Flight Operations

Jack Knight
Gail Chapline
Marissa Herron
Mark Kelly
Jennifer Ross-Nazzal

For nearly 3 decades, NASA's Johnson Space Center (JSC) Mission Operations organization planned, trained, and managed the on-orbit operations of all Space Shuttle missions. Every mission was unique, and managing a single mission was an extremely complex endeavor. At any one time, however, the agency simultaneously handled numerous flights (nine in 1985 alone). Each mission featured different hardware, payloads, crew, launch date, and landing date. Over the years, shuttle missions became more complicated—even more so when International Space Station (ISS) assembly flights began. Besides the JSC effort, Kennedy Space Center managed all launches while industry, the other centers, and other countries managed many of the payloads.

NASA defined the purpose of each mission several years before the mission's flight. Types of missions varied from satellite releases, classified military payloads, science missions, and Hubble Space Telescope repair and upgrades to construction of the ISS. In addition to completion of the primary mission, all flights had secondary payloads such as education, science, and engineering tests. Along with executing mission objectives, astronauts managed Orbiter systems and fulfilled the usual needs of life such as eating and sleeping. All of these activities were integrated into each mission.

This section explains how NASA accomplished the complicated tasks involved in flight operations. The Space Transportation System (STS)-124 (2008) flight provides examples of how mission operations were conducted.

Plan, Train, and Fly

Planning the Flight Activities

NASA's mission operations team planned flight activities to assure the maximum probability of safe and complete success of mission objectives for each shuttle flight. The planning process encompassed all aspects of preflight assessments, detailed preflight planning and real-time replanning, and postflight evaluations to feed back into subsequent flights. It also included facility planning and configuration requirements. Each vehicle's unique characteristics had to be considered in all flight phases to remain within defined constraints and limitations. The agency made continual efforts to optimize each flight's detailed execution plan, including planning for contingencies to maximize safety and performance margins as well as maximizing mission content and probability of mission success.

During the initial planning period, NASA selected the flight directors and determined the key operators for the Mission Control Team. This team then began planning and training. The flight crew was named 1 to 1½ years prior to launch. The commander acted as the leader for the flight crew through all planning, training, and execution of the mission while the flight directors led the mission operations team.

Approximately 14 months before launch, the mission operations team developed a detailed flight plan. To create the comprehensive timeline, team members worked closely with technical organizations like engineering, the astronaut office, specific NASA contractors, payload suppliers, government agencies, international partners, and other NASA centers including Kennedy Space Center (KSC) and Marshall Space Flight Center (MSFC). Crew timeline development required balancing crew task completion toward mission objectives and the individual's daily life needs, such as nutrition, sleep, exercise, and personal hygiene. The timeline was in 5-minute increments to avoid overextending the crew, which could create additional risks due to crew fatigue. Real-time changes to the flight plan were common; therefore, the ground team had to be prepared to accommodate unexpected deviations. Crew input was vital to the process.

Collaboration Paved the Way for a Successful Mission… of International Proportions

In 2000, Mission Operations Directorate worked with Japan in preparation for the flight of STS-124 in 2008. To integrate Japan Aerospace Exploration Agency (JAXA) into the program, the US flight team worked closely with the team from Japan to assimilate JAXA's Japanese Experiment Module mission with the requirements deemed by the International Space Station Program. The team of experts taught Japanese flight controllers how Mission Operations Directorate handled flight operations—the responsibilities of mission controllers, dealing with on-orbit failures, writing mission rules and procedures, structuring flight control teams—to help them determine how to plan future missions and manage real-time operations. The downtime created by the Columbia accident (2003) provided additional time to the Japanese to develop necessary processes, since this was the first time JAXA commanded and controlled a space station module.

In addition to working closely with Japan on methodology and training, flight designers integrated the international partners (Russian Federal Space Agency, European Space Agency, Canadian Space Agency, and JAXA) in their planning process. The STS-124 team worked closely with JAXA's flight controllers in the Space Station Integration and Promotion Center at Tsukuba, Japan, to decide the sequence of events—from unberthing the module to activating the science lab. Together, they determined plans and incorporated these plans into the extensive timeline.

Initial Planning: Trajectory Profile

Planning included the mission's trajectory profile. This began with identifying the launch window, which involved determining the future time at which the planes from the launch site and the targeted orbit intersect. The latitude of the launch site was important in determining the direction of launch because it defined the minimum inclination that could be achieved, whereas operational maximum inclinations were defined by range safety limits to avoid landmass. For International Space Station (ISS) missions, the shuttle launched from the launch site's 28.5-degree latitude into a 51.6-degree inclination orbit, so the launch ground track traveled up the East Coast. For an orbit with a lower inclination, the shuttle headed in a more easterly direction off the launch pad. Imagine that, as the ISS approached on an ascending pass, the shuttle launched along a path that placed it into an orbit just below and behind the ISS orbit. NASA optimized the fuel usage (for launch and rendezvous) by selecting an appropriate launch time. The optimal time to launch was when the ISS orbit was nearest the launch site. Any other time would have resulted in an inefficient use of expensive fuel and resources; however, human factors and mission objectives also influenced mission design and could impose additional requirements on the timing of key mission events. The availability of launch days was further constrained by the angle between the orbital plane and the sun vector. That angle refers to the amount of time the spacecraft spends in sunlight. When this angle exceeded 60 degrees, it was referred to as a "beta cutout." This variable, accounted for throughout a shuttle mission, limited the availability of launch days.

Operational Procedures Development

NASA developed crew procedures and rules prior to the first shuttle flight—Space Transportation System (STS)-1 in 1981—and refined and modified them after each flight, as necessary. A basic premise was that the crew should have all requisite procedures to operate the vehicle safely with respect to the completion of launch, limited orbit operations, and deorbit without ground involvement in the event of a loss of communication. This was not as simple as it might sound. Crew members had no independent knowledge of ground site status, landing site weather, or on-board sensor drift, and they had considerably less insight into the total set of vehicle telemetry available to the ground.

During the early flights, NASA established the core elements of the mission operations shuttle processes. The emblem for Johnson Space Center Mission Operations included a sigma to indicate that the history of everything learned was included in planning for the next missions.

Each flight increased NASA's experience base with regard to actual vehicle, crew, and ground operations performance. Each mission's operational lessons learned were incorporated into the next mission's crew procedures, flight team training, Flight Rules modifications, and facilities modifications (mostly software).

