IIE. Process Flow: Ground and Ferry Operations

Ground Operations

Typical Landing Procedures

Throughout an entire Space Shuttle mission, weather conditions at KSC were monitored by JSC's Spaceflight Meteorology Group. Considered part of the National Weather Service, they worked with the Range Weather Operations at CCAFS to prepare landing forecasts, using data gathered by instrumentation throughout KSC and at CCAFS. About five hours before touchdown, when the shuttle's crew began to prepare the orbiter for its return to Earth, other NASA astronauts flew reconnaissance planes along the planned landing approach to assist in the evaluation of weather conditions. Based on the gathered data, as well as how many days the orbiter had been in space, Flight Controllers at Mission Control decided if the orbiter would land at KSC's SLF as scheduled, later in the day, or over the next day or two.[967] Weather conditions that dictated if a landing at the SLF was possible included the amount of observed cloud cover below 8,000', the range of visibility, crosswind speeds, and thunderstorms in the vicinity. The decision to land at KSC, as well as the final "go/no go" for landing, occurred approximately thirty minutes prior to the deorbit burn (about ninety minutes prior to the landing).[968]

In addition to deciding whether the orbiter would land at KSC, Flight Controllers had to determine which of the two runway approaches would be used. There were two approaches to the KSC SLF Runway, Runway 15 from the northwest and Runway 33 from the southeast. The Flight Controllers used the wind direction and the angle of the sun to determine which runway approach was used. In ideal conditions, the orbiter landed into the wind, and the sun was outside of the pilot's field of view.[969]

Roughly two hours before touchdown, KSC's Orbiter Recovery Convoy began their preparations at the SLF. The Convoy consisted of approximately twenty-five specially designed vehicles and units, and 150 trained personnel, who performed safing operations, assisted the crew in leaving the vehicle, and prepared the orbiter for transfer to the OPF. Also around this time, SLF personnel began to periodically fire air cannons and circle the runway perimeter to clear the area of wildlife; they also walked along the Runway to check for foreign object debris (FOD) that

---

[967] If a landing at KSC was not possible, the principle alternative was a landing at Edwards AFB in California. Thus, similar weather monitoring procedures were carried out at both locations. NASA, *National Space Transportation System: An overview*, September 1988, 13; NASA KSC, "Landing the Space Shuttle Orbiter at KSC," news release, March 1992, revised October 1995, 7, http://www-pao.ksc.nasa.gov/kscpao/release/1992/1-92.htm.
[968] Since the orbiter reentered the atmosphere and landed in an unpowered, high-speed glide, once the deorbit burn was performed, the orbiter had to land; where the deorbit burn occurred was dictated by the landing site chosen. Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Shuttle Landing Facility (John F. Kennedy Space Center)," HAER No. FL-8-11-J. Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, April 2011, 17-18.
[969] Slovinac, "Shuttle Landing Facility," 18.

could potentially damage the orbiter. The walking activities continued until roughly fifteen minutes before landing; air cannons were regularly fired until touchdown.[970]

Approximately one hour before touchdown, the orbiter performed the deorbit burn. About twenty-five minutes before landing, the vehicle began to pass through the reentry blackout period, from which it emerged roughly twelve minutes before touchdown. At this point, the orbiter was roughly 550 miles from the SLF, at an altitude of about 34 miles (179,520'). When the vehicle reached the Gulf of Mexico (within 300 miles of the Runway and at an altitude of no more than 145,000'), the SLF's TACAN system began to communicate with the vehicle, providing azimuth and distance measurements to the on-board computers. About two minutes prior to touchdown, when the orbiter was approximately 10 miles from the designated Runway approach and at an altitude of roughly 15,500', the MSBLS took over for the TACAN system, to provide more precise guidance signals on slant range, azimuth, and elevation to the orbiter. As the orbiter approached an altitude of 12,000', the commander and pilot began to use different visual aids at the SLF to ensure that the vehicle was at the proper angle. The orbiter touched down at roughly the 2,500' mark on the Runway with its main landing gear, traveling at a speed of roughly 213 to 216 miles per hour.[971]

Once the orbiter came to a complete stop, the Orbiter Recovery Convoy began their work. First, a safety assessment team, fitted with special suits and breathing attire, checked vapor readings and tested for explosive and toxic gases, at a distance of about 1,250' from the orbiter. Once they declared the area clear, the special Purge and Coolant Umbilical Access Vehicles were brought in behind the orbiter, where they checked for hydrogen vapors. If there was no hydrogen, the umbilicals were connected and the vehicle was purged with air to remove any residual explosive or toxic fumes. All of this occurred within forty-five to sixty minutes following full stop.[972] When it was determined that the area in and around the orbiter was clear, the crew exited the orbiter into a crew transport vehicle.[973]

Once the orbiter's crew had left the vehicle, a team of support personnel entered the orbiter to prepare it for towing operations. Outside of the vehicle, technicians installed landing gear lock pins, disconnected the nose landing gear drag link, and positioned the towing vehicle in front of the orbiter. The orbiter was attached to the tow vehicle with a tow bar. Approximately four hours after landing, the tow vehicle pulled the orbiter from the Runway, along the Orbiter Towway, to

---

[970] Slovinac, "Shuttle Landing Facility," 18. For more information about the SLF and its design features, see Slovinac, "Shuttle Landing Facility."
[971] Slovinac, "Shuttle Landing Facility," 19.
[972] Slovinac, "Shuttle Landing Facility," 19. If hydrogen was detected, which never happened, the crew was immediately evacuated and the convoy personnel are cleared from the area. These same procedures were followed at EAFB. NASA, *An overview*, 13.
[973] It was at this point that responsibility for the vehicle passed from JSC to KSC. Slovinac, "Shuttle Landing Facility," 20. The same procedures were followed if the orbiter landed at EAFB. The orbiter was then ferried to KSC via a Shuttle Carrier Aircraft.

