National Aeronautics and Space Administration

NASA Facts

Landing the Space Shuttle Orbiter

As the processing and launch site of the nation's Space Shuttle Program, NASA's Kennedy Space Center (KSC) in Florida is making the Vision for Space Exploration a reality.

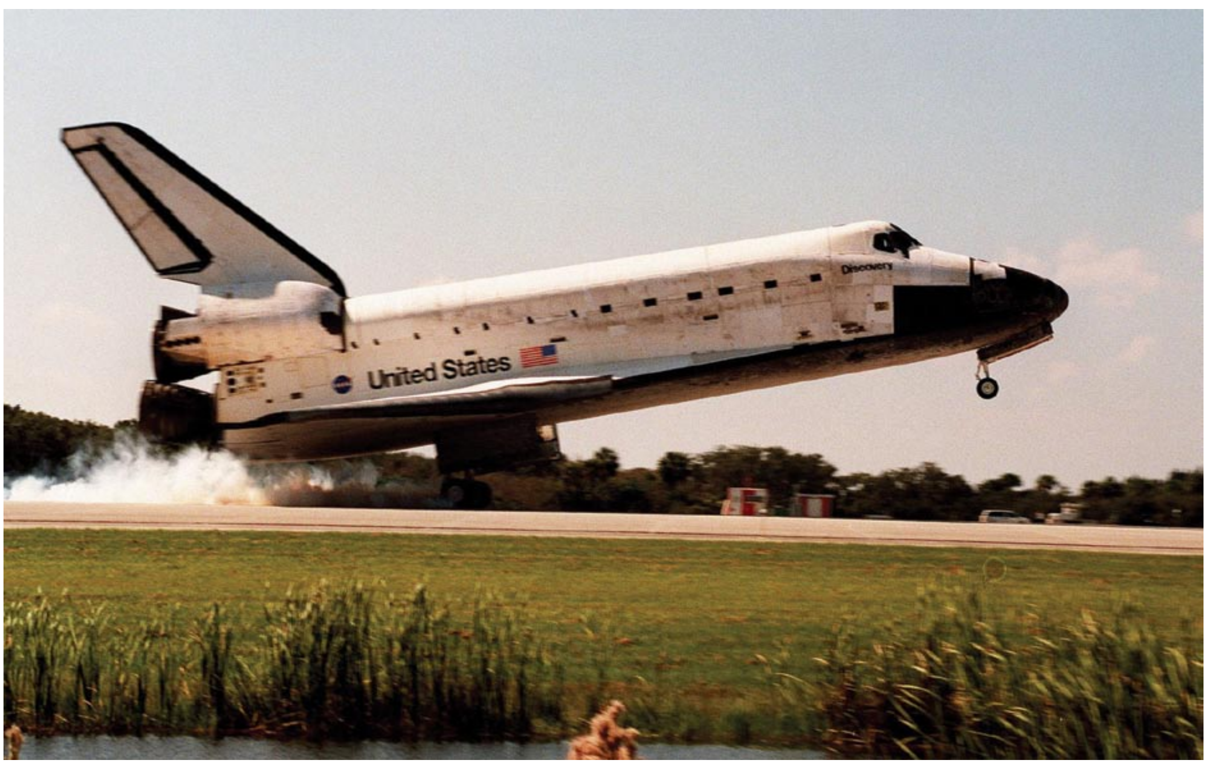
Kennedy is the primary end-of-mission landing site for the shuttle orbiter. An alternate site is Edwards Air Force Base (EAFB) in California.

The Space Shuttle Program began with landings at EAFB because the site offered more stable and predictable weather conditions and a diverse choice of concrete and spacious dry lake bed runways. But landing the orbiter at KSC's Shuttle Landing Facility is preferred because it saves about five days of processing time for its next mission.

A KSC landing also eliminates exposing the orbiter, a national resource, to the uncertainties and potential dangers of a cross-country ferry trip atop one of NASA's two modified Boeing 747 Shuttle Carrier Aircraft.

Unlike launches, for which a "go" for liftoff can be given within minutes of changing weather conditions during the launch window, a change in the landing site must be chosen up to 90 minutes prior to landing.

From 1981 through February 2003, there were 113 Shuttle missions: 61 landed at Kennedy, 49 at EAFB, and one at the Northrup Strip in New Mexico. The Space Shuttle Challenger on Mission



Orbiter Discovery approaches touch-down on runway 33 at KSC's Shuttle Landing Facility, successfully completing mission STS-95 in 1998.