Flight Control Team

Flight controllers were a vital part of every mission. For each flight control position in the flight control room, one or more supporting positions were in the back room, or the multipurpose support room. For example, the flight dynamics officer and the guidance procedures officer, located in "the trench" of the flight control room, relied on a team of flight controllers sitting just a few feet away in the multipurpose support room to provide them with recommendations. These back room flight controllers provided specialized support in areas such as aborts, navigation, and weather as well as communications with external entities (i.e., Federal Aviation Administration, US State Department).

Back room support had more time and capabilities to perform quick analyses while front room flight controllers were working higher level issues and communicating with the other front room controllers (i.e., propulsion engineer, booster engineer) and the flight director. This flow of communications enabled analyses to be performed in real time, with appropriate discussions among all team players to result in a recommended course of action that was then passed on to the front room. The front room remained involved in back room discussions when feasible and could always redirect their support if they received new information from another front room flight controller, the flight director, or the capsule communicator (responsible for all communications with the on-orbit crew).

It can easily be surmised that being a flight controller required a quick and decisive mindset with an equally important team player attitude. The pressure to make immediate decisions was greatest during the launch phase and similarly so during the re-entry phase. During those times, flight controllers worked under a high level of pressure and had to trust their counterparts to work together through any unplanned challenges that may have occurred.

Flight Controller Preparation

Preparations for any off-nominal situations were regularly practiced prior to any mission through activities that simulated a particular phase of flight and any potential issue that could occur during that timeframe. These simulated activities, simply referred to as "Sims," involved both the front room

Flight Rules

Part of the planning process included writing Flight Rules. Flight Rules were a key element of the real-time flight control process and were predefined actions to be taken, given certain defined circumstances. This typically meant that rules were implemented, as written, during critical phases such as launch and re-entry into Earth's atmosphere. Generally, during the orbit phase, there was time to evaluate exact circumstances. The Flight Rules defined authorities and responsibilities between the crew and ground, and consisted of generic rules, such as system loss definition, system management, and mission consequence (including early mission termination) for defined failures.

For each mission, lead flight directors and their teams identified flight-specific mission rules to determine how to proceed if a failure occurred. These supplemented the larger book of generic flight rules. For instance, how would the team respond if the payload bay doors failed to open in orbit? The rules minimized real-time rationalization because the controllers thoroughly reviewed and simulated requirements and procedures before the flight.

and the back room flight controllers, just as if the Sim were the real thing. Sims allowed the flight control team and the astronauts to familiarize themselves with the specifics of the missions and with each other. These activities were just as much team-building exercises as they were training exercises in what steps to take and the decisions required for a variety of issues, any of which could have had catastrophic results. Of course, the best part of a simulation was that it was not real. So if a flight controller or an astronaut made a mistake, he or she could live and learn while becoming better prepared for the real thing.

Training to become a flight controller began long before a mission flew. Flight controllers had to complete a training flow and certification process before being assigned to a mission. The certification requirements varied depending on the level of responsibility of the position. Most trainees began by reading technical manuals related to their area of flight control (i.e., electrical, environmental, consumables manager or guidance, navigation, and controls system engineer), observing currently certified flight controllers during simulations, and performing other hands-on activities appropriate to their development process. As the trainee became more familiar with the position, he or she gradually began participating in simulations until an examination of the trainee's performance was successfully completed to award formal certification. Training and development was a continually improving process that all flight controllers remained engaged in whether they were assigned to a mission or maintaining proficiency. A flight controller also had the option to either remain in his or her current position or move on to a more challenging flight control position with increased responsibilities, such as those found in the front room. An ascent phase, front room flight control position was typically regarded as having the greatest level of responsibility because this flight controller was responsible for the actions of his or her team in the back room during an intense and time-critical phase of flight. Similarly, the flight director was responsible for the entire flight control team.

Flight Techniques

The flight techniques process helped develop the procedures, techniques, and rules for the vehicle system, payload, extravehicular activities (EVAs), and robotics for the flight crew, flight control team, flight designers, and engineers. NASA addressed many topics over the course of the Space Shuttle Program, including abort modes and techniques, vehicle power downs, system loss integrated manifestations and responses, risk assessments, EVA and robotic procedures and techniques, payload deployment techniques, rendezvous and docking or payload capture procedures, weather rules and procedures, landing site selection criteria, and others. Specific examples involving the ISS were the development of techniques to rendezvous, conduct proximity operations, and dock the Orbiter while minimizing plume impingement contamination and load imposition.