one of the OPF High Bays for between mission processing, which nominally required 125 days to complete.[974]

Orbiter Processing Activities

The first set of processing activities performed in the OPF High Bay were generally referred to as the "end-of-mission roll-in operations." Once the vehicle was aligned inside the High Bay, its "T-0" umbilicals were connected to ground support equipment within the facility, the orbiter's systems were connected to facility-provided utilities, and the vehicle's fuel cells were powered down. The orbiter was raised with hydraulic floor lifts, and mated to four orbiter jacks, two at the forward end and two at the aft end. The vehicle was then leveled, the connections were tightened, and the floor lifts were lowered. Two additional activities were begun during the "end-of-mission roll-in operations," and finished during the second set of operations. One task involved purging the three SSMEs to remove any moisture that was produced by the combustion of the LH2 and LO2. In addition, the cryogenic tanks for the orbiter's fuel cells were drained of residual reactants, and filled with gaseous nitrogen (oxidizer tanks) or gaseous helium (fuel tanks) to render them inert. A third task was to open the payload bay doors and install access platforms as required to support processing and safing activities.[975]

The second general set of operations performed in the OPF High Bay included "system safing and deservicing" activities. During this period, any remaining OMS and RCS oxidizer and fuel were drained, and the systems were purged. If necessary, the OMS pods and the FRCS module were removed and sent to KSC's Hypergol Maintenance Facility for further processing and maintenance. In addition, the three SSMEs were removed from the orbiter and taken to the SSME Processing Facility for processing.[976] Other activities included in the safing process were the removal, deservicing, and flushing of the waste control system; draining, filter removal, and purging of the potable water system and the water spray boilers; venting high pressure gases from the vehicle's ECLSS; and draining and purging the APUs.[977]

---

[974] Slovinac, "Shuttle Landing Facility," 20; USA, "Orbiter Processing Facility (Day One)," (presentation materials used for training, no date), 44. KSC had three OPF High Bays, distributed between two facilities (OPF and OPF-3). Prior to the *Columbia* accident in February 2003, when there were four active orbiters, the High Bays were assigned on a "first available" basis. Afterwards, the two bays in the OPF, High Bay No. 1 and High Bay No. 2, were devoted to *Atlantis* and *Endeavour*, respectively, and the OPF-3 High Bay (or High Bay No. 3) was dedicated to *Discovery*. Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Orbiter Processing Facility, High Bay No. 3 (John F. Kennedy Space Center)," April 2011, 23.

[975] Slovinac, "Orbiter Processing Facility," 23-24; USA, "Day One," 44; USA, "Orbiter Processing Facility (Day Two)," (presentation materials used for training, no date), 3. See Slovinac, "Orbiter Processing Facility," for more information about the OPF and its design features.

[976] The SSME Processing Facility was attached to OPF-3. Slovinac, "Orbiter Processing Facility," 24; USA, "Day Two," 6. See Slovinac, "Orbiter Processing Facility," for more information about the SSME Processing Facility and its design features.

[977] Slovinac, "Orbiter Processing Facility," 24; USA, "Day One," 44; USA, "Day Two," 6-8.

The major phase of orbiter processing operations was the "system testing, verification, and servicing" of every required functional orbiter system. This included the OMS/RCS, the fuel cell system, the window cavity conditioning system, the GNC system, the communications system, the OBSS (following the *Columbia* accident), the RMS, the APUs, the mechanical systems, and structural inspections. As part of these routine operations, individual components of each system could be removed, inspected, tested independently, and then reinstalled. If the component sustained significant wear or damage, it was generally replaced and tested as part of the system to ensure compatibility. At the same time, if a particular component presented problems during the mission, the troubleshooting of those problems occurred during this phase, and included removal of the element and its repair or replacement.[978]

Also during this phase of operations, visual inspections were conducted on the orbiter's TPS, the landing gear, and selected structural elements to determine if they sustained any damage during the flight. If technicians discovered significant damage to a TPS tile, either they created a foam version of the tile using the tile cavity as a mold, or they took a set of photographic images of the tile cavity. They then sent this information to the Thermal Protection System Facility, where a new tile was produced and delivered to the OPF for installation.[979] If damage to an insulation blanket was discovered, the component could be removed and sent to the Thermal Protection System Facility for repair if appropriate, or to be used as a pattern for a replacement.[980] In addition, after every flight, NASA engineers re-waterproofed all components of the vehicle's TPS. The procedure was necessary because the dimethylethoxysilane burned out when the temperature reached 1,050 degrees F, and exposed the TPS to water absorption.[981]

All of the tires from the nose and main landing gear were sent to the Shuttle Wheel and Tire Shop within the VAB.[982] Here, a bead breaker was used to remove the tire from the rim, which was then split and cleaned. The old tire was sent to the Logistics Facility for scrap, and the new tire was brought in from Logistics and installed on the rim.[983] After this, the tire underwent an initial inflation and a twenty-four hour pressure check. If it passed, an electrical check was performed on the tire, followed by a second pressure check that lasted for forty-eight hours. If all went well, the tire was then placed in a large freezer for 96 hours, after which it was checked for air and nitrogen loss.[984] Once all of this was completed, three longer-term checks were

