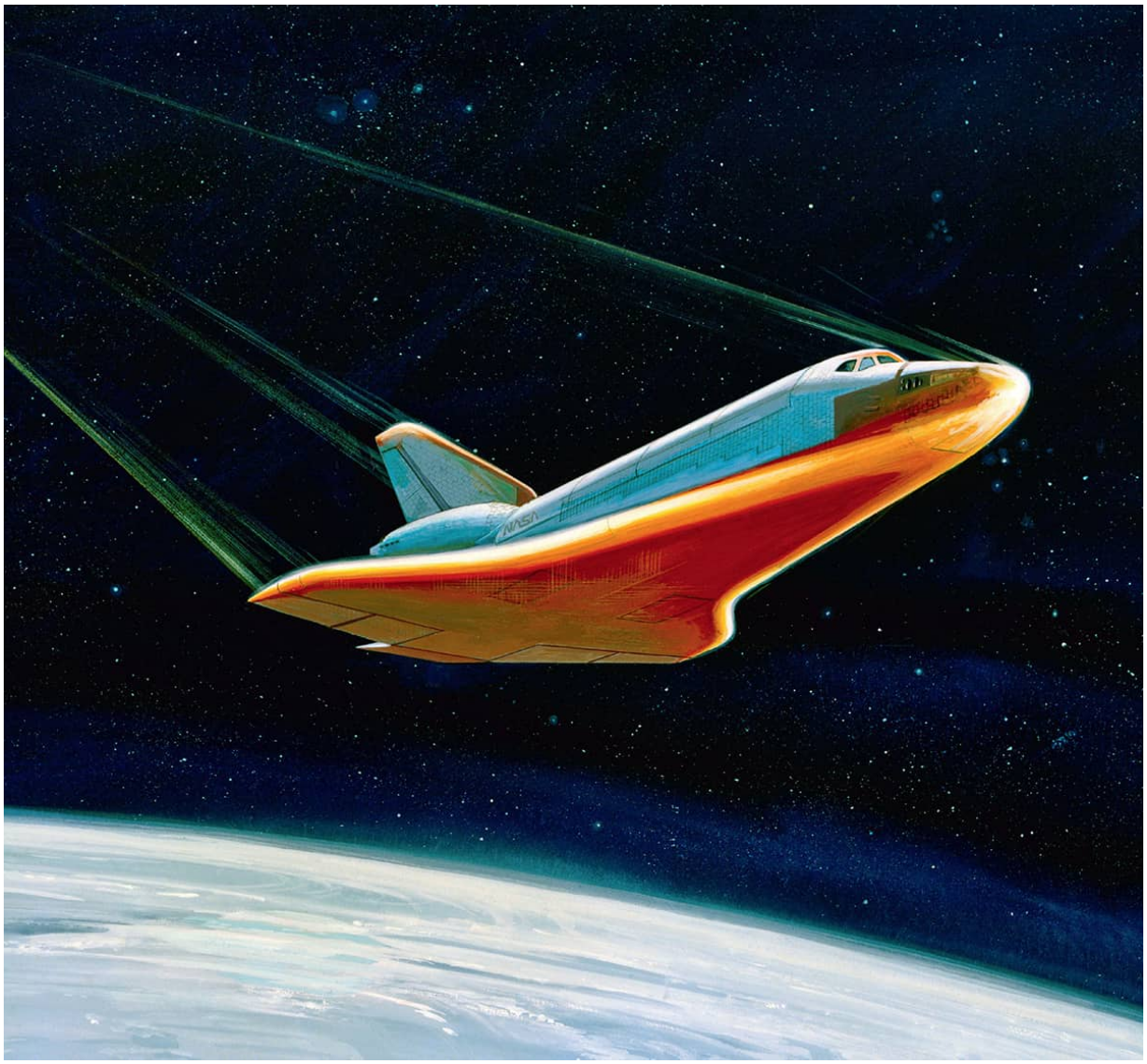
A new dawn for Hubble
Scott Kahler's dramatic interpretation of the first HST servicing mission, created in early 1993. The stars and galaxies depicted in the telescope's forward protective cover are fanciful.

Remembering the human element
Sometimes the people of space flight are obscured by the hardware, but not so in this 1988 painting by Pamela Lee. STS-51-I Mission Specialist William Fisher waits in shuttle *Discovery*'s payload bay in August 1985, while colleague James Van Often (reflected in Fisher's visor) retrieves malfunctioning satellite Leasat 3 prior to making repairs and sending it back into space.

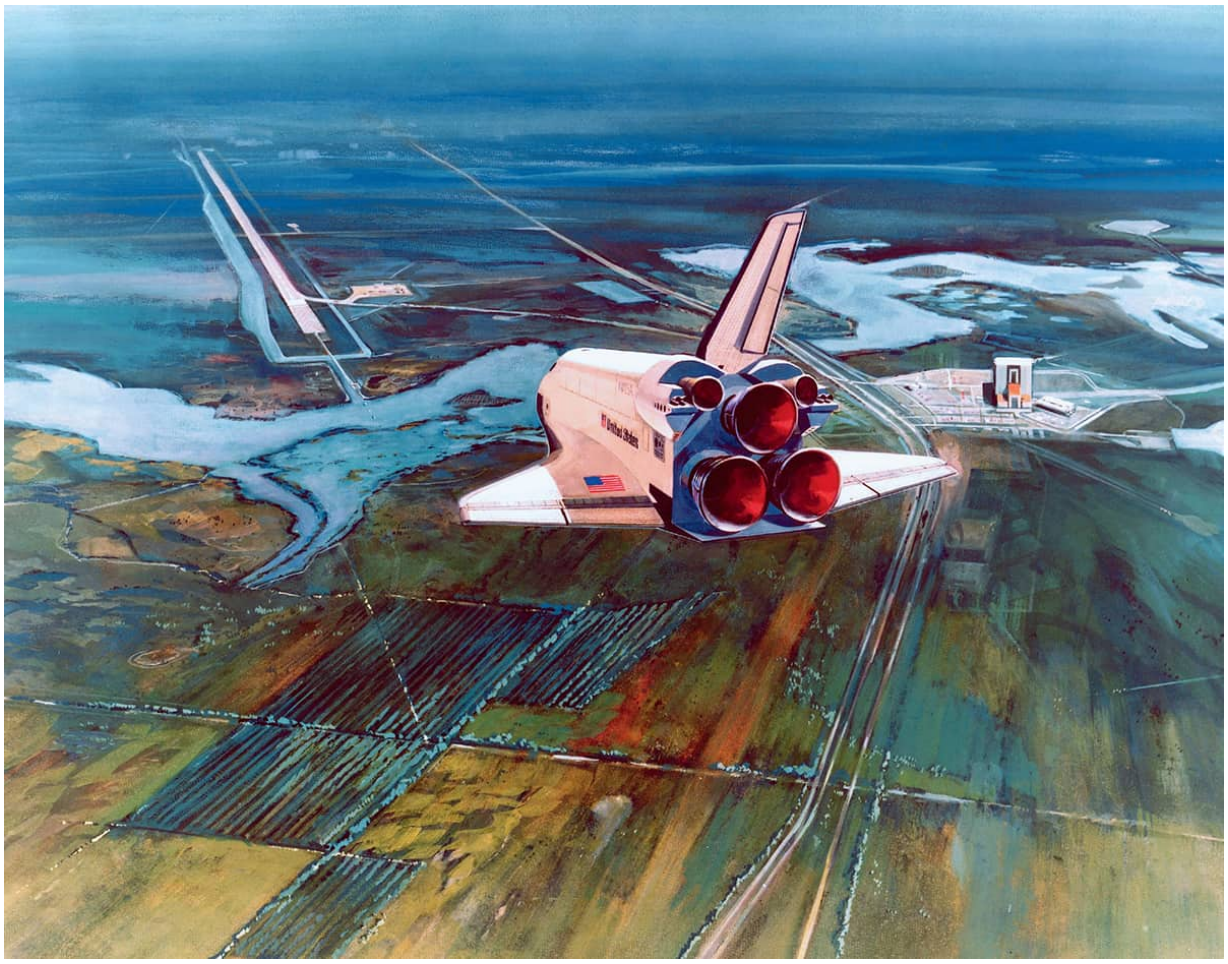
Life on a shuttle
This illustration gives at least some sense of the scale relationship between a space shuttle and its human occupants. Up to seven astronauts could be accommodated.



Workhorse of space
Paul Hudson's view of a space shuttle equipped with an infra-red telescope. This painting was completed in 1979, just as the shuttle system was preparing for its first operational missions.



Coming in hot
An unidentified artist made this impressive late-1970s illustration of atmospheric friction making the underside of a shuttle orbiter glow red-hot during the most dangerous phase of reentry.



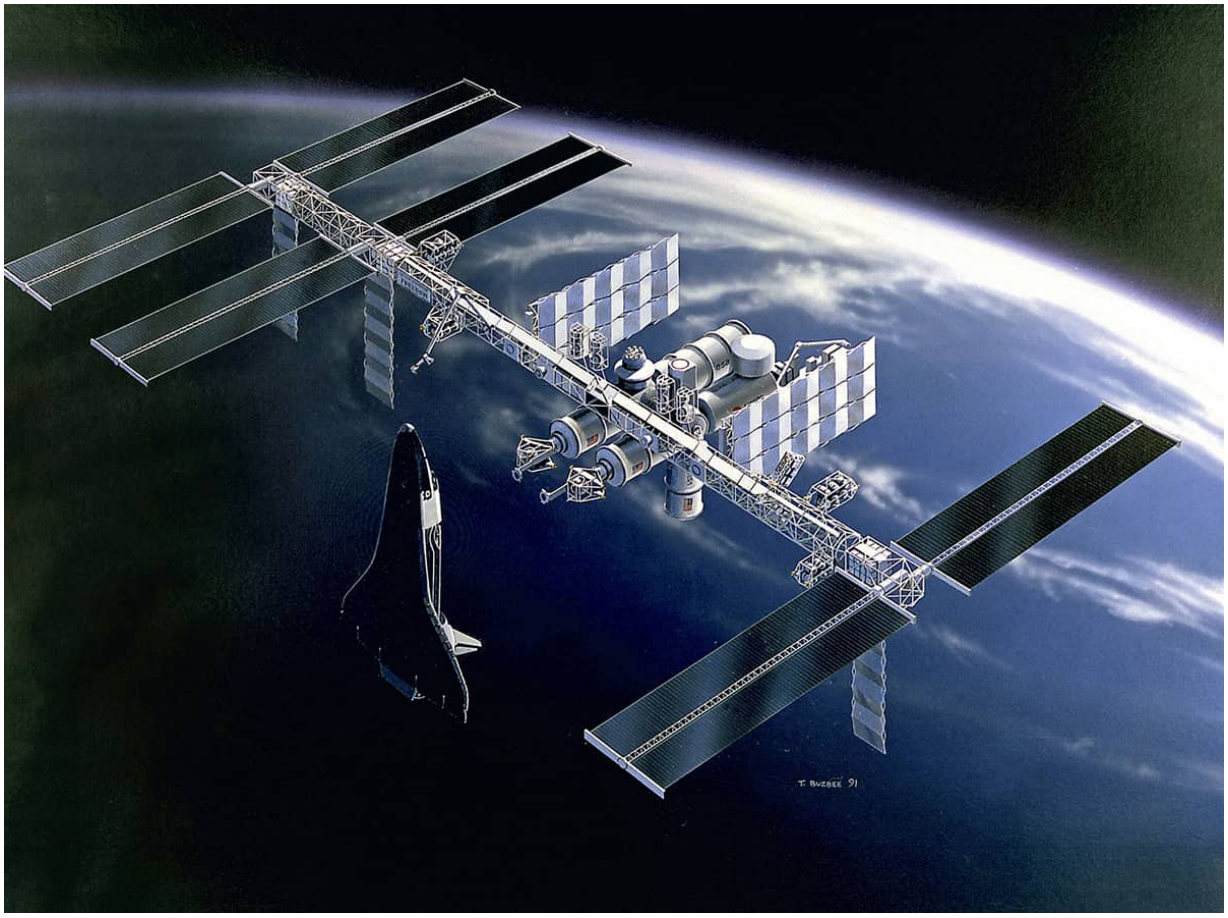
Landing on land

A shuttle heads toward touchdown at NASA's Kennedy Space Center, Florida. The winged vehicle landed on a conventional runway similar to those used by most conventional aircraft. This M. Alvarez painting was made for the shuttle's main contractors, Rockwell International, and subsequently distributed by NASA.

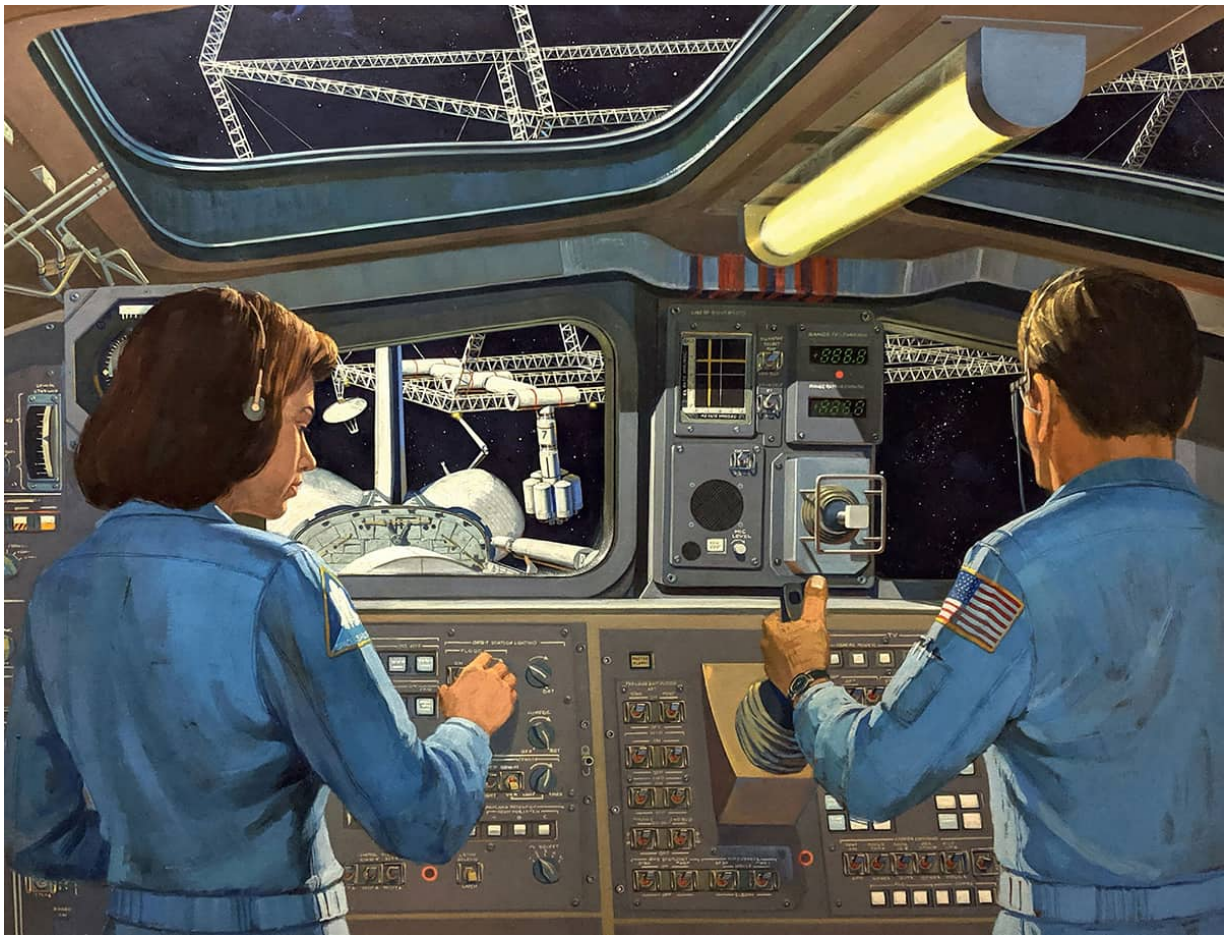
Hitching a ride
Occasionally, when transferring between distant landing sites and NASA maintenance facilities, shuttle orbiters were installed atop a converted Boeing 747 aircraft. Both illustrations here, dating from the late 1970s, show the “Mate-Demate” structure that enabled the process.


USA
NASA

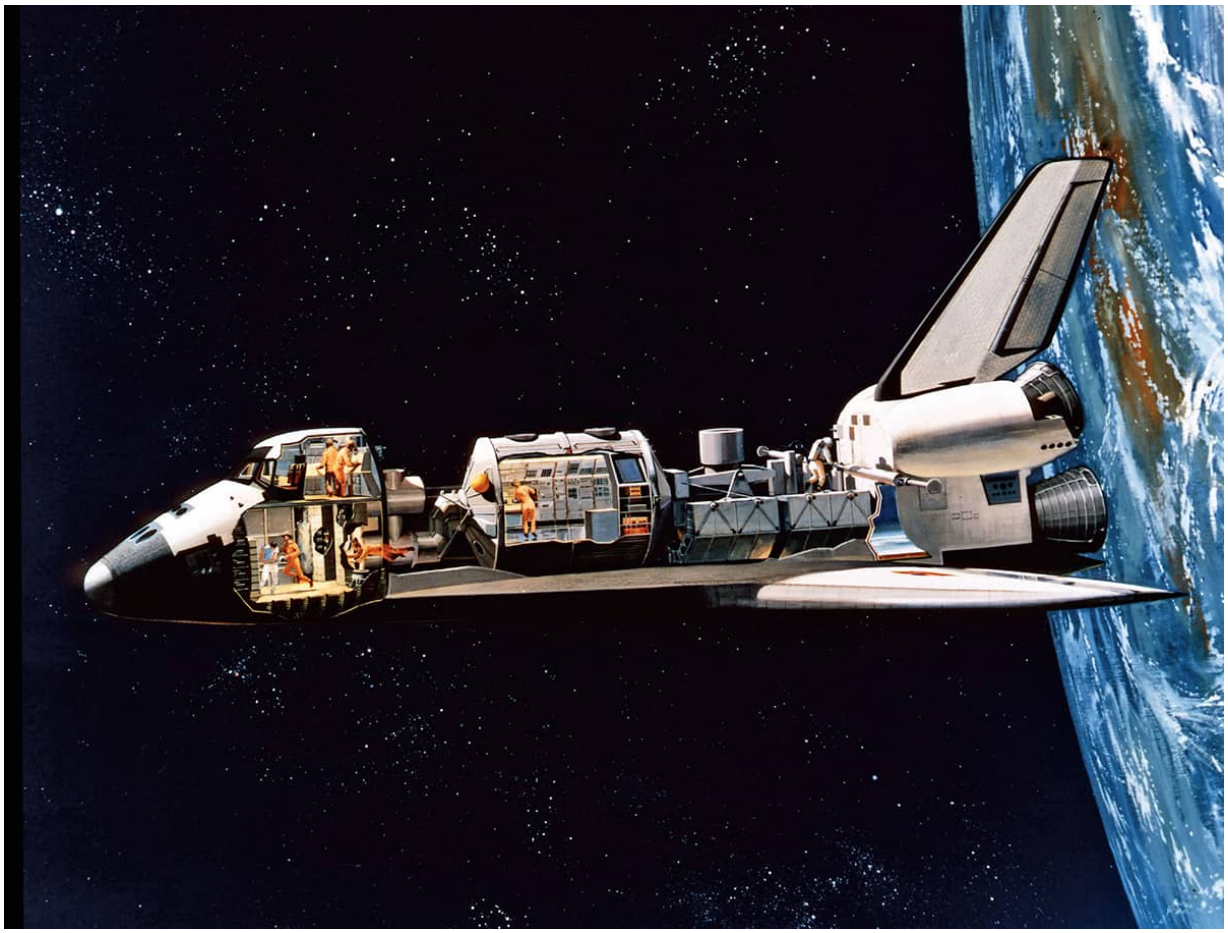
Still the template for future space stations
Poster art by Robert Mccall for Stanley Kubrick's major 1968 film *2001: A Space Odyssey*. Above, an astronaut shows off his spacesuit in a centrifuge that creates artificial gravity, and (below) a giant orbiting space hotel exploits the same principle.



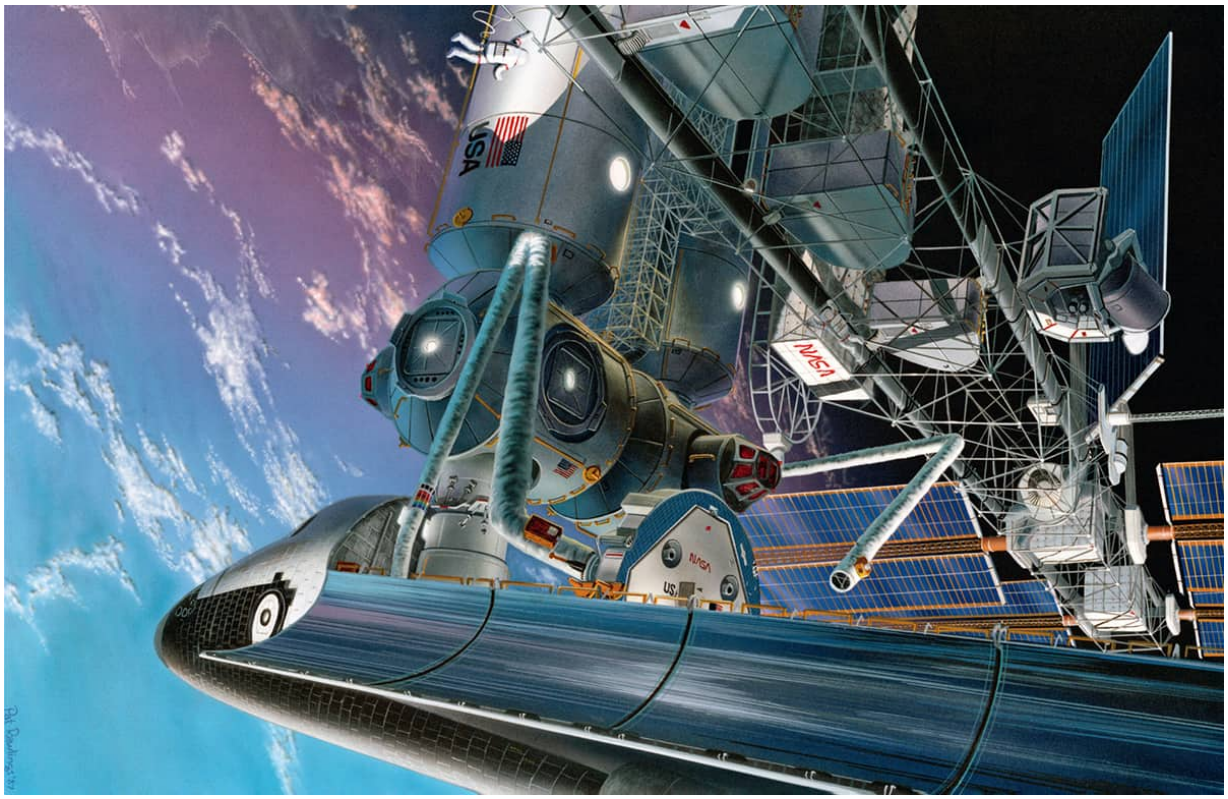
Two kinds of freedom
NASA Marshall Space Flight Center artist Tom Buzbee's 1991 concept (above) for space station *Freedom*, a slightly smaller configuration of what eventually became the International Space Station (ISS), and (at below) an unknown artist's similarly engineered conception of *Freedom*.



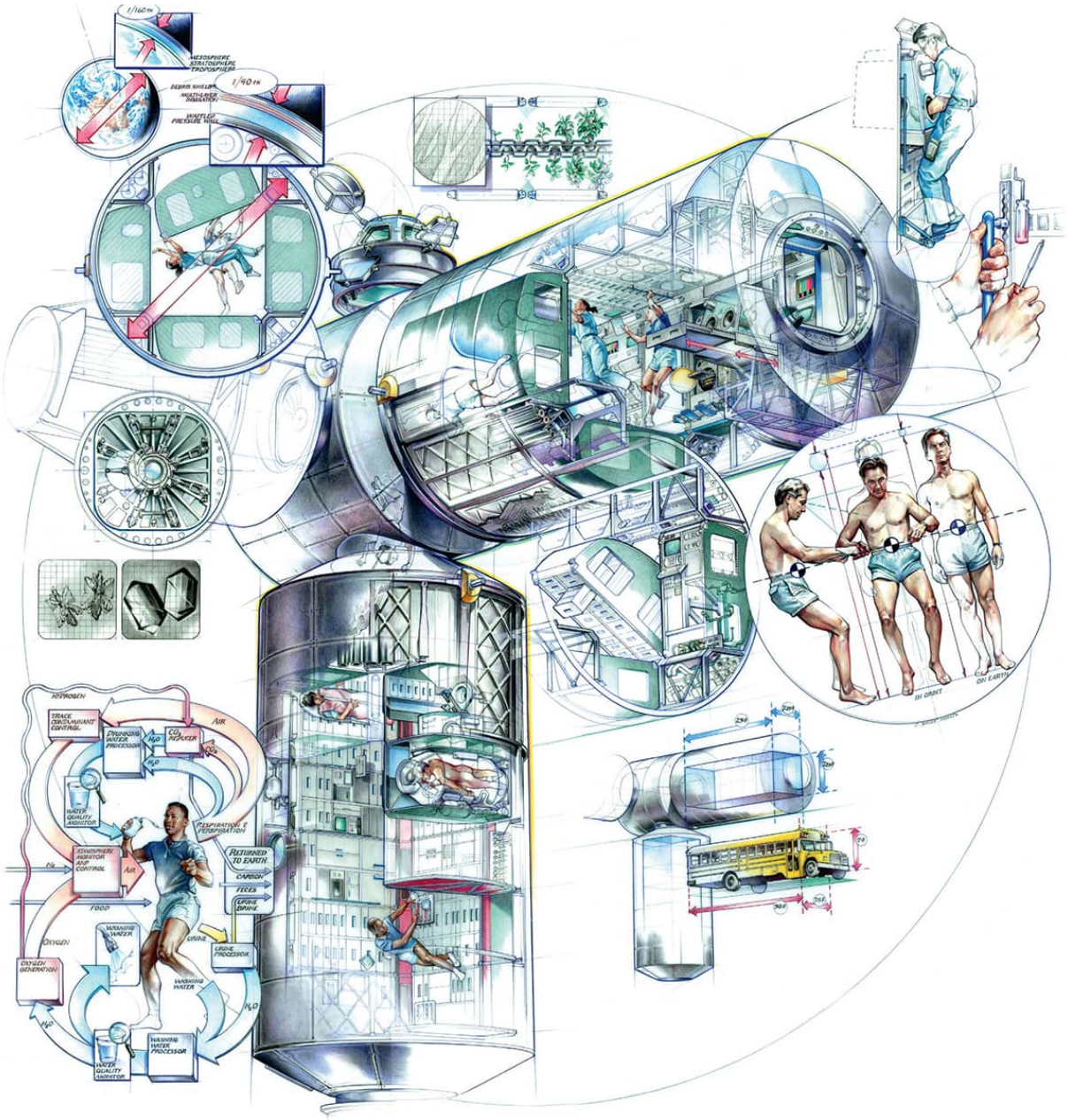
Revising assumptions
A Rockwell-sponsored concept shows two astronauts at the rendezvous and docking controls of a shuttle, carefully maneuvering the craft in the vicinity of a space station. These controls are located in the aft of the flight deck. An earlier version of this illustration depicted two males and was revised in 1978 after NASA recruited its first female astronauts.



