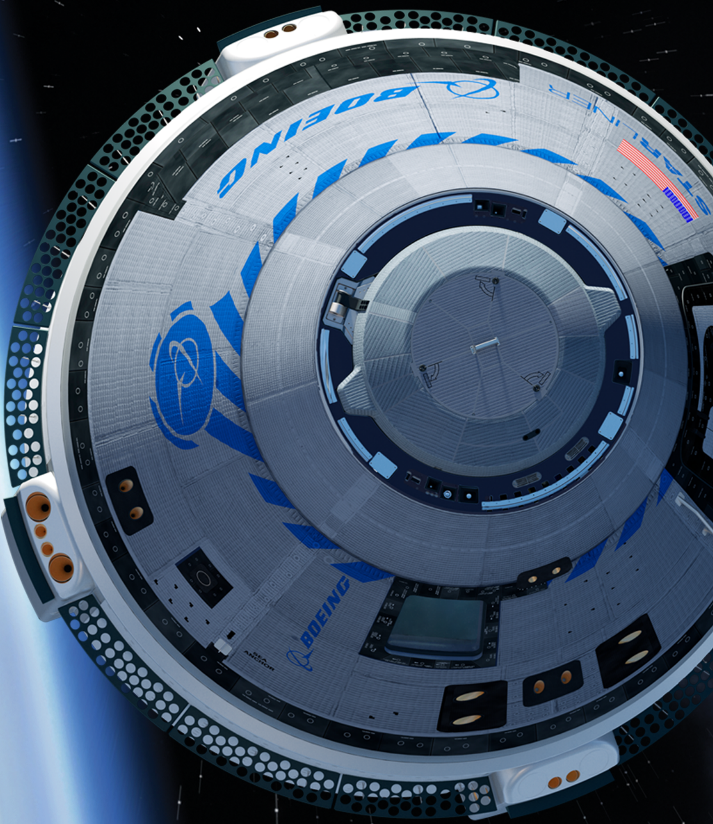
STARLINER

Orbital Flight Test-2



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Launching a New Space Age

Boeing in Space

Boeing is designing and building the future of space exploration. With experience gained from supporting every major U.S. endeavor to space, Boeing is focused on the future and proud to be part of all of NASA's human space exploration efforts. Boeing is developing the CST-100 Starliner spacecraft to ensure NASA and the United States have redundant crew launch capabilities, enabling critical research on the International Space Station (ISS) laboratory and testbed, building heavy-lift propulsion to deep space with the Space Launch System (SLS) rocket, and delivering orbital satellites and deep-space exploratory missions with the United Launch Alliance (ULA) joint venture between Boeing and Lockheed Martin.

Boeing is designing, building, testing and flying the CST-100 Starliner under a contract with NASA's Commercial Crew Program for the safe, reliable and sustainable transportation of astronauts to and from the International Space Station. In 2020, the team made significant progress on the production of the Orbital Flight Test-2 vehicle; began the refurbishment of the reusable crew module that will conduct the Crew Flight Test; and continued working through engineering analyses, hazard analyses, software testing and deliveries, vehicle testing, team training and certification products for the spacecraft's next flight.

Boeing in Space

As NASA's lead industry partner for the International Space Station (ISS), Boeing will continue to support the orbiting laboratory through September 2024 under a $916 million contract extension awarded in July 2020. In November, ISS marked its 20th year of human habitation, science and technology research that improves life on Earth while enabling future deep-space exploration and additional commercial opportunities. Sustainment work in 2020 included installation of a new set of Boeing-built lithium-ion batteries, and in 2021 the first set of new solar arrays were installed. These and other upgrades improve the station's operating efficiency and technical capabilities in its third decade.

In 2020, the Boeing-built NASA Space Launch System (SLS) core stage for the Artemis I lunar mission was completed and delivered to the agency's Stennis Space Center in Mississippi, where it completed a series of verification tests known as Green Run in 2021. That rocket stage is now being integrated with the other elements of the SLS at the Kennedy Space Center in Florida ahead of launch. Meanwhile, all the main core stage structures for Artemis II, the first mission with astronauts, have been built and are being outfitted with components, while technicians weld the core stage structures for the Artemis III mission that will land the first woman and first person of color on the lunar surface. The company also completed a NASA Critical Design Review for the Exploration Upper Stage that will replace the current SLS upper stage on future deep-space missions.