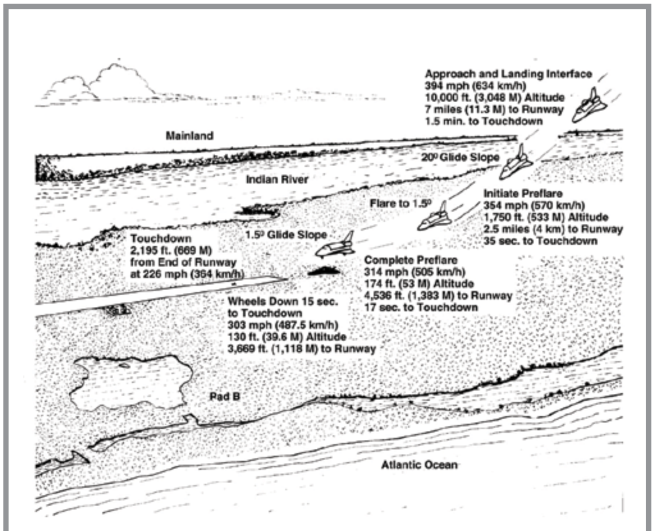
STS 51-L in 1986 was destroyed in an accident shortly after liftoff. The Shuttle Columbia was destroyed over Texas in 2003 as it was making its landing approach.

Landing History

The initial six shuttle missions from April 1981 through April 1983 were planned to end at EAFB so the crews and support teams could gain experience in landings. For STS-3, the scheduled California landing had to be switched to the Northrup Strip at White Sands, N.M., because of wet conditions at Edwards. STS-7 in June 1983 was the first end-of-mission landing scheduled for KSC. The orbiter Challenger on that flight landed instead at EAFB, two orbits later than planned, because of marginal weather conditions at KSC.

The first landing at KSC was Mission 41-B on Feb. 11, 1984. KSC was the landing site for four of the next six missions. Extensive brake damage and a blown tire at the conclusion of the 51-D mission in April 1985 prompted officials to postpone further KSC landings until nose wheel steering and improved brakes were installed in the orbiters. Landings were scheduled to resume at KSC with Mission 61-C in January 1986, but that flight also was diverted to EAFB due to bad weather in Florida. The Space Shuttle Challenger accident less than two weeks later resulted in renewed concerns about safety, weather and runway conditions. KSC landings again were put on hold.

Planned end-of-mission landings at KSC resumed in 1991 after safety modifications and improvements were begun on the orbiters and KSC's runway. The orbiters were outfitted with upgraded main landing gear, carbon brakes,



The figures above for a KSC landing are approximate. They will vary for each mission, depending on several factors. In this case, the returning orbiter weighs less than 220,000 pounds (99,792 kilograms) and the glide-slope approach is 20 degrees.

additional nose wheel steering capability and improved tires. Drag chutes also were installed on the four orbiters to help reduce rollout speed after touchdown. Endeavour, delivered to KSC in 1991, was the first to have this modification.

The original lateral cross grooves that were cut on the KSC runway to help prevent hydroplaning were ground down on the first 3,500 feet (1,067 meters) at both ends of the landing strip to reduce the friction and abrasion levels on the orbiter's tires at the time of touchdown. In 1994, the entire runway surface was abraded to a smoother texture to reduce tire wear even further. Other enhancements or upgrades implemented were resurfacing the 1,000-foot (305-meter) overruns and rebuilding, strengthening and paving the 50-foot (15-meter) runway shoulders, and replacing runway edge lights.

Returning From Space

A returning orbiter's glide to Kennedy Space Center begins on the opposite side of the planet. The deorbit burn that will bring the orbiter back to Earth occurs about an hour before landing.

Approximately 30 minutes before touchdown, the orbiter begins entering the atmosphere at an altitude of about 400,000 feet (121,920 meters). At approximately 45,000 feet (13,716 meters), the orbiter starts maneuvers that enable it to intercept the landing approach corridor at the desired altitude and velocity. As the orbiter nears the landing site, the commander takes manual control and steers the vehicle into the nearest of two Heading Alignment Cones (HACs) to line up the spacecraft with the center line of the runway.