The valued partner
The European Space Agency ESA is one of NASA's key international collaborators. This 1977 cutaway shows Spacelab, a reusable laboratory module developed by ESA and flown in various configurations on 22 shuttle missions.

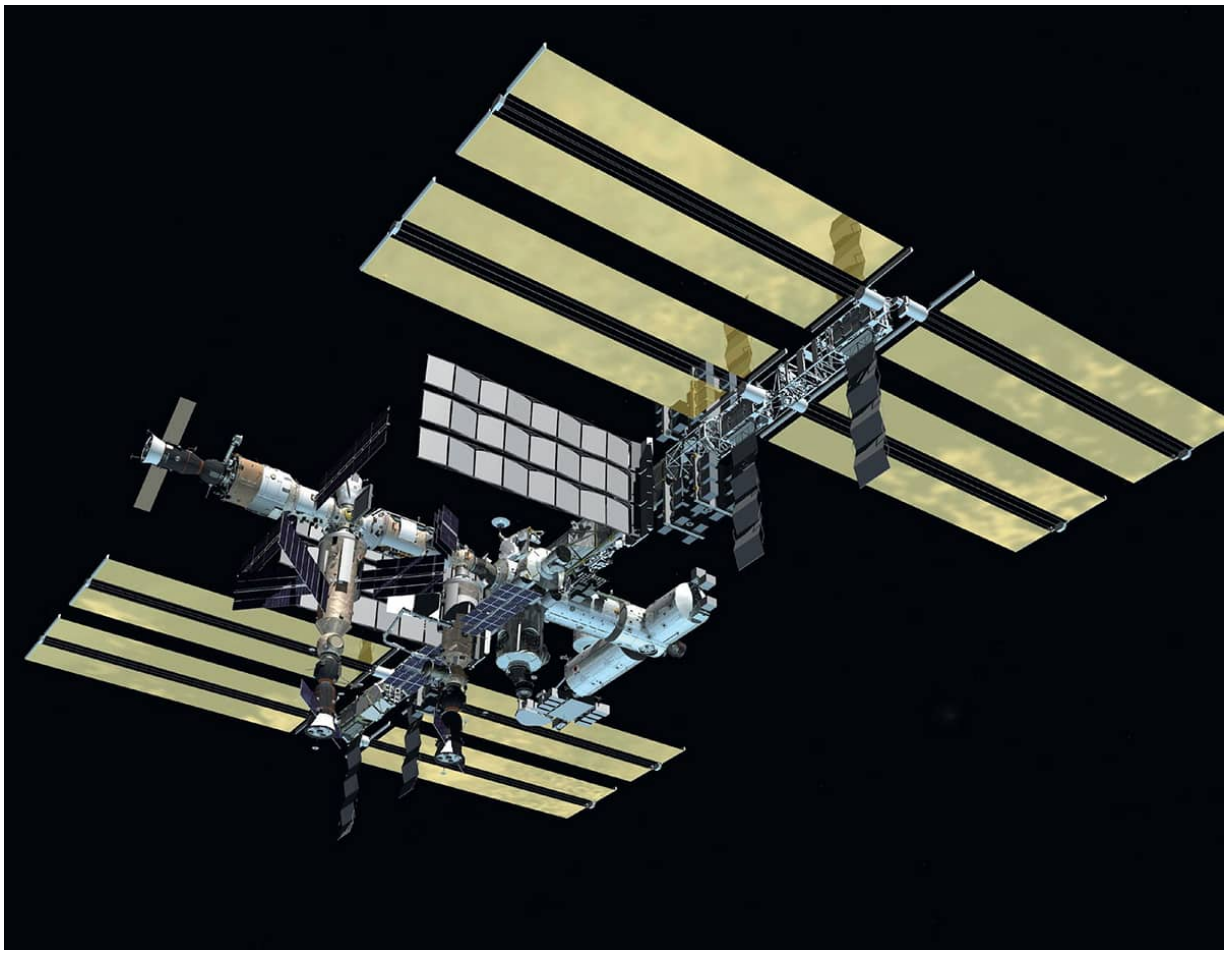


Restlessly shape-shifting
Pat Rawlings has been one of NASA's most prominent artists for more than three decades. This 1987 view of a space shuttle docked to *Freedom* shows just one of many design iterations for the orbiting international outpost.



Interchangeable elements

This 1990 artwork by Bruce Morser emphasises the removable racks on the Space Station containing science experiments and other equipment.



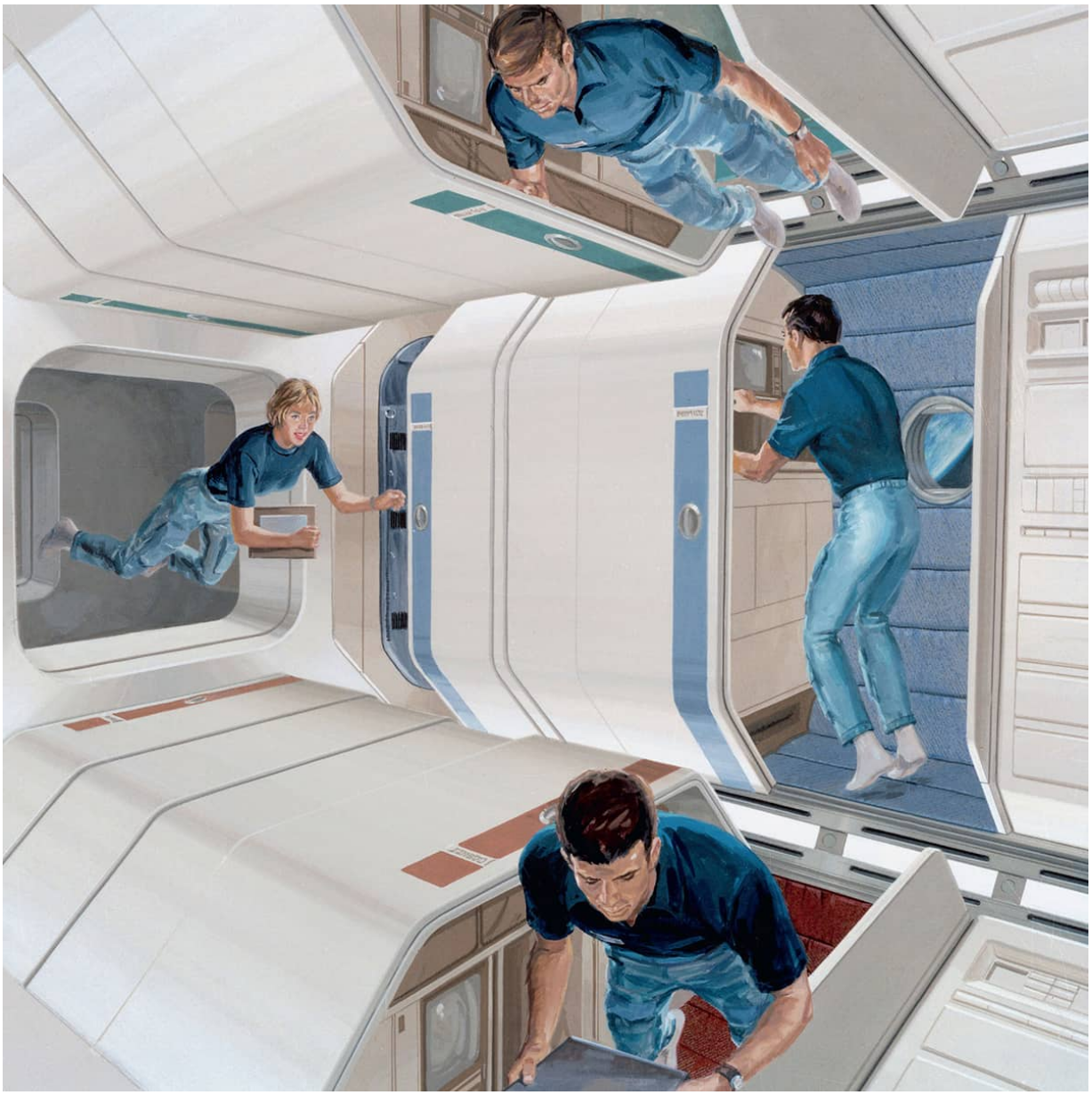
Just another drawing tool

Images created with help from a computer are not necessarily less labor-intensive than those made with pencils and brushes. This 2006 Johnson Space Center (JSC) rendering is a photo-realistic view of the International Space Station.

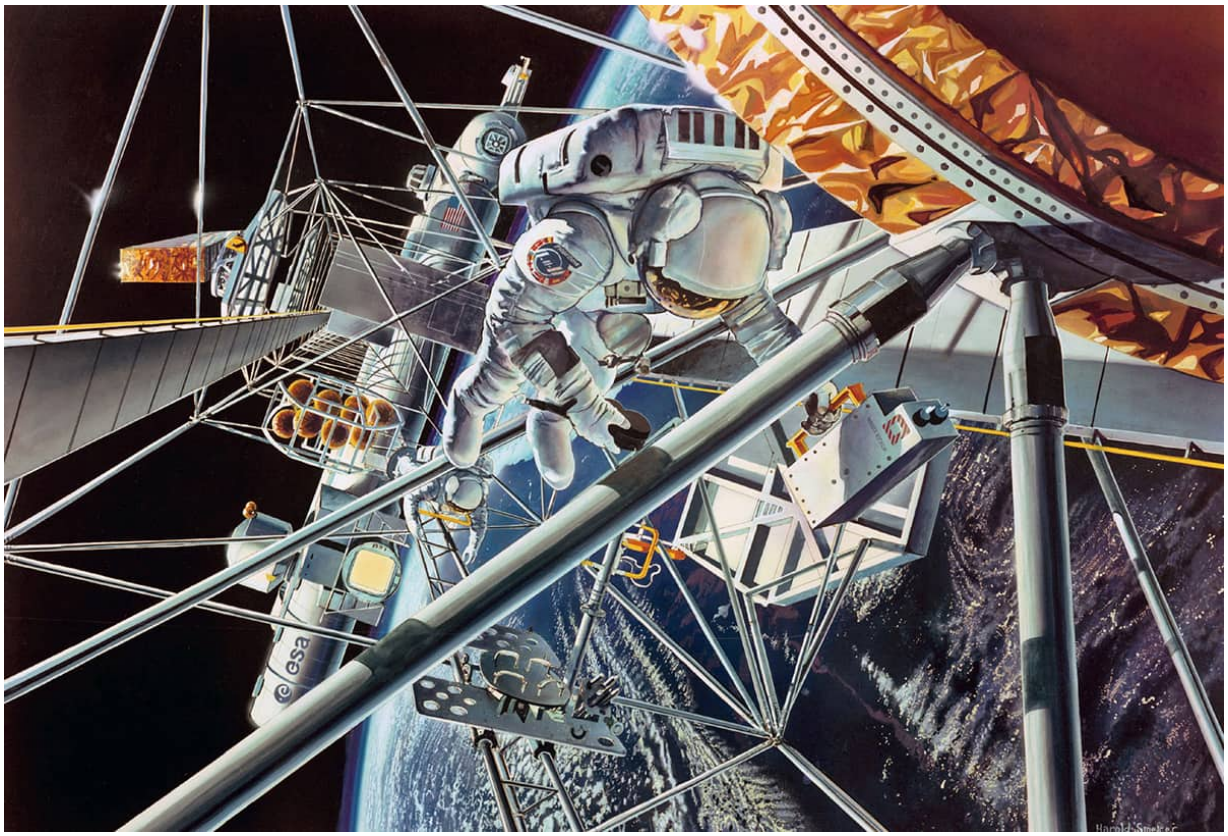
Useful ferry

European Space Agency (ESA) artist David Ducros's 2014 rendering of an Automated Transfer Vehicle (ATV) fulfilling a supply role in partnership with NASA. The ATV will become the main propulsion module for NASA's new Orion spacecraft.

Commercial enterprise
A Space X-manufactured Dragon craft approaches the Space Station as part of a servicing contract with NASA. This illustration shows the crew-carrying version, which is expected to become operational soon.



Ideal home in orbit
Real space station modules are much more cluttered with equipment than this idealised NASA view of sleek living conditions from the late 1970s.



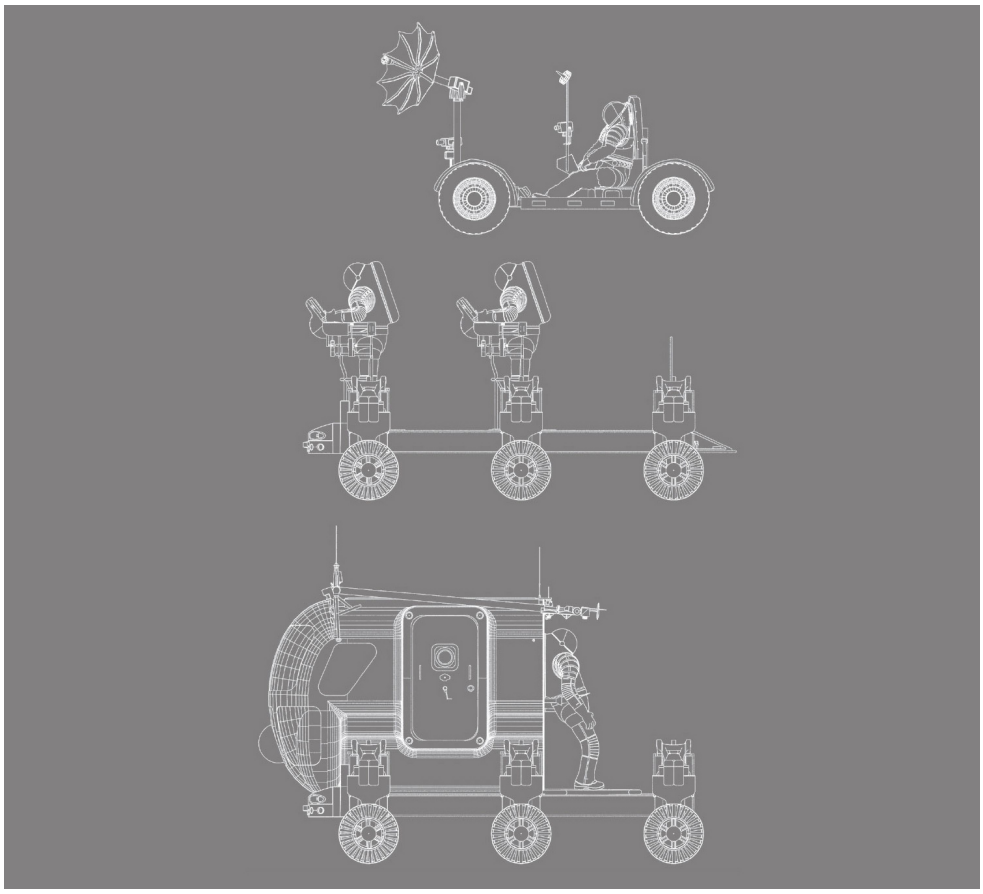
Running repairs
Undated view by Harold Smelcer of an International Space Station astronaut on EVA preparing to swap out a component. Crews aboard the Station do indeed spend much of their time maintaining its systems.

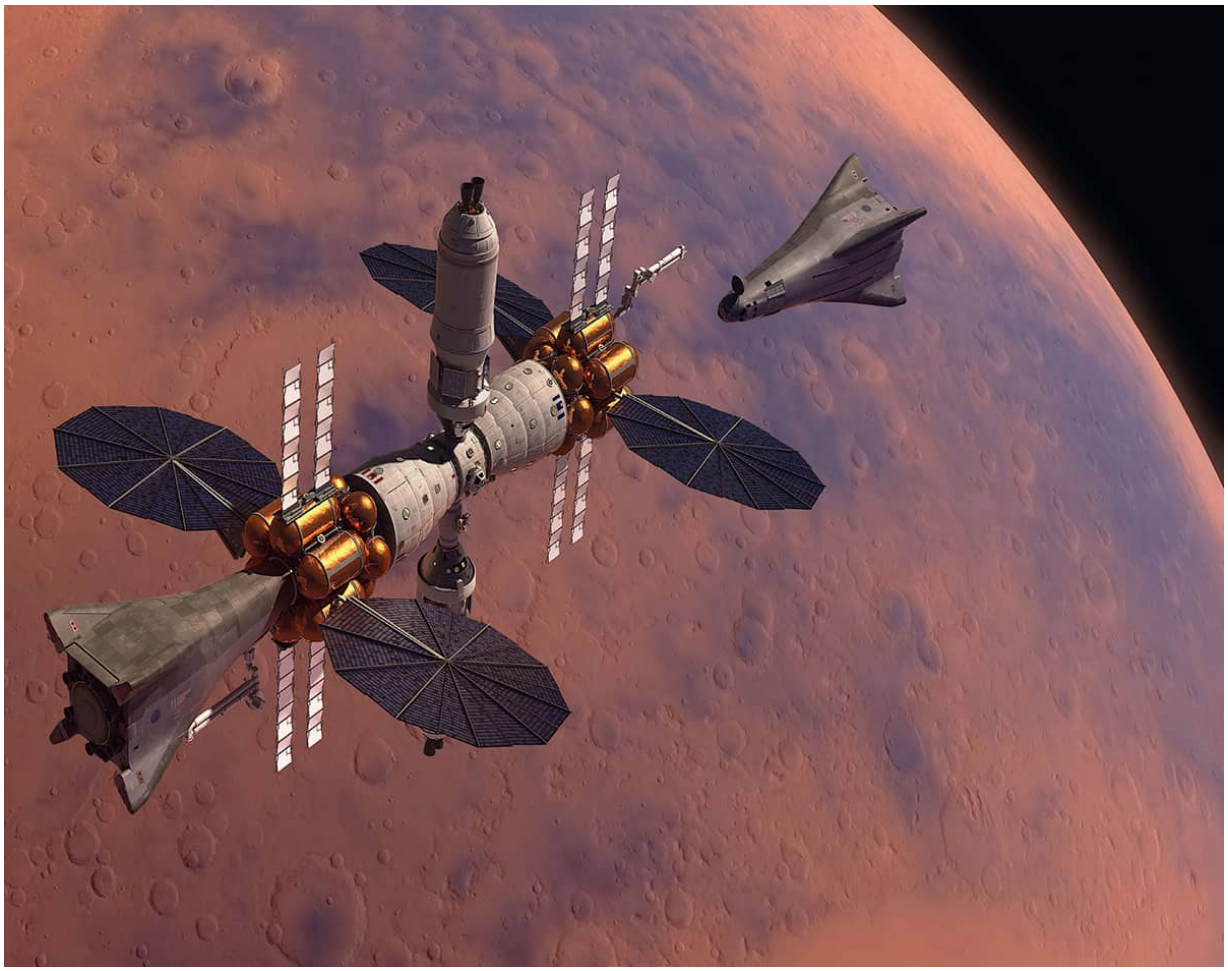
4

BRAVE NEW WORLDS

Back to the Moon & Toward the Red Planet

Ever since the triumphant Apollo 11 lunar landing mission of 1969 both NASA and the United States as a whole have struggled to identify the next major goals for human space exploration. Today we may be getting close to finding the answers.



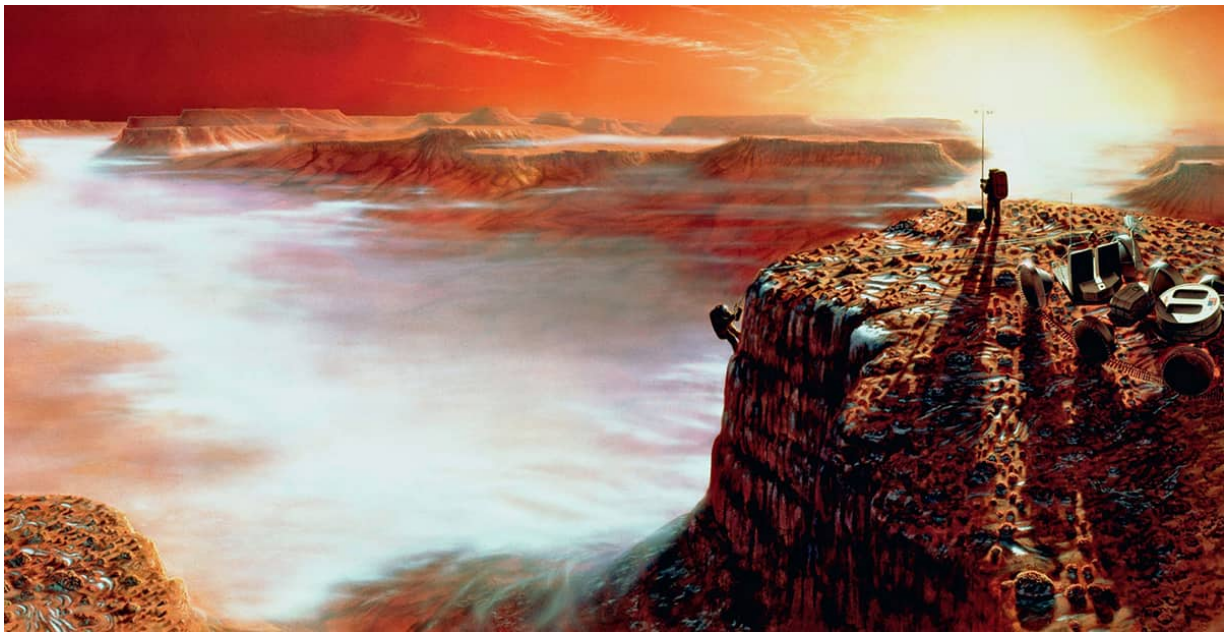


The lure of Mars
In this 2017 Lockheed Martin concept for NASA, a reusable single-stage Mars Ascent/Descent Vehicle (MADV) is seen during rendezvous and docking with a Mars Base Camp (MBC).

4: Brave New Worlds

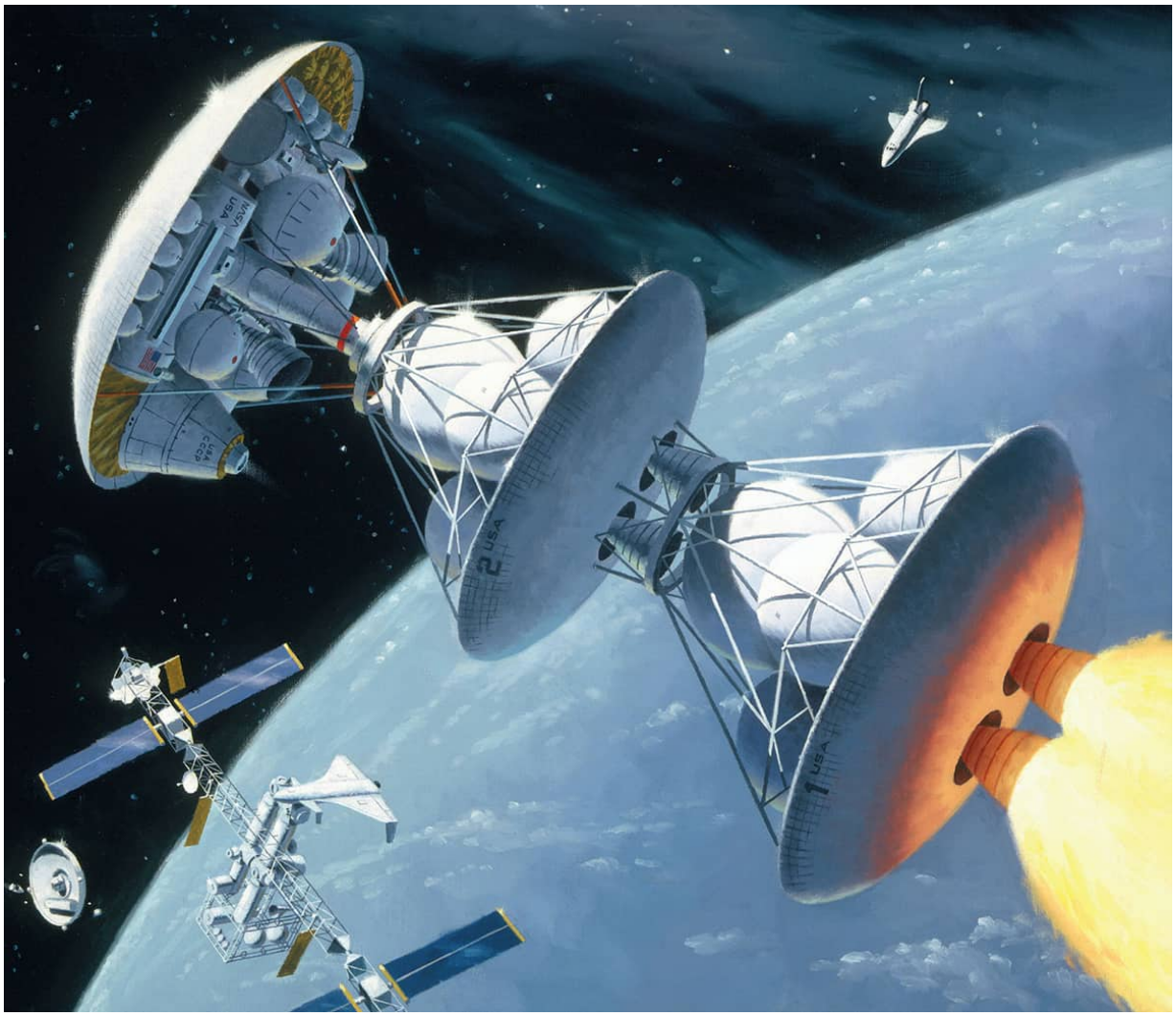
Today Mars seems almost as accessible as our backyard. High-definition images can be downloaded on home computers within days or even hours of transmission. But what about us going there in person? The presence of people on Mars seems so much a part of our cultural landscape we have to remember sometimes that it hasn't happened yet. It is easy to imagine that NASA could send humans to Mars within a decade if only the politicians would let them get on with it. In 1961, at a time when we barely knew how to fly into low earth orbit, President John F. Kennedy championed the idea of a manned lunar landing, and the task was accomplished in less than nine years. Today we surely know enough about space systems to make even faster progress across the solar system. So why cannot a modern president give the green light to the Red Planet? Some presidents have tried, with only modest levels of success. On July 20, 1989, George Bush Sr. celebrated Apollo 11's twentieth anniversary. With Armstrong, Aldrin, and Collins standing at his side, he said, "For the 1990s, we have the space station. For the new century ahead, we should go back to the Moon." Then, in words that were music to the space community's ears, he talked of "a journey into tomorrow, a journey to another planet, a manned mission to Mars."

A year or so later, the project was deemed too costly and quietly abandoned. In January 2004 president George H. W. Bush announced a similar plan "to explore space and extend a human presence across our solar system." A new spacecraft to replace the flawed shuttle system and known as the Crew Exploration Vehicle (CEV) would carry astronauts beyond Earth orbit for the first time since 1972 to "undertake extended human missions to the Moon as early as 2015, with the goal of living and working there." Not long after, Bush suggested NASA would be ready for "human missions to Mars and to worlds beyond."