Starliner Facts

PROPULSION

Crew Module

12 Reaction Control System (RCS) thrusters,
100 pound-force (lbf) each

Service Module

- 28 RCS thrusters, 85 lbf each
- 20 Orbital Maneuvering and Attitude Control (OMAC) thrusters, 1,500 lbf each
- 4 Launch Abort Engines, 40,000 lbf each

DIMENSIONS

Starliner Height: 16.5 ft (5 m) (Crew Module + Service Module)

Starliner Diameter: 15 ft (4.6 m)

ASCENT ABORT LANDING ZONE CONSIDERATIONS

- Wave height below 4 meters (13.1 ft)
- Surface wind below 27 knots (13.9 m/s)
- No thunderstorms within abort landing area
- No lightning within abort landing area

LANDING CONSTRAINTS

- Average near-surface (110 ft, 33.5 m) wind speed to not exceed 19 knots (10.3 m/s), 23 knots (11.8 m/s) in a contingency
- Peak near-surface wind speed to not exceed 23 knots
- Temperature to be no lower than 15 degrees Fahrenheit (-9.4 C)
- Cloud ceiling to be no lower than 1000 ft (305 m) with a visibility of 1 nautical mile (1.9 km)
- No precipitation, lightning or anvil clouds within 21.5 mi (35 km)

Starliner Facts

FAQ

Q. How many people can fly on Starliner?

A. Starliner is designed to fit a maximum crew of seven, but NASA missions will carry a crew of four to five.

Q. Is Starliner reusable?

A. The crew modules are designed to fly up to 10 missions. Service modules are made for each mission.

Q. How many missions will Starliner fly?

A. Boeing is currently planning to fly three test flights and six missions to the International Space Station. Future Starliner missions depend on NASA's needs for station crews and commercial demand.

Q. Are you planning to fly private astronauts?

A. Yes. We are selling the extra fifth seat on NASA missions. Potential customers include commercial and government-sponsored astronauts and even private citizens flying as tourists.

Q. How long does it take to get to the space station?

A. Most flights on operational missions will be about six to 12 hours from launch to docking, but times will vary on specific missions depending on launch and rendezvous requirements.

Q. Can Starliner fly only on an Atlas V?

A. Starliner is designed to be launch vehicle agnostic and is compatible with various current and future launch vehicles in the Atlas V's class.

Q. Where will Starliner land?

A. We have identified five landing sites in the western United States. There are two on the White Sands Missile Range in New Mexico, one on the Dugway Proving Ground in Utah, one on the Willcox Playa in Arizona and one on Edwards Air Force Base in California.

The Rocket

UNITED LAUNCH ALLIANCE ATLAS V

Propulsion

- RD-180 booster engine, 860,000 lbf
- 2 solid rocket boosters, 380,000 lbf each
- Dual RL-10 Centaur engines, 46,000 lbf

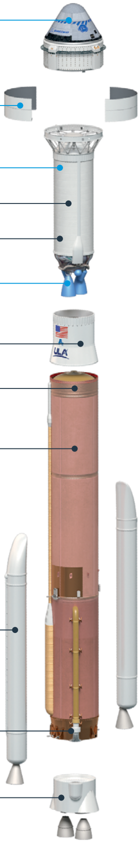
Dimensions

- Atlas V Starliner total height: 171 ft (52 m)

Launch Weather Constraints

- Wind at the launchpad exceeds 61 kilometers per hour; 38 miles per hour (33 kn)
- Upper-level conditions containing wind shear that could lead to control problems for the launch vehicle
- Cloud layer greater than 1,400 meters (4,500 ft) thick that extends into freezing temperatures
- Cumulus clouds with tops that extend into freezing temperatures within 5 to 10 miles (8.0 to 16.1 km)
- 19 kilometers (10 nmi) of the edge of a thunderstorm that is producing lightning, for 30 minutes after the last lightning is observed
- Field mill instrument readings within 9.3 kilometers (5 nmi) of the launch pad or the flight path exceeds plus or minus 1,500 volts per meter, for 15 minutes after they occur
- Thunderstorm anvil is within 19 kilometers (10 nmi) of the flight path
- Thunderstorm debris cloud is within 5.6 kilometers (3 nmi) or fly through a debris cloud for three hours
- Launch prohibition through disturbed weather that has clouds that extend into freezing temperatures and contain moderate or greater precipitation, or launch within 9.3 kilometers (5 nmi) of disturbed weather adjacent to the flight path
- Launch prohibition through cumulus clouds formed as the result of or directly attached to a smoke plume
- Starliner unique precipitation restriction, No-Go if precipitation is within plus or minus 2 nautical miles of the flight path