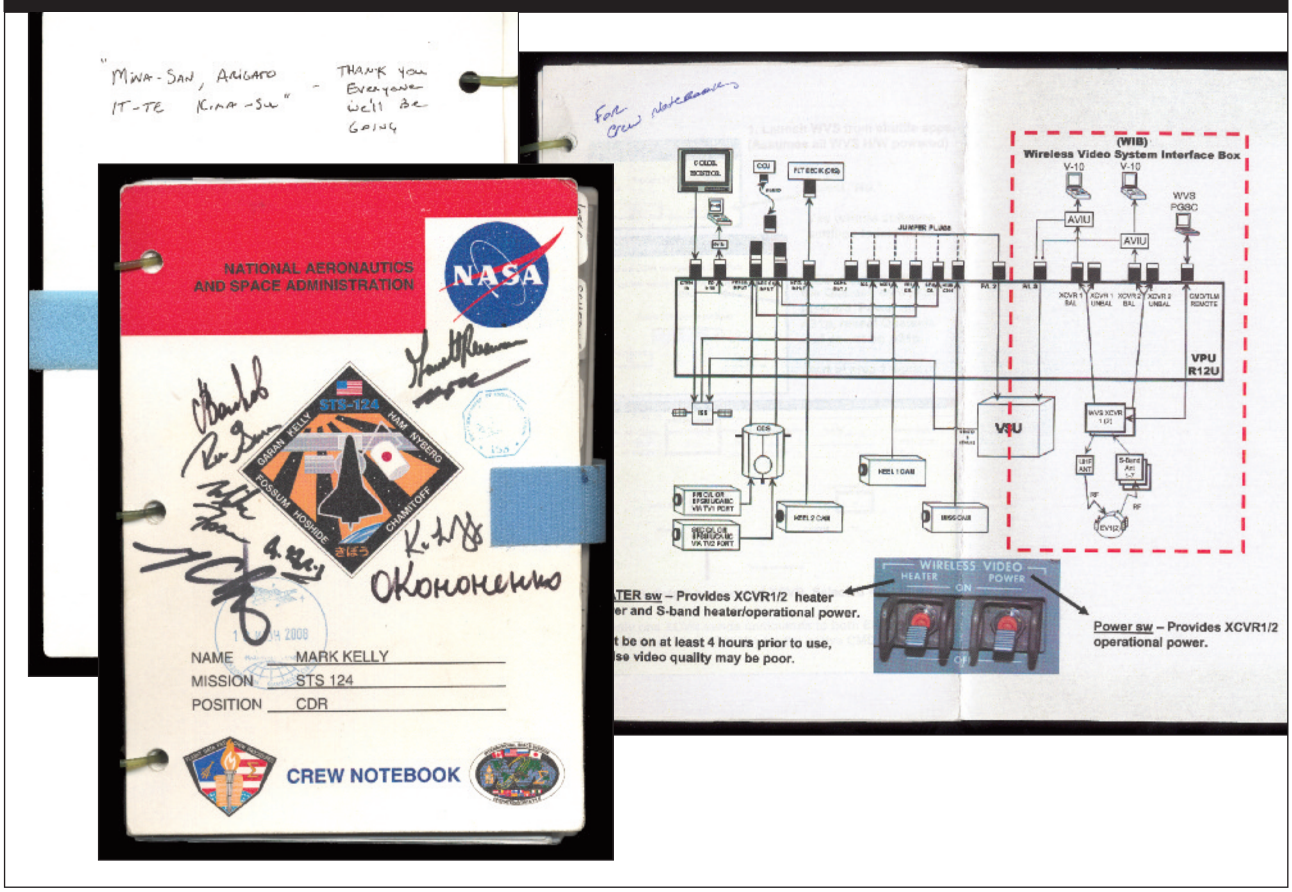
Crew Procedures

Prior to the first shuttle flight, NASA developed and refined the initial launch, orbit, and re-entry crew procedures, as documented in the Flight Data File. This document evolved and expanded over time, especially early in the program, as experience in the real operational environment increased rapidly.

A "fish-eye" lens on a digital still camera was used to record this image of the STS-124 and International Space Station (ISS) Expedition 17 crew members as they share a meal on the middeck of the Space Shuttle Discovery while docked with the ISS. Pictured counterclockwise (from the left bottom): Astronaut Mark Kelly, STS-124 commander; Russian Federal Space Agency Cosmonaut Sergei Volkov, Expedition 17 commander; Astronaut Garrett Reisman; Russian Federal Space Agency Cosmonaut Oleg Kononenko, Astronaut Gregory Chamitoff, Expedition 17 flight engineers; Astronaut Michael Fossum, Japan Aerospace Exploration Agency Astronaut Akihiko Hoshide, Astronaut Karen Nyberg; and Astronaut Kenneth Ham, pilot.

The three major flight phases—ascent, orbit, and re-entry—often required different responses to the same condition, many of which were time critical. This led to the development of different checklists for these phases. New vehicle features such as the Shuttle Robotic Arm and the airlock resulted in additional Flight Data File articles. Some of these, such as the malfunction procedures, did not change unless the underlying system changed or new knowledge was gained, while flight-specific articles, such as the flight plan, EVA, and payload operations checklists, changed for each flight. The Flight Data File included in-flight maintenance

Commander Mark Kelly's personal crew notebook from STS-124.



procedures based on experience from the previous programs. Checklist formats and construction standards were developed and refined in consultation with the crews. NASA modeled the pocket checklists, in particular, after similar checklists used by many military pilots for their operations. Flight versions of the cue cards were fitted with Velcro® tabs and some were positioned in critical locations on the various cockpit panels for instantaneous reference.

In addition, the crew developed quick-reference, personal crew notebooks that included key information the crew member felt important, such as emails or letters from individuals or organizations. During ISS missions, the crews established a tradition where the shuttle crew and the ISS crew signed or stamped the front of each other's notebook.

Once the official Flight Data File was completed, crew members reviewed the flight version one last time and often added their own notes on various pages. All information was then copied and the flight versions of the Flight Data File were loaded on the shuttle. Multiple copies of selected Flight Data File books were often flown to enhance on-board productivity.

All flight control team members and stakeholders, including the capsule communicator and flight director, had nearly identical copies of the Flight Data File at their consoles. This was to ensure the best possible communications between the space vehicle and the flight control team. The entire flown Flight Data File with crew annotations, both preflight and in-flight, was recovered Postflight and archived as an official record.

Detailed Trajectory Planning

Trajectory planning efforts, both preflight and in real time, were major activities. Part of the preflight effort involved defining specific parameters called I-loads, which defined elements of the ascent trajectory control software, some of which were defined and loaded on launch day via the Day-of-Launch I-Load Update system. The values of these parameters were uniquely determined for each flight based on the time of year, specific flight vehicle, specific main engines, mass properties including the specific Solid Rocket Boosters (SRBs), launch azimuth, and day-of-launch wind measurements. It was a constant optimization process for each flight to minimize risk and maximize potential success. Other constraints were space radiation events, predictable conjunctions, and predictable meteoroid events, such as the annual Perseid meteor shower period in mid August. The mission operations team developed the Flight Design Handbook to document, in detail, the process for this planning.

Re-entry trajectory planning was initially done preflight and was continuously updated during a mission. NASA evaluated daily landing site opportunities for contingency deorbit purposes, and continuously tracked mass properties and vehicle center of gravity to precisely predict deorbit burn times and re-entry maneuvers. After the Columbia accident (STS-107) in 2003, the agency established new ground rules to minimize the population overflown for normal entries.

Planning also involved a high level of NASA/Department of Defense coordination, particularly following the Challenger accident (STS-51L) in 1986. This included such topics as threat and warning, orbital debris, and search and rescue.

Orbiter and Payload Systems Management

Planning each mission required management of on-board consumables for breathing oxygen, fuel cell reactants, carbon dioxide, potable water and wastewater, Reaction Control System and Orbital Maneuvering System propellants, Digital Auto Pilot, attitude constraints, thermal conditioning, antenna pointing, Orbiter and payload data recording and dumping, power downs, etc. The ground team developed and validated in-flight maintenance activities, as required, then put these activities in procedure form and uplinked the activity list for crew execution. There was an in-flight maintenance checklist of predefined procedures as well as an in-flight maintenance tool kit on board for such activities. Unique requirements for each flight were planned preflight and optimized during the flight by the ground-based flight control team and, where necessary, executed by the crew on request.