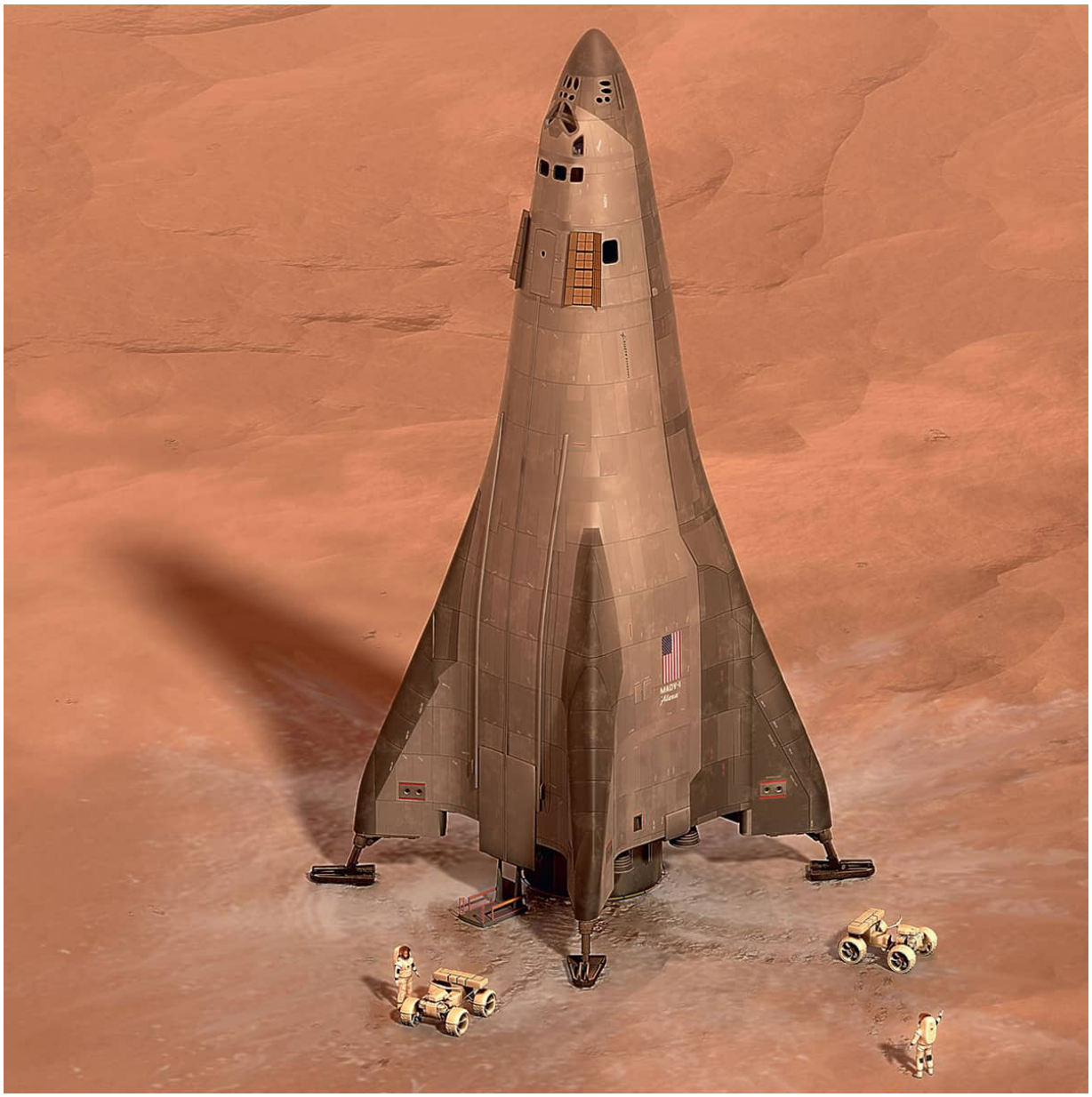


A daunting vista

Pat Rawlings' 1988 depiction of the first human visitors to Mars, exploring the gigantic Noctis Labyrinthus canyon system. Just after sunrise, early morning fog obscures the canyon floor four miles below.



Ambitions for Mars
Pierre Mion's 1984 notion of a Mars spacecraft escaping Earth orbit after staying for many months within reach of the Space Station during construction. The "aeroshell" at the front is designed for entry into the Martian atmosphere.



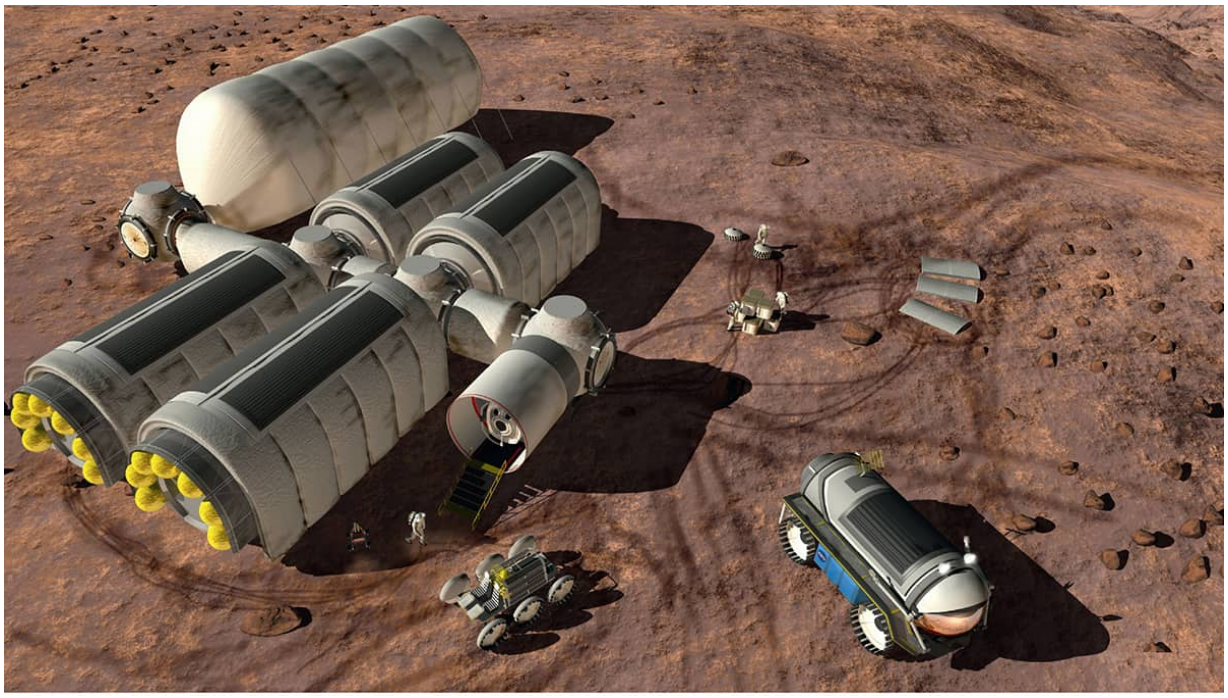
Touchdown one day soon?
Lockheed Martin's 2017 idea for a Mars Ascent/Descent Vehicle (MADV) shown after landing, with astronauts preparing to explore the surface using small one-seat rovers.

And still we wait while NASA develops what's now known as the Orion spacecraft and its carrier, the Saturn V–sized Space Launch System (SLS) while the political establishment veers between skipping the Moon and heading for Mars at some point in the future, or putting Mars on hold and returning American astronauts to the surface of the Moon as a matter of urgency in case China makes a bid for it. Even so, it feels as if the day is getting closer when the first boot prints appear in the rusty-red surface dust

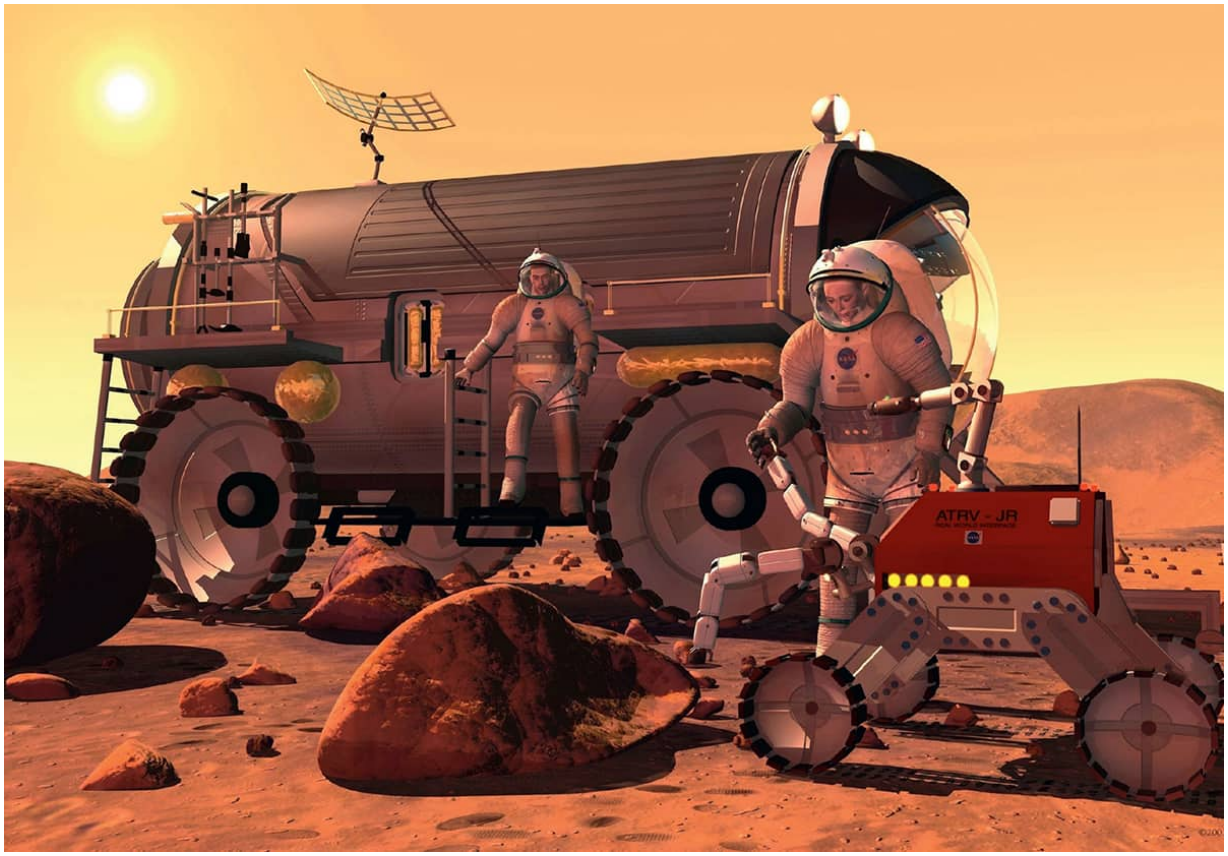
of Mars—or, more likely, new boot prints appear in the gray lunar dust. Certainly we have been planning crewed expeditions to the Red Planet for a long time, and the back catalog of concept illustrations for future missions is immense. In The Mars Project (1952), Wernher von Braun described how a fleet of ships, 4,000 tons apiece, could make the trip. Landings would be accomplished with gliders, their vast wings specially designed to get a grip on the thin Martian atmosphere.

In the 1960s NASA conceived the idea of a Nuclear Engine for Rocket Vehicle Application (NERVA) that would carry humans to Mars.

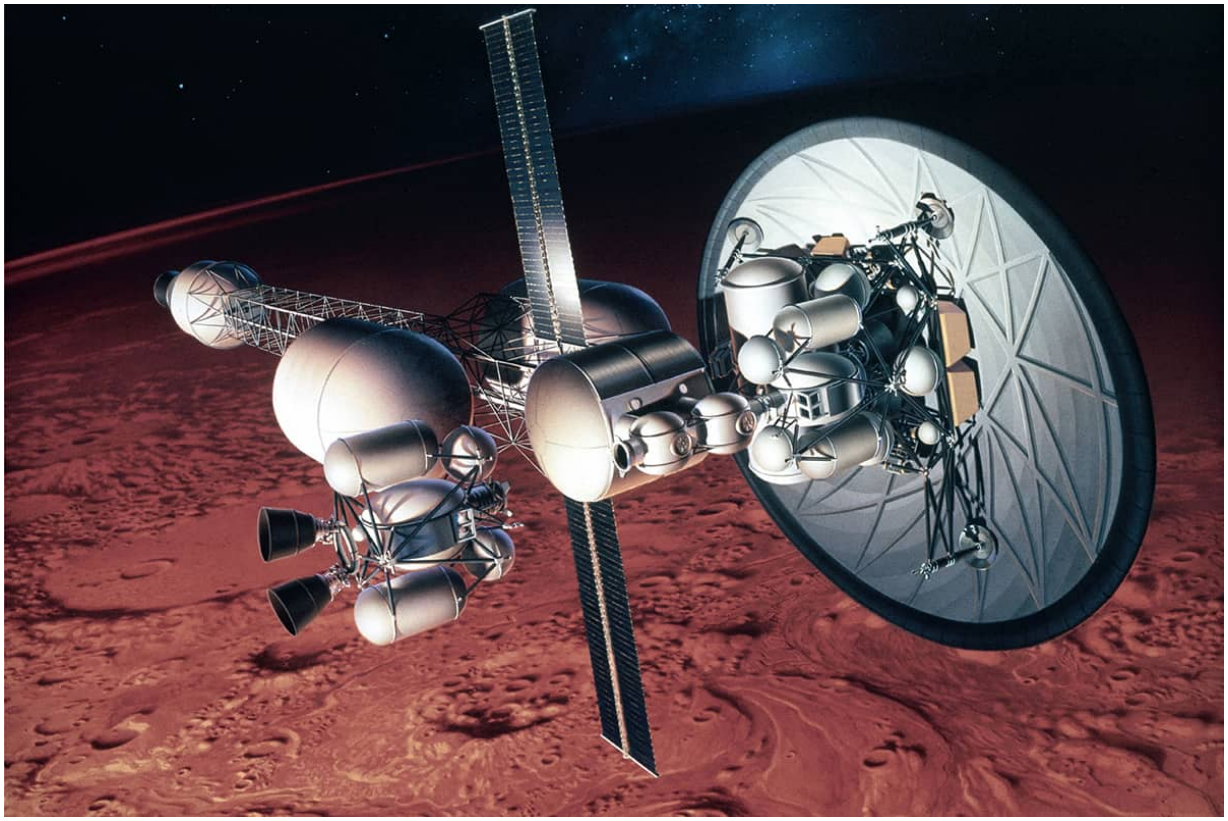
By the end of the twentieth century nuclear technologies for space propulsion were too controversial even to consider. Engineers such as Robert Zubrin at the Martin Marietta company wondered if more efficient use could be made of conventional chemical rockets and a variety of Mars missions were conceived around the idea of sending vital cargo ahead of humans, including uncrewed Earth Return modules. Only when a full supply of equipment was safely settled on Mars would humans risk the trip, in relatively small outward-only vehicles. NASA and its international collaborators continue working out how to reach Mars. Money aside (and money is a major stumbling block), uncertainties persist about radiation hazards, the problem of food supplies, and the challenges of landing humans in craft larger than even the heftiest robotic rovers.



Inflatable Martian home
This 2003 CGI rendering by John Frassanito shows a Mars habitat made from a strong, lightweight material similar to bullet-proof vest fabric.



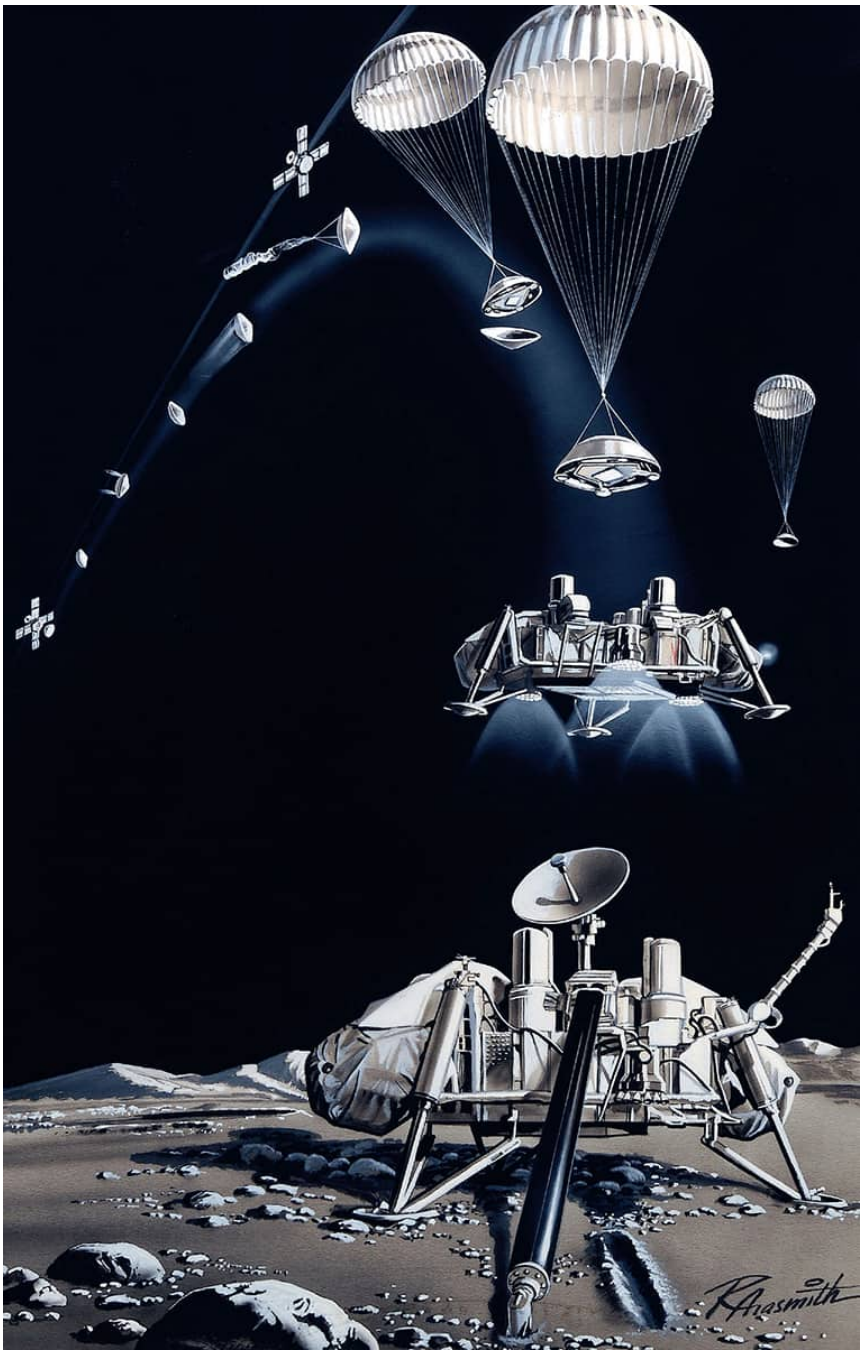
Mobile base camp
This 2003 CGI rendering by John Frassanito shows a Mars expeditionary crew benefiting from a pressurized rover attended by by a remotely controlled robot.



A lander for each generation

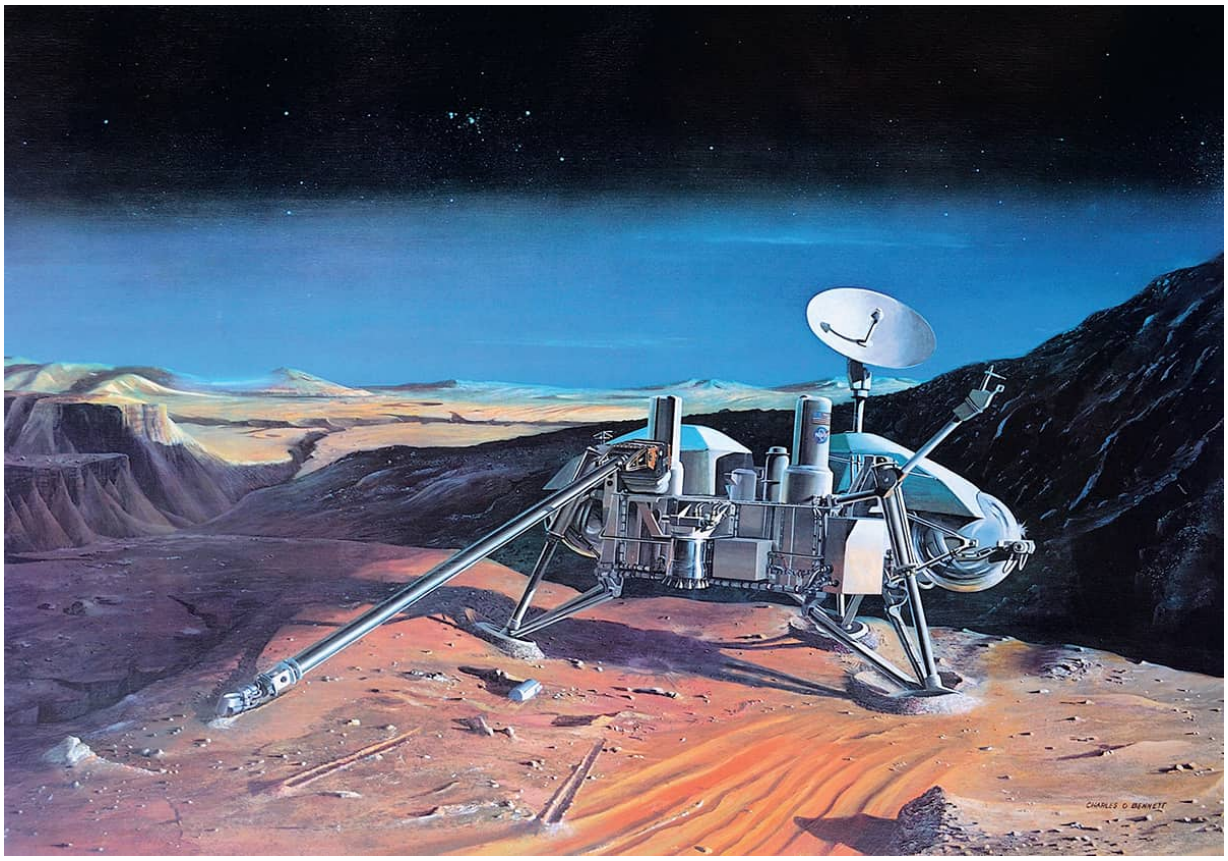
Every decade sees the creation by NASA of a new “Mars Architecture” for a possible human mission, against the day when it might be possible to build something for real. This 1984 idea was based on the “aeroshell” concept that enables large payloads to survive entry into the Martian atmosphere.

Useful rocket
Martin Marietta engineer-artist Charles Bennett's 1972 cutaway of a Titan Centaur launch vehicle, a "workhorse" for several robotic NASA space missions, including the mid-1970s Mars Viking lander project.



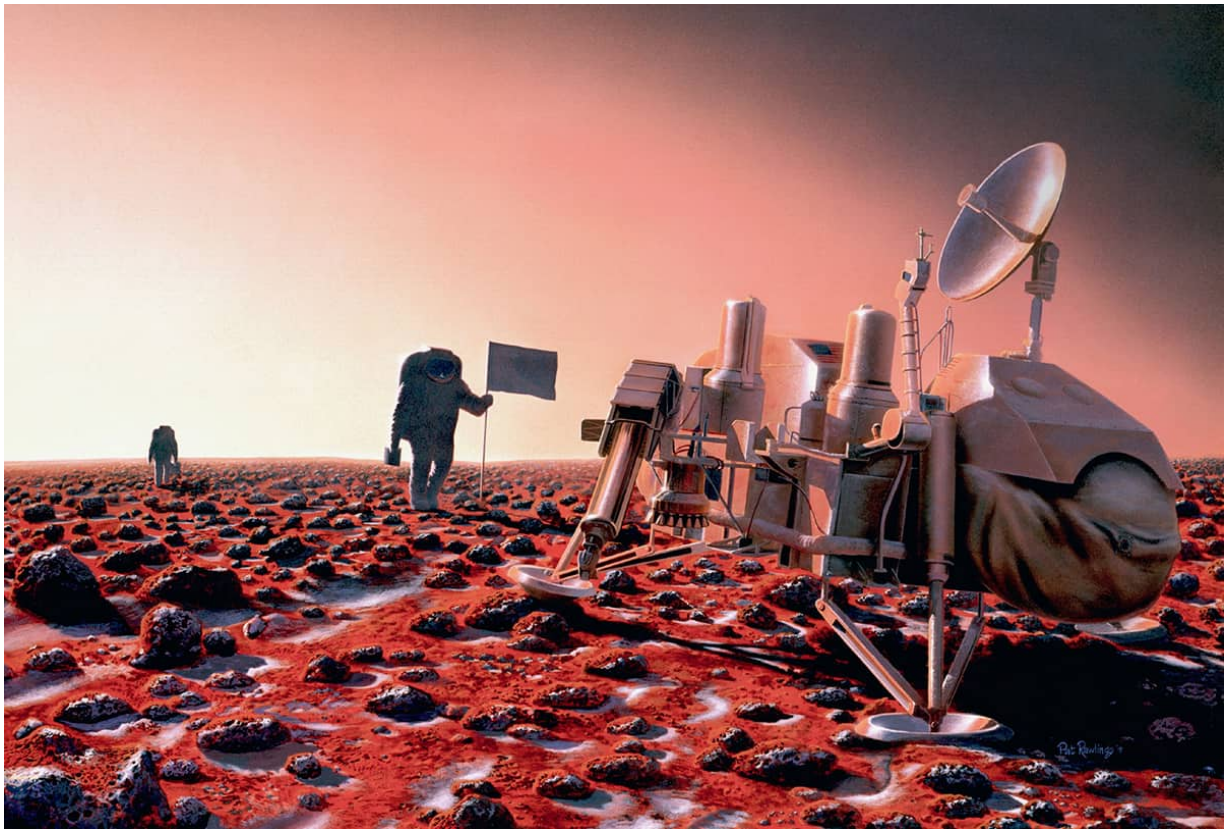
Steps toward touchdown

Russ Arasmith depicts a Viking landing sequence, from separation from the Orbiter mothership, to atmospheric entry, parachute descent, final powered touchdown on the surface, and culminating in sample collection with the extendable robotic arm.

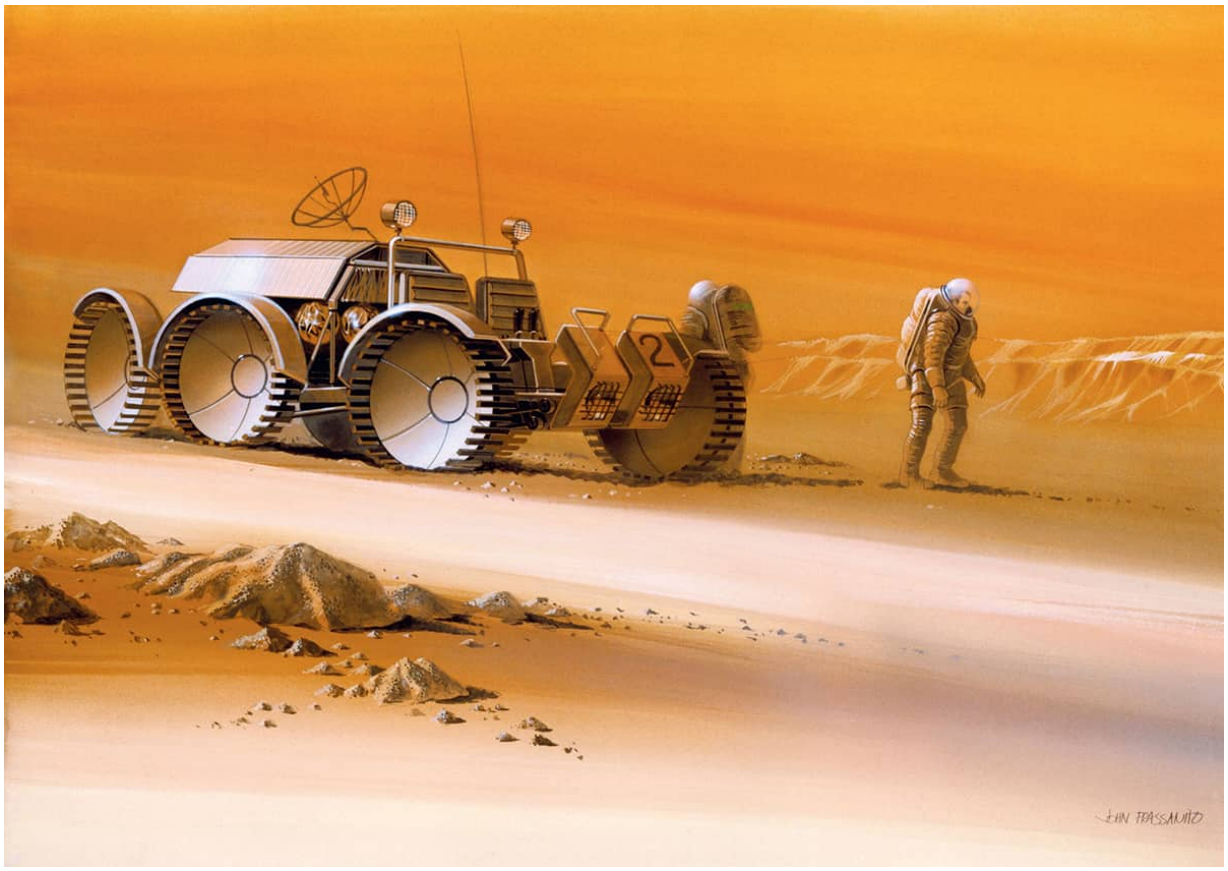


Smart robot
Charles Bennett depicts a Viking on the surface of Mars three years before the successful landings by the twin spacecraft. Viking was semi-autonomous, and featured the most advanced robotic systems.