The Rocket


CST-100 Starliner
Launch Vehicle Stage Adapter and 70-inch Skirt
Emergency Detection System and Software
Centaur Forward Adapter
Common Centaur
Dual RL10A-4-2 Centaur Engine
Centaur Aft Stub Adapter
400 Series Interstage Adapter
Atlas V Booster
Solid Rocket Booster (2)
Aft Transition Structure and Heat Shield
RD-180 Engine
Legend: Heritage New Systems

Starliner's Story

Development

Boeing and its heritage companies have been a part of every U.S. human spaceflight program. Continuing to support NASA's human spaceflight efforts is a priority for the company, and providing reliable, regular and safe crew transport services to the International Space Station is our next step.

In 2014, NASA chose Boeing as one of two companies that will fly the first crews to International Space Station as a part of NASA's Commercial Crew Program. While the company has a long history of spacecraft development and manufacturing, Starliner is the first time Boeing has been tasked with operating the entire mission, from astronaut training to launch, on-orbit operations, landing, recovery and refurbishment.

Exterior of the C3PF at NASA's Kennedy Space Center

Boeing's program is housed in what had been the space shuttle Orbiter Processing Facility 3 at NASA's Kennedy Space Center in Florida. Now known as the Commercial Crew and Cargo Processing Facility (C3PF), the renovated building is a full-fledged spacecraft factory where Boeing assembles and processes Starliner's crew and service modules.

The first pieces of hardware to roll out of the C3PF were mainly for test purposes, but a secondary goal was to refine manufacturing techniques. Meanwhile, Boeing teams across the country launched into component testing and manufacturing, and suppliers spread across 38 states began manufacturing flight hardware.

Once the first test articles had rolled out, attention turned toward the flight test hardware. Spacecraft 1 was used for testing the launch abort system during the program's Pad Abort Test in New Mexico. Spacecraft 2 went to Boeing's facility in El Segundo, California, for the Environmental Qualification Test campaign. It's now being prepared to fly OFT-2. Spacecraft 3 was the first to fly to space on OFT-1, and will fly the first crew.

Land Landing Qualification Test campaign at NASA's Langley Research Center

While Starliner manufacturing continued in Florida, integrated test campaigns and operational training ramped up around the country. Mission control teams in Houston worked with the software team to develop and refine how Starliner flies in orbit and autonomously docks to the space station. Recovery teams practiced the complex task of recovering a vehicle from the desert — which has never been done before with an American orbital crew capsule. Meanwhile, test programs continued to prove Starliner would not be able to fly just one mission safely; it would be able to reliably fly over and over again.

Members of the Starliner team pose in front of a crew module.

Taking Flight

ORBITAL FLIGHT TEST-1

Starliner's first mission to orbit, called Orbital Flight Test-1 (OFT-1), launched at 6:36 a.m. EST Dec. 20, 2019, atop a United Launch Alliance Atlas V rocket from Cape Canaveral Air Force Station in Florida. Shortly after separation from the Atlas V rocket, an internal mission timer anomaly caused the Starliner to perform a sequence of maneuvers at the incorrect time and miss its orbital insertion burn. Quick intervention from mission controllers placed the spacecraft in a lower, but stable, orbit. After assessing all possible options, a joint NASA-Boeing team decided to forgo a rendezvous and docking attempt with the International Space Station and focused on setting up for an early return landing opportunity while completing as many mission objectives as possible.

Launch of OFT-1

Even though the mission was abbreviated and rendezvous and docking mission objectives were not met, the Starliner demonstrated nominal or better-than-nominal performance during launch, orbital flight, reentry and landing operations. The mission validated many key subsystems, including the

launch vehicle, power, propulsion, environmental control and life support, thermal protection, mechanisms, separation events and landing sequence.