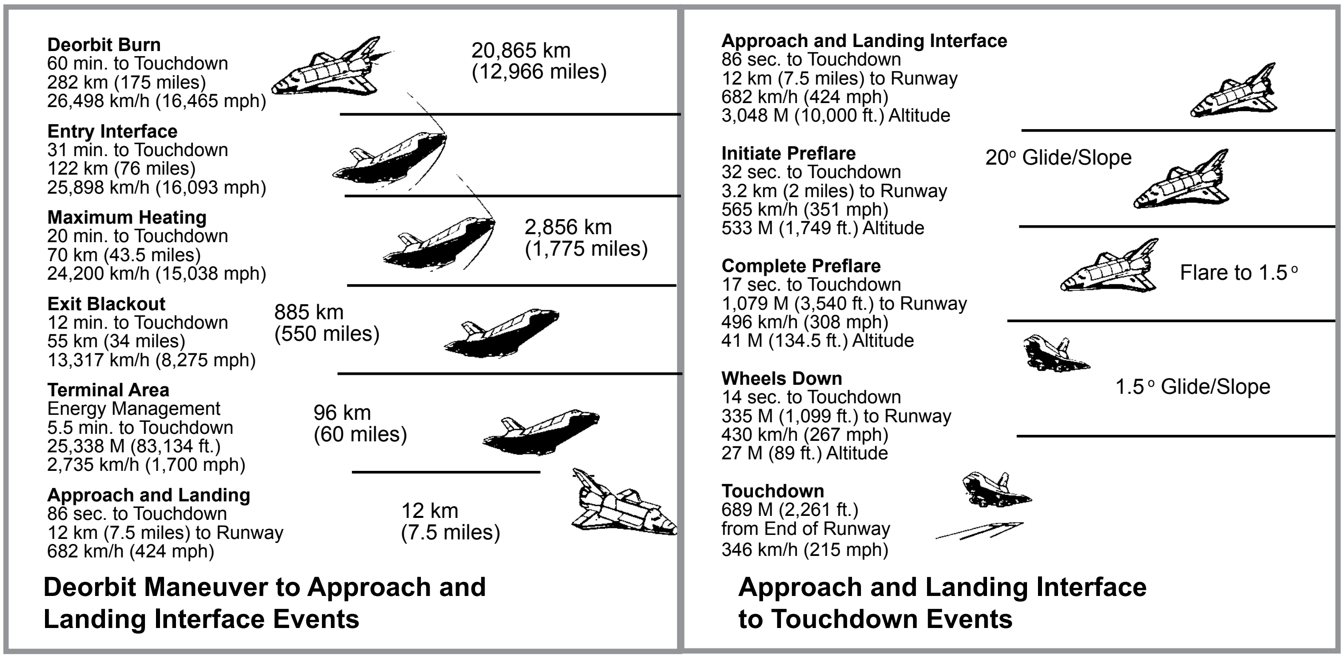
Depending on the mission and its orbital parameters, the path the vehicle takes as it enters the atmosphere and lands can vary greatly.

The ground track is determined by the inclination of launch. Generally, re-entry will follow one of two general patterns, either from a low-inclination or a high-inclination orbit.

For example, space shuttles carrying most communication satellites usually have a low-inclination orbit – a launch azimuth of about 90 degrees – which places the vehicle in an orbit that has a 28.5-degree inclination to the equator.

That means that as it circles the Earth, the orbiter's ground track ascends to approximately 28.5 degrees above the equator (28.5 degrees north latitude) and 28.5 degrees below the equator (28.5 degrees south latitude) – a relatively narrow band of the globe.

Typically, re-entry from this orbit begins with a deorbit burn over the Indian Ocean off the western coast of Australia. Usually, the flight path of the orbiter then



These two charts represent an example of the sequence of events or flight milestones from the deorbit maneuver of the orbiter through touchdown. The times, distances and speeds will vary for different missions, according to a variety of factors such as mission inclination, trajectory and glide slope.

proceeds across the Pacific Ocean to the Baja Peninsula, across Mexico and southern Texas, out over the Gulf and on to the west coast of Florida.

Depending on the mission, the orbiter passes over Florida's west coast somewhere between Sarasota and Yankeetown and proceeds across the central part of the state, with its telltale twin sonic booms heralding its arrival.

The final approach to the KSC landing strip takes the orbiter over the Titusville-Mims area, and out over the Atlantic Ocean, where it circles for a landing approach from either the southeast (Runway 33) or the northwest (Runway 15), depending largely on wind direction and speed.

Shuttles launched into high-inclination orbits generally follow the second major re-entry pattern. Usually, these missions fly in an orbit with a 57-degree inclination to the equator. The ground track of these orbits covers a much broader section of the globe, as the orbiter reaches as far north as 57 degrees above the equator and 57 degrees below the equator. This type of orbit is well-suited to Earth-observation missions.