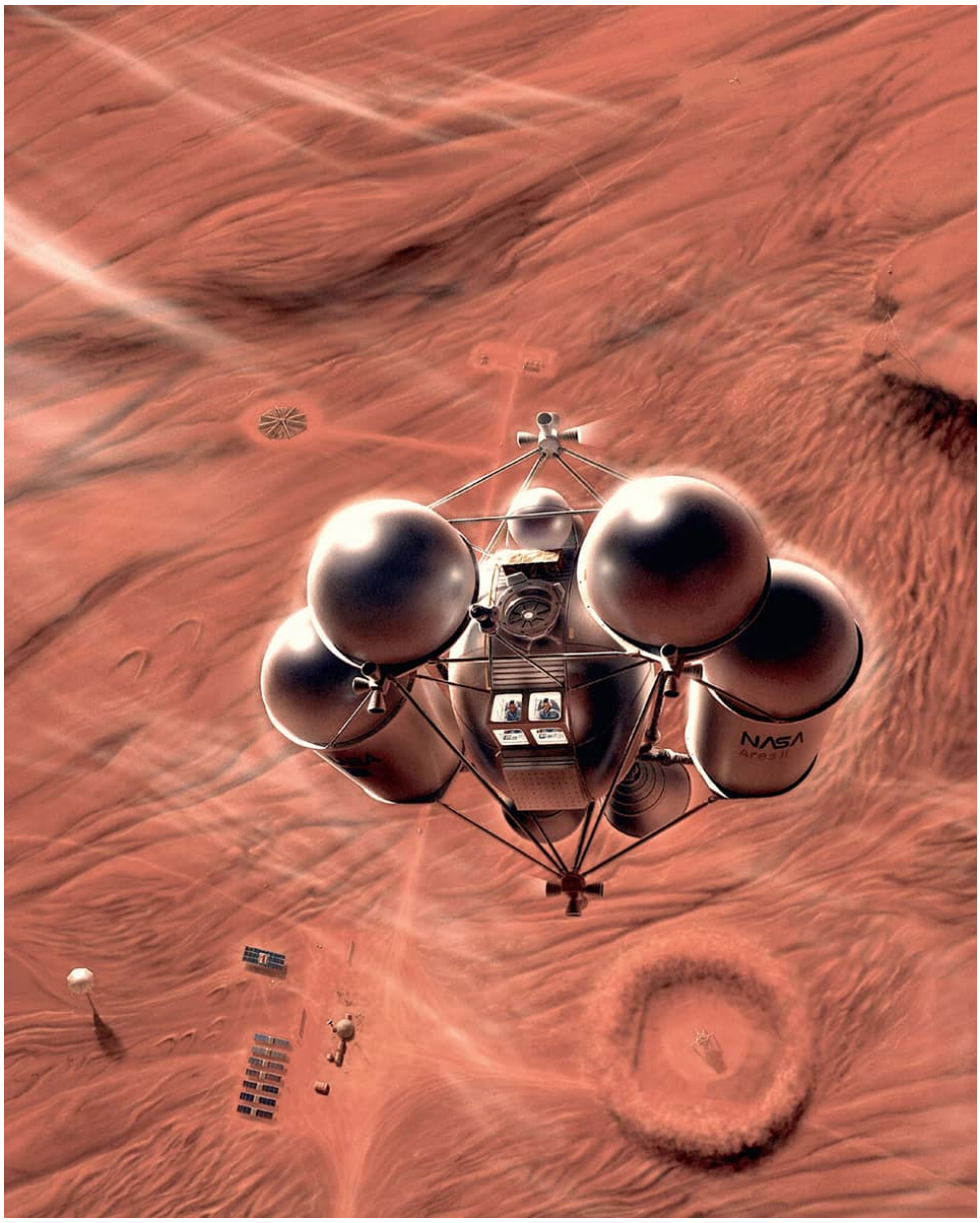
Keeping the dream alive
Pat Rawlings' 1997 painting, optimistically entitled *2020 Vision*. An exobiologist seems to have encountered a sample that confirms the existence of life on Mars, either ancient or current.



Visit to an old friend
Rawlings' 1991 image for NASA JSC imagines the first humans on Mars inspecting a by-now ancient and dust-shrouded Viking lander to study the effects that the planet has had on the spacecraft.

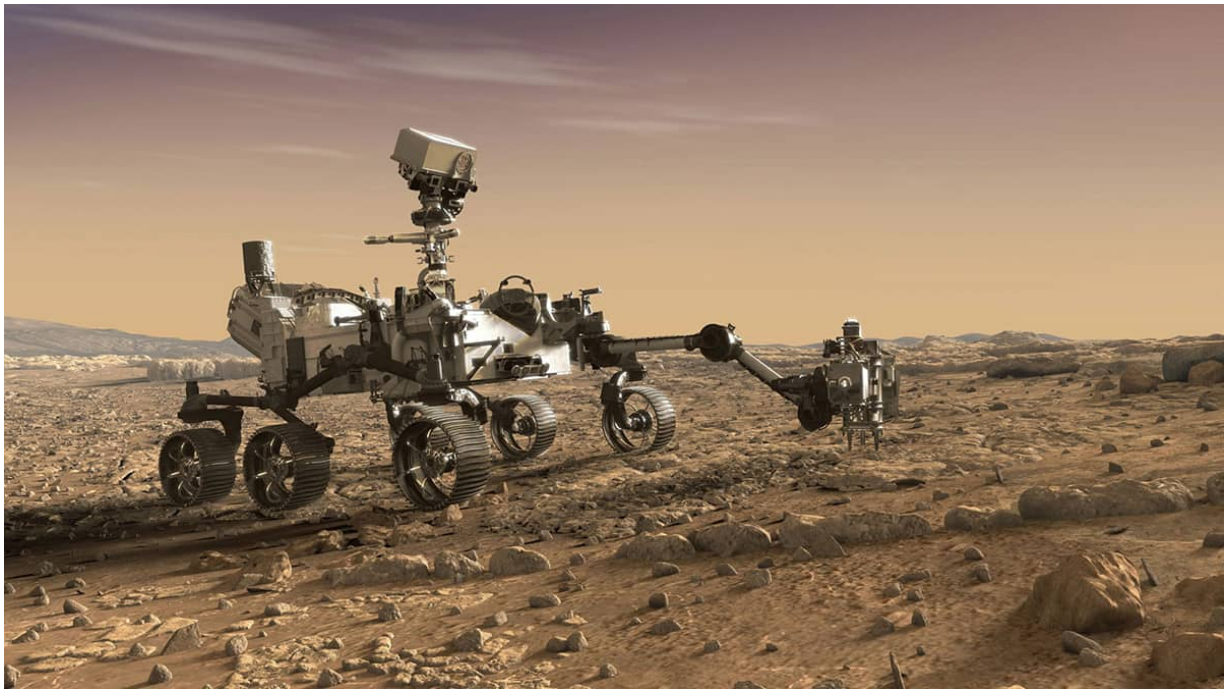


Wheels for the job
A 2002 study by John Frassanito of a Mars rover with wheels specially adapted to clamber safely over rocks and boulders.



A long way from home

The ascent module of a two-stage lander climbs through the tenuous Martian atmosphere during the first phase of a long trek back to Earth, in this 1995 painting by Pat Rawlings.



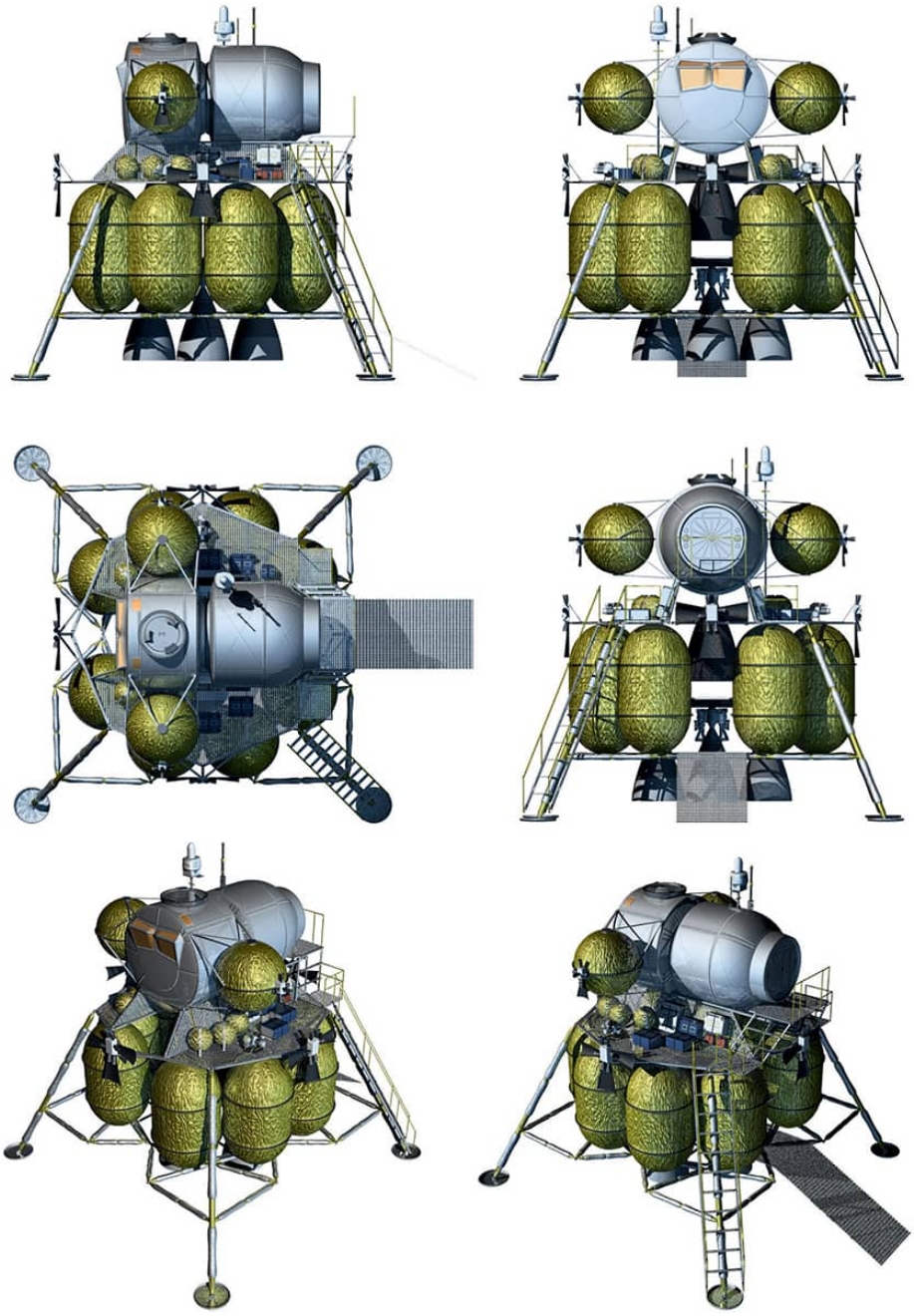
Biggest rover yet

The car-sized Mars 2020 Mars Rover is scheduled to touch down inside the 28-mile-wide Jezero Crater in February 2021. It will hunt for signs of ancient life, test out technology that could aid human exploration, and collect and cache soil and rock samples for possible future return to Earth.

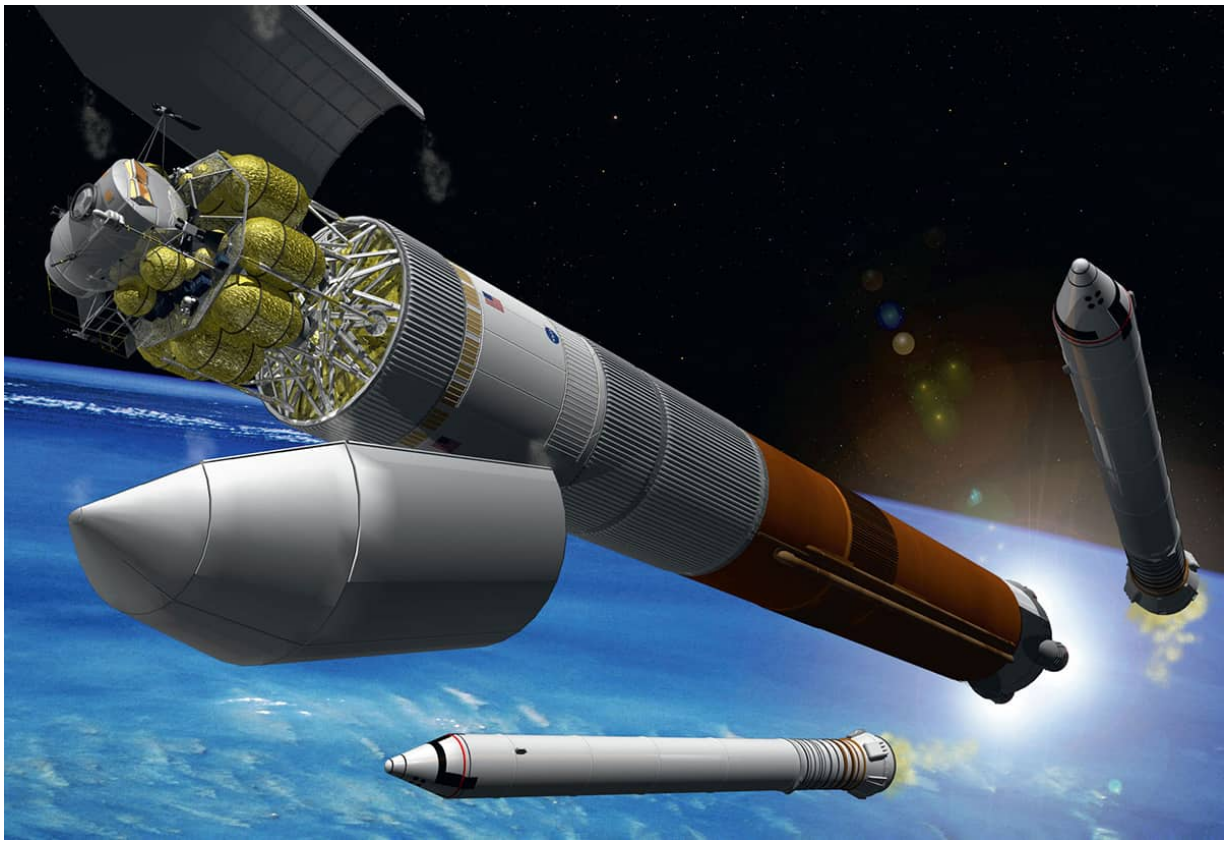
Next steps in space

NASA's official 2015 concept of the Space Launch System (SLS) that will lift America's new crewed spacecraft Orion. The most powerful rocket since the Saturn V, SLS should allow Orion to break free of Earth's gravity and head out toward the Moon, and one day, Mars. Orion is built to take humans farther into space than they've ever gone before.

Orion at full speed
This is how Orion will appear (and below). The main module looks similar to an Apollo, but is substantially larger and has room for up to six astronauts.



Future recently past
Views of Altair, the lunar lander that NASA hoped to use for a human return to the Moon by 2018 as part of a project known as Constellation, which was cancelled in 2011, then partially revived in the form of today's Orion and SLS projects.

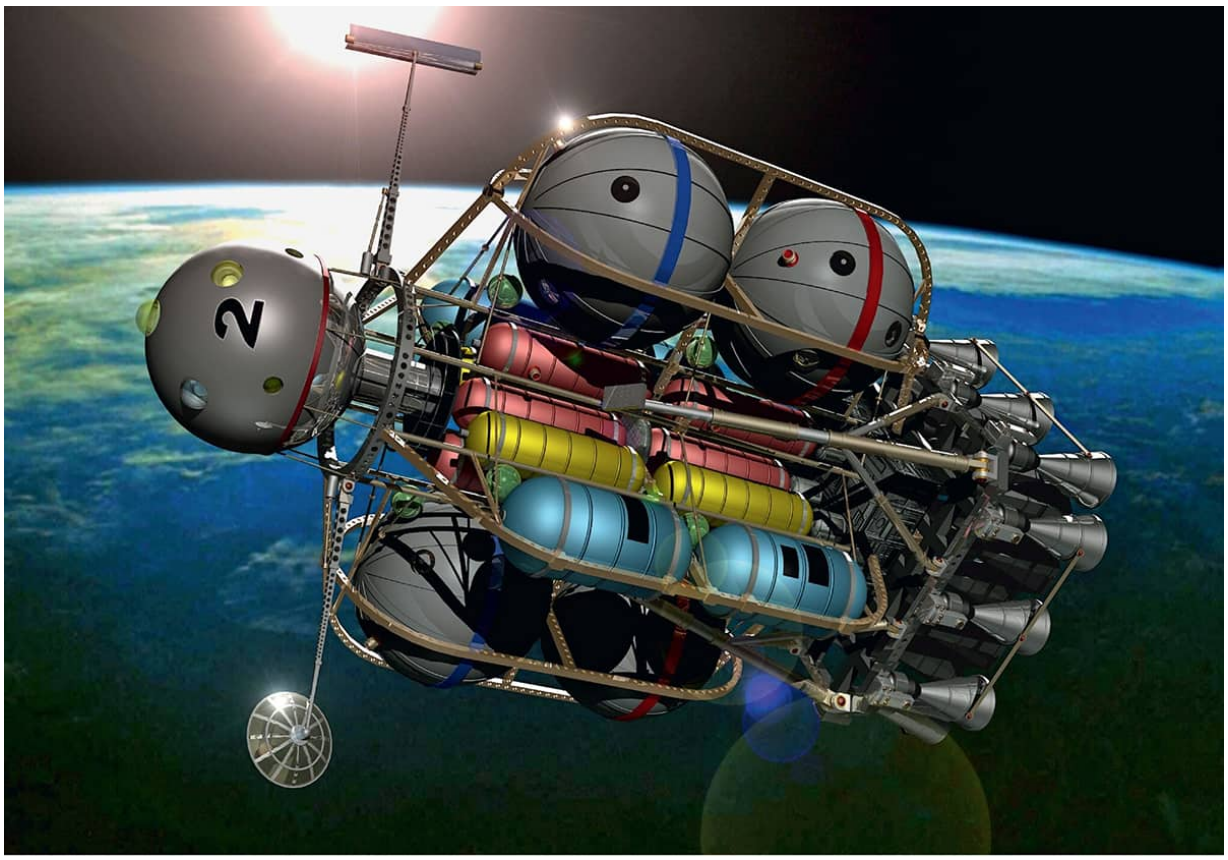


Back to the Moon?

There’s one world that we already know how to each and occupy safely. The questions now concern mission durations and purposes. Do we go back to the Moon again for a few days, or do we try and settle there for good? Or does the optimal path lie somewhere in between? Every artist’s impression yields a slightly different answer, but most gravitate toward something depicted time and again in the literature of space from the 1930s to the present day: a permanent lunar colony, partially buried in the soil to protect its inhabitants from cosmic radiation, and to maintain a comfortable temperature.

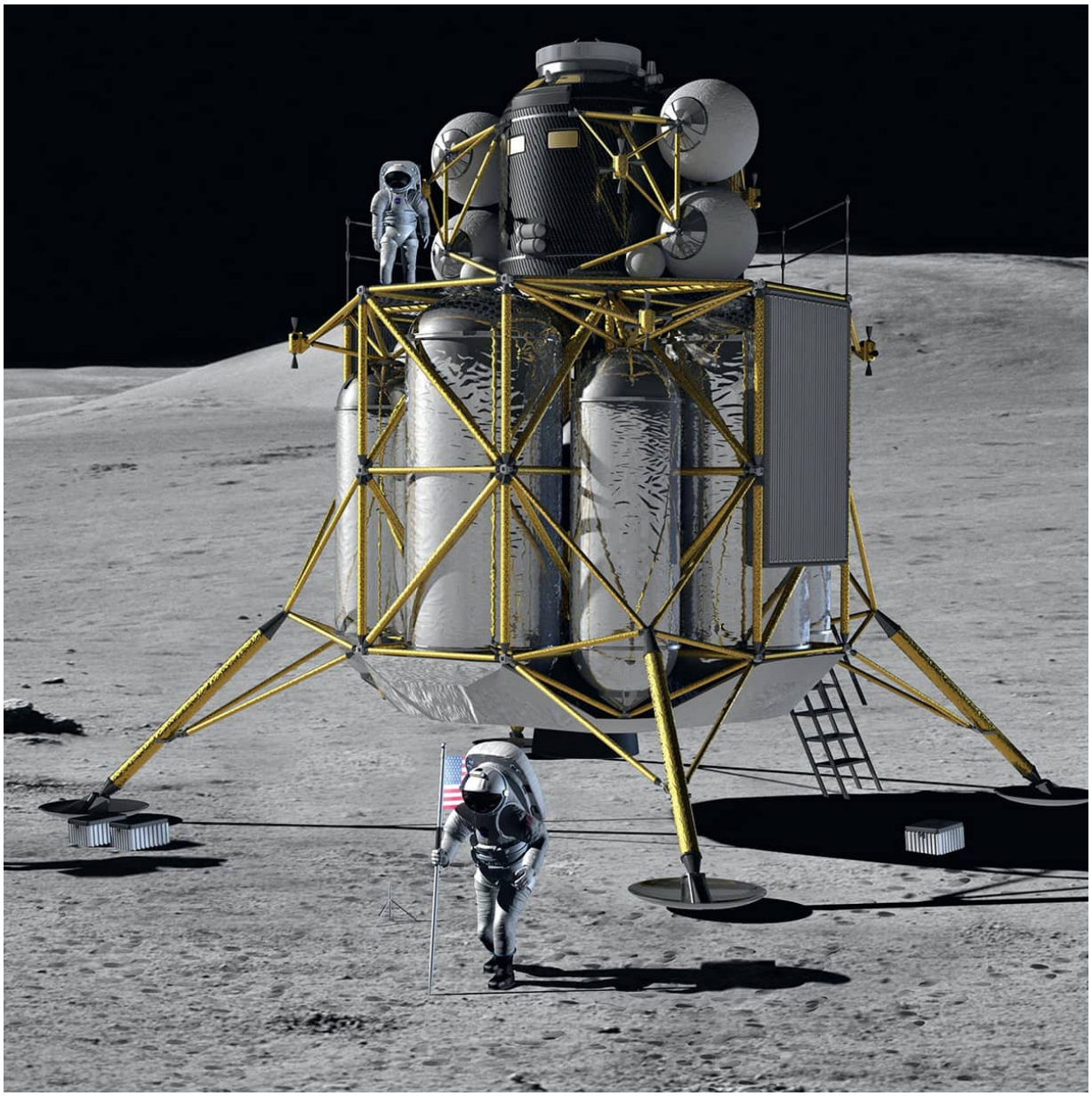
We can do all this any time we choose. We used 1960s technology to land humans on the moon. Surely in the 21st century we can do even better, and put them down on the surface for longer periods, to live, work, and perhaps even settle? In terms of safety, help is only three day’s flight time away. Likewise, the problem of radiation can be dealt with by using the Moon’s lavish building materials as protection. Mars keeps taunting us, but

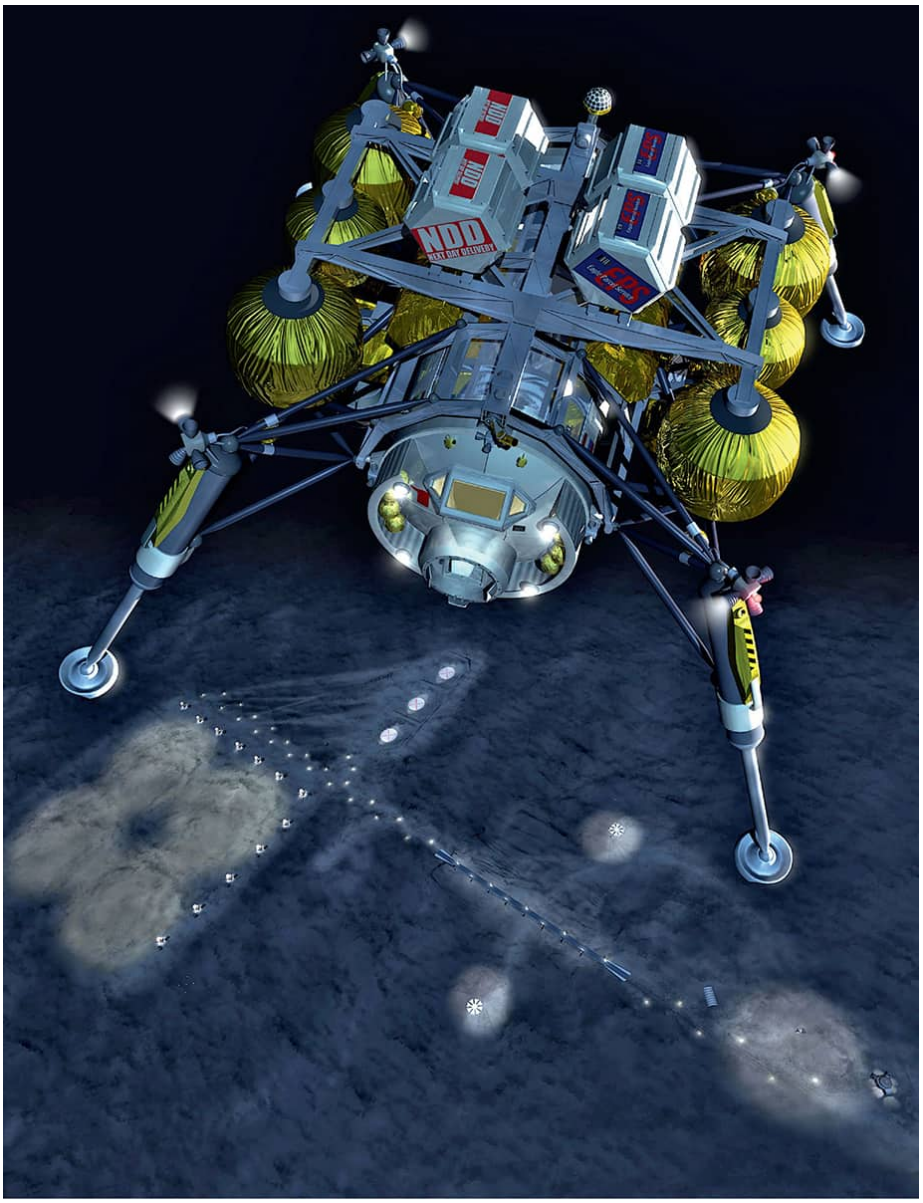
it’s the lunar adventure that holds out the more immediate promise of new missions, and new opportunities for us to increase our presence in space.