During the uncrewed flight test, the spacecraft orbited the Earth 33 times and covered a total distance of 854,367 miles (1.4 million km). Starliner made history at 5:58 a.m. MST Dec. 22, 2019, with a bull's-eye landing at the U.S. Army's White Sands Missile Range in New Mexico, becoming the first American-made orbital crew capsule to land on U.S. soil.

Boeing worked hand in hand with NASA and an independent review team to complete rigorous post-test flight reviews, including sweeping assessments of Starliner's flight software and improvements to its communications system. The lessons learned from OFT-1 have been shared across the industry for the benefit and safety of everyone in human spaceflight. At no cost to the taxpayer, Boeing decided to fly another uncrewed mission to demonstrate the quality of the Starliner system and evaluate the performance of a second reusable spacecraft.

OFT-1 lands at the White Sands Missile Range in New Mexico

ORBITAL FLIGHT TEST-2

Boeing's Orbital Flight Test-2 (OFT-2) mission is the second orbital flight for the Starliner program and the first for the second crew module in the Starliner fleet. It will also be the Starliner's second attempt at reaching the International Space Station, prior to proceeding with the tremendous responsibility and privilege of flying astronauts.

The uncrewed test will fly a full mission profile, testing end-to-end capabilities of the Starliner system from pre-launch to docking and undocking to landing and recovery.

The spacecraft will execute a number of demonstrations on the way to the space station to demonstrate Starliner's ability to hold docking attitude, receive commands from the space station crew, and command holds and retreats during final approach.

While docked, Starliner will undergo a number of checkouts, including charging batteries, transferring files through the station for downlink, opening and closing the hatch, establishing joint ventilation with the station and transferring cargo.

The flight test will provide valuable data toward NASA certifying Boeing's crew transportation system for carrying astronauts to and from the space station.

CREWED FLIGHTS

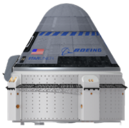
NASA astronauts Barry “Butch” Wilmore, Nicole Mann and Mike Fincke will be the first people to fly in Starliner on the Crew Flight Test (CFT). They continue to train for their mission at NASA’s Johnson Space Center and Boeing’s facilities in Houston. Integrated crew testing with the Starliner spacecraft at Kennedy Space Center in Florida is ongoing, along with comprehensive mission operations simulations with flight control teams from Boeing, NASA and ULA.

NASA astronauts Sunita “Suni” Williams, Josh Cassada and Jeanette Epps will fly Starliner’s first operational mission, called Starliner-1, along with one additional crew member yet to be named.

Boeing astronaut Chris Ferguson continues to lead Starliner’s mission integration and operations teams while overseeing Boeing’s crew systems and training services on the ground.

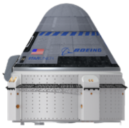
STARLINER FLEET

Boeing built three crew modules for flight tests and operational missions. Known originally as Spacecraft 1, 2 and 3, respectively, only Spacecraft 2 and 3 will fly in space. New service modules are built for each flight.



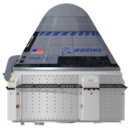
SPACECRAFT 1

Pad Abort Test (PAT)



SPACECRAFT 2

To be named after first orbital flight — Environmental Qualification Testing (EQT), OFT-2, Starliner-1



SPACECRAFT 3

Named “Calypso” by NASA astronaut Suni Williams — OFT-1, CFT, Starliner-2

Launch and Ascent

The ascent phase of the mission starts at T-0 after ignition of the Atlas V's RD-180 main engine and two solid rocket boosters. As the Atlas V continues to climb, it works its way through each launch milestone, including Max Q, solid booster jettison, booster stage separation and Centaur ignition. Just before 15 minutes after liftoff, the Centaur upper stage separates from Starliner, sending the capsule on its way to the space station. But the ascent profile isn't complete until about 31 minutes after launch, when Starliner fires four of its orbital maneuvering and attitude control thrusters to conduct the orbital insertion maneuver.