Astronaut Training

Training astronauts is a continually evolving process and can vary depending on the agency's objectives. Astronaut candidates typically completed 1 year of basic training, over half of which was on the shuttle. This initial year of training was intended to create a strong foundation on which the candidates would build for future mission assignments. Astronaut candidates learned about the shuttle systems, practiced operation of the shuttle in hands-on mock-ups, and trained in disciplines such as space

Shuttle Training Aircraft

Commanders and pilots used the Shuttle Training Aircraft—a modified Gulfstream-2 aircraft—to simulate landing the Orbiter, which was often likened to landing a brick, especially when compared with the highly maneuverable high-speed aircraft that naval aviators and pilots had flown. The Shuttle Training Aircraft mimicked the flying characteristics of the shuttle, and the left-hand flight deck resembled the Orbiter. Trainers even blocked the windows to simulate the limited view that a pilot experienced during the landing. During simulations at the White Sands Space Harbor in New Mexico, the instructor sat in the right-hand seat and flew the plane into simulation. The commander or pilot, sitting in the left-hand seat, then took the controls. To obtain the feel of flying a brick with wings, he or she lowered the main landing gear and used the reverse thrusters. NASA requirements stipulated that commanders complete a minimum of 1,000 Shuttle Training Aircraft approaches before a flight. Even Commander Mark Kelly—a pilot for two shuttle missions, a naval aviator, and a test pilot with over 5,000 flight hours—recalled that he completed at least "1,600 approaches before [he] ever landed the Orbiter." He conceded that the training was "necessary because the Space Shuttle doesn't have any engines for landing. You only get one chance to land it. You don't want to mess that up."

Two aircraft stationed at Ellington Air Force Base for Johnson Space Center are captured during a training and familiarization flight over White Sands, New Mexico. The Gulfstream aircraft (bottom) is NASA's Shuttle Training Aircraft and the T-38 jet serves as a chase plane.

Flight Simulation Training

For every hour of flight, the STS-124 crew spent 6 hours training on the ground for a total of about 1,940 hours per crew member. This worked out to be nearly a year of 8-hour workdays.

Commander Mark Kelly and Pilot Kenneth Ham practiced rendezvousing and docking with the space station on the Shuttle Engineering Simulator, also known as the dome, numerous times (on weekends and during free time) because the margin of error was so small.

and life sciences, Earth observation, and geology. These disciplines helped develop them into "jacks-of-all-trades."

Flight assignment typically occurred 1 to 1½ years prior to a mission. Once assigned, the crew began training for the specific objectives and specialized needs for that mission. Each crew had a training team that ensured each crew member possessed an accurate understanding of his or her assignments. Mission-specific training was built off of past flight experience, if any, and basic training knowledge. Crew members also received payload training at the principal investigator's facility. This could be at a university, a national facility, an international facility, or another NASA facility. Crew members were the surrogates for the scientists and engineers who designed the payloads, and they trained extensively to ensure a successfully completed mission. As part of their training for the payloads, they may have actually spent days doing the operations required for each day's primary objectives.

Crew members practiced mission objectives in simulators both with and without the flight control teams in Mission Control. Astronauts trained in Johnson Space Center's (JSC's) Shuttle Mission Simulator, shuttle mock-ups, and the Shuttle Engineering Simulator. The Shuttle Mission Simulator contained both a fixed-base and a motion-based high-fidelity station. The motion-based simulator duplicated, as closely as possible, the experience of launch and landing, including the release of the SRBs and External Tank (ET) and the views seen out the Orbiter windows. Astronauts practiced aborts and disaster scenarios in this simulator. The fixed-base simulator included a flight deck and middeck, where crews practiced on-orbit activities. To replicate the feeling of space, the simulator featured views of space and Earth outside the mock-up's windows. Astronauts used the full-fuselage mock-up trainer for a number of activities, including emergency egress practice and EVA training. Crew compartment trainers (essentially the flight deck and the middeck) provided training on Orbiter stowage and related subsystems.

A few months before liftoff, the crew began integrated simulations with the flight control teams in the Mission Control Center. These simulations prepared the astronauts and the flight control teams assigned to the mission to safely execute critical aspects of the mission. They were a crucial step in flight preparation, helping to identify any problems in the flight plan.

With the exception of being in Earth environment, integrated simulations were designed to look and feel as they would in space, except equipment did not malfunction as frequently in space as it did during simulations. Elaborate scripts always included a number of glitches, anomalies, and failures. Designed to bring the on-orbit and Mission Control teams together to work toward a solution, integrated simulations tested not only the crews and controllers but also the mission-specific Flight Rules.

An important part of astronaut crew training was a team-building activity completed through the National Outdoor Leadership School. This involved a camping trip that taught astronaut candidates how to be leaders as well as followers. They had to learn to depend on one another and balance each other's strengths and weaknesses. The astronaut candidates needed to learn to work together as a crew and eventually recognize that their crew was their family. Once a crew was assigned to a mission, these team-building

Team Building

Commander Mark Kelly took his crew and the lead International Space Station flight director to Alaska for a 10-day team-building exercise in the middle of mission training. These exercises were important, Kelly explained, as they provided crews with the "opportunity to spend some quality time together in a stressful environment" and gave the crews an opportunity to develop leadership skills. Because shuttle missions were so compressed, Kelly wanted to determine how his crew would react under pressure and strain. Furthermore, as a veteran, he knew the crew members had to work as a team. They needed to learn more about one another to perform effectively under anxious and stressful circumstances. Thus, away from the conveniences of everyday life, STS-124's crew members lived in a tent, where they could "practice things like team building, Expedition behavior, and working out conflicts." Building a team was important not only to Kelly, but also to the lead shuttle flight director who stressed the importance of developing "a friendship and camaraderie with the crew." To build that support, crew members frequently gathered together for social events after work. A strong relationship forged between the flight control team and crews enabled Mission Control to assess how the astronauts worked and how to work through stressful situations.

The STS-124 crew members celebrate the end of formal crew training with a cake-cutting ceremony in the Jake Garn Simulation and Training Facility at Johnson Space Center. Pictured from the left: Astronauts Mark Kelly, commander; Ronald Garan, mission specialist; Kenneth Ham, pilot; Japan Aerospace Exploration Agency Astronaut Akihiko Hoshide, Astronauts Michael Fossum, Karen Nyberg, and Gregory Chamitoff, all mission specialists. The cake-cutting tradition shows some of the family vibe between the training team and crew as they celebrate key events in an assigned crew training flow.