---

[978] Slovinac, "Orbiter Processing Facility," 24-25; USA, "Day Two," 9.
[979] In general, approximately seventy tiles were replaced on an orbiter after a flight.
[980] Slovinac, "Orbiter Processing Facility," 25; Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Thermal Protection System Facility (John F. Kennedy Space Center)," HAER No. FL-8-11-L, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, April 2011, 18-21.
[981] Jenkins, *Space Shuttle*, 395-401.
[982] Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Vehicle Assembly Building (John F. Kennedy Space Center)," HAER No. FL-8-11-B, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, July 2009, 18-19.
[983] The main tires (aft end) were generally good for one flight; the nose tires were good for two flights. Slovinac, "Vehicle Assembly Building," 18.
[984] This freezer test is highly important since it mimics conditions in space, and ensures that the tires are capable of being used for landing after a mission. Slovinac, "Vehicle Assembly Building," 19.

performed on the tires to certify them for flight. All of this required roughly sixty days to complete. Once certified, the tires were taken back to the OPF for installation on the orbiter.[985]

Another key task conducted during the "system testing, verification, and servicing" phase of orbiter operations was payload processing. The first step was to deconfigure the vehicle from the previous mission. This included disconnecting any vehicle power or mechanical systems that were attached to the previous payloads, removing any remaining payloads and their supports, and deconfiguring the appropriate control panels on the aft flight deck. The vehicle was then reconfigured for the next mission's payload requirements. Tasks included in this process were to install payload support mechanisms in designated places, perform payload pre-mate testing, configure the appropriate control panels on the aft flight deck, install the payloads, connect the payloads to the vehicle power and mechanical systems as required, and complete a payload integration verification test.[986]

OPF technicians also used this time to perform planned vehicle modifications, which were carried out in conjunction with the routine procedures. These changes to the vehicle were made based on future mission requirements, the need to resolve an identified deficiency, or to replace existing equipment with new, improved components designed to enhance the orbiter's performance.[987] The OPF High Bay also periodically served as the location for OMDPs and OMMs.[988]

One of the last tasks in the "system testing, verification, and servicing" phase of operations was a crew equipment interface test. For this procedure, the crewmembers for the upcoming mission traveled to KSC from their headquarters at JSC. They inspected the payload bay for sharp edges, which could pose a hazard to on-orbit operations, and familiarized themselves with the locations of specific payloads and how they would be accessed during the mission. In addition, the crew familiarized themselves with the arrangement of the middeck level of the crew cabin, including

---

985 Slovinac, "Vehicle Assembly Building," 19.

986 Slovinac, "Orbiter Processing Facility," 25; USA, "Day Two," 16-19. Payloads were processed separately from the orbiter. Historically, payloads fell into one of two categories, horizontal payloads, meaning they were built up, integrated, and installed into the orbiter horizontally, or vertical, meaning they were built up, integrated, and installed into the orbiter vertically. Typically, all of the payload components were fabricated at their sponsor's laboratories, before being delivered to one of several facilities at KSC or CCAFS for additional processing for flight. The components were then moved to one of four facilities for final integration and testing; afterwards, one of two payload canisters, carried by one of two canister transporters, picked up the payload at its processing facility for transport to either the OPF (horizontal payloads) or the launch pad (vertical payloads) for installation into the orbiter. Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Canister Rotation Facility (John F. Kennedy Space Center)," HAER No. FL-8-11-K, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, April 2011, 14-15.

987 Slovinac, "Orbiter Processing Facility," 25-26.

988 Up through February 2001, the OPFs at KSC shared this duty with the Shuttle Orbiter Final Assembly Building (Building 150) at AFP 42 in Palmdale, California. Beginning with *Discovery's* third OMDP in September 2002, all Down Period and Major Modifications were completed at KSC. ACI and Weitze Research, "NASA-wide Survey and Evaluation of Historic Facilities and Properties in the Context of the US Space Shuttle Program, Air Force Plant 42, 1 North, Palmdale, California" (survey report, NASA JSC, 2007).

the stowage locations of equipment planned for use during the mission, as well as the airlock configuration.[989]

The final set of operations conducted in the OPF High Bay was referred to as "vehicle closeouts/preparations for roll-over." One of the tasks included reinstalling the SSMEs, which then underwent a leak test to ensure the integrity of the entire main propulsion system. The maneuvering capabilities of the engine gimbals, as well as all vehicle aerosurfaces, were then checked. Also during this time period, any issues discovered during the crew equipment interface test were resolved, an orbiter compartment positive pressure check was performed, and a final checkout of the TPS was conducted. Technicians also serviced the potable water system, the gaseous nitrogen pressure vessels, and installed the electrically-initiated pyrotechnic devices. As the final checks were completed for each of the systems, the access panels were reattached to the vehicle.[990]

Various additional activities were completed in the OPF High Bay just prior to the vehicle's roll-over to the VAB. First, a weight and center of gravity verification of the vehicle was performed. Then, the orbiter transporter was brought into the High Bay, and the orbiter was mated to it through one forward attach point and two aft attach points. Then, the final landing gear strut inspection was performed, the tires were pressurized, and the wheel wells were inspected. Following these steps, the landing gear was retracted, and the doors closed. Once this was completed, the technicians performed the final power down of the vehicle and removed all connections to facility services, the attach points between the orbiter and the transporter were confirmed, and the transporter carried the orbiter out of the High Bay.[991]