Not so different then as now

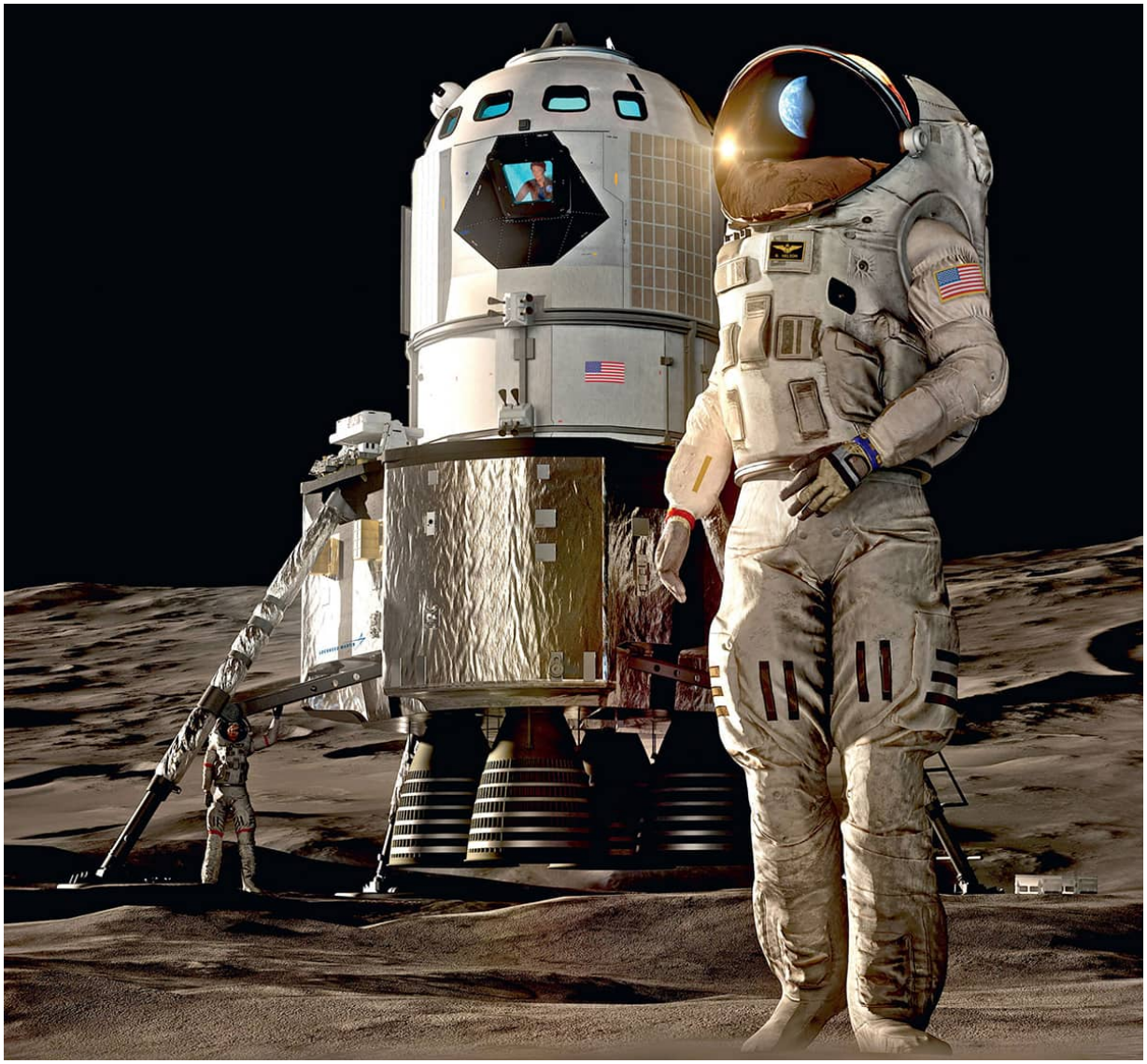
Terry L. Sunday’s colorful 1999 digital rendering of Wernher von Braun’s 1953 design for a lunar landing craft (above). Although this idea dates from nearly 70 years ago, its fundamental elements are as valid today as they ever were. In a 2007 NASA rendering, (below) the once-proposed Altair seems a direct descendant of von Braun’s ideas.





Selling space services

The markings on this lunar delivery vehicle suggest the likely commercialization of many activities surrounding humankind's future presence on the Moon.

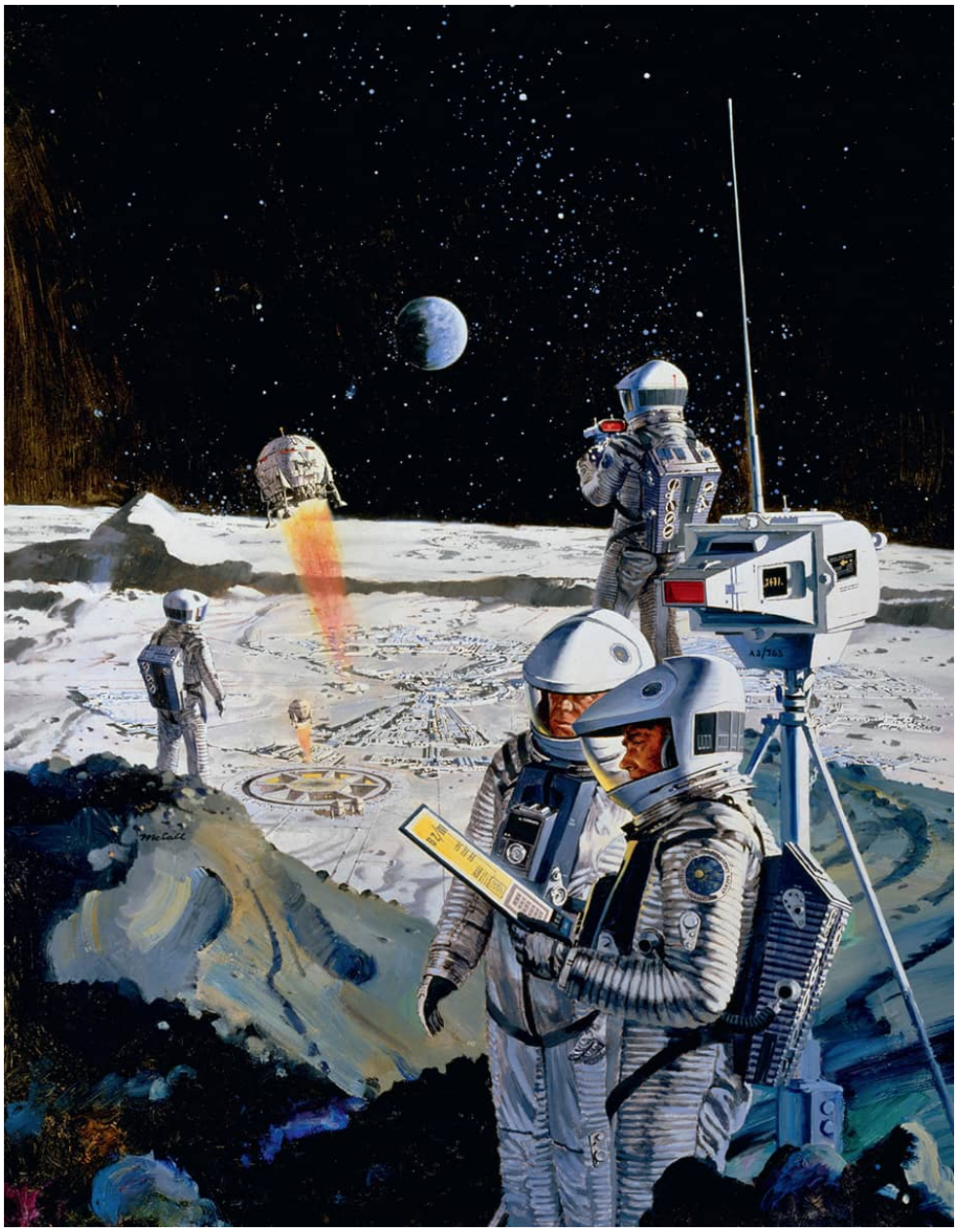


Up-and-down routine

With NASA's latest goal of returning to the Moon by 2024 in mind, Lockheed Martin proposes a two-stage lander which will travel between the surface and the Lunar Gateway, a new space station that NASA wants to build near the Moon.

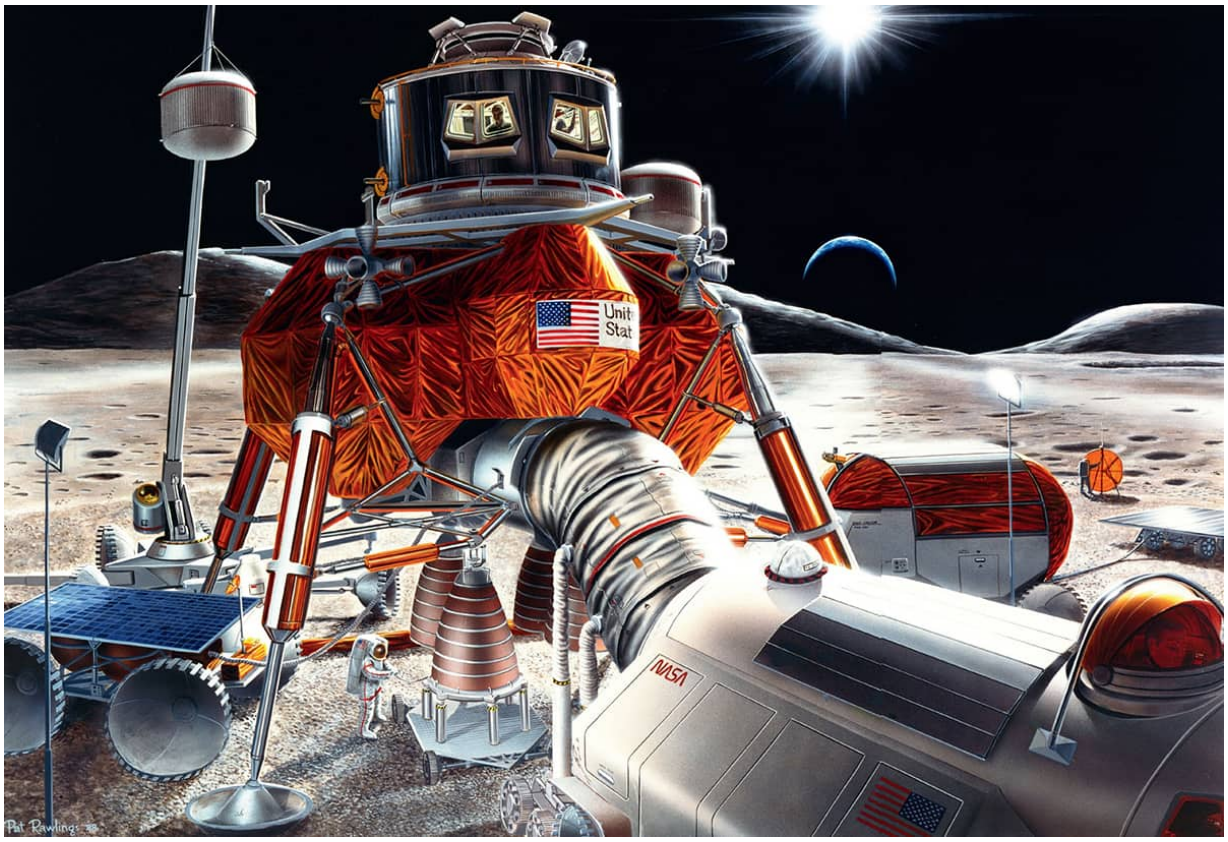
Plug-in people
Future space suits for lunar exploration may feature rear-facing hatchways that enable them to dock directly onto similarly shaped hatches on rover vehicles. Astronauts can climb out of the suits without bringing gritty and irritating lunar dust particles into their living quarters. This is a John Frassanito scene from 2009.

Temporarily lost lunar vision
Davis Meltzer's vision of post-Apollo spacefarers inhabiting a substantial lunar base, commissioned by *National Geographic* for its February 1969 issue and influential for many years after, even though this painting was made in a year when space funding was being curtailed and Apollo missions 18, 19, and 20 were struck off the rota.



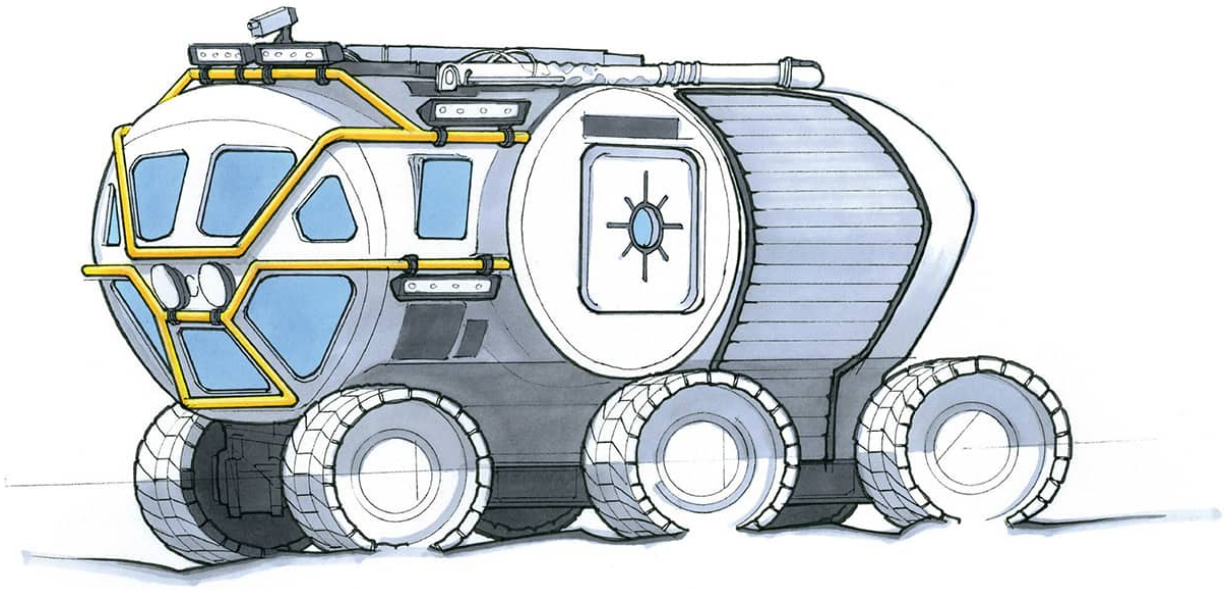
When will it happen?

One of Robert McCall's most famous artworks for the 1968 film *2001: A Space Odyssey* shows astronauts with a lunar city in the background. One astronaut holds a tablet-style computer.



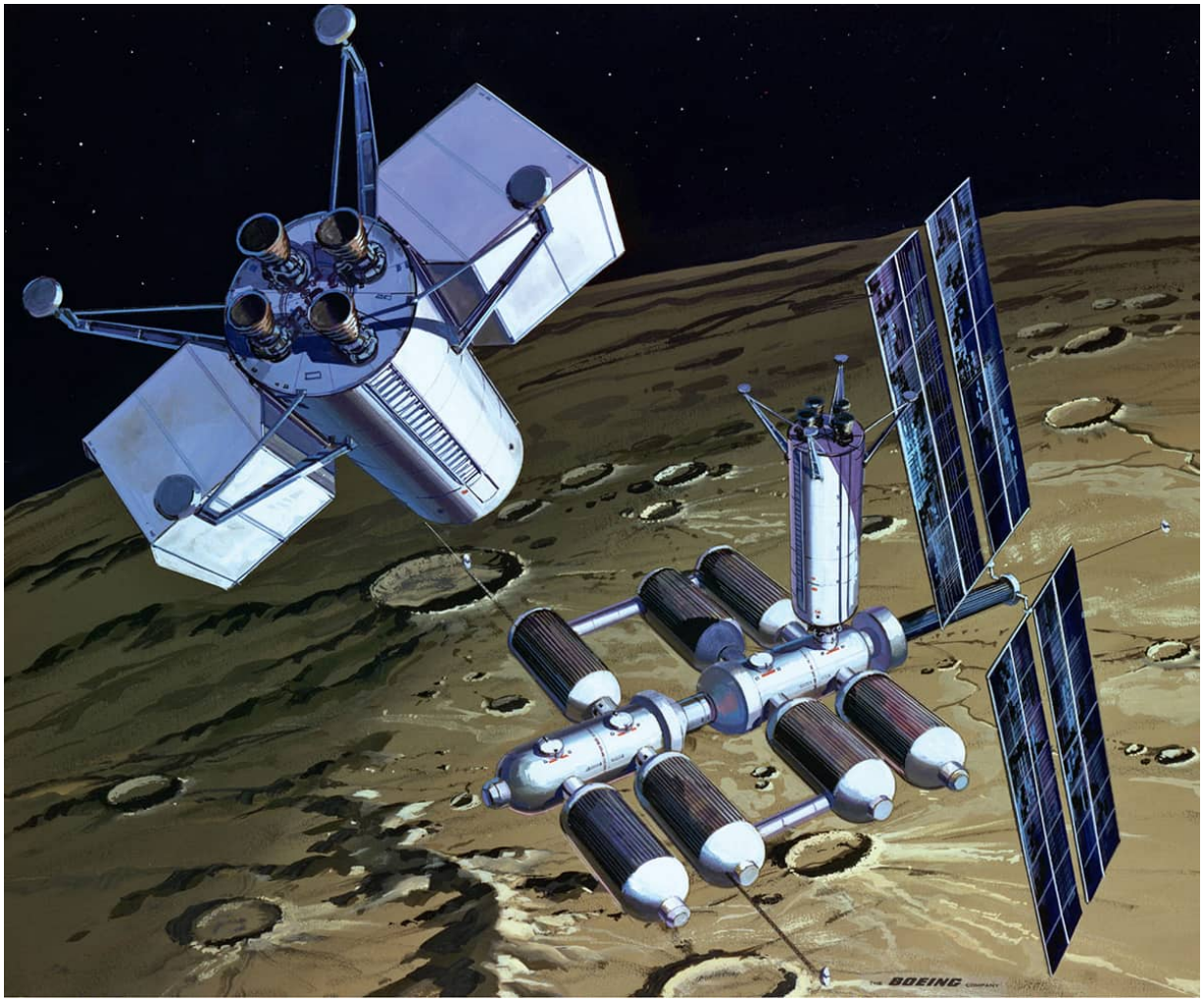
Eagle returns to the lunar dream

This illustration was made in 1988 by Pat Rawlings as part of a NASA research contract. The image also promoted an April 1988 industry conference in Houston titled *Lunar Bases and Space Activities of the 21st Century*.



The next car on the Moon?

A concept by automotive designer Mark Twyford for a multi-purpose habitable rover, created as part of a 2011 NASA study contract.



Last stop before the Moon
An orbiting lunar station conceived by Boeing in 1977 has many of the characteristics of today's plan for a Lunar Gateway. The picture appeared in a 1977 NASA publication, *A Compendium of Future Space Activities*.

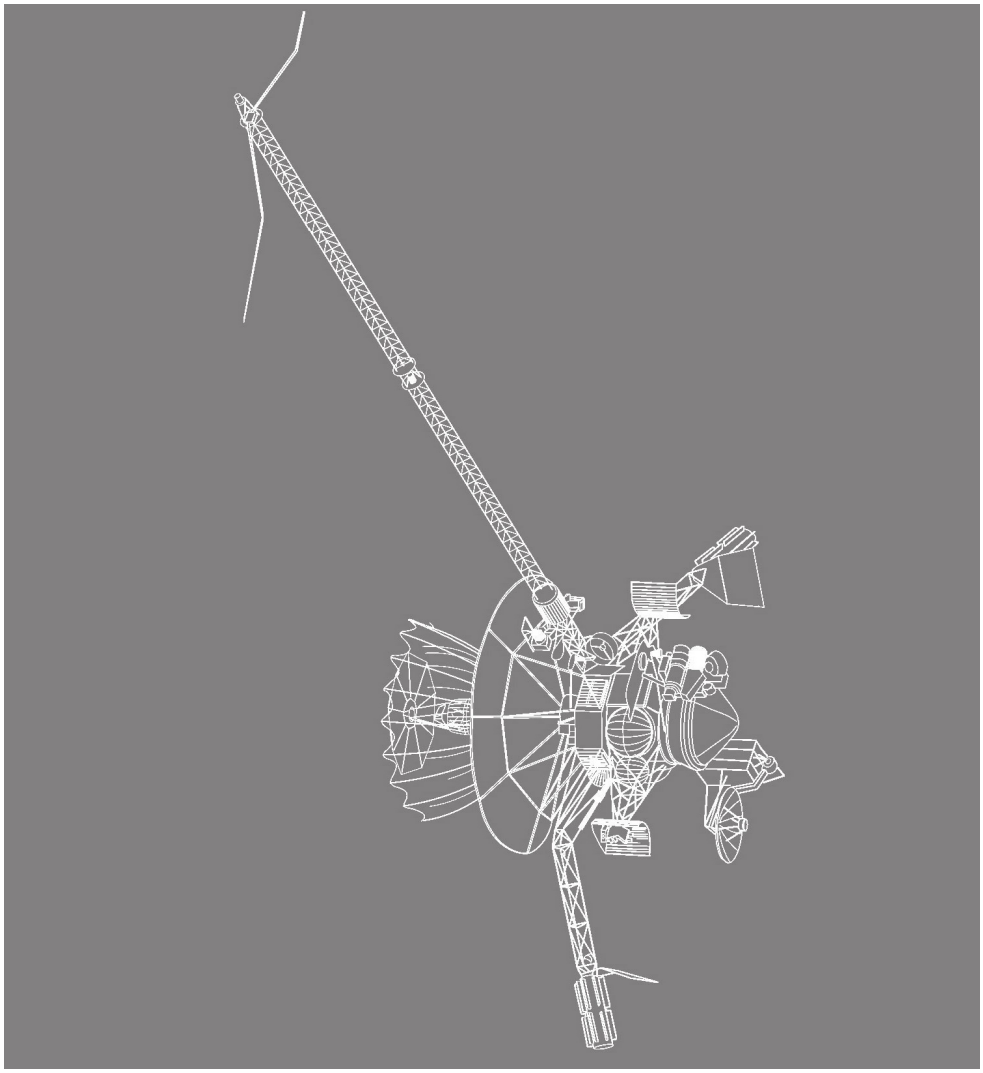
Lunar waystation

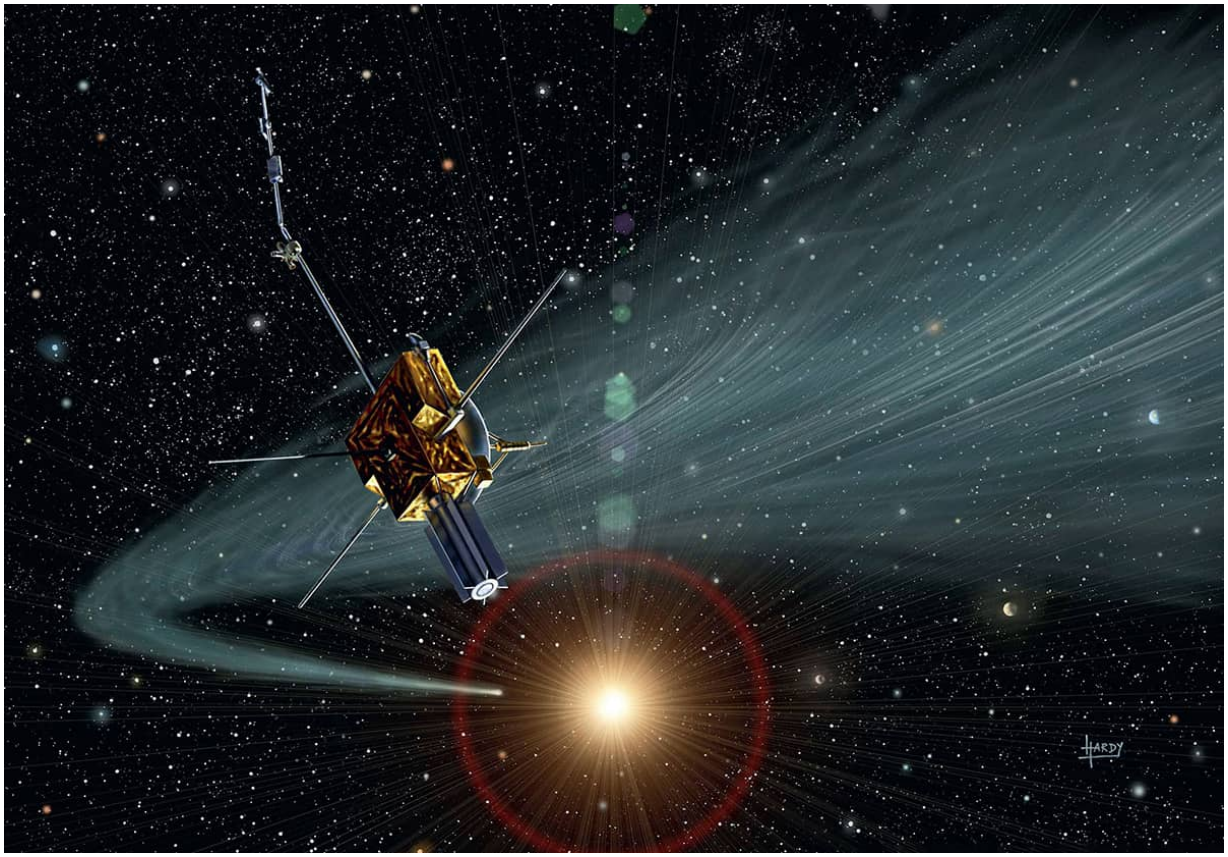
Lockheed Martin is the contractor building NASA's new Orion spacecraft. This cutaway shows an Orion docked to a version of the Lunar Gateway, the departure point from which lunar exploration is expected to resume in the next few years.

5
THE EXPANSE

Exploring Depths of Space Beyond Mars

What we know of the universe is the tiniest fraction of what's out there. The fact that we understand any of it at all is a staggering achievement.