The entry ground track of high-inclination orbits will vary. Depending on where re-entry occurs, landing on a descending portion of an orbit could take the orbiter across Canada and the eastern United States; or, from an ascending portion of an orbit, above the Southern Pacific and across South America.

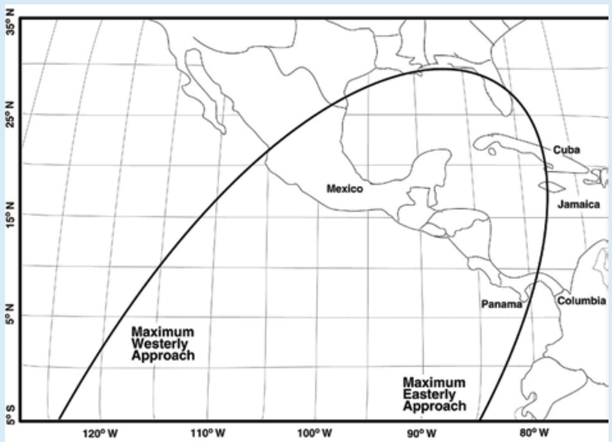
On these re-entries, the orbiter may parallel the northeast Florida coast after cutting across Georgia, or it will fly over the Florida Everglades and up the southeast coast of the state.

The sonic boom as the orbiter slices through the atmosphere at velocities greater than the speed of sound may be heard across the width of Florida, depending on the flight path.

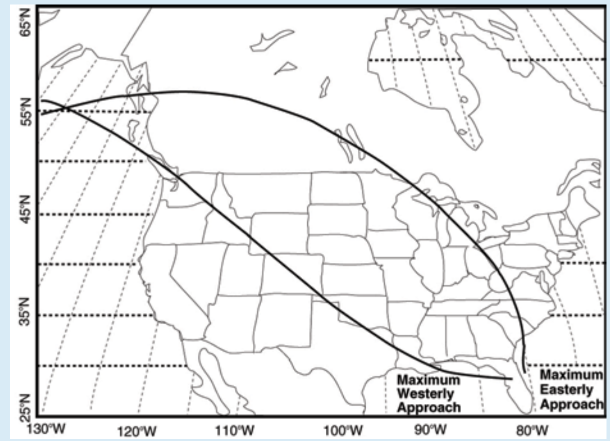
The sonic boom is really two distinct claps that occur a fraction of a second apart, and are audible to the human ear. It is the noise produced by an aircraft flying at supersonic speeds. The vehicle, in effect, compresses the air in front of the nose and the wing, creating shock waves that spread away from the aircraft.

Although the boom may rattle some windows, it has little or no effect on humans, wildlife or property. At peak intensity, the boom is about as loud as an automobile backfiring on the next block or the clap of thunder from a lightning strike about a half mile (0.8 kilometer) away. The pressure wave of the boom at its maximum intensity is equivalent to about half the force exerted on a person's ears when the door of a full-sized car is slammed with the windows shut.

The boom should be barely audible as the orbiter crosses the western part of the state. It will get louder as the orbiter drops in altitude, although for much of Central Florida it may be at a level that goes unnoticed by persons indoors.



This map shows the ascending portion of a high-inclination orbit of 51.6 degrees with the easternmost and westernmost ground tracks for approach to KSC.



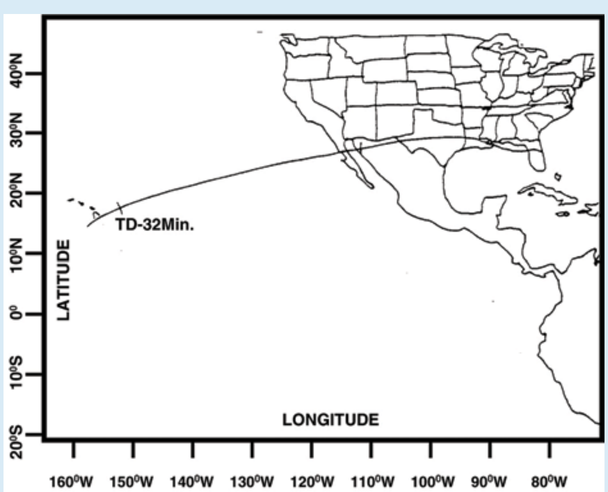
This map shows the descending portion of a high-inclination orbit of 51.6 degrees with the easternmost and westernmost ground tracks for approach to KSC.