Rendering of Atlas V Starliner on LC-41

ASCENT

01 L-6:00 HOURS
Atlas V Fueling

02 L-1:30 HOURS
Hatch Close

03 L-1:00 HOURS
Cabin Leak Checks

04 L-11:00 MINUTES
Crew Access Arm Retraction

05 T-0
Liftoff

06 T+0:45 SECONDS
Maximum Dynamic Pressure (Max Q)

07 T+2:21 MINUTES
Solid Rocket Booster (SRB) Jettison

08 T+4:29 MINUTES
Booster Engine Cutoff (BECO) + Separation

09 T+4:41 MINUTES
Ascent Cover Jettison

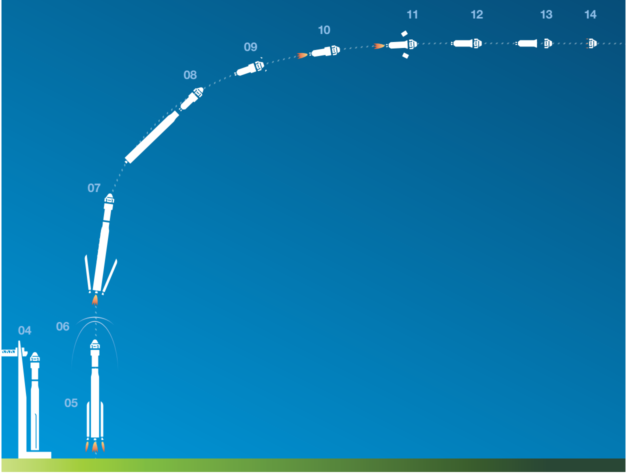
10 T+4:45 MINUTES
Centaur Ignition

11 T+5:05 MINUTES
Aeroskirt Jettison

12 T+11:54 MINUTES
Main Engine Cutoff (MECO)

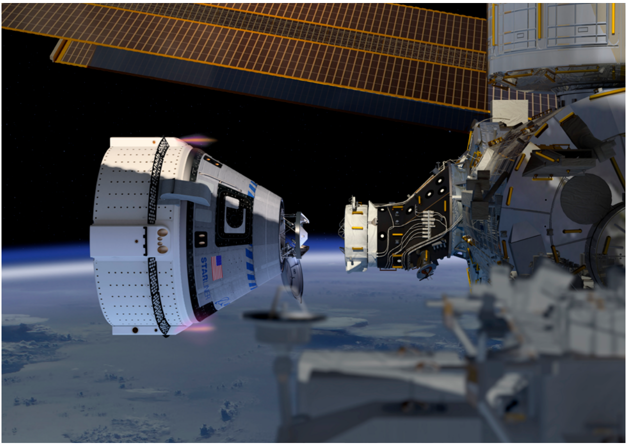
13 T+14:54 MINUTES
Spacecraft Separation

14 T+31:00 MINUTES
Orbital Insertion



Rendezvous and Docking

Once in a stable orbit on course for the International Space Station, Starliner begins its rendezvous procedures. Unique to the Orbital Flight Test mission, Starliner will conduct a series of demonstration burns a few hours after launch to prove the spacecraft can maneuver itself safely in space. As Starliner closes on the station, the vehicle's star tracker cameras will first see the orbiting lab as a distant, but bright, point of light moving in front of a background of fixed stars. Over the next few hours, Starliner will slowly move itself closer to the station and then pause before entering the 200-meter "keep out sphere" until station flight controllers clear it to enter. Starliner then begins the docking process, pausing once more 10 meters away from a Boeing-built International Docking Adapter and then continuing to final approach and docking.



