The Final Count Down: A Review of Three Decades of Flight Controller Training Methods for Space Shuttle Mission Operations

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Operations of human spaceflight systems is extremely complex; therefore, the training and certification of operations personnel is a critical piece of ensuring mission success. Mission Control Center (MCC-H), at the Lyndon B. Johnson Space Center in Houston, Texas, manages mission operations for the Space Shuttle Program, including the training and certification of the astronauts and flight control teams. An overview of a flight control team's makeup and responsibilities during a flight, and details on how those teams are trained and certified, reveals that—while the training methodology for developing flight controllers has evolved significantly over the last thirty years—the core goals and competencies have remained the same. In addition, the facilities and tools used in the control center have evolved. Changes in methodology and tools have been driven by many factors, including lessons learned, technology, shuttle accidents, shifts in risk posture, and generational differences. Flight controllers share their experiences in training and operating the space shuttle. The primary training method throughout the program has been mission simulations of the orbit, ascent, and entry phases, to truly "train like you fly." A review of lessons learned from flight controller training suggests how they could be applied to future human spaceflight endeavors, including missions to the moon or to Mars. The lessons learned from operating the space shuttle for over thirty years will help the space industry build the next human transport space vehicle.

I. Introduction

FOR 30 years, NASA's Space Transportation System (STS), also known as the shuttle program, was the United States' launch vehicle for the human spaceflight program. With the last shuttle launch on July 8, 2011, NASA is exploring alternatives for future launch vehicles; attention to lessons learned during the shuttle program will serve NASA well in making its launch vehicle decision. Therefore, it is timely to review and assess an essential aspect of the STS program: training and certification of operations personnel.

Johnson Space Center (JSC) is the center for human spaceflight training, research, and flight control. The daily operation of the space shuttle has been conducted at the JSC Mission Control Center (MCC-) in Houston, Texas. The main task of an MCC is to manage space missions, from lift-off until the landing or the end of the mission. Flight controllers, flight crew, and other support personnel provide real-time support of all aspects of the mission, including vehicle telemetry monitoring, commanding, mission planning, and trajectory design. MCC personnel include operations subject matter experts for the attitude control system, power, propulsion, thermal, attitude dynamics, orbital operations, and other subsystem disciplines.[1] Each controller is an expert in a specific technical area, and is in constant communication with additional experts.

Training and certification of operations personnel are critical elements in mission success. Training for human spaceflight missions usually falls under the responsibility of dedicated training personnel. The flight controller and mission crew training typically includes extensive rehearsals in the MCC called simulations (also known as "sims"). A review of training methods and simulations developed over the 30-year shuttle program, as well as related lessons learned, can help NASA plan for the next era of human spaceflight.

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II. The Mission Control Room

Before the space shuttle program began, the room where the flight controllers worked was called the Mission Operations Control Room (MOCR); for the last three decades it has been called the Flight Control Room (FCR). A description of the control room layout and the responsibilities of each participant sets the stage for understanding the complexity of each subsystem role, the importance of effective flight controller training, and how the training is implemented in the human flight program.

The FCR has four rows of consoles; each console is dedicated to a specific area of expertise. Each console is labeled with an abbreviation that clearly identifies the responsibility. MCC seat assignments are shown in Figure 1; Table 1 describes controller roles and responsibilities.

Every flight controller is a subject matter expert in his or her system and makes recommendations about the system to the flight director. Any controller may call for an abort if certain flight rules are violated or if circumstances require an abort to keep the crew and vehicle safe. Before major mission events (such as an on-orbit space burn) in the flight plan take place, the flight director "