The orbiter reaches subsonic speeds as it flies over the Indian River before circling to the north or to the south for a final landing approach.

Shuttle Landing Facility

KSC's Shuttle Landing Facility (SLF), first opened for flights in 1976, was specially designed for returning space shuttle orbiters. The SLF is located approximately three miles (4.8 kilometers) northwest of the huge Vehicle Assembly Building, with the launch pads only an additional three to four miles (4.8 to 6.4 kilometers) to the east. The runway is longer and wider than those found in most commercial airports, yet comparable in size to runways designed for research and development facilities.

The paved runway is 15,000 feet (4,572 meters) long, with a 1,000-foot (304.8-meter) overrun on each end. The width is about the length of a football field, 300 feet (91.4 meters), with 50-foot (15.2-meter) asphalt shoulders on each side. The KSC concrete runway is 16 inches (40.6 centimeters) thick in the center, and 15 inches (38.1 centimeters) thick on the sides. The landing strip is not perfectly flat; it has a slope of 24 inches (61 centimeters) from the center line to the edge to facilitate drainage.



This map shows the ground track of a typical low-inclination orbit.

The Shuttle Landing Facility includes a 550-foot by 490-foot (167.6-meter by 149.3-meter) parking apron, or ramp, on the southeastern end of the runway. On the northeast corner of the ramp is the mate/demate device (MDD). The MDD is 150 feet (45.7 meters) long, 93 feet (28.3 meters) wide and 105 feet (32 meters) high. It can lift up to 230,000 pounds (104,328 kilograms).

Although a single landing strip, it is considered two runways, depending on the approach: from either the northwest on Runway 15 or from the southeast on Runway 33.

In comparison, Orlando International Airport's longest runway is 12,004 feet (3,659 meters) long and 200 feet (61 meters) wide. The John F. Kennedy International Airport in New York has a runway nearly as long, 14,572 feet (4,441.5 meters), but much narrower at 150 feet (45.7 meters). O'Hare International Airport in Chicago has a runway 13,000 feet (3,962.4 meters) long and 200 feet (61 meters) wide; and Miami International Airport's longest runway is 13,002 feet (3,963 meters) long by 150 feet (45.7 meters) wide.

In contrast, the prime alternate orbiter landing site, Edwards Air Force Base in California, has several dry lake bed runways and one hard surface runway on which an orbiter can land. The longest strip, part of the 44-square-mile (114-square-kilometer) Rogers Dry Lake, is 7.5 statute miles (12.1 kilometers) long. Concrete runways are generally preferred for night landings so dust from the lake bed does not obscure the lighting.

About the size of a DC-9 jetliner, a space shuttle orbiter does not require such a large runway for landing. However, EAFB offers an extra safety margin because of its choice and size of landing strips.

The orbiter differs in at least one major aspect from conventional aircraft: it is unpowered during re-entry and landing so its high-speed glide must be perfectly executed the first time — there is no go-around capability. The orbiter touchdown speed is 213 to 226 miles (343 to 364 kilometers) per hour.

In the case of a landing orbiter, Foreign Object Debris (FOD) becomes a potential hazard. Any material that does not belong on or over the surface of the runway environment is considered FOD. Workers check the runway for FOD up to about 15 minutes prior to landing.

Birds also are a hazard to the orbiter, as well as to other aircraft. This "airborne FOD" could damage the orbiter's delicate outer skin of thermal protection system materials. Birds are of special concern at KSC because most of the Center is a national wildlife refuge that provides a home to more than 330 native and migratory species of birds. SLF employees use special pyrotechnic and noise-making devices, as well as selective grass cutting, to discourage birds around the runway.

When an orbiter lands anywhere other than KSC, it must be ferried back to Kennedy Space Center riding piggyback-style atop the Shuttle Carrier Aircraft, landing at the SLF. The mate/demate device at the SLF enables the orbiter to be lifted off the Shuttle Carrier Aircraft and placed on the runway.