Space Shuttle Vehicle Stacking Operations

In preparation for vehicle stacking procedures in the VAB, the Crawler Transporter (Crawler) left its parking site, and using the special "Crawlerway," was driven to the MLP parking site.[992] There, one of three MLPs was attached to the Crawler at four places; the Crawler lifted the platform and carried it to the east side of the VAB, where it entered either High Bay 1 or 3. Once in position in the specified High Bay, the MLP was lowered and mated to six support pedestals,

---

[989] Slovinac, "Orbiter Processing Facility," 26; USA, "Day Two," 20.
[990] Slovinac, "Orbiter Processing Facility," 26-27; USA, "Day Two," 21.
[991] Slovinac, "Orbiter Processing Facility," 27; USA, "Day Two," 22-25.
[992] The Crawlers were constructed during the Apollo era, with the specific task of transporting assembled space flight vehicles from the VAB to the launch pad. For a detailed description of the Crawler, see Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Crawler Transporters (John F. Kennedy Space Center)," HAER No. FL-8-11-C, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, September 2009. The MLP provided a base for the vertical integration and stacking of the complete Space Shuttle vehicle, and served as a launch platform. For a detailed description of the MLP, see Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Mobile Launcher Platforms (John F. Kennedy Space Center)," HAER No. FL-8-11-D, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, September 2009.

and the platform was then detached from the Crawler, which was lowered and driven out of the VAB.[993]

With the MLP in place, the first part of the shuttle to be stacked was either the starboard or port SRB aft motor, which was brought to the VAB from the Rotation, Processing, and Surge Facility. The motor was placed on its designated hold down posts, to which it was attached using pyrotechnic bolts. Then, either the next segment for that SRB, or the second aft motor was brought in and attached to its hold down posts. The SRB stacking operations followed these procedures until each booster was four segments high, with the joint seals being visually inspected after every segment was mated. Once all four segments for each SRB were in place, a leak check and decay test was performed to verify the system's integrity. After verification, the forward skirt/nose assemblies were brought to the VAB from the SRB Assembly and Refurbishment Facility for integration. Then, an alignment check was performed, and the integrated and automated systems were tested using the Launch Processing System (LPS) to simulate the ET and the orbiter. This entire process generally required eighteen to twenty-two working days to complete, assuming no problems.[994]

When stacking and testing of the two SRBs was complete, the ET was lifted out of storage in VAB High Bay 4. It was positioned alongside the bay where the vehicle was being stacked, and moved into place. The ET was then mated to the SRBs, after which an interface test was conducted to ensure that the SRBs and ET were communicating with each other properly. Typically, the ET mating process was completed over one working day, and the close-out and interface tests required two to three working days. Once this was complete, the orbiter was brought to the VAB for stacking.[995]

The orbiter (*Discovery*, *Atlantis*, or *Endeavour*) entered the VAB atop the orbiter transporter, and was positioned next to the High Bay where the stacking was taking place. While in the transfer aisle, the two overhead cranes were attached to the orbiter with special slings, and the orbiter was rotated to a vertical position. While in the vertical position, photographs were taken of the wing leading edges and the underside of the orbiter.[996] The orbiter was then lifted, carried into the High Bay, and lowered into position. The orbiter was first attached to the ET at its aft end, and then at the forward end. This process generally required seven working days. Afterwards, various check-out procedures were completed. As part of this process, all umbilicals were connected, and then electrical and mechanical verification tests were conducted to verify all connections.

---

[993] Slovinac, "Vehicle Assembly Building."
[994] Slovinac, "Vehicle Assembly Building," 16-17.
[995] Slovinac, "Vehicle Assembly Building," 17.
[996] This action was initiated in response to the *Columbia* accident. Once in space, the orbiter conducted a roll-over, which allowed the astronauts in the ISS to photograph the same areas. These images were sent to KSC, where they were compared with those taken in the VAB, to ensure the TPS was intact. Slovinac, "Vehicle Assembly Building," 17.

Following this, all vehicle and vehicle-to-ground interfaces were checked using the LPS. Finally, the pyrotechinic devices were installed on the vehicle.[997]

Once the Space Shuttle vehicle was ready to go to the launch pad, the Crawler returned to the High Bay, and was mated to the MLP. Then, the Crawler carried the Shuttle and MLP combination along the Crawlerway to either LC 39A (3.5 miles) or LC 39B (5 miles), at a speed of one mile per hour, requiring 160 gallons of fuel per mile.[998] With its leveling system, the Crawler was able to keep the Shuttle within one foot of vertical during the approximate six hour trip from the VAB to the launch complex. Inside the launch complex gate, the Crawler was slowed to approximately one-third of a mile per hour to travel up the 0.25 mile, five degree inclining ramp to the launch pad.[999]

Launch Pad Preparations

At the pad, the Shuttle and MLP combination was aligned and attached to the six standard support pedestals, as well as four additional supports, which help to stiffen the platform against rebound loads in the case of main engine cutoff.[1000] Afterwards, all ground electrical power, data and communications interfaces, and ET propellant transfer lines between the launch pad and the Space Shuttle were connected through the MLP's Tail Service Masts and validated.[1001] Once this was complete, the Crawler was driven to the outside of the launch complex's perimeter fence, where it waited to carry the MLP back to its parking site after the Shuttle was launched.[1002]

At the pad, the orbiter's propulsion, EPS, and ECLSS, as well as the vehicle itself, underwent their final preparations for flight. When the Space Shuttle reached the launch pad, the orbiter was missing its base heat shield carrier panels, a part of its TPS, because technicians needed to access the orbiter's aft compartment to complete the final processing of the SSMEs. At the pad, the SSMEs were subjected to a walkdown inspection, followed by a helium signature test to check for any systems leaks, an electrical system checkout, a ball seal leak check, and finally, a Flight Readiness Test to ensure that all of the hydraulic systems were working properly. The final closeout of the aft compartment typically occurred within one week prior to launch, after the "aft