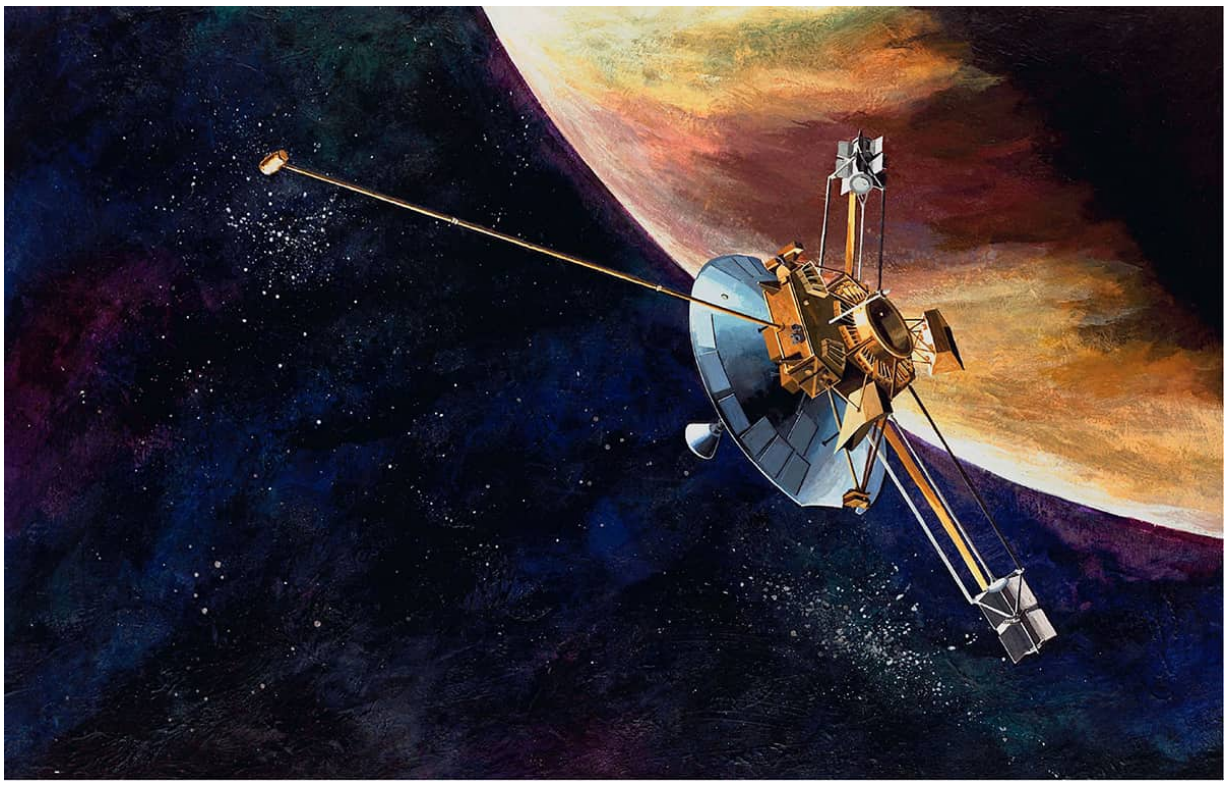




Through a long tail
British space artist Artist David Hardy's 1996 impression for NASA and the European Space Agency ESA of the joint Ulysses spacecraft passing through the tail of comet Hyakutake.

5: The Expanse

For the time being, targets beyond the Moon and Mars are not within human reach, despite the compelling vision of a nuclear-powered spaceship exploring Jupiter in Stanley Kubrick and Arthur C. Clarke's famous 1968 collaboration, *2001: A Space Odyssey*. Poster artworks for the film rendered by Robert McCall are part of the canon of space art, although they portray human missions that are beyond our current scope, even five decades after *2001* was released. On the positive side, NASA's robotic ambassadors have explored impressive tracts of the Solar System. The Cassini probe, a joint project with the European Space Agency (ESA), spent thirteen years orbiting Saturn and occasionally skimming past some of its equally intriguing moons. On January 14, 2005, Cassini's detachable payload, ESA's Huygens probe, touched down on Titan, revealing liquid methane seas and rivers flowing down the flanks of ice mountains, thus proving the existence of organic chemistry on this cold, eerie world. Perhaps life exists here?

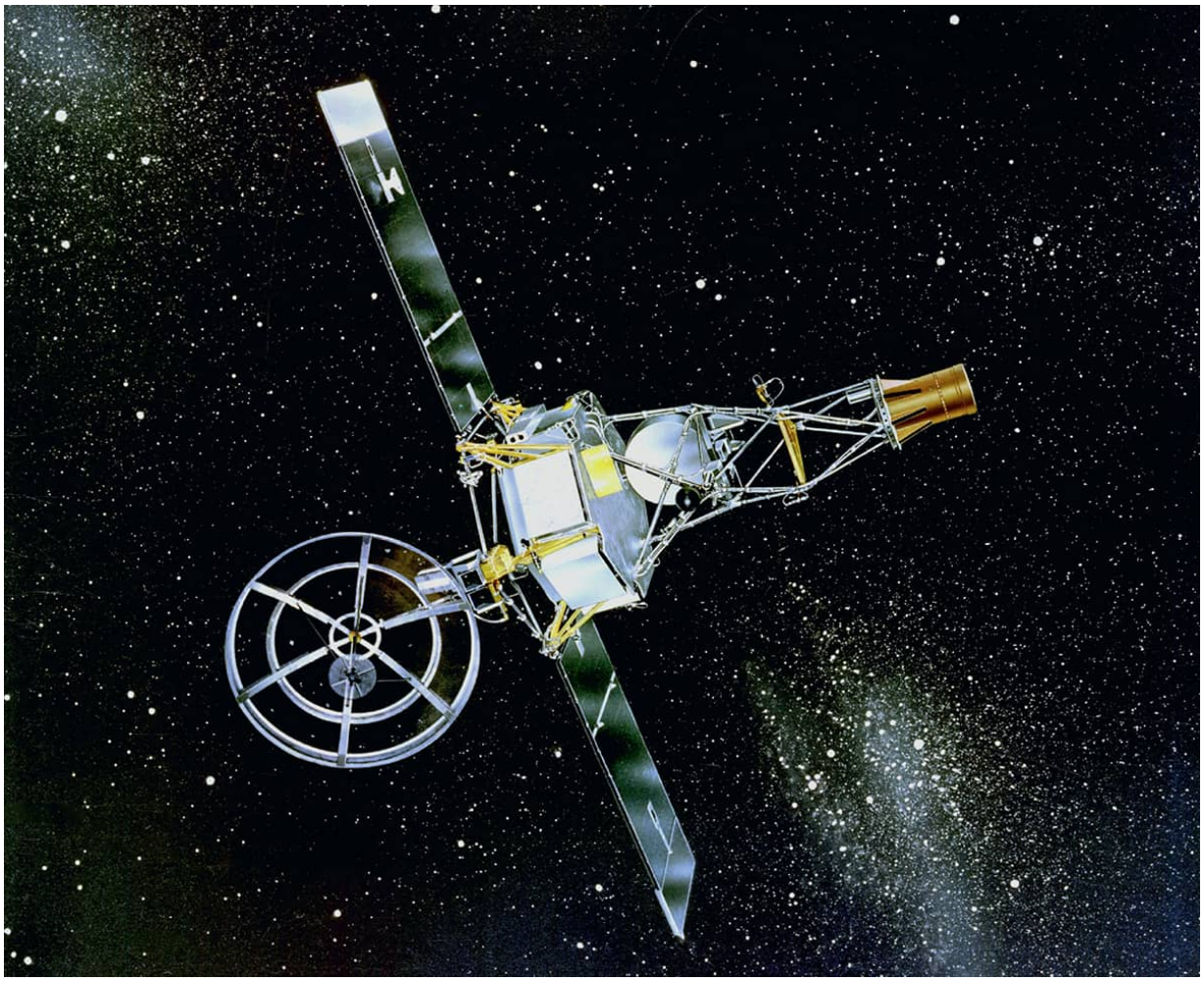


Meeting with a giant

Unidentified artist’s concept of Pioneer 10 during its encounter with Jupiter during November 1973.

Cassini ended its mission on September 15, 2017, by deliberately diving into Saturn’s atmosphere to prevent accidental biological contamination of Titan, or of Enceladus, another Saturnian moon that might be capable of supporting biology. In September 2015 Cassini’s imaging team leader, Dr. Carolyn Porco, said that NASA had found on Enceladus at least one habitat “where, perhaps, a second genesis has taken hold. It is a possibility that can bewitch the mind and strike awe and exaltation in the most stolid of souls.” NASA’s similarly ambitious Jupiter probe Galileo was retired in a similar way in 2003 to protect Europa, a small Jovian moon whose icy surface hides a liquid water ocean apparently also teeming with organic possibilities.

New Horizons, launched in January 2006, flew past the “dwarf planet” Pluto in July 2015, calling into question Pluto’s demotion, for the stunning images revealed a world as rich and complex, and as cleanly spherical, as any planet, even down to a wispy atmosphere. Now the probe is aiming for the Kuiper Belt, a hitherto unexplored region inhabited by stray fragments of rock and ice left over from the Solar System’s formation more than four billion years ago. After that, the probe will keep on, until it too has left the Sun far behind. But it trails behind interstellar emissaries launched long before New Horizons even reached the computer-assisted design phase. Perhaps NASA’s most incredible space enterprise, initiated more than half a century ago, was to build machines that have every chance of journeying to other stars and surviving intact long after the human race and all its Earthly constructions have vanished into dust.



A historic probe
Mariner 2 was the world's first successful interplanetary probe. Launched by NASA in August 1962 on an Atlas-Agena rocket, it passed within 21,000 miles of Venus in December that year, and captured the first close-ups of another planet.

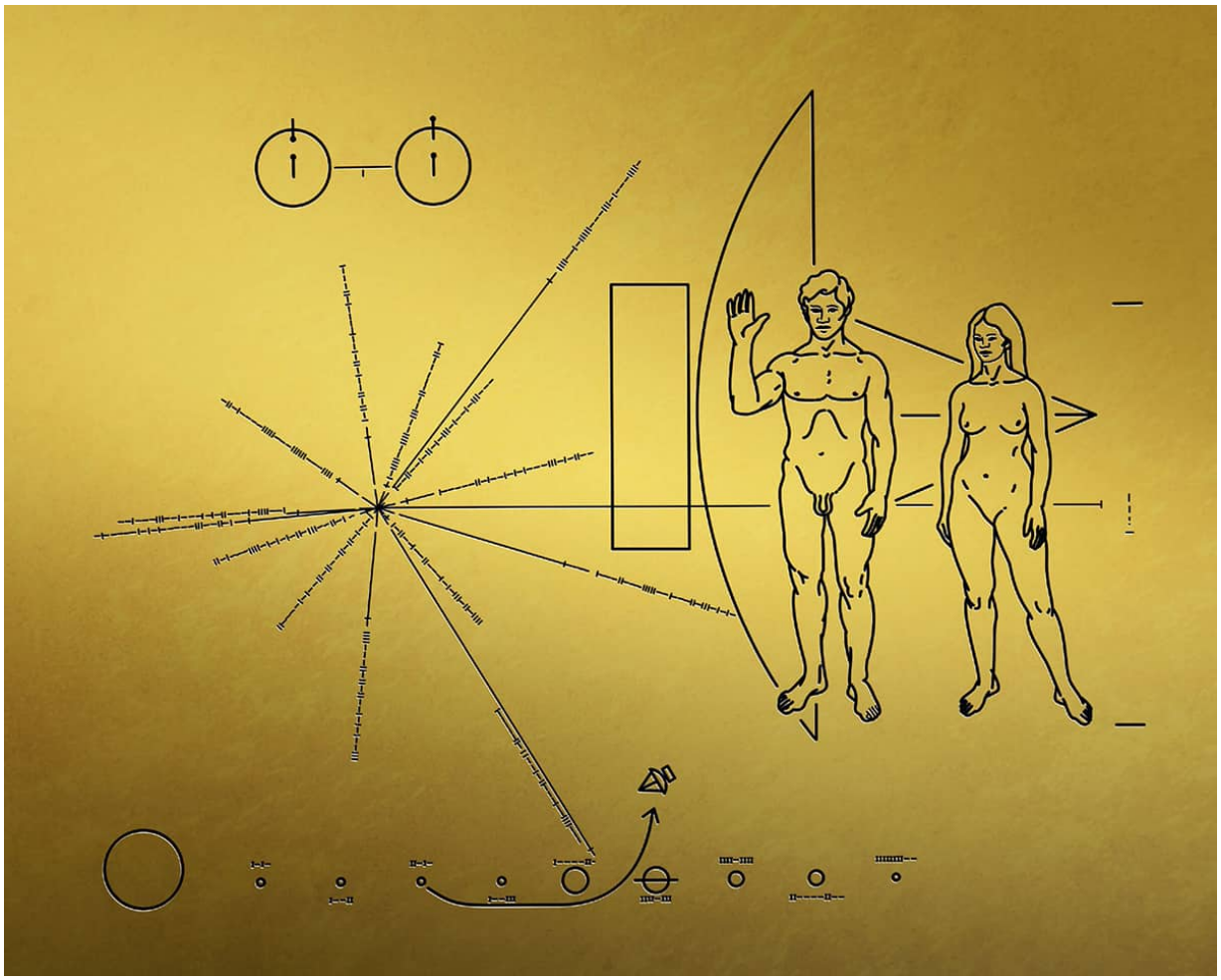
In the late 1960s, it was difficult enough simply to reach the Moon, but NASA's JPL in Pasadena, California, laid plans for a robotic journey across the Solar System. Every 176 years, the giant outer planets—Jupiter, Saturn, Uranus, and Neptune—are lined up on the same side of the Sun. NASA knew that such a conjunction was due in the late 1970s and was too special an opportunity to be missed. JPL devised a project that would exploit planetary gravitational fields so that each world would divert and accelerate a passing probe toward the next target. The plan was nicknamed the Grand Tour. NASA's twin probes, Voyager I and II, were launched a month apart, in August and September 1977. Two years later they swung past Jupiter and returned stunning images of a world in turmoil, with complex banded cloud

systems and a permanent red-tinged hurricane, the Great Red Spot, that could swallow several Earths. Jovian gravity accelerated the Voyagers towards Saturn, where they encountered a ring system more complex and finely structured than anyone had expected. Voyager I was steered so that it could study some of Saturn's many moons before leaving that region of space, while Voyager II continued outward to Uranus in 1986 and Neptune three years after that. As Voyager I finally slipped the bonds of Saturn's gravity and drifted deeper into space, its final transmitted image showed Earth as a tiny spark in the darkness, shepherded by a single distant star, the Sun.

Our messages to "them"

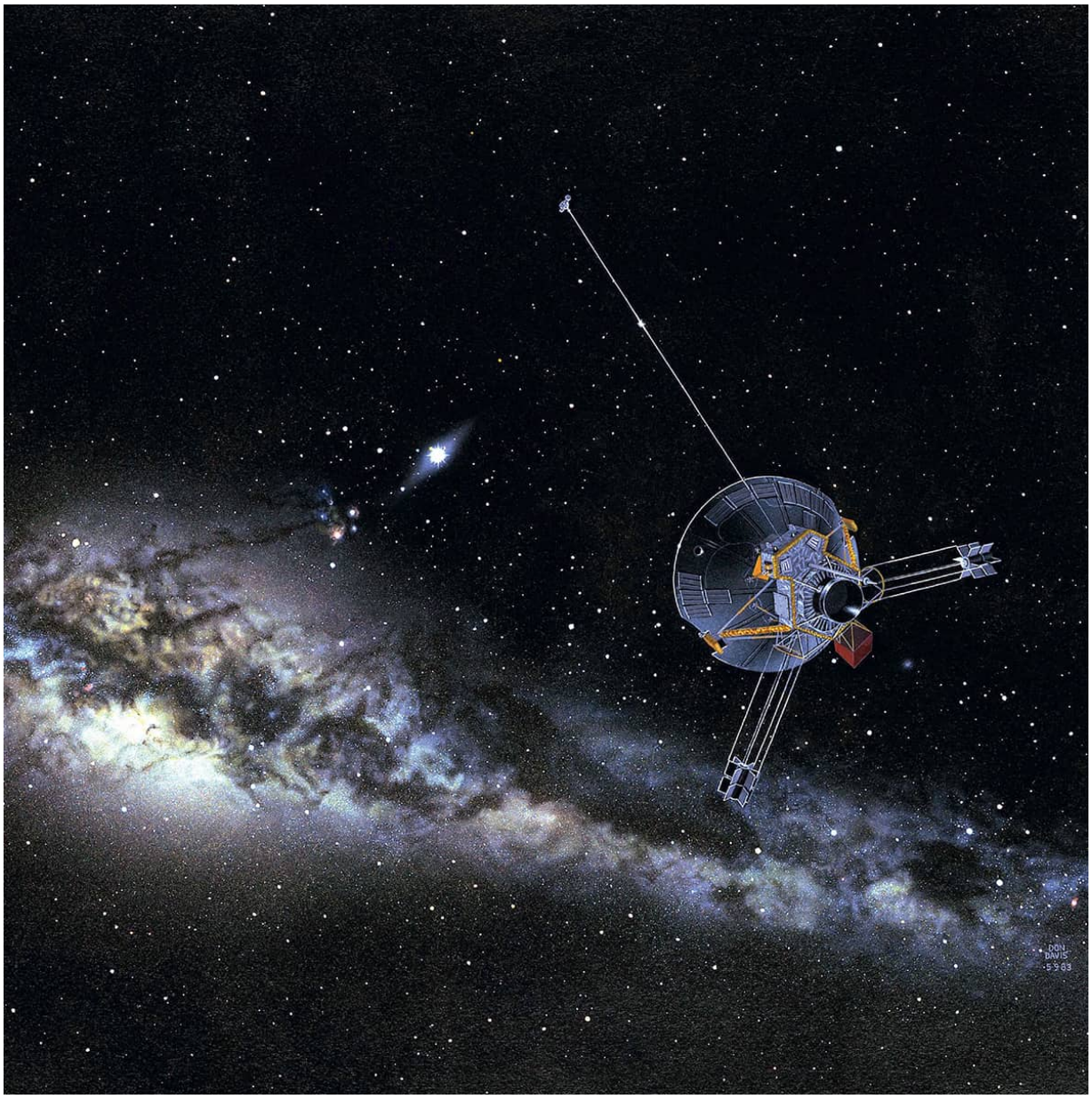
Just in case any alien intelligences ever intercept these emissaries from Earth, each Voyager carries a twelve-inch gold-plated copper disc engraved with a spiral of dips and dents, using the best phonograph technology available at that time, prior to the age of laser discs and DVDs. The protective case included a diagram of how the stylus (included in the kit) could be used to play the record, a Space Age LP of Earth's greatest hits as chosen by NASA and its special committee of cultural advisors. The discs contain more than a hundred encoded images of life on Earth, such as dolphins, an elephant, a toad, and of course, humans. Audio selections include a variety of natural sounds, such as surf, wind, and thunder, along with the songs of birds and whales. Music chosen to delight aliens ranged from Bach and Beethoven to Peruvian panpipes and Chuck Berry. Humanity also introduces itself in short greetings in fifty-five languages and written messages from President Jimmy Carter, UN Secretary-General Kurt Waldheim, and other leaders from a global civilization that, in all likelihood, will have vanished into dust by the time anyone out there in the depths of the galaxy finds those recordings.

Another famous pair of star-bound NASA probes was launched half a decade before the Voyagers. Pioneer 10 was the first spacecraft to fly by Jupiter in December 1973. It is now on a two-million-year-long journey to the red star Aldebaran in the constellation Taurus. Sister ship Pioneer 11 is now more than ten billion miles from the Sun. Although the Voyagers were launched more recently, the Pioneers' different trajectories placed them on a faster track for interstellar space.



Ambassadors to the stars

Pioneers 10 and 11 both carried a small golden plaque identifying their place of origin for the benefit of any aliens that might find them in the distant future. Pioneer 10 is heading toward the star Aldebaran in Taurus, and will take two million years to get there. Pioneer 11 will next encounter a star in about four million years. It is possible that some of the hardware will survive long after humanity has vanished into dust.



Our star from a vast distance
A 1983 painting for NASA by Donald E. Davis shows Pioneer 10 looking back at the Sun as it heads out of the solar system on a limitless voyage.

Each of the Pioneers carries a graphical design engraved on a rectangular metallic plaque. At top left is a schematic of a molecule consisting of two bound hydrogen atoms. This is such a basic material in the universe, it should be known to any alien civilization capable of intercepting an ancient NASA probe. Other clues reveal the Pioneers' origins: the third planet from the particular bright star that we see in our sky. Most prominently, a human

couple, a man and woman, are depicted with a Pioneer outlined behind them as a scale marker.

Intelligent extraterrestrials conceivably might unravel these mysteries many centuries in the future, but for our generation the plaques and golden records stand as messages to ourselves rather than to aliens. They signify that we aimed toward the stars at last once or twice in the course of human history, even if we never manage to do so again. The encoded Pioneer and Voyager sounds and images are technological cave paintings, created as much because we felt like it as for any other reason: a flattering portrait of ourselves as we would like to be seen by other intelligences. Attitudes have changed since those missions were launched, and we no longer share all the assumptions in the drawn symbols. In particular, why is the man waving and not the woman? NASA decided that if both humans were shown holding up their hands in greeting, aliens would think all of us walk around all day with one arm in the air. It made sense to show a variety of postures, although it never occurred to anyone in the 1970s that a woman might be the first human to say "Hi, there" to an alien entity.

All artists' depictions of deep space missions involve massive fib-telling in terms of the scales involved. Almost all depictions of space probes, space telescopes, robotic landers, and fly-by platforms shrink the distances into something that can fit onto a single image. We also frequently see trajectories of hurtling craft depicted as neatly colored curving lines. This too is an abstraction, although it has become so pervasive it's hard for us to envision the word "orbit" without seeing in our mind's eye those brightly colored egg-shaped and elliptical routes. No artist has ever drawn an imaginary line beyond the Solar System because the very meaning of "trajectory" becomes impossible to convey at cosmic scales, when the Sun and earth are drifting through the void, and in turn the galaxy of which they form an infinitesimally tiny part is hurtling on its own strange voyage, while slowly rotating once every 225 million years…

The farthest reaches of the cosmos

The Solar System represents just the low-hanging fruit of space exploration. Although almost all cosmic existence is too far away for us to reach, we can see a fair proportion of it through NASA's space-based instruments. The Hubble Space Telescope was launched on April 24, 1990, and released into space the next day from the payload bay of shuttle *Discovery*. Despite more

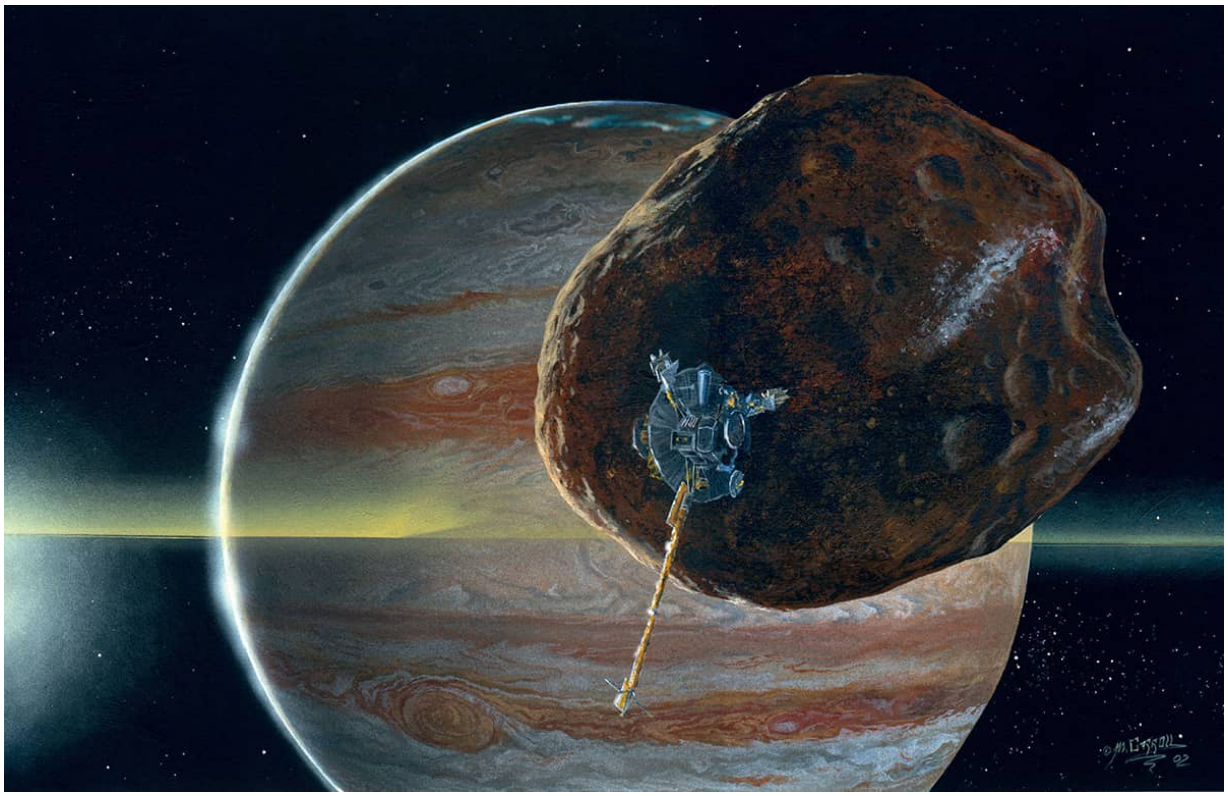
than a decade of preparations prior to launch, Hubble's operational debut was marred by a substantial problem. The $2 billion instrument was supposed to deliver the sharpest views of deep space ever seen, but the first test images that it acquired were out of focus. Urgent detective work on the ground suggested that the edge of Hubble's primary mirror had been manufactured too flat by a depth of 2.2 microns, or about one-fiftieth the thickness of a human hair. Equally troubling was the fact that Hubble's huge solar power arrays flexed and buckled every time its orbit carried it through transition zone between the warmth of earth's day side and the extreme cold of the night side.

Fortunately, Hubble was designed from the outset to be serviced by shuttle astronaut teams. NASA and its collaborators designed an ingenious device, the Corrective Optics Space Telescope Axial Replacement, or COSTAR. Around the size of an old-style phone booth, its key components were tiny corrective mirrors smaller than a once-cent coin. On December 2, 1993, shuttle *Endeavour* lifted off with a rescue team. Hubble was pulled into *Endeavour*'s cargo bay using the shuttle's robot arm. Astronauts Story Musgrave, Jeffrey Hoffman, Thomas Akers, and Kathryn Thornton replaced the faulty solar arrays and installed COSTAR and other equipment during five spacewalks totaling thirty-five hours. Hubble's shaky first phase was quickly forgotten as it became one of the most popular and scientifically productive instruments in history. Stunning images of stellar nurseries and distant galaxies in uncountable billions gave astronomers and cosmologists countless new insights. These beautiful representations also utterly transformed the public's understanding of the universe and our place within it.

The “Grand Tour”
Lou Nolan’s 1970 depiction for NASA’s Jet Propulsion laboratory (JPL) of Pioneer 10 arcing beyond the orbit of Pluto. Its trajectory is traced back to Jupiter, as it continues its journey through the depths of interstellar space.

Hubble’s successor, the James Webb Telescope (JWST) will launch soon. It consists of a segmented twenty-one-foot diameter primary mirror mounted on a flat sunshade the size of a tennis court. The supporting spacecraft, with propulsion, communication equipment, and solar power panels, is positioned on the other side of the sunshade. JWST will observe extremely distant galaxies and often it will pick up no more than a single photon of light per second from a given target. The mirror (the largest ever deployed in space) is designed to intercept as many of those photons as

possible and, most particularly, in the infrared region. This extreme need for sensitivity requires JWST to operate in deep space. It will occupy an orbit just under a million miles from Earth in a special realm known as L2, where the combined gravitational influences ensure that the Sun, Earth, and Moon are always safely "behind" the telescope's sunshield, thereby protecting the primary mirror and its light-gathering instruments from stray heat and glare generated by those celestial bodies.



Small Jovian satellite
Michael Carroll's 2002 depiction of NASA's Galileo spacecraft passing near Jupiter's tiny inner moon Amalthea. The gas giant's northern aurora, the Great Red Spot, and faint ice rings are all depicted. The malfunctioning antenna can just be seen to the left of the spacecraft hardware.