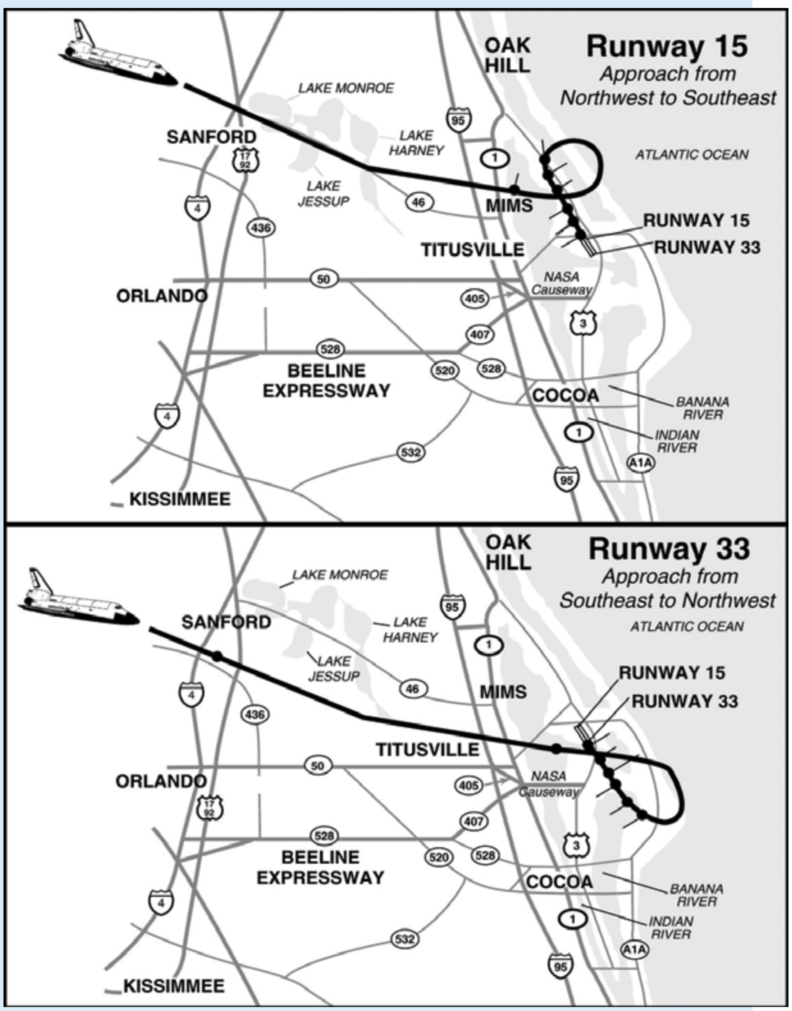
Whether an orbiter lands here on its own or atop the Shuttle Carrier Aircraft, it is then towed by a diesel-powered tractor to processing facilities via a two-mile (3.2-kilometer) tow-way from the Shuttle Landing Facility.

Adjacent to the MDD is the Landing Aids Control Building, which houses equipment and the personnel who operate the Shuttle Landing Facility on a daily basis. Other aircraft that use the SLF include the astronauts' T-38 trainers; the Shuttle Training Aircraft – NASA's flying orbiter simulators – military and civilian cargo, and helicopters.

South of the midfield point east of the runway are the control tower, the orbiter recovery convoy staging area for the recovery team, and a fire station. The control tower provides positive control of all local flights and ground traffic, including support aircraft for Shuttle launches and landings; Department of Defense and NASA helicopters for security, medical evacuation and rescue; and NASA weather assessment aircraft.

After a landing, the orbiter recovery convoy staging area can hold 20 to 30 specially designed vehicles or units to safe the orbiter, assist in crew departure and tow the vehicle to processing facilities. Responsibility for the orbiter is usually handed from Johnson Space Center in Houston to Kennedy Space Center after the orbiter's cool-down and crew departure, usually within an hour after touchdown.

Press and guest viewing areas are on a mound east of the convoy area. The entrance is from Sharkey Road.



Approach and Landing Runways 15 and 33 at the Shuttle Landing Facility

Landing Aids

An array of visual aids as well as sophisticated guidance equipment at the Shuttle Landing Facility help guide the orbiter to a safe landing.

The *Tactical Air Navigation (TACAN)* system on the ground provides range and bearing measurements to the orbiter when the vehicle is at an altitude of up to 145,000 feet (44,196 meters).

The *Microwave Scanning Beam Landing System (MSBLS)* provides more precise guidance signals on slant range, azimuth and elevation when the orbiter gets closer — up to 18,000 to 20,000 feet (5,486 to 6,096 meters). Both TACAN and MSBLS are automatic systems that update the orbiter's onboard navigation systems.