---

[997] Slovinac, "Vehicle Assembly Building," 17-18.
[998] Unloaded, the Crawler can travel up to two miles per hour. The Crawlerway is an Alabama River Rock-covered roadway designed during the Apollo era to support the combined weight of the Crawler and the spacecraft. Slovinac, "Crawler Transporters," 16.
[999] Although the driving time typically amounted to six hours, the entire process could take twelve to fourteen hours. Slovinac, "Crawler Transporters," 16; Linda Herridge, "Crawler group keeps shuttle rolling along," *Spaceport News,* May 30, 2008, 8.
[1000] For a more detailed description of the Launch Pad, see Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Pad A (John F. Kennedy Space Center)," HAER No. FL-8-11-F, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, August 2010.
[1001] Slovinac, "Mobile Launcher Platform," 14. The Launch Processing System, which controlled all launch operations from the LCC, was linked to the Space Shuttle/MLP through the Pad Terminal Connection Room within the pad hardstand. Slovinac, "Launch Complex 39, Pad A," 15.
[1002] Slovinac, "Crawler Transporter," 17.

confidence test," in which all aft systems were powered up to ensure everything was working properly. Once the aft compartment was closed, the base heat shield carrier panels were installed, and various checkouts and systems purges were performed in preparation for propellant loading; the final SSME checkouts were conducted the day before the scheduled launch.[1003]

Processing of the orbiter's OMS and RCS began approximately one week after the vehicle's arrival at the pad. Over a period of roughly seven days, these two systems underwent a propellant servicing process, which included filling the fuel and oxidizer tanks and checking for leaks or other problems. The orbiter's APU/hydraulic system also underwent final processing at the pad, which included filling the fuel tanks. Additional work on the APU system included servicing the gaseous nitrogen pressurization tanks; a hot fire of the APUs to be sure all components were working properly; and a leak test. The hydraulic components underwent their own specific tests.[1004]

Typically, small payloads were installed in the orbiter's payload bay while it was in the OPF High Bay; larger payloads, however, were installed at the launch pad. These payloads were brought to the launch pad inside one of two payload canisters, usually before the arrival of the Space Shuttle vehicle. The payload canister was lifted and aligned with the payload changeout room doors, and the payloads were then moved into the changeout room. After the Space Shuttle vehicle was in place and the rotating service structure was moved into position, enclosing the orbiter's Payload Bay, the payloads were transferred to the vehicle. Once the payloads were installed, all payload connections were made and a payload/orbiter interface test was conducted, followed by a payload contamination walkdown. After all these tasks were completed, the payload bay doors were closed.[1005]

Approximately two days before launch, the EPS's power reactant storage and distribution system tanks were loaded with LO2 and LH2. The three fuel cells were activated roughly fifteen hours before launch so technicians could perform a variety of tests to check for leaks or other problems.[1006] The processing of the orbiter's ECLSS was aided by the Environmental Control Systems Room below the pad surface, which provided air to the orbiter's crew cabin at specified temperatures, humidities, and pressures to maintain a controlled environment in these areas. Final checkout procedures on the ECLSS included a flash evaporator purge, necessary to ensure the system functions properly, as well as the removal of the plugs on the ammonia boiler, vacuum, and flash evaporator vent ports. Subsequently, the vacuum vent was purged every twenty-four hours in the event of launch scrubs, when the fuel cells were kept on-line.[1007] Approximately one week prior to the launch, pad personnel installed all of the equipment lockers and flight seats into the orbiter's middeck.[1008]

[1003] Slovinac, "Launch Complex 39, Pad A," 16.
[1004] Slovinac, "Launch Complex 39, Pad A," 17.
[1005] Slovinac, "Launch Complex 39, Pad A," 20-21.
[1006] Slovinac, "Launch Complex 39, Pad A," 17.
[1007] Slovinac, "Launch Complex 39, Pad A," 17-18.
[1008] Slovinac, "Launch Complex 39, Pad A," 18.

There was little processing work to be done on the SRBs at the launch pad. The only booster-specific process was the use of moveable carts to fill the SRBs' hydraulic power units with MMH. Additional work on the boosters fell under the procedures for overall Space Shuttle systems processing, which included various electrical tests and checkouts to ensure that the electrical systems and connections between the shuttle components were operational. One such test was the Range Safety System functional test to ensure that the shuttle's range safety system, meant to destroy the SRBs and ET in the event of a trajectory violation, was operational. Also performed was a checkout of the shuttle's pyrotechnic system, which included completing the wiring of all circuitry, resistance and load testing, and the final "Pyro Initiator Controller" test.[1009]

Launch Countdown

A call to stations from KSC's Launch Control Center firing room initiated the Shuttle countdown sequence.[1010] A typical Space Shuttle launch countdown began approximately seventy-two hours prior to launch, at T-43 hours and counting.[1011] For the next sixteen hours, final checkouts of the vehicle were conducted, software was loaded, and the middeck and flight deck platforms were removed. Around T-28 hours, preparations began for loading the orbiter's fuel cell power reaction and storage distribution systems. At T-27 hours and holding, a four-hour hold commenced while the launch pad was cleared of all non-essential personnel. When the countdown began again, the cryogenic reactants for the fuel cells were officially loaded into the storage tanks. Another hold began at T-19 hours and holding, when the orbiter's midbody umbilical unit was demated; this hold usually lasted about four hours.[1012] When the countdown began again, at T-19 hours and counting, final preparations were made for loading the ET with the fuel and oxidizer for the main engines, filling the water tank for the sound suppression system, and closing out the Tail Service Masts on the MLP.[1013]