Rendering of Starliner docking to the ISS' Node 2 Forward port

DOCKING

01 Height Adjustment + Plane Change

02 Height Adjustment + Plane Change

03 Coelliptic + Plane Change

04 Terminal Phase Initiation Burn + Approach Ellipsoid Entry

05 Inbound Flyaround 1

06 Inbound Flyaround 2

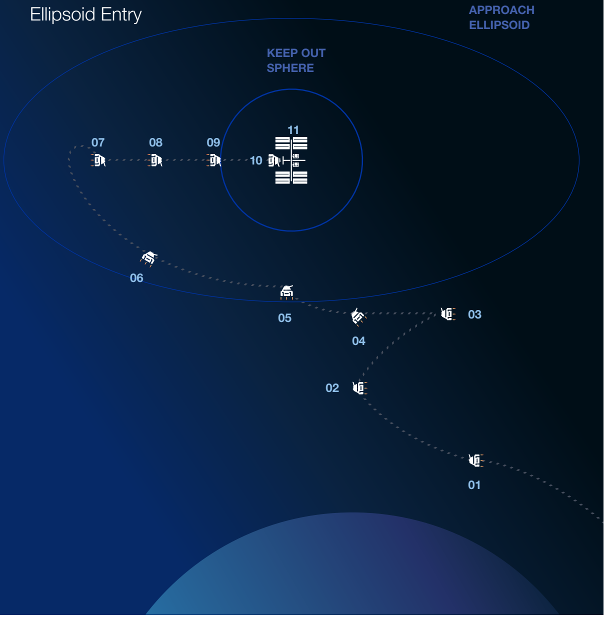
07 Corridor Approach

08 250-Meter Hold + Resume Approach

09 200-Meter Retreat + Keep Out Sphere Entry

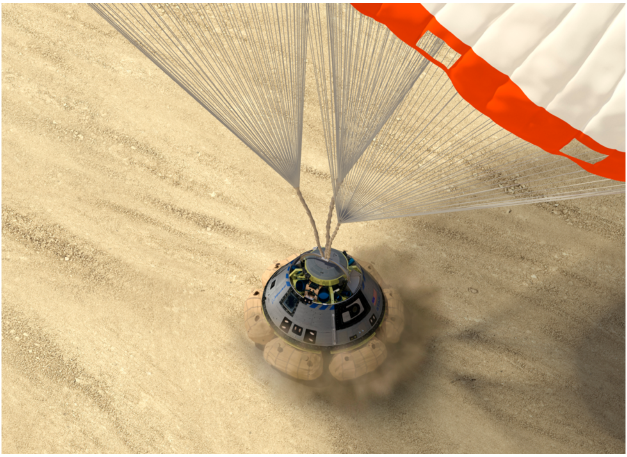
10 10-Meter Hold + Final Approach

11 Docking



Undocking, Reentry and Landing

Once Starliner is ready and cleared to leave the International Space Station, the undocking process begins and the spacecraft slowly backs away from the station. After a flyaround maneuver, Starliner positions itself for the deorbit burn. A short time later, when Starliner is in the right position over the Pacific Ocean, the service module conducts the deorbit burn, slowing down Starliner from orbital speeds, and then the service module detaches. The crew module begins its descent through the atmosphere, facing reentry heat of 3,000 degrees Fahrenheit (1,650 degrees Celsius). The parachute sequence begins around 30,000 feet (9 km) above the ground, when Starliner jettisons the forward heat shield that protects the parachutes during reentry. Two drogue parachutes begin slowing Starliner down, then detach. The three main parachutes are then deployed and inflated, and about 3,000 feet (0.9 km) off the ground, the airbags inflate. On touchdown, those airbags absorb the initial forces of landing, cushioning the crew for a soft, safe return to Earth.



Rendering of touchdown

UNDOCKING

01 Undocking

02 Corridor Separation

03 Outbound Flyaround

04 Departure + Entry Cover Close

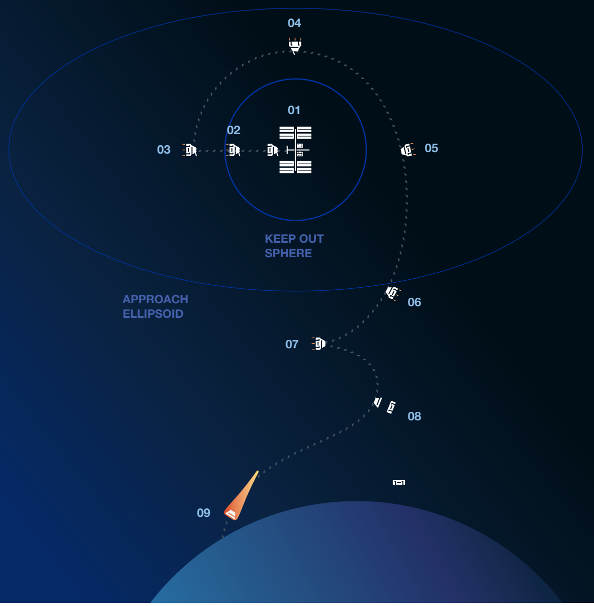
05 Departure Resume + Approach Ellipsoid Exit

