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’s CST-100 Starliner is a full service system. It provides all elements needed to transport crew and cargo to and from low-Earth orbit destinations, including crew training and mission planning, spacecraft and launch vehicle assembly, integration and testing, and crew and cargo recovery. The goal is to provide safe, reliable and sustainable access to space, beginning with missions to the International Space Station and with NASA as the flagship customer. In 2014, Boeing was awarded up to $4.2 billion by NASA to build, test and fly the Starliner. The contract includes six service missions as well as an uncrewed and crewed flight test to the space station. To demonstrate its commitment to crew safety and mission success, Boeing decided to fly a second uncrewed flight test, called Orbital Flight Test-2.
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. The ISS marked its 20th year of human habitation in November 2020. It continues to set records every day in 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 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.
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)
Ascent Cover
Forward Heat Shield
Entry Cover
Parachutes
Reusable Crew Module
Landing Airbags
Base Heat Shield
Service Module
RCS and OMAC Thrusters (48)
Launch Abort Engines (4)
Solar Arrays
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 safe, reliable and sustainable 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.
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 then went into preparations for orbital flight. Spacecraft 3 was the first to fly to space on OFT, and is expected to fly the first crew on CFT.
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 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

Starliner’s first mission to orbit, called Orbital Flight Test (OFT), 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 from Cape Canaveral Space Force Station in Florida.

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 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 lands at the White Sands Missile Range in New Mexico.
ORBITAL FLIGHT TEST-2

Boeing’s Orbital Flight Test-2 (OFT-2) 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 who have either contributed to the development of Starliner or trained for flight tests and missions aboard the spacecraft, include Barry “Butch” Wilmore, Mike Fincke, Nicole Mann, Suni Williams, Dr. Jeanette Epps, Eric Boe, Robert “Bob” Behnken and Doug Hurley.

Boeing astronaut Chris Ferguson is the flight crew representative for Boeing’s Commercial Crew Program. In this role, Ferguson’s focus is on ensuring the Starliner spacecraft and training systems meet the needs of NASA’s astronauts. Ferguson also trained for the Starliner’s first crewed flight test before transitioning his commander position to a NASA astronaut in 2020. As flight crew representative, he will continue to be the eyes and ears for his astronaut friends and colleagues throughout the Starliner’s development.

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, 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.
### ASCENT

<table>
<thead>
<tr>
<th>Time</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>L-6:00 HOURS</td>
<td>Atlas V Fueling</td>
</tr>
<tr>
<td>L-1:30 HOURS</td>
<td>Hatch Close</td>
</tr>
<tr>
<td>L-1:00 HOURS</td>
<td>Cabin Leak Checks</td>
</tr>
<tr>
<td>L-11:00 MINUTES</td>
<td>Crew Access Arm Retraction</td>
</tr>
<tr>
<td>L-1:30 MINUTES</td>
<td>Maximum Dynamic Pressure (Max Q)</td>
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<tr>
<td>0:45 SECONDS</td>
<td>Solid Rocket Booster (SRB) Jettison</td>
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<tr>
<td>2:21 MINUTES</td>
<td>Booster Engine Cutoff (BECO) + Separation</td>
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<tr>
<td>4:29 MINUTES</td>
<td>Ascent Cover Jettison</td>
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<tr>
<td>4:41 MINUTES</td>
<td>Orbital Insertion</td>
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<tr>
<td>4:45 MINUTES</td>
<td>Centaur Ignition</td>
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<td>5:05 MINUTES</td>
<td>Aeroskirt Jettison</td>
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<td>11:45 MINUTES</td>
<td>Main Engine Cutoff (MECO)</td>
</tr>
<tr>
<td>14:54 MINUTES</td>
<td>Spacecraft Separation</td>
</tr>
<tr>
<td>21:00 MINUTES</td>
<td>Orbital Insertion</td>
</tr>
</tbody>
</table>

Times subject to change, based on the flight’s profile.
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.
**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 Starliner 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

LANDING
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.
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.
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.

NASA has expanded commercial opportunities on the ISS to help foster a broader market including manufacturing on orbit. Recent additions to the ISS include a commercially owned and operated airlock called Bishop. New modules from private companies are expected to add more to the ISS as early as 2024. A NASA directive announced in 2019 is enabling commercial manufacturing and production and allowing both NASA and private astronauts to conduct new commercial activities aboard the orbiting laboratory. The directive also set prices for industry use of U.S. government resources on the space station for commercial and marketing activities.
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.