Prior to launch, astronauts walk around their launch vehicle at Kennedy Space Center.

activities became an important part of the mission-specific training flow. Teamwork was key to the success of a shuttle mission.

When basic training was complete, astronauts received technical assignments; participated in simulations, support boards, and meetings; and made public appearances. Many also began specialized training in areas such as EVA and robotic operations. Extensive preflight training was performed when EVAs were required for the mission.

Each astronaut candidate completed an EVA skills program to determine his or her aptitude for EVA work. Those continuing on to the EVA specialty completed task training and systems training, the first of which was specific to the tasks completed by an astronaut during an EVA while the latter focused on suit operations. Task training included classes on topics such as the familiarization and operation of tools. For their final EVA training, the astronauts practiced in a swimming pool that produced neutral buoyancy, which mimicked some aspect of microgravity. Other training included learning about their EVA suits, the use of the airlock in the Orbiter or ISS, and the medical requirements to prevent decompression sickness.

Mission-specific EVA training typically began 10 months before launch. An astronaut completed seven neutral buoyancy training periods for each spacewalk that was considered complex, and five training periods for noncomplex or repeat tasks. The last training runs before launch were usually completed in the order in which they would occur during the mission. Some astronauts found that the first EVA was more intimidating than the others simply because it represented that initial hurdle to overcome before gaining their rhythm. This concern was eased by practicing an additional Neutral Bouyancy Laboratory training run for their first planned spacewalk as the very last training run before launch.

EVA and robotic operations were commonly integrated, thereby creating the need to train both specialties together and individually. The robotic arm operator received specialized training with the arm on the ground using skills to mimic microgravity and coordination through a closed-circuit television.

EVA training was also accomplished in the Virtual Reality Laboratory, which was similarly used for robotic training. The Virtual Reality Laboratory complemented the underwater training with a more comfortable and flexible environment for reconfiguration changes. Virtual reality software was also used to increase an astronaut's situational awareness and develop effective verbal commands as well as to familiarize him or her with mass handling on the arm and r-bar pitch maneuver photography training.

T-38 aircraft training was primarily used to keep astronauts mentally conditioned to handle challenging, real-time situations. Simulators were an excellent training tool, but they were limited in that the student had the comfort of knowing that he or she was safely on the ground. The other benefit of T-38 training was that the aircraft permitted frequent and flexible travel, which was necessary to accommodate an astronaut's busy training schedule.

In Need of a Plumber

Just a few days before liftoff of STS-124, the space station's toilet broke. This added a wrinkle to the flight plan redrafted earlier. Russia delivered a spare pump to Kennedy Space Center, and the part arrived just in time to be added to Discovery's middeck. Storage space was always at a premium on missions. The last-minute inclusion of the pump involved some shifting and the removal of 15.9 kg (35 pounds) of cargo, including some wrenches and air-scrubber equipment. This resulted in changes to the flight plan—Discovery's crew and the station members would use the shuttle's toilet until station's could be used. If that failed, NASA packed plenty of emergency bags typically used by astronauts to gather in-flight urine specimens for researchers.

When the crew finally arrived and opened the airlock, Commander Mark Kelly joked, "Hey, you looking for a plumber?" The crews, happy to see each other, embraced one another.

Crew Prepares for Launch

With all systems "go" and launch weather acceptable, STS-124 launched on May 31, 2008, marking the 26th shuttle flight to the International Space Station. Three hours earlier, technicians had strapped in seven astronauts for NASA's 123rd Space Shuttle mission. Commander Mark Kelly was a veteran of two shuttle missions. By contrast, the majority of his crew consisted of rookies—Pilot Kenneth Ham along with Astronauts Karen Nyberg, Ronald Garan, Gregory Chamitoff, and Akihiko Hoshide of the Japan Aerospace Exploration Agency. Although launch typically represented the beginning of a flight, more than 2 decades of work went into the coordination of this single mission.

After suiting up, STS-124 crew members exited the Operations and Checkout Building to board the Astrovan, which took them to Launch Pad 39A for the launch of Space Shuttle Discovery. On the right (front to back): Astronauts Mark Kelly, Karen Nyberg, and Michael Fossum. On the left (front to back): Astronauts Kenneth Ham, Ronald Garan, Akihiko Hoshide, and Gregory Chamitoff.

There were roughly two dozen T-38 aircraft at any time, all of which were maintained and flown out of Ellington Field in Houston, Texas. As part of astronaut candidate training, they received T-38 ground school, ejection seat training, and altitude chamber training. Mission specialists frequently did not have a military flying background, so they were sent to Pensacola, Florida, to receive survival training from the US Navy. As with any flight certification, currency requirements were expected to be maintained. Semiannual total T-38 flying time minimum for a pilot was 40 hours. For a mission specialist, the minimum flight time was 24 hours. Pilots were also required to meet approach and landing minimum flight times.

Launching the Shuttle

Launch day was always exciting. KSC's firing room controlled the launch, but JSC's Mission Operations intently watched all the vehicle systems. The Mission Control Center was filled with activity as the flight controllers completed their launch checklists. For any shuttle mission, the weather was the most common topic of discussion

The Countdown Begins

The primary objective of the STS-124 mission was to deliver Japan's Kibo module to the International Space Station. As Commander Mark Kelly said, "We're going to deliver Kibo, or hope, to the space station, and while we tend to live for today, the discoveries from Kibo will certainly offer hope for tomorrow." The Japanese module is an approximately 11-m (37-ft), 14,500-kg (32,000-pound) pressurized science laboratory, often referred to as the Japanese Pressurized Module. This module was so large that the Orbiter Boom Sensor System had to be left on orbit during STS-123 (2008) to accommodate the extra room necessary in Discovery's payload bay.

During the STS-124 countdown, the area experienced some showers. By launch time, however, the sea breeze had pushed the showers far enough away to eliminate any concerns. The transatlantic abort landing weather proved a little more challenging, with two of the three landing sites forecasted to have weather violations. Fortunately, Moron Air Base, Spain, remained clear and became the chosen transatlantic abort landing site.

Space Shuttle Discovery and its seven-member STS-124 crew head toward low-Earth orbit and a scheduled link-up with the International Space Station.

and the most frequent reason why launches and landings were delayed. Thunderstorms could not occur too close to the launch pad, crosswinds had to be sufficiently low, cloud decks could not be too thick or low, and visibility was important. Acceptable weather needed to be forecast at the launch site and transatlantic abort landing sites as well as for each ascent abort option.