06 Coelliptic + Thrust Align

07 Deorbit

08 Service Module Separation

09 Entry Interface



LANDING

01 Forward Heat Shield Jettison

02 Drogue Parachute Deployment

03 Main Parachute Deployment

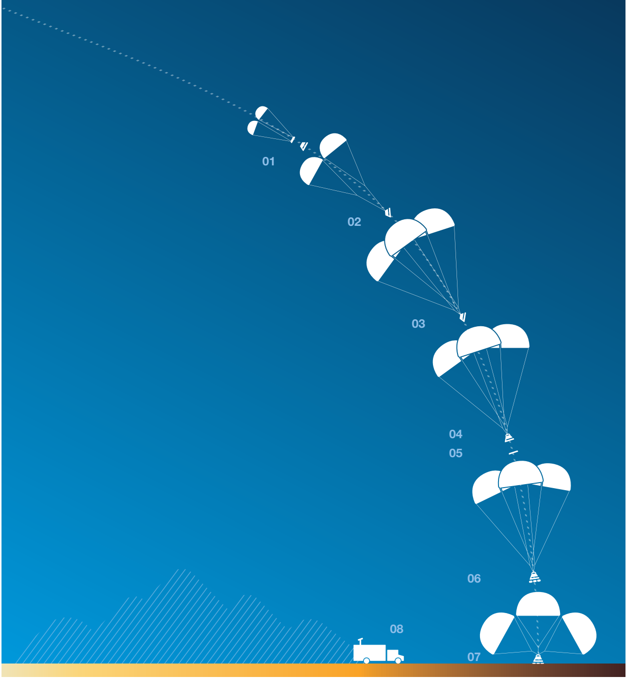
04 Rotation Handle Release

05 Base Heat Shield Jettison

06 Airbag Inflation

07 Landing

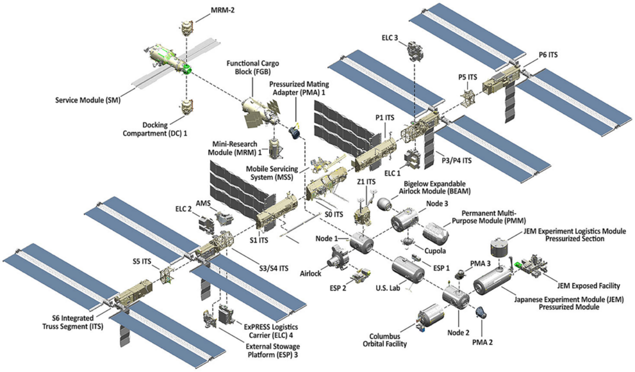
08 Recovery



The Destination

International Space Station

The International Space Station (ISS) is a permanently crewed, orbiting laboratory that enables scientific research supporting innovation on Earth and future deep-space exploration. From design to launch, 15 countries collaborated to assemble the world's only permanently crewed orbital facility, which can house a crew of six and dozens of experiments across an array of disciplines. The ISS represents a global effort to expand our knowledge while providing a technological test bed to extend our reach throughout the solar system. By far the largest spacecraft ever built, the ISS has been inhabited continuously since Nov. 1, 2000.



NASA is the principal customer for the International Space Station. The space agencies of the United States, Russia, Canada, Japan and Europe operate the ISS. Boeing was the prime contractor for ISS construction and continues to support processing of the laboratory experiment racks to facilitate experiments as well as regular capability enhancements. Some of these include a new communications system for visiting spacecraft, lithium-ion batteries to collect power from the solar arrays and a new NASA docking system. In 2016, the installation of the International Docking Adapter onto the station prepared the ISS to receive Commercial Crew Program spacecraft, including the Boeing Starliner. A second International Docking Adapter was added in 2019 to provide a second docking port for next-generation spacecraft.

Astronaut Karen Nyberg prepares samples for experimentation aboard the International Space Station.

Research for Earth and Deep Space

Astronauts on the ISS work together daily with scientists on Earth to perform about 300-400 experiments every month. The microgravity lab has hosted more than 1,500 experiments involving scientists from more than 65 countries. This research is benefiting scientific knowledge across a broad spectrum of disciplines, from physiology and medicine to robotics and astrophysics. In addition, the ISS is the only facility that allows researchers to investigate the physiological and psychological effects of long-duration spaceflight in preparation for future missions to the moon and Mars.

Astronaut Ricky Arnold conducts a DNA replication experiment aboard the International Space Station as part of the Boeing-sponsored Genes in Space contest during Expedition 56.