At T-11 hours and holding, the orbiter's communications systems were activated. This hold sequence typically lasted twelve to thirteen hours. Once countdown resumed, the orbiter's fuel cells were activated, and non-essential personnel were cleared from the blast area. At T-6 hours and holding, typically a two-hour hold, the launch team verified that there were no violations of the launch commit criteria, and all personnel were cleared from the launch pad. In addition,

[1009] Slovinac, "Launch Complex 39, Pad A," 18.
[1010] For additional information on the Launch Control Center, see Patricia Slovinac, "Cape Canaveral Air Force Station, Launch Complex 39, Launch Control Center (John F. Kennedy Space Center)," HAER No. FL-8-11-A, Historic American Engineering Record (HAER), National Park Service, US Department of the Interior, January 2009.
[1011] The discrepancy between the official designation of T-43 hours and the reality that the clock was started roughly seventy-two hours prior to launch, was due to built in hold periods throughout the sequence, in which certain actions were performed, and conditions and processes were verified. These holds lasted from as little as ten minutes to as long as thirteen hours, assuming there were no unanticipated delays. Slovinac, "Launch Control Center," 17.
[1012] The orbiter midbody umbilical unit was comprised of flexible hoses that fed propellants, GN2 and GHe into the orbiter's fuel cells. Slovinac, "Launch Complex 39, Pad A," 17.
[1013] Slovinac, "Launch Control Center," 17.

fueling procedures for the ET began; ET fueling continued through the T-6 hours and counting stage. The two propellants, LO2 and LH2, were loaded onto the tank, through the two Tail Service Masts on the MLP; LO2 through the starboard mast and LH2 through the port mast. Gaseous nitrogen was pumped to a vent arm, with a vent hood at its end (commonly referred to as the "beanie cap"), to warm the oxygen vapors being vented at the top of the ET from the LO2 tank. This prevented ice from forming at the top of the tank, which could potentially break loose during launch and damage the orbiter.[1014]

At T-3 hours and holding, the final inspection team proceeded to the launch pad for a detailed analysis of the Space Shuttle vehicle. In addition, the closeout crew began to configure the crew module for countdown and launch. After this two hour hold, at T-3 hours and counting, the astronauts arrived at the launch pad and began their entry into the orbiter. Additional air-to-ground voice checks were conducted between the Launch Control Center and Mission Control. The orbiter crew hatch was closed and checked for leaks before the closeout crew retreated to the fallback area.[1015]

Beginning at T-20 minutes and holding, the Shuttle Test Director conducted the final briefings for the launch team, and preflight alignments of the inertial measurement units were completed. After this ten-minute hold, the countdown began again at T-20 minutes and counting. During this period, the orbiter's GPCs and backup flight system were switched to launch configuration, and the thermal conditioning for the fuel cells was begun. The final built-in hold occurred at T-9 minutes and counting, when the Launch Director, the Shuttle Test Director and the Mission Management Team confirmed a go/no go for launch. This hold varied in length depending on the mission. Final countdown began at T-9 minutes and counting. At this time, the automatic ground launch sequencer was started, and final tests and preparations for launch were completed.[1016]

At about two-and-a-half minutes before launch, the ET vent hood was raised, and its arm was retracted. The arm was not latched into place until SRB ignition (at lift-off) in the event of a hold on the launch, which allowed the arm to be re-extended. Ten seconds prior to SSME ignition, the hydrogen burnoff system, located within the MLP Tail Service Masts, engaged. This system eliminated any hydrogen molecules floating around the engines to prevent an explosion at launch. At sixteen seconds prior to SRB ignition, the water-based sound suppression system initialized from the water tower to the northeast of the launch pad. This water blanketed the surfaces of the MLP to absorb the acoustical pressures and prevent damage to the orbiter and its payloads.[1017]

[1014] Slovinac, "Launch Control Center," 17, Slovinac, "Launch Complex 39, Pad A," 18. At different stages during launch preparation and countdown, these lines fed propellants to the two OMS pods, the FRCS, the orbiter fuel cells, and the ET. Additionally, the masts provided umbilicals for various gases, including GH2, GO2, GHe, and GN2; connections for ground and flight coolants; lines for electrical power and purge air; and links for ground-to-vehicle data and communications.
[1015] Slovinac, "Launch Control Center," 17.
[1016] Slovinac, "Launch Control Center," 17-18.
[1017] Slovinac, "Launch Complex 39, Pad A," 18-20; Slovinac, "Mobile Launcher Platform," 15.