The MSBLS also provides an autoland capability that can electronically acquire and guide the orbiter to a completely "hands off" landing. So far, shuttle mission commanders have taken control of the orbiter for all final approach and landing maneuvers during subsonic flight, usually about 22 miles (35 kilometers) from the touchdown point.

The initial landing approach at a glide slope of 20 degrees is more than six times steeper than the 3-degree slope of a typical commercial jet airliner as it approaches landing. Two series of lights help pilots determine the correct approach.

The *Precision Approach Path Indicator (PAPI)* lights are an electronic visual system that shows pilots if they are on the correct outer glide slope. PAPI lights are used at airports all over the world, but these have been modified for the unique configuration of the orbiter. A set of PAPI lights are at 7,500 feet (2,286 meters) and another at 6,500 feet (1,981 meters) to delineate an outer glide slope of between 18 and 20 degrees.

The *Ball-Bar Light System* is a visual reference to provide inner glide slope information. The bar lights are 24 red lamps in horizontal sets of four each. They are 2,200 feet (671 meters) from the runway threshold, and 300 feet (91 meters) from the first nominal touchdown point. Five hundred feet (152 meters) closer to the runway threshold are three white lights — the ball — at a higher elevation.

If the orbiter is above the glide slope of 1.5 degrees, the white PAPI lights will appear to be below the bar of red lights. If the vehicle is below the glide slope, the white lights will appear to be above the red lights. If the red and white lights are superimposed, the orbiter is on the correct glide slope.

Lighted distance markers show the crew the distance remaining to the end of the runway during landing and rollout. Just before touchdown, a flare or a pull-up maneuver brings the orbiter into its final landing configuration. Touchdown nominally is 2,500 to 2,700 feet (762 to 823 meters) beyond the runway threshold.

For night lights, the SLF has 16 powerful xenon lights, each of which produces up to 1 billion candlepower (1 billion candela). Flatbed trailers hold eight lights, in two groups of four, at each end of the runway. To avoid blinding the crew, workers only turn on the lights at the end of the runway that will be behind the orbiter at landing.

Orbiter Drag Chutes

After touchdown, the orbiter begins its rollout with the two main landing gears in contact with the runway. Rudder control is used primarily to maintain alignment. As the speed decreases to about 185 knots or 185 nautical miles per hour (343 kilometers per hour), the nose of the orbiter begins to pitch down. At this time, the red, white and blue 40-foot-diameter (12.2-meter-diameter) drag parachute is extended with the aid of a mortar-deployed, 9-foot-diameter (2.7-meter-diameter) pilot chute.

At around 160 knots or 160 nautical miles per hour (296 kilometers per hour), the nose gear tires make contact with the runway, and the chute disreefs and becomes fully inflated, thus creating a drag force to rapidly slow down the orbiter while providing a safety margin during the rollout.

Once the nose gear is down, steering with the nose wheel becomes the primary control system for alignment down the rest of the runway. At approximately 30 knots or 30 nautical miles per hour (56 kilometers per hour), the chute has completed its function and disconnects from the orbiter, which rolls to a stop using its brakes.

Weather Constraints

Weather plays a major role in determining whether an end-of-mission landing is at KSC or at Edwards Air Force Base, or is postponed until a later orbit.

The weather constraints below apply to KSC:

- At the time of the deorbit burn go/no-go decision, which occurs approximately 90 minutes prior to landing, observed cloud cover below 8,000 feet (2438 meters) should not exceed 25 percent coverage and must be forecast not to exceed 50 percent at landing time.

- Also, observed visibility at deorbit burn and the forecast visibility for landing time must be 5 statute miles (8043 meters) or greater.

- Crosswinds must not be greater than 15 knots or 15 nautical miles per hour (17 statute miles/28 kilometers per hour) if it is a daytime landing, and 12 knots or 12 nautical miles per hour (14 statute miles/22 kilometers per hour) if it is a nighttime landing. In more restrictive landings — because of weight or mission duration, for example — crosswinds must not exceed 12 knots or 12 nautical miles per hour (14 statute miles/22 kilometers per hour).

- Thunderstorms within 30 nautical miles (34.5 statute miles/56 kilometers) and/or rain within 30 nautical miles (34.5 statute miles/56 kilometers) also are landing constraints.

- Wind direction usually will be the key factor in determining the final approach to the runway. The sun angle, if it is in the pilot's field of view, is also considered. Under normal circumstances, the orbiter will land into the wind. If the wind direction is from the south, the final approach will be from the north; if the wind direction is from the north, the orbiter will approach from the south.