Into the future

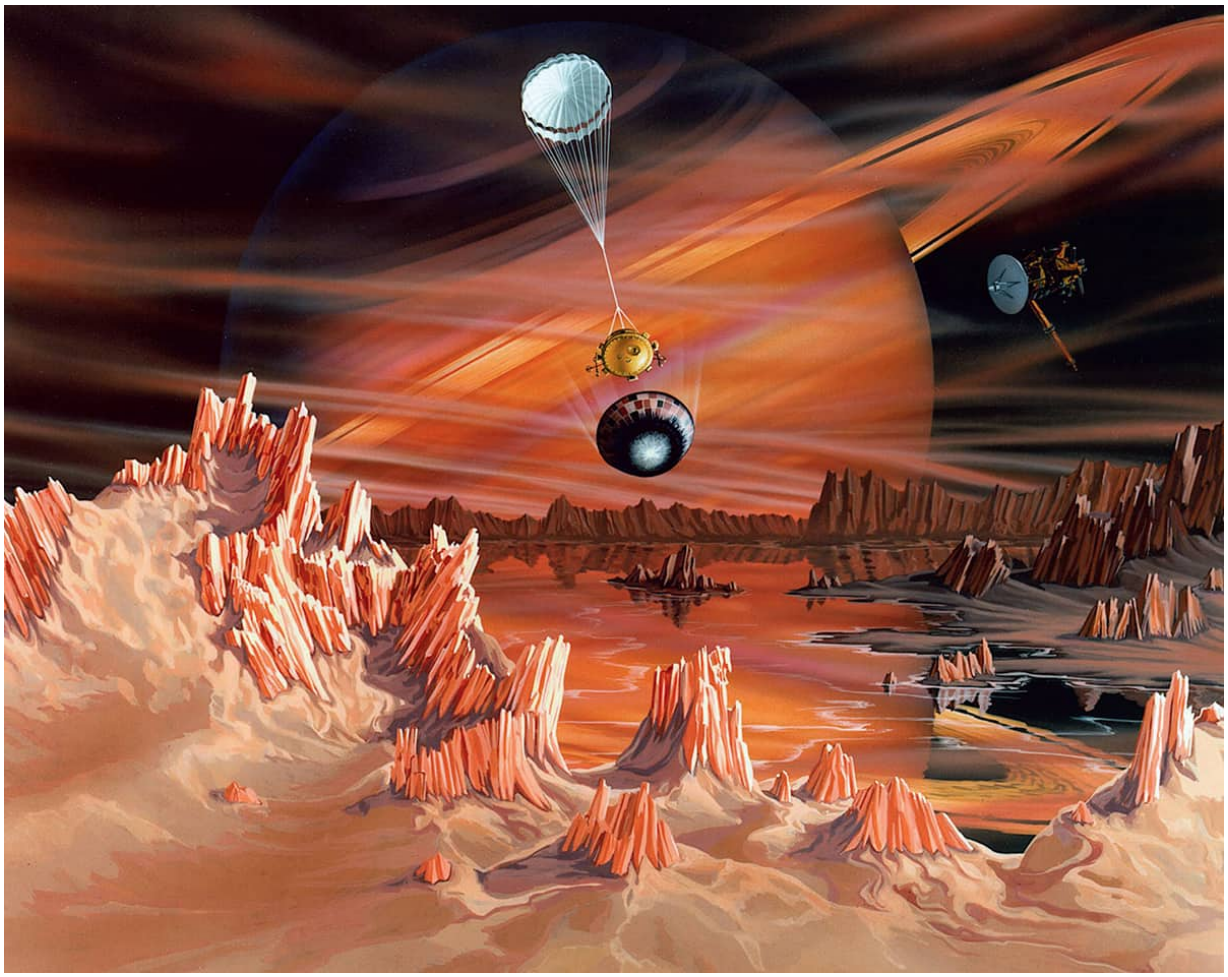
The famous science fiction author and space enthusiast Arthur C. Clarke said, "One day we will not travel in spaceships. We will *be* spaceships." In a sense we already are. Robot probes are extensions of our minds and our physical reach, allowing us to scrabble in the soil of far-distant worlds with remotely operated claws. Does that mean that we no longer have to go to the trouble of turning up in person to clutch handfuls of alien dust in our

own hands? This has been the great debate ever since the Space Age began. Logic suggests that machine probes are the safest and most cost-efficient tools for space exploration. Instinct and emotion cause many of us to think differently. Science and technology suggest that whatever part of humanity does eventually reach beyond the Solar System probably will be some hybrid of human consciousness and machine fabric. Who knows?

If all had gone to plan

This 1989 rendering of Galileo shows what the spacecraft would have looked like if the main antenna had deployed fully.

NASA has to be careful speculating about such distant ideas. Even so, the agency does occasionally flirt with speculative studies of exotic notions, such as faster-than-light physics or huge rotating space colonies occupied by thousands of settlers. There was a time not so long ago when US senators listened in awe to another charismatic lecturer talking about space as a way of easing environmental pressures on Earth. During the late 1970s Dr. Gerard Kitchen O'Neill, a physics professor at Princeton University, proposed space habitats several miles long, each supporting tens of thousands of people living in leafy suburbs within gigantic egg-shaped or toroidal shells that rotate to provide artificial gravity, all powered and illuminated by vast yet featherlight solar mirrors floating nearby. NASA artists brought these visions to life as a way of reminding people that we are only at the start of the space adventure and can venture so much farther if we choose to.



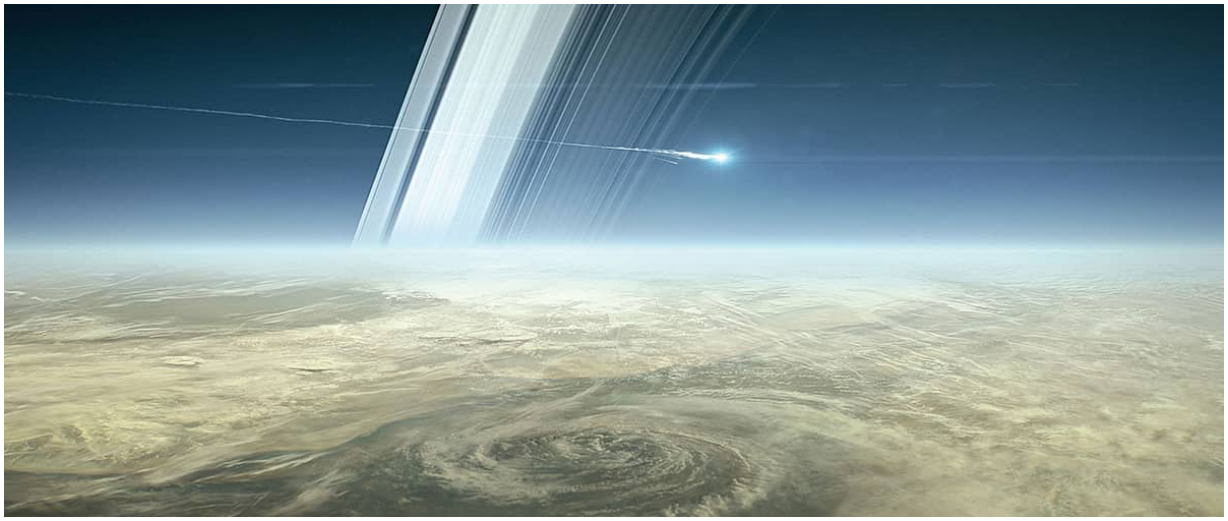
A truly alien world
Craig Attebery made this appropriately wild intepretetation for ESA of the 2005 Huygens probe descending into the atmosphere of the Saturnian moon Titan, which has a thick methane atmosphere, rivers and lakes of methane fed by hydrocarbon rains, and mountains made of ice.

NASA even has a starship proposal. In 1994, physicist Michael Alcubierre proposed a warp drive that could shrink the four-light-year gulf between Earth and the nearest star, Proxima Centauri, to just five months without breaking Albert Einstein's rule that no object can travel faster than light. Rather than flying through space, a stationary ship would create a "negative energy" field that warps the environment around it, expanding space-time to the rear and contracting space-time up ahead. NASA researchers invite us to imagine a moving walkway such as can be found in many airports. Although a passenger hastening toward a terminal can only walk as fast as the maximum walking speed possible for a human, the walkway (space-time) can move considerably faster. The net effect is that the passenger reaches her destination in much less time than her walking

speed alone could account for. Exotic forms of energy would be needed to create such a warp—what's more, energy in the dangerous form of anti-matter. However, if we can harness these energies safely and economically, they might yet open the road to the stars. NASA allows itself the luxury of portraying an Alcubierre starship, specially envisioned by digital designer Mark Rademaker. Whether or not reality catches up with such a dream, only time will tell. And how much time do we have left to fulfil the potential of our species? Perhaps best not to look at the starkest paintings in the space artists' canon, in which giant asteroids are depicted smashing into Earth and bringing all our hopes and dreams to a sudden end. Let's keep our fingers crossed and keep our gaze fixed on the distant stars, while continuing to draw inspiration from more than half a century's worth of gorgeous NASA-related paintings and illustrations.

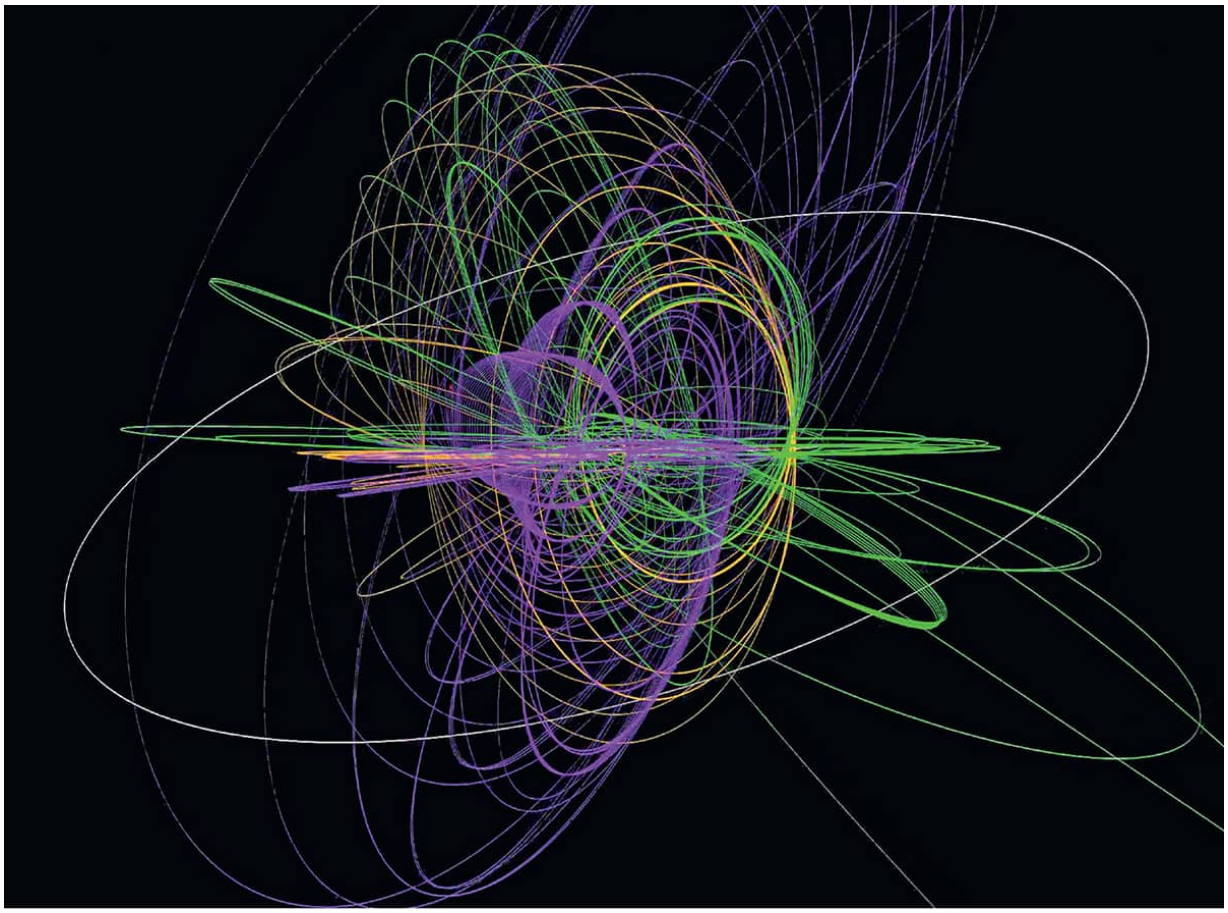
Flying close to the Sun
The MESSENGER spacecraft revealed Mercury's landscape as never before. After a mission lifetime of eleven years the probe was deliberately crashed in 2015 to gain close-up science data.

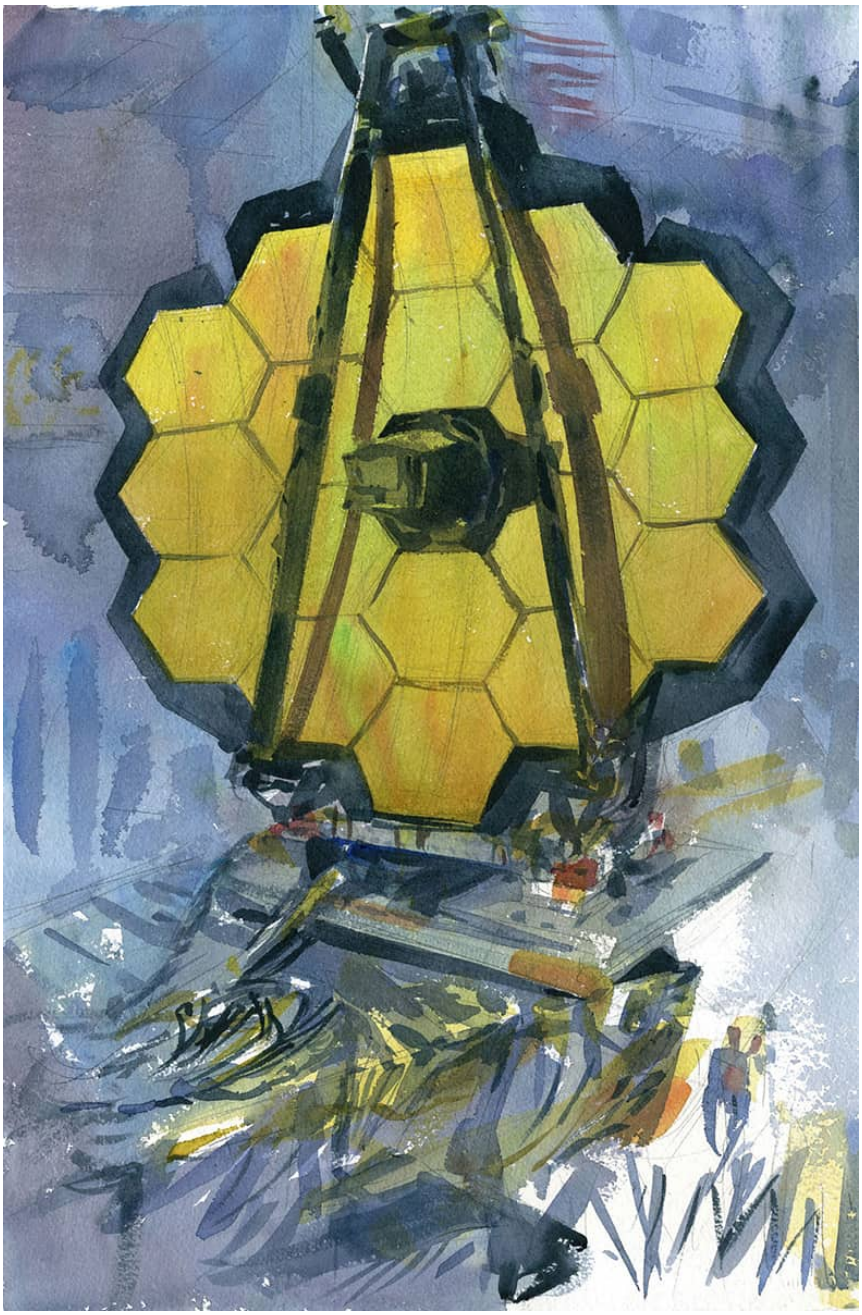
Noble self-destruction
The “Grand Finale” of Cassini’s mission to Saturn: a final glimpse of sunset, a steep descent into Saturn’s upper atmosphere, and the probe’s spectacular and bitter-sweet destruction, transmitting precious data until the very end.



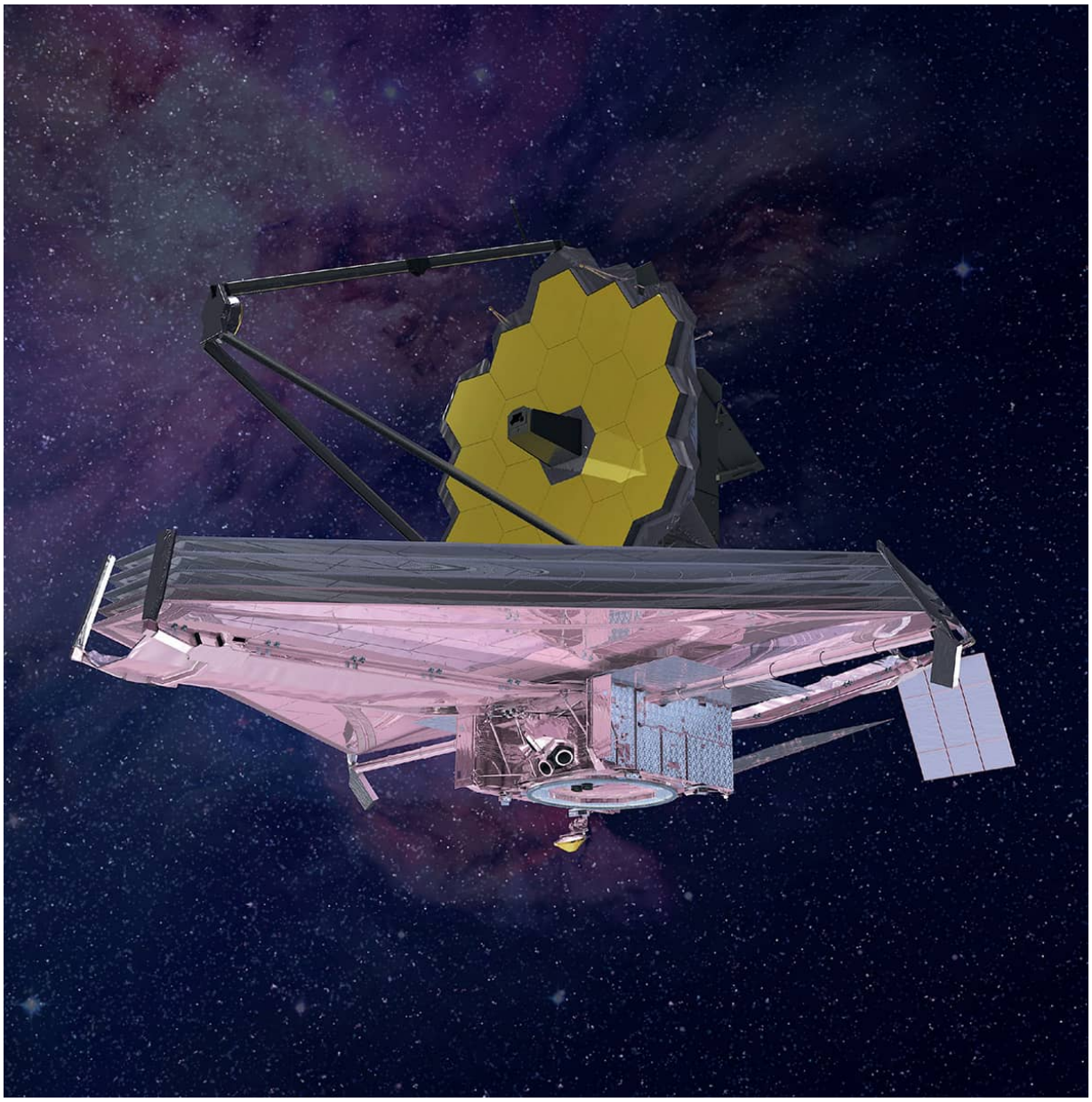
Math as art

Cassini's entire multi-year trajectory within the Saturnian system is plotted on a NASA JPL computer. Green represents the prime mission, conducted from 2004 to 2008, orange is the "Equinox" phase of the mission (2008 - 2010), and purple is the "Solstice" mission (2010 - 2017). From arrival until the end of its life, Cassini traveled 1.2 billion miles.





Painting from experience
In November 2016, NASA invited a select group of 25 artists to visit the James Webb Space Telescope (JWST) at the Goddard Space Center in Maryland, VA. This is Joanna Barnum's delicately rendered watercolour of the primary mirror.



Hubble's successor
Northrop Grumman is building JWST, which willl occupy a special orbit a million miles from Earth. The metal foils prevent heat, light and other solar radiations from swamping the instruments. JWST will be launched by an ESA Ariane rocket (next image).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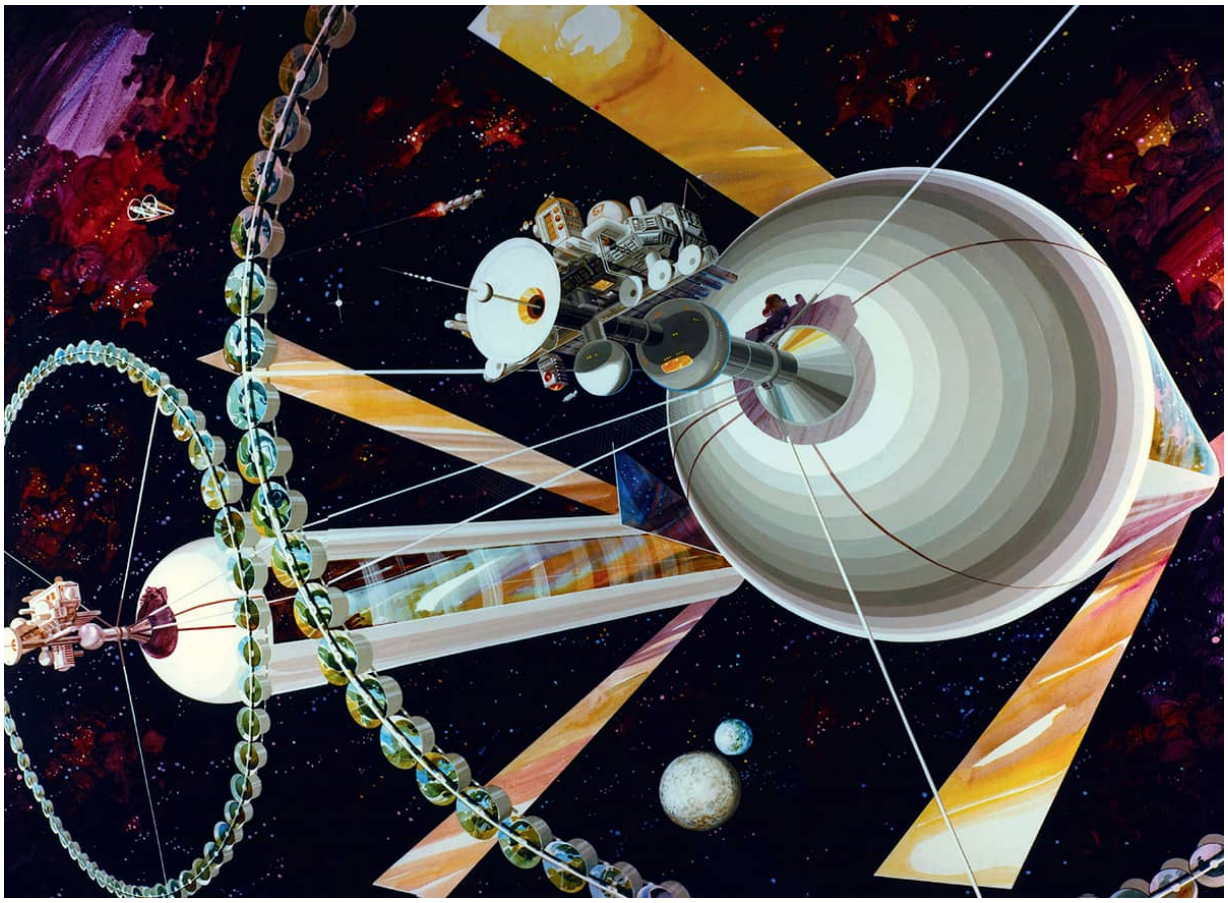
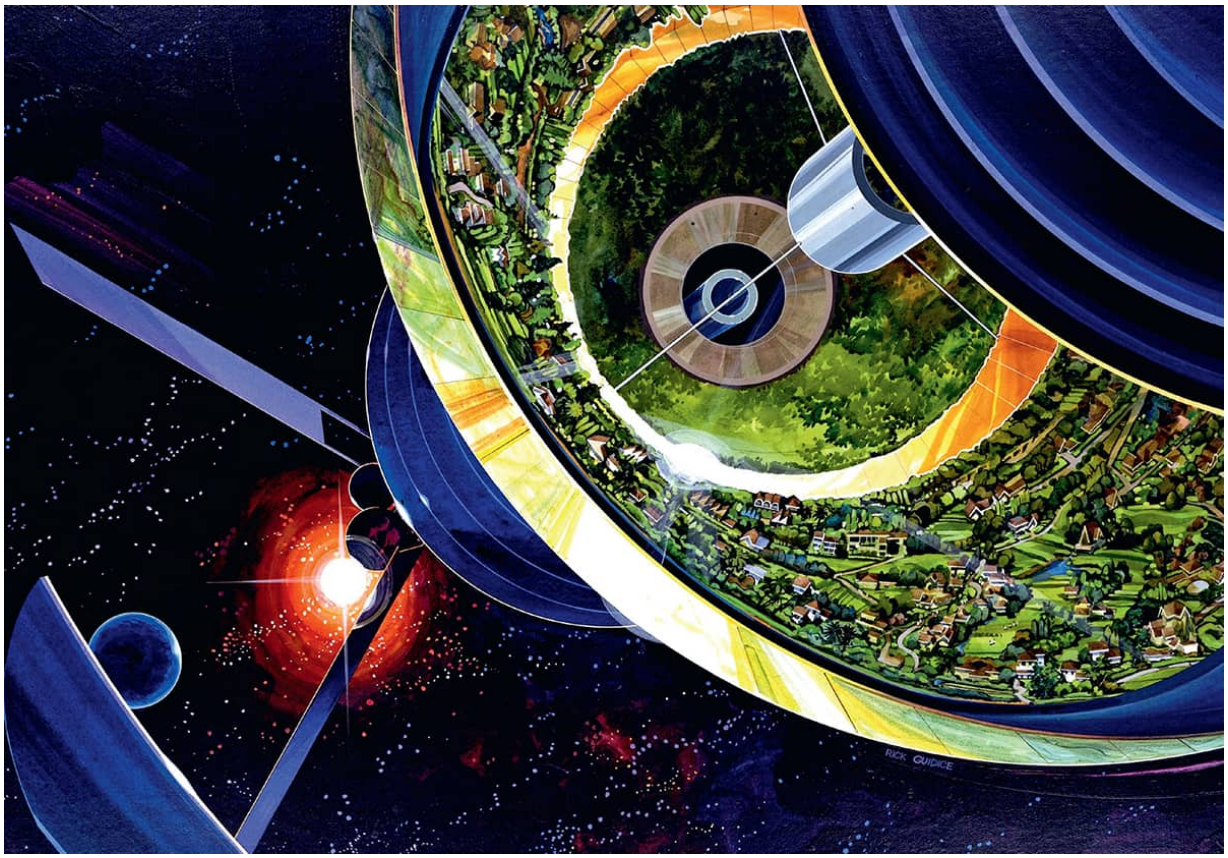