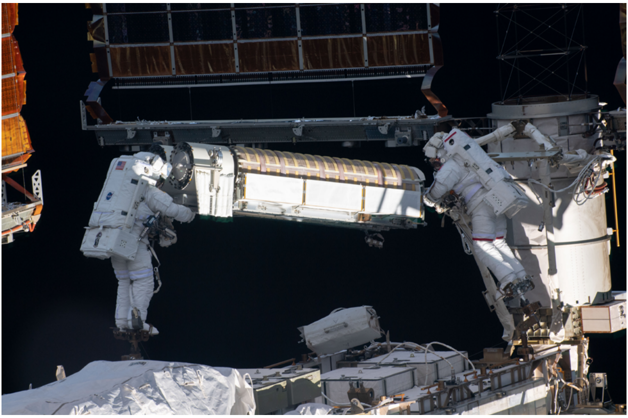
Genes in Space

The Genes in Space competition, founded by Boeing and miniPCR bio, is a science, technology, engineering and math contest that challenges students in grades seven through 12 to design DNA analysis experiments using the ISS U.S. National Laboratory. The competition's other partners are miniPCR and New England Biolabs Inc. Genes in Space winners give a presentation on their research and are invited to watch their experiments launch on ISS resupply missions. They have published scientific studies based on their results and are contributing to the knowledge base researchers are using to develop deep-space-exploration mission profiles and system requirements.

Increasing Commercial Opportunities

The unique opportunities offered by the International Space Station are being made increasingly more available to commercial, private and other organizations. More than 50 companies already conduct commercial research and development via the ISS U.S. National Laboratory. In addition, NASA has worked with 10 different companies to install more than 14 commercial facilities on the station that support research and development projects for NASA and the ISS National Lab.

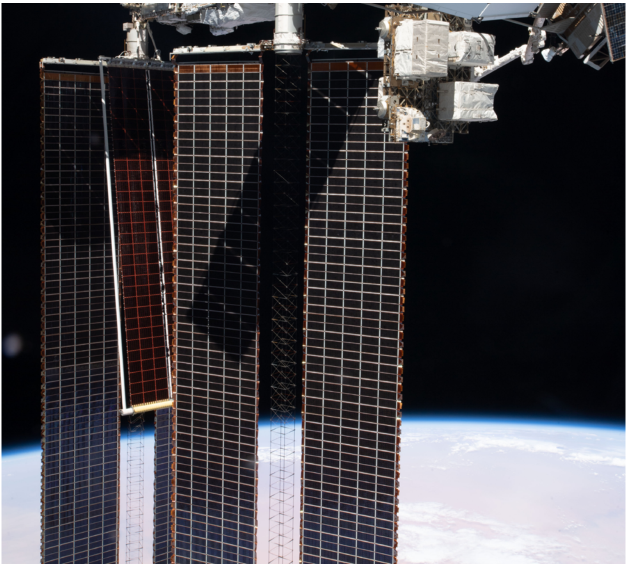
This effort is intended to broaden the scope of commercial activity on the space station beyond the ISS National Lab mandate, which is limited to research and development. A NASA directive announced in 2019 will enable commercial manufacturing and production and allow both NASA and private astronauts to conduct new commercial activities aboard the orbiting laboratory. The directive also sets prices for industry use of U.S. government resources on the space station for commercial and marketing activities.



Astronauts Shane Kimbrough and Thomas Pesquet installing the new ISS Roll-Out Solar Arrays (iROSA)

Upgrading Station

NASA and partners around the world upgrade International Space Station systems frequently to keep it at the cutting edge of its laboratory and workspace capability. One of the most extensive augmentations began with the installation of the first two new Boeing-provided solar arrays designed to boost the power-generating capacity of the station. Although they are half the size of the original arrays, the new ones produce twice as much power and are built to unroll on their own without a heavy motor. The new arrays are mounted over the existing solar "wings" of the ISS, meaning that the old ones can continue producing power. Together, the six new arrays and the originals will produce 215 kilowatts of energy for the ISS, a 20 to 30 percent boost for the laboratory. This increased capacity will allow the ISS to continue to meet research goals for years to come and offer proven infrastructure for new, commercially built modules later this decade.



The first two iROSA arrays fully deployed on station

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