Space Shuttle Endeavour's drag chute slows down the orbiter as it lands on runway 33 at the SLF.

Pre-landing weather forecasts are issued by the Spaceflight Meteorology Group at Johnson Space Center. The group is part of the National Weather Service and works closely in coordinating its forecasts with Range Weather Operations at Cape Canaveral Air Force Station (CCAFS). Weather instrumentation at KSC and at the adjacent CCAFS provides some of the data that the Spaceflight Meteorology Group uses in preparing its landing forecast. Weather conditions also are evaluated by NASA astronauts piloting reconnaissance aircraft along the orbiter's landing approach before the orbiter is committed to re-entry.

Post-Landing Operations

Although on call during an entire mission in case of an earlier-than-scheduled landing, the orbiter convoy normally begins recovery operations in earnest about two hours before the orbiter is scheduled to land.

The convoy consists of about 25 specially designed vehicles or units and a team of about 150 trained personnel who assist the crew in leaving the orbiter, and who "safe" the orbiter, prepare it for towing and tow the vehicle to the Orbiter Processing Facility. The team that recovers the orbiter is primarily composed of KSC personnel, whether the landing takes place at KSC, at Edwards AFB in California, or elsewhere.

The first staging position of the convoy after landing is 1,250 feet (381 meters) from the orbiter. Safety assessment teams dressed in protective attire and with breathing apparatus use detectors to obtain vapor level readings around the orbiter and to test for possible explosive or toxic gases such as hydrogen, hydrazine, monomethyl-hydrazine, nitrogen tetroxide or ammonia.

Once the forward and aft safety assessment teams successfully complete their vapor readings, Purge and Coolant Umbilical Access Vehicles are moved into position behind the orbiter to get access to the umbilical areas. The ground halves of the onboard hydrogen detection sample lines are connected to determine the hydrogen concentration.

If no hydrogen is present, convoy operations continue. If hydrogen is detected, the crew is evacuated immediately, convoy personnel are cleared from the area, and an emergency power-down of the orbiter is conducted. Thankfully, this condition has never happened after landing.

After the carrier plates for the hydrogen and oxygen umbilicals are installed, coolant and purge air begins flowing through the umbilical lines. Purge air provides cool and humidified air conditioning to the payload bay and other cavities to remove any residual explosive or toxic fumes.

The purge of the vehicle normally occurs within approximately 45 to 60 minutes after the orbiter comes to a full stop. Cooling transfer to ground services occurs at about the same time, allowing onboard cooling to be shut down.

When it is determined that the area in and around the orbiter is safe, the crew prepares for departure from the orbiter. The crew hatch access vehicle can move to the hatch side of the orbiter and a "white room" can be mated to the orbiter hatch. The hatch is opened and a physician performs a brief preliminary medical examination of the crew members before they leave the vehicle. Crew egress generally occurs within an hour after landing.

Normally astronauts can egress from the orbiter more quickly and more comfortably by transferring from the white room directly into a crew transport vehicle (CTV), a modified "people mover" used at airports. Crew members cannot be seen as they pass through a curtained ramp to the CTV.

The commander, and sometimes other crew members, usually will perform a post-flight walk around the orbiter. Finally, the crew departs in the CTV.

NASA Facts

As Space Shuttle Endeavour lands at the Shuttle Landing Facility, concluding mission STS-113, the landing convoy in the foreground is ready to approach and safe the vehicle after it comes to a full stop.

It is only after the crew has left the orbiter and the orbiter ground cooling has been established that Johnson Space Center "hands over" responsibility of the vehicle to KSC.

The flight crew is replaced aboard the orbiter by exchange support personnel who prepare the orbiter for ground tow operations, install switch guards and remove data packages from any onboard experiments.

After a total safety downgrade, vehicle ground personnel make numerous preparations for the towing operation, including installing landing gear lock pins, disconnecting the nose landing gear drag link, positioning the towing vehicle in front of the orbiter and connecting the tow bar. Towing normally begins within four hours after landing and is completed within six hours, unless removal of time-sensitive experiments is needed on the runway.

In addition to convoy operations on the runway, a KSC engineering test team monitors data from the orbiter from a station in one of the Launch Control Center's firing rooms. After the orbiter "hand-over" to KSC, this team is enabled to issue commands to the orbiter to configure specific orbiter systems for the tow to one of three bays of the Orbiter Processing Facility. In the OPF, the process flow begins to ready the vehicle for its next flight.

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FS-2005-08-026-KSC (Rev. 2006)