The Right SSME was ignited at T-6.60 seconds, followed by the Left SSME at T-6.48 seconds and the Center SSME at T-6.36 seconds. The SRBs were ignited at liftoff, or T-0. At SRB ignition, the pyrotechnic bolts that attached the boosters to their hold-down posts exploded. With this explosion, the stud to which the SRB was mounted was forced downward into a deceleration stand, and the pieces of the bolt assembly were captured within a spherical debris catcher at the top of the hold-down post. Once the Space Shuttle successfully launched, the MLP was left in place at the pad to cool, and was then washed down to remove any chemicals from the vehicle's propellants. Afterwards, all umbilicals and interfaces were disconnected from the launch pad, and the MLP was transported back to the VAB or the maintenance site by the Crawler.[1018]

Mission Control

Once the Space Shuttle cleared the Launch Pad's Fixed Service Structure, responsibility for the vehicle was transferred to Mission Control. Approximately two days before launch, the Ground Controller (see below) began to man his station, and communicate with the now powered-up vehicle at the launch pad. At T-12 hours to launch, the remainder of the flight controllers arrived at the flight control room, and began their preparations for the flight. The flight control team operated over three shifts, to cover the entire twenty-four hour day. There were twenty-three designated flight controller positions, as follows:

1. The Flight Director (FLIGHT) was the designated leader of the team, who controlled the overall mission and payload operations and made decisions with regards to the crew's safety.
2. The Mission Operations Directorate Manager (MOD) provided an interface between the Flight Control Room (FCR) and top NASA officials and mission managers.
3. The Spacecraft Communicator (CAPCOM) served as the link between the FCR and the astronauts.
4. The Flight Activities Officer (FAO) planned and supported all crew checklists, procedures and schedules, and planned and managed the orientation of the orbiter in space.
5. The Payload Deployment and Retrieval Systems (PDRS) Manager supported the operations of the remote manipulator system, or robot arm, and coordinated the deployment, retrieval, and positioning of satellites and other cargo.
6. The Public Affairs Officer (PAO) provided mission commentary to the news media and the public.
7. The Instrumentation and Communications Officer (INCO) monitored the in-flight communications and instrument systems, and controlled the orbiter's TV system.
8. The Data Processing Systems Engineer (DPS) Manager monitored the status of the data processing systems, including the five GPCs on the orbiter, the flight-critical and launch data lines, and the multifunction display systems. In addition, the manager watched the mass memories and systems level software.

[1018] Slovinac, "Mobile Launcher Platform," 15-16.

9. The Payloads Officer (PAYLOADS) coordinated the interfaces between the flight crew and the payload users, and monitored the on-board experiments and satellites.
10. The PAYLOADS console was shared with the Assembly and Checkout Officer (ACO), who was responsible for the development of ISS.
11. The Guidance, Navigation and Control Systems Engineer (GNC) monitored the vehicle's GNC system and advised the crew of any guidance hardware malfunctions. He/she also notified the flight director and crew of any impending aborts.
12. The Propulsion Officer (PROP) monitored and evaluated the orbiter's RCS and OMS jets and propellants.
13. The Flight Dynamics Officer (FDO) planned maneuvers and monitored trajectories.
14. The Trajectory Officer (TRAJECTORY) assisted the FDO during the dynamic phases of flight, and was responsible for maintaining the trajectory processors in Mission Control.
15. The Ground Controller (GC) monitored Mission Control hardware, software and support facilities. In addition, he/she maintained the links between the Ground Space Flight Tracking and Data Network (GSTDN) and the TDRSS, with Goddard Space Flight Center.
16. The Maintenance, Mechanical, Arm and Crew Systems Officer (MMACS) monitored the orbiter's structural and mechanical systems, and on-board crew hardware and equipment.
17. The Electrical Generation and Illumination Engineer (EGIL) monitored the orbiter's electrical systems, fuel cells and their cryogenics, the ac and dc circuits, pyrotechnics, lighting, and the caution and warning systems.
18. The Emergency, Environment and Consumables Operations Manager (EECOM) monitored the passive and active thermal controls, the cabin atmosphere, the avionics cooling, the supply and waste water system, and the fire detection and suppression system.
19. The Surgeon (SURGEON) monitored the crew's health and coordinated any medical operations.
20. The Rendezvous Guidance and Procedures Officer (RENDEZVOUS) monitored a shuttle mission during deployment, rendezvous and proximity operations, and docking and undocking operations.
21. The Ascent/Entry Guidance and Procedures Officer (GUIDANCE), who monitored the guidance and navigation systems and execution of crew procedures in an ascent abort contingency, shared a console with RENDEZVOUS.
22. The Booster Systems Engineer (BOOSTER) monitored and evaluated the MPS, SSMEs, SRBs, and ET during launch and ascent, and the MPS during entry.
23. The Extravehicular Systems Activities Director (EVA) coordinated spacewalks from both the shuttle and the ISS and shared a console with BOOSTER.[1019]

During the mission, each of the flight controllers had three to five specialists who monitored both ground and orbiter systems. This enabled a quick response to a contingency situation.

[1019] Patricia Slovinac and Joan Deming, "Mission Control Center (Building 30)" (documentation package, NASA JSC, 2011), 21-23.

Additionally, these specialists provided detailed analysis information to the controllers, if requested.[1020]

Ferry Flights

Turnaround Operations

According to Donald L. McCormack, NASA Ferry Operations manager, preparing the orbiter for ferry operation from Edwards AFB to KSC was done over a period of seven days. This was referred to as a "turnaround operation." After landing at Edwards, the orbiter was towed to Shuttle Area A at DFRC (at Edwards AFB), and "spotted" in the MDD.[1021] Operations performed during this time included the following:

- A dry nitrogen purge of the SSMEs to remove moisture
- Power reactant and storage distribution system off-load to remove the cryogenic oxygen and hydrogen from the tanks as well as fuel cell purging
- De-stowing the crew module to remove middeck payloads, the EMUs, and various other equipment
- Installing mechanical locks on the SSMEs and the elevon flight control surfaces to lock them into the position required for ferry
- Draining a small quantity of propellant from the OMS engine ball valves to prevent seal deterioration
- Installing the tail cone for the reduction of aerodynamic drag. The tail cone was attached to the orbiter's base heat shield at eight attach points. This was one of the last operations performed prior to actual mating, and took two to three shifts to accomplish. Tail cone installation typically began about five days after landing.
- Raising the orbiter about fifty feet. The SCA was towed into the MDD, and the orbiter was lowered into position on the SCA and attached at two aft and one forward points. These three attach locations were the same as those used when the orbiter was mated to the ET. The mate process typically took about twelve hours.[1022]

The around-the-clock turnaround operation team at Edwards AFB consisted of approximately 150 people, which included a large group from KSC who arrived about twenty-four hours after the shuttle landed.[1023] Typically, the orbiter was mated to the SCA and ready to be ferried within seven to nine days of landing.