Not far from the launch pad, search and rescue forces were always on standby for both launch and landing. This included pararescue jumpers to retrieve astronauts from the water if a bailout event were to occur. The more well-known assets were the support ships, which were also supported by each of the military branches and the US Coast Guard. This team of search-and-rescue support remained on alert throughout a mission to ensure the safe return of all crew members.

Shortly before a launch, the KSC launch director polled the KSC launch control room along with JSC Mission Control for a “go/no go” launch decision. The JSC front room flight controllers also polled their back room flight controllers for any issues. If no issues were identified, the flight controllers, representing their specific discipline, responded to the flight director with a “go.” If an issue was identified, the flight controller was required to state “no go” and why. Flight Rules existed to identify operational limitations, but even with these delineations the decision to launch was never simple.

Fly

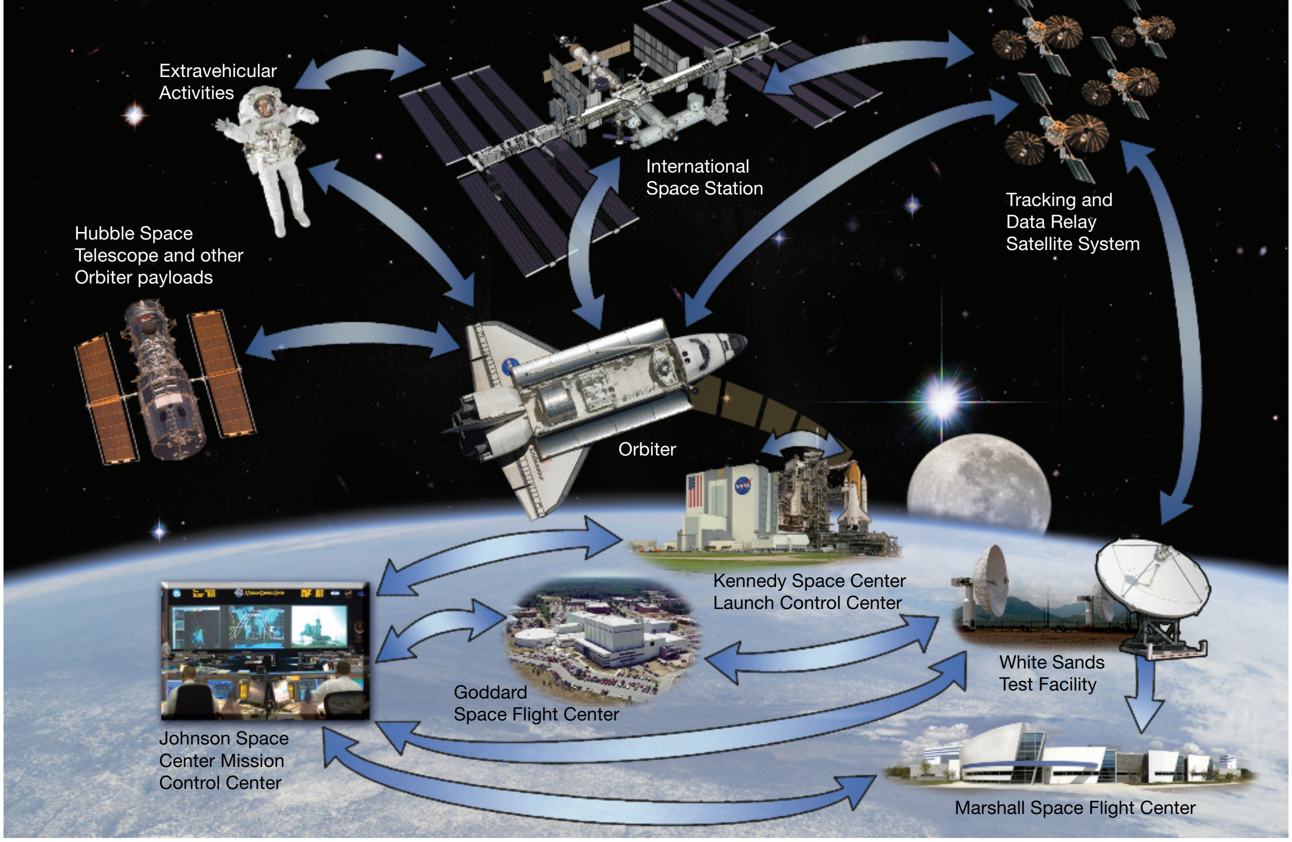
Ground Facilities Operations

The Mission Control Center relied on the NASA network, managed by Goddard Space Flight Center (GSFC), to route the spacecraft downlink telemetry, tracking, voice, and television and uplink voice, data, and command. The primary in-flight link was to/from the Mission Control Center to the White Sands Ground Terminal up to the tracking and data relay satellites and then to/from the Orbiter. In addition, there were still a few ground sites with a direct linkage to/from the Orbiter as well as specific C-band tracking sites for specific phases as needed. The preflight planning function included arranging for flight-specific support from all these ground facilities and adjusting them, as necessary, based on in-flight events. The readiness of all these support elements for each flight was certified by the GSFC network director at the Mission Operations Flight Readiness Review.

The Mission Control Center was the focus of shuttle missions during the flight phase. Control of the mission and communication with the crew transferred from the KSC firing room to the JSC Mission Control Center at main engine ignition. Shuttle systems data, voice communications, and television were relayed almost instantaneously to the Mission Control Center through the NASA ground and space networks. In many instances, external facilities such as MSFC and GSFC as well as US Air Force and European Space Agency facilities also provided support for specific payloads. The facility support effort, the responsibility of the operations support team, ensured the Mission Control Center and all its interfaces were ready with the correct software, hardware, and interfaces to support a particular flight.