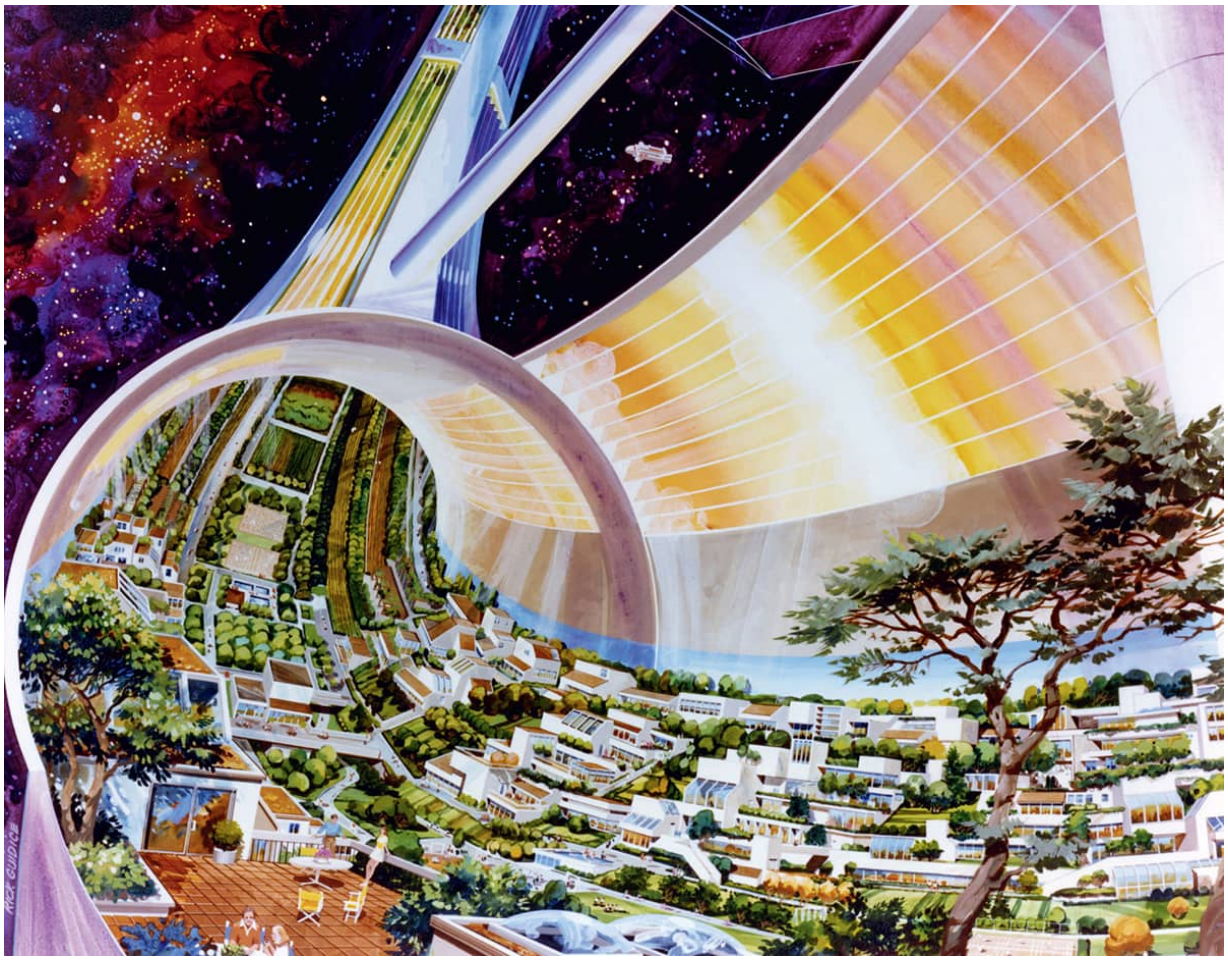
The dream in the shell

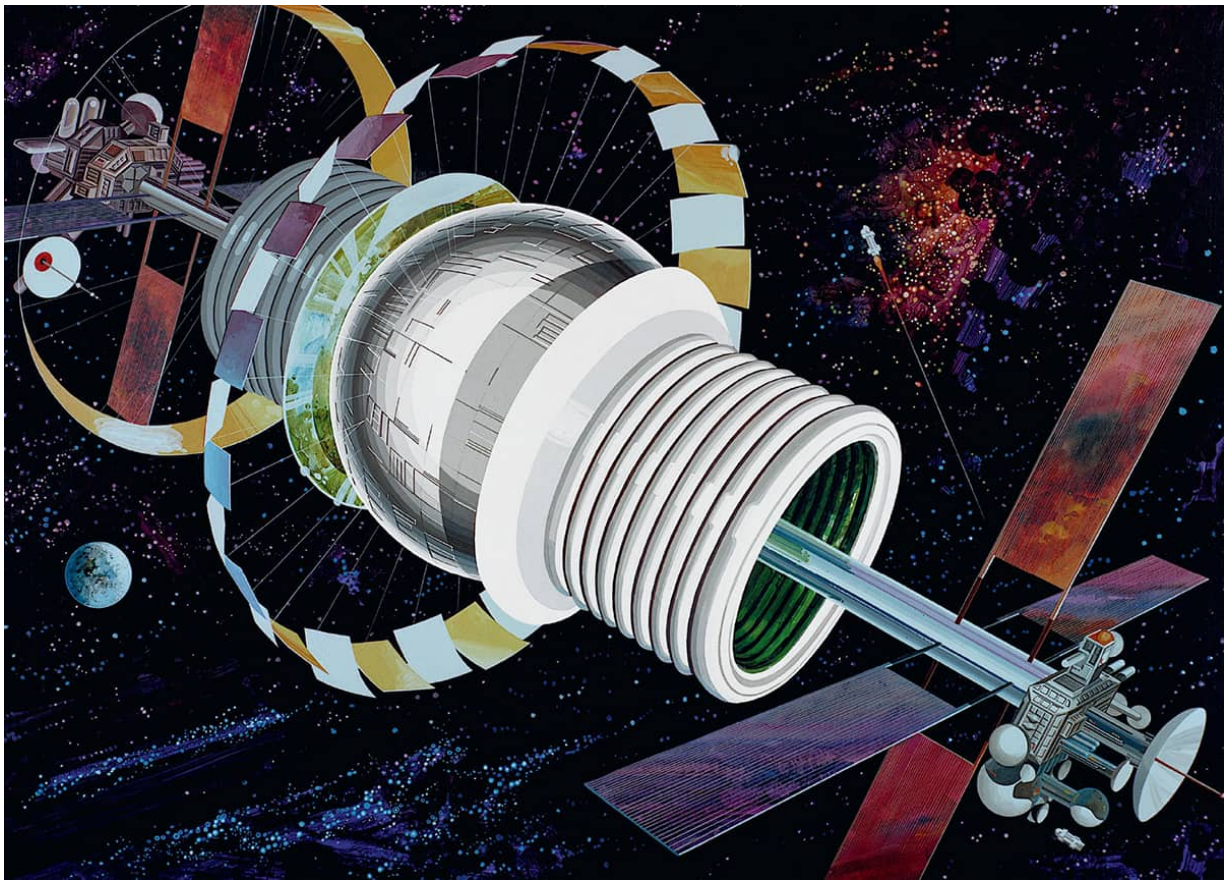
Rick Guidice made a series of famous paintings in the mid-1970s, depicting vast space colonies designed by Princeton University physics professor Gerard K. O'Neill. NASA gave tacit support to these speculative research efforts. This structure has three sunlight-reflecting mirrors revolving around two habitation cylinders, each 20 miles long. The pods at the ends of the cylinders are for growing crops.

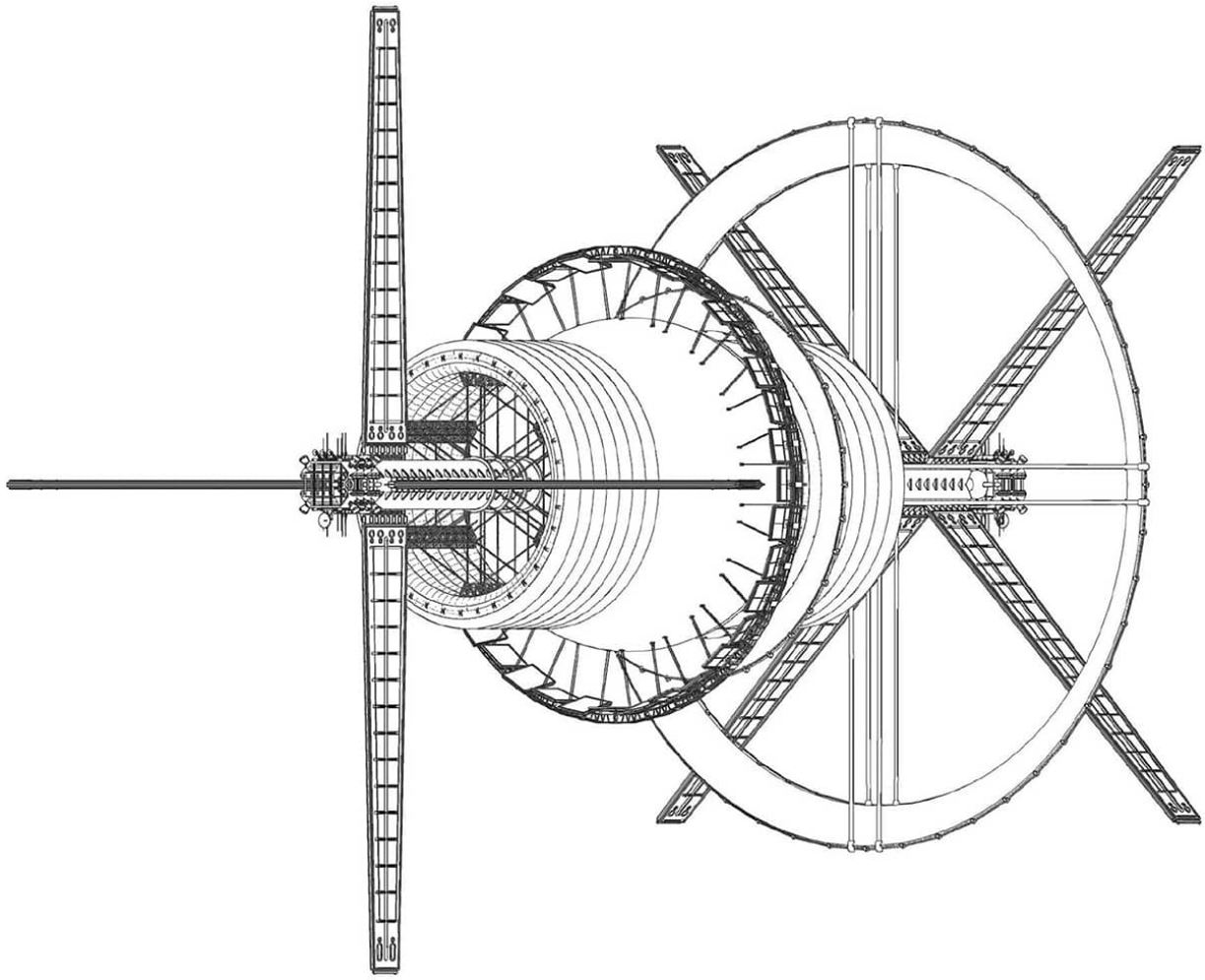


Easing the burden on mother Earth?

Further Rick Guidice interpretations from the mid-1970s of life aboard vast space colonies. Materials for construction would be mined from the Moon. The idea was to ease population pressures on Earth. In fact, some of the “closed loop” environmental studies that formed part of these proposals proved of genuine value to the budding environmental movement back on the ground.


NICK GUDICE

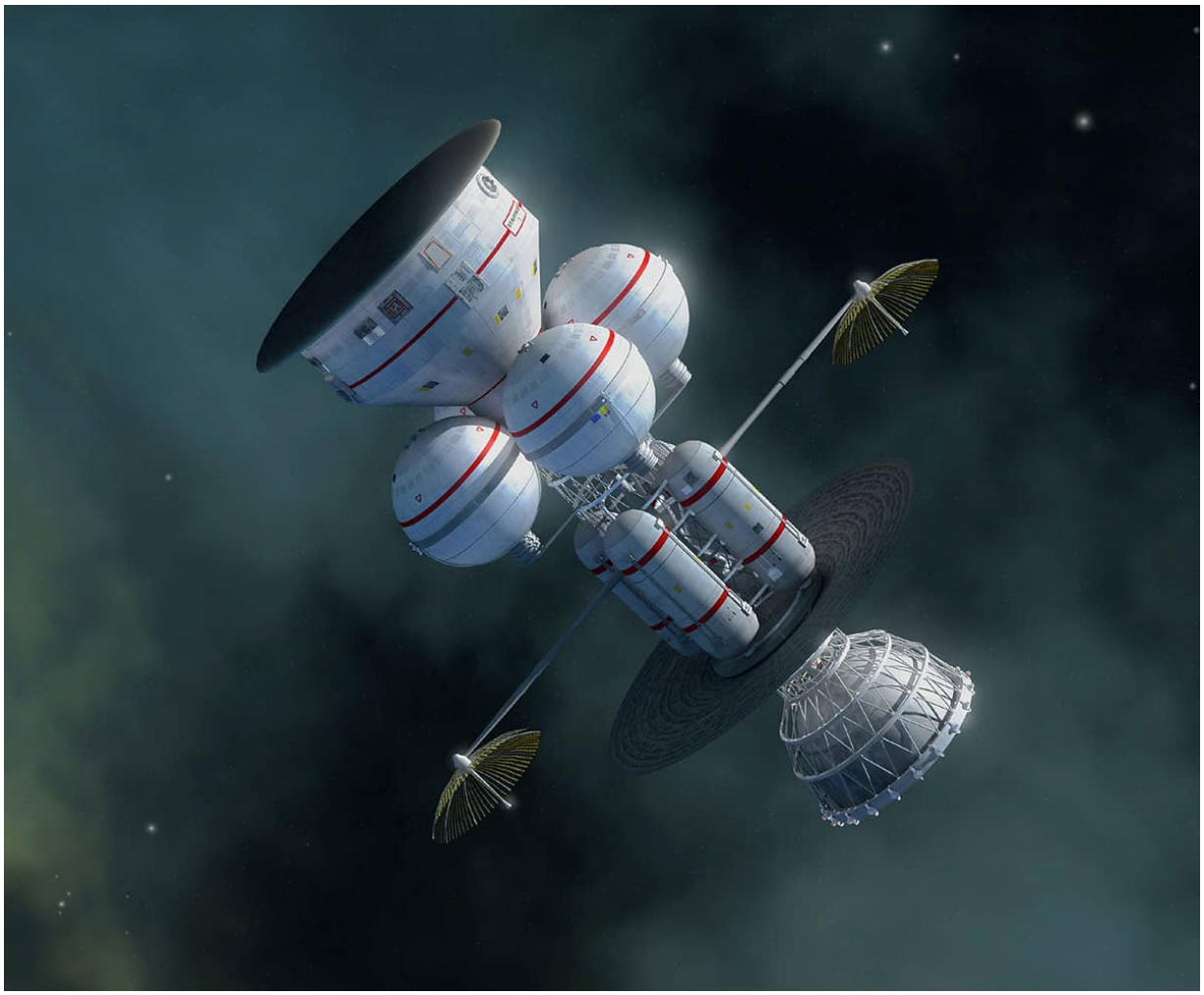




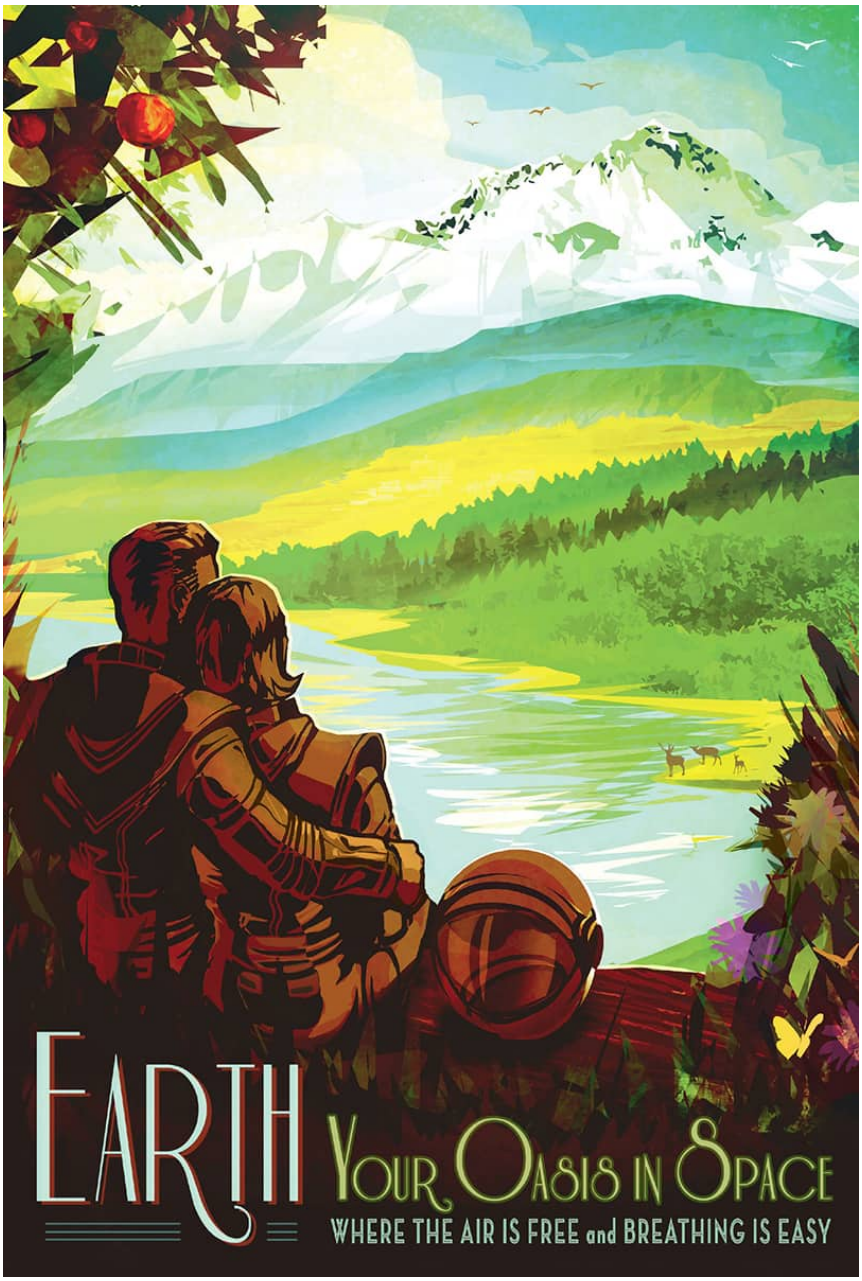
Restless species

Adam Benton's 2009 depiction of a cylindrical space colony sporting all the comforts of home, including artificial gravity generated by the cylinder's gentle rotation. Every generation seems to dream of a future world with possibilities wider than the one they currently inhabit. What dreams might impel the restless inhabitants of a cylinder such as this to try and leave it and live elsewhere?

Journey beyond the infinite
The giant nuclear-powered spaceship *Discovery* despatches a one-man space pod for a strange alien encounter in this 1968 Robert McCall painting for *2001: A Space Odyssey*. McCall exaggerated the rocket plume for dramatic effect.

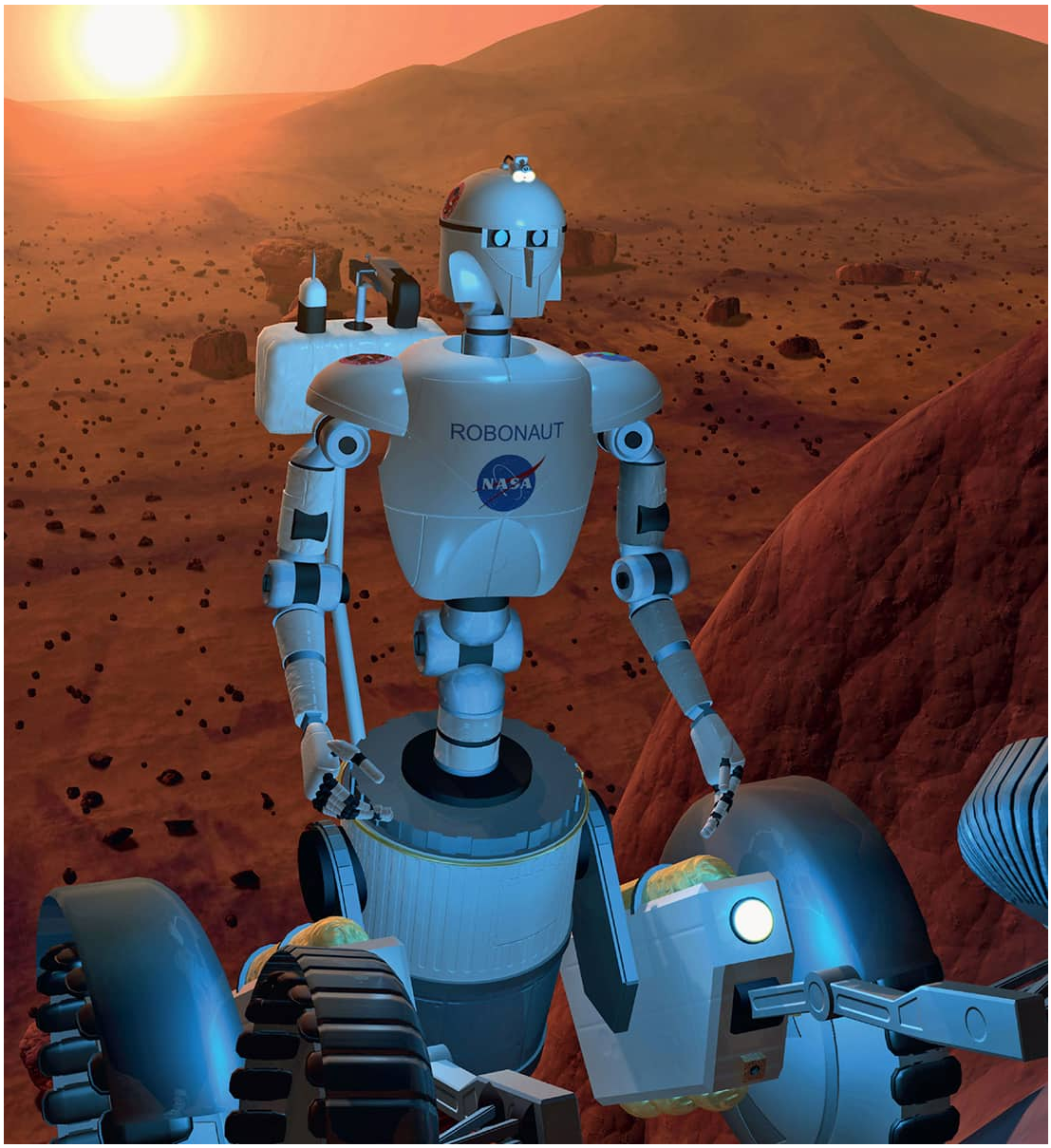


Realistic starship
British graphical artist Adrian Mann's depiction of Project Icarus, a huge robotic interstellar spacecraft based on concepts developed by the British Interplanetary Society (BIS) in the 1970s, and updated to take account of the latest research into nuclear fusion. Many BIS ideas, from the 1930s onward, helped inform NASA's plans.



No place like home

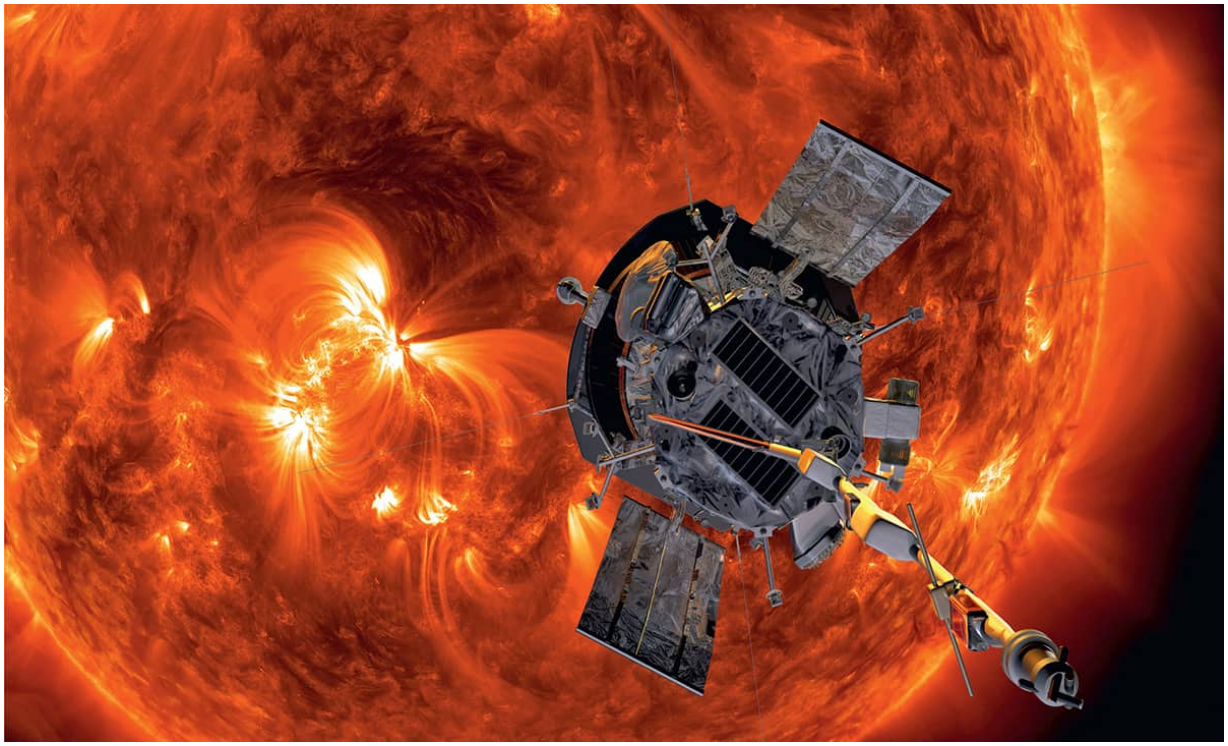
NASA continues to work with artists and graphic designers to maintain public awareness of exciting possibilities for the future of space exploration. A creative team at NASA JPL recently created an art print series in a nostalgic style echoing mid-20th century travel posters, entitled *Visions of the Future*. Nine artists were involved in designing fourteen posters suggesting the fantastic opportunites that await us throughout the solar system. But this one by Joby Harris reminds us not to forget the one world that is better than any others: our own.



Our machine shadows
A humanoid device known as a “Robonaut” explores Mars in this 2004 idea from NASA in which humans extend their reach via machine intelligences. A prototype Robonaut is on the International Space Station, and one day it could assist astronauts by holding tools during space walks.

Ad Astra

A concept for a warp-speed spacecraft designed by NASA's Advanced Propulsion Team lead scientist Harold White, and brought into focus by artist Mark Rademaker in 2014. The design depends on exotic "negative mass" particles and other as-yet unrealizable ideas, but the underlying physics suggest that warp drive may be feasible one day.



Exploring the nearest star

NASA's Parker Solar Probe spacecraft approaching the Sun in this rendering from 2018. The mission makes critical contributions to our understanding of "space weather" events that impact all life on Earth.

The most important planet

The more we explore space, the more it tells us about the one world that we can call home, and where the vast majority of humans must make their futures, because even the grandest space proposals cannot accommodate seven billion peolle, not to mention all the plants and animals that share our home planet. This 2005 NASA painting depicts Cloudsat, one of many international spacecraft whose target of scientific interest is the Earth rather than the distant stars.

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Image credits

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