[1020] Slovinac and Deming, "Mission Control," 23.
[1021] The MDDs located at both Edwards AFB and at the KSC SLF were specially designed and built to provide structural support for the mate (attachment) and demate (detachment) of the orbiter and the SCA. The mate and demate processes are relatively straightforward, and are essentially opposite of one another. Slovinac, "Shuttle Landing Facility."
[1022] McCormack, interview, 2-4.
[1023] McCormack, interview, 3.

Flight Procedures

The crew for the post-mission ferry flight consisted of two pilots and two flight engineers aboard the SCA. The flight path was not the same for each ferry operation. McCormack stated that "the weather always drives when we fly and the route we take."[1024] The orbiter could not be flown through rain, to prevent damage to the tiles. Severe weather also was avoided. Temperature and pressure were additional constraints; the minimum temperature was 15 degrees F and the minimum ambient pressure was 8 psia. Because of these limits, the SCA generally flew low, in the range of 11,000' to 16,000'.[1025] Before every flight leg, a weather briefing was conducted to determine if the flight could proceed. The SCA also was required to fly only during daylight hours. According to Flight Engineer Henry Taylor, the SCA was allowed to take off up to twenty minutes before sunrise, and had to land no later than twenty minutes after sunset. The mated SCA/orbiter could weigh no more than 710,000 pounds at takeoff.[1026]

The weight of the orbiter impacted the performance of the SCA. Variable orbiter weight resulted, foremost, from what was returned in the payload bay. The typical weight range for end-of-mission ferry flights was about 195,000 to 230,000 pounds.[1027] When the orbiters were initially delivered to KSC their estimated weights ranged from 158,289 pounds (*Columbia*) to 151,205 pounds (*Endeavour*), without the engines installed[1028]. Following the eight major modifications performed at Palmdale, orbiter weight ranged between approximately 154,000 and 161,000 pounds. The heaviest orbiter ever ferried was *Discovery* after STS-114; it carried a MPLM in the payload bay, and weighed almost 228,000 pounds.

A "pathfinder" aircraft, flown by an experienced SCA pilot, took off prior to the SCA and flew approximately 100 miles ahead. The type of aircraft used as the pathfinder varied. In the winter, there were requirements to provide a heated purge of the orbiter at overnight stopovers if the overnight temperature was expected to be below 45 degrees F for more than four hours. Therefore, specialized purge equipment was needed. In these cases, a USAF C-141 or C-17 was used. When purge equipment was not needed, a NASA JSC aircraft, such as a KC-135 or a C-9, typically served as the pathfinder vehicle. The pilot in the pathfinder was in radio contact with the pilots in the SCA, providing guidance to safely navigate through challenging weather conditions.[1029] This aircraft also transported all required support equipment and the thirty to thirty-five person ferry flight team, including the ferry manager, weather officers, all the KSC support personnel, the mechanics and maintenance crew, and safety and security personnel.[1030]

[1024] McCormack, interview, 6.
[1025] McCormack, interview, 6.
[1026] Taylor, interview, 7.
[1027] McCormack, interview, 8.
[1028] The SSMEs added approximately 20,000 pounds to the total empty weight of each orbiter. NASA KSC, "Orbiter Vehicles," http://www.pao.ksc.nasa.gov/shuttle/resources/orbiters.html.
[1029] McCormack, interview, 8-9.
[1030] Taylor, interview, 22.

During the transcontinental trip between California and Florida, the SCA typically stopped several times to refuel. A heavier orbiter required at least three refueling stops, sometimes four. Historically, more than twenty military bases and a few international airports located across the southern one-third of the US supported ferry operations. Military bases were used almost all the time because of their security and support capabilities.[1031] Under the most favorable conditions, with good weather and a light orbiter, the cross country trip could be made in one day with two legs; with bad weather, it could stretch out to four days or more. Typically, a ferry flight was accomplished in three or four legs flown over a period of two to three days, with one or two rest stops. A refuel required only a few hours on the ground. The average fuel burn for the SCA during a ferry flight was about 5,750 gallons per hour.[1032] Each SCA contained seven fuel tanks, including four main, one center wing, and two reserve. "We normally only use fuel out of the mains and reserves," Taylor related.[1033]

Upon landing at a stopover, a safety assessment was performed before the flight crew could depart the SCA. This consisted of toxic vapor tests and visual inspections for damage performed by KSC personnel. In the case of an overnight stop, base security personnel set up a perimeter that was at least 200' from the SCA. Military personnel controlled the single entry point established and monitored the restricted area.[1034] When the plane landed at KSC, a safety assessment was conducted, and then the mated vehicle was towed to the MDD. Typically, within about sixteen hours, the orbiter was demated from the SCA and towed to the OPF.[1035]

[1031] Taylor, interview, 21.
[1032] McCormack, interview, 10, 12.
[1033] Taylor, interview, 7.
[1034] McCormack, interview, 12.
[1035] McCormack, interview, 15.