The Mission Control Center front room houses the capsule communicator, flight director and deputy, and leads for all major systems such as avionics, life support, communication systems, guidance and navigation, extravehicular activity lead and robotic arm, propulsion and other expendables, flight surgeon, and public affairs officer. These views show the extensive support and consoles. ***Left photo:*** *At the front of the operations center are three screens. The clocks on the left include Greenwich time, mission elapsed time, and current shuttle commands. A map of the world with the shuttle position-current orbit is in the center. The right screen shows shuttle attitude.* ***Center photo:*** *Flight Director Norman Knight (right) speaks with one of the leads at the support console.* ***Right photo:*** *Each console in the operations center has data related to the lead’s position; e.g., the life support position would have the data related to Orbiter air, water, and temperature readings and the support hardware functions.*

Primary Communication and Data Paths for the Space Shuttle



Just before shuttle liftoff, activity in the Mission Control Center slowed and the members of the flight control team became intently focused on their computer screens. From liftoff, the performance of the main engines, SRBs, and ET were closely observed with the team ready to respond if anything performed off-nominally. If, for example, a propulsion failure occurred, the flight control team would identify a potential solution that may or may not require the immediate return of the Orbiter to the ground. If the latter were necessary, an abort mode (i.e., return to launch site, transatlantic abort landing) and a landing site would be selected. The electrical systems and the crew environment also had to function correctly while the Orbiter was guided into orbit. For the entire climb to orbit, personnel in the Mission Control Center remained intensely focused. Major events were called out during the ascent. At almost 8½ minutes, when target velocity was achieved, main engine cutoff was commanded by the on-board computers and flight controllers continued verifying system performance. Every successful launch was an amazing accomplishment.

Before and after a shuttle launch, KSC personnel performed walkdowns of the launch pad for a visual inspection of any potential debris sources. Shuttle liftoff was a dynamic event that could cause ice/frost or a loose piece of hardware to break free and impact the Orbiter. Finding these debris sources and preventing potential damage was important to the safety of the mission.

Debris Impact on the Orbiter

Debris from launch and on orbit could make the Orbiter unable to land. The Orbiter could also require on-orbit repair.

Ascent Inspection

After the Columbia accident (2003), the shuttle was closely observed during the shuttle launch and for the duration of the ascent phase by a combination of ground and vehicle-mounted cameras, ground Radio Detection and Ranging, and the Wing Leading Edge Impact Detection System. The ground cameras were located on the fixed service structure, the mobile launch platform, around the perimeter of the launch pad, and on short-, medium-, and long-range trackers located along the Florida coast. The ground cameras

Orbiter Survey

Astronaut Karen Nyberg, STS-124, works the controls on the aft flight deck of Space Shuttle Discovery during Flight Day 2 activities.

The Orbiter survey included the Orbiter's crew cabin Thermal Protection System and the wing leading edge and nose cap reinforced carbon-carbon using the Shuttle Robotic Arm and the Orbiter Boom Sensor System. The survey involved detailed scanning in a specified pattern and required most of the day to complete. A focused inspection was only performed when a suspect area was identified and more detailed information was required to determine whether a repair or alternative action was necessary.

Due to the unique nature of the STS-124 mission, the Shuttle Robotic Arm was used instead of the Orbiter Boom Sensor System. Astronaut Karen Nyberg operated the robotic arm for the inspection of the Thermal Protection System. The nose cap and wing leading edge reinforced carbon-carbon survey was scheduled for post undock after the Orbiter Boom Sensor System had been retrieved during a Flight Day 4 extravehicular activity.

provided high-resolution imagery of liftoff and followed the vehicle through SRB separation and beyond. The vehicle-mounted cameras were strategically placed on the tank, boosters, and Orbiter to observe the condition of specific areas of interest and any debris strikes. The crew took handheld video and still imagery of the tank following separation when lighting conditions permitted. This provided another source of information to confirm a clean separation or identify any suspect areas on the tank that might potentially represent a debris concern for the Orbiter Thermal Protection System. The Wing Leading Edge Impact Detection System used accelerometers mounted within the Orbiter's wing leading edge to monitor for impacts throughout the ascent and orbit phases, power permitting.

The world's largest C-band radar and two X-band radars played an integral role in the ascent debris observation through a valuable partnership with the US Navy. The C-band radar watched for falling debris near the Orbiter, and the X-band radar further interpreted the velocity characteristics of any debris events with respect to the vehicle's motion. The X-band radars were on board an SRB recovery ship located downrange of the launch site and a US Army vessel south of the groundtrack. The US Navy C-band radar sat just north of KSC.

Data collected from ground and vehicle-mounted cameras, ground radar, and the Wing Leading Edge Impact Detection System created a comprehensive set of ascent data. Data were sent to the imagery analysis teams at JSC, KSC, and MSFC for immediate review. Each team had its area of specialty; however, intentional overlap of the data analyses existed as a conservative measure. As early as 1 hour after launch, these teams of imagery specialists gathered in a dark room with a large screen and began reviewing every camera angle captured. They watched the videos in slow motion, forward, and backward as many times as necessary to thoroughly analyze the data. The teams were looking for debris falling off the vehicle stack or even the pad structure that may have impacted the Orbiter. If the team observed or even suspected a debris strike on the Orbiter, the team reported the location to the mission management team and the Orbiter damage assessment team for on-orbit inspection. The damage assessment team oversaw the reported findings of the on-orbit imagery analysis and delivered a recommendation to the Orbiter Project Office and the mission management team stating the extent of any damage and the appropriate forward action. This cycle of obtaining imagery, reviewing imagery, and recommending forward actions continued throughout each phase of the mission.

On-orbit Inspections

The ISS crew took still images of the Orbiter as it approached the station and performed maneuvers, exposing the underside tiles. Pictures were also taken of the ET umbilical doors to verify proper closure as well as photos of the Orbiter's main engines, flight deck windows, Orbital Maneuvering System pods, and vertical stabilizer. The shuttle crew photographed the pods and the leading edge of the vertical stabilizer from the windows of the flight deck. The ISS crew took still images of the Orbiter. All images were downlinked for review by the damage assessment team.

For all missions to the ISS that took place after the Columbia accident, late inspection was completed after the Orbiter undocked. This activity included a survey of the reinforced carbon-carbon to look for any micrometeoroid orbital debris damage that may have occurred during the time on orbit. Since the survey was only of the reinforced carbon-carbon, it took less time to complete than did the initial on-orbit survey. As with the Flight Day 2 survey, the ground teams compared the late inspection imagery to Flight Day 2 imagery and either cleared the Orbiter for re-entry or requested an alternative action.

On-orbit Activities

Extravehicular Activity Preparation

For missions that had EVAs, the day after launch was reserved for extravehicular mobility unit checkout and the Orbiter survey. EVA suit checkout was completed in the airlock where the suit systems were verified to be operating correctly. Various procedures developed over the nearly 30-year history for an EVA mission were implemented to prevent decompression sickness and ensure the crew and all the hardware were ready. The day of the EVA, both crew members suited up with the assistance of the other crew members and then left the airlock. EVAs involving the Shuttle Robotic Arm required careful coordination between crew members. This was when the astronauts applied the meticulously practiced verbal commands.

For missions to the ISS, the primary objective of Flight Day 3 was to rendezvous and dock with the ISS. As the Orbiter approached the ISS, it performed a carefully planned series of burns to adjust the orbit for a smooth approach to docking.

A Flawless Rendezvous

On day three, STS-124 rendezvoused and docked with the space station. About 182 m (600 ft) below the station, Commander Mark Kelly flipped Discovery 360 degrees so that the station crew members could photograph the underbelly of the shuttle. Following the flip, Kelly conducted a series of precise burns with the Orbital Maneuvering System, which allowed the shuttle—flying about 28,200 km/hr (17,500 mph)—to chase the station, which was traveling just as fast. Kelly, who had twice flown to the station, described the moment: “It’s just incredible when you come 610 m (2,000 ft) underneath it and see this giant space station. It’s just an amazing sight.” Once the Orbiter was in the same orbit with the orbiting lab, Kelly nudged the vehicle toward the station. As the vehicle moved, the crew encountered problems with the Trajectory Control System, a laser that provided range and closure rates. This system was the primary sensor, which the crew members used to gauge how far they were from the station. Luckily, the crew had simulated this failure numerous times, so the malfunction had no impact on the approach or closure. The lead shuttle flight director called the rendezvous “absolutely flawless.” Upon docking ring capture, the crew congratulated Kelly with a series of high fives.

Trust and Respect Do Matter

During activation of the Japanese Experiment Module, the flight controllers in Japan encountered a minor hiccup. As the crew attached the internal thermal control system lines, ground controllers worried that there was an air bubble in the system’s lines, which could negatively impact the pump’s performance. Controllers in Houston, Texas, and Tsukuba, Japan, began discussing options. The International Space Station (ISS) flight director noticed that the relationship she had built with the Japanese “helped immensely.” The thermal operations and resource officer had spent so many years working closely with his Japan Aerospace Exploration Agency counterpart that, when it came time to decide to use the nominal plan or a different path, “the respect and trust were there,” and the Japanese controllers agreed with his recommendations to stay with the current plan. “I think,” the ISS flight director said, “that really set the mission on the right course, because then we ended up proceeding with activation.”

On-orbit Operations

Within an hour of docking with the ISS, the hatch opened and the shuttle crew was welcomed by the ISS crew. For missions consisting of a crew change, the first task was to transfer the custom Soyuz seat liners to crew members staying on station. Soyuz is the Russian capsule required for emergency return to Earth and for crew rotations. Completion of this task marked the formal change between the shuttle and ISS crews.

Every mission included some housekeeping and maintenance. New supplies were delivered to the station and old supplies were stowed in the Orbiter for return to Earth. Experiments that completed their stay on board the ISS were also returned home for analyses of the microgravity environment's influence.

Returning Home

If necessary, a flight could be extended to accommodate extra activities and weather delays. The mission management team decided on flight extensions for additional activities where consideration was given for impacts to consumables, station activities, schedule, etc. Landing was typically allotted 2 days with multiple opportunities to land. NASA's preference was always to land at KSC since the vehicle could be processed at that facility; however, weather would sometimes push the landing to Dryden Flight Research Center/Edwards Air Force Base. If the latter occurred, the Orbiter was flown back on a modified Boeing 747 in what was referred to as a "ferry flight."

Once the Orbiter landed and rolled to a stop, the Mission Control Center turned control back to KSC. After landing, personnel inspected the Orbiter for any variations in Thermal Protection System and reinforced carbon-carbon integrity. More imagery was taken for comparison to on-orbit imagery. Once the Orbiter was at the Orbiter Processing Facility, its cameras were removed for additional imagery analysis and the repairs began in preparation for another flight.

Returning to Earth

Space Shuttle Discovery's drag chute is deployed as the spacecraft rolls toward a stop on runway 15 of the Shuttle Landing Facility at Kennedy Space Center, concluding the 14-day STS-124 mission to the International Space Station.

After nearly 9 days at the space station, the crew of STS-124 undocked and said farewell to Gregory Chamitoff, who would be staying on as the flight engineer for the Expedition crew, and the two other crew members. When watching the goodbyes on video, it appeared as if the crew said goodbye, closed the hatch, and dashed away from the station. "It's more complicated than that," Commander Mark Kelly explained. "You actually spend some time sitting on the Orbiter side of the hatch." About 1 hour passed before the undocking proceeded. Afterward, the crew flew around the station and then completed a full inspection of the wing's leading edge and nose cap with the boom.

The crew began stowing items like the Ku-band antenna in preparation for landing on June 15. On the day of landing, the crew suited up and reconfigured the Orbiter from a spaceship to an airplane. The re-entry flight director and his team worked with the crew to safely land the Orbiter, and continually monitored weather conditions at the three landing sites. With no inclement weather at Kennedy Space Center, the crew of STS-124 was "go" for landing. The payload bay doors were closed several minutes before deorbit burn. The crew then performed checklist functions such as computer configuration, auxiliary power unit start, etc. Sixty minutes before touchdown the deorbit burn was performed. After the Columbia accident, the re-entry profiles for the Orbiter changed so that the crew came across the Gulf of Mexico, rather than the United States. As the Orbiter descended, the sky turned from pitch black to red and orange. Discovery hit the atmosphere at Mach 25 and a large fireball surrounded the glider. It rapidly flew over Mexico. By the time it passed over Orlando, Florida, the Orbiter slowed. As they approached the runway, Kelly pulled the nose up and lowered the landing gear. On touchdown—after main gear touchdown but before nose gear touchdown—he deployed a parachute, which helped slow the shuttle as it came to a complete stop.

The Shuttle Carrier Aircraft transported the Space Shuttle Endeavour from Dryden Research Center, California, back to Kennedy Space Center, Florida.

Solid Foundations Assured Success

Two pioneers of flight operations, Christopher Kraft and Gene Kranz, established the foundations of shuttle mission operations in the early human spaceflight programs of Mercury, Gemini, and Apollo. Their “plan, train, fly” approach made controllers tough and competent, “flexible, smart, and quick on their feet in real time,” recalled the lead flight director for STS-124 (2008). That concept, created in the early 1960s, remained the cornerstone of mission operations throughout the Space Shuttle Program, as exemplified by the flight of STS-124.

Endeavour touches down at Dryden Flight Research Center located at Edwards Air Force Base in California to end the STS-126 (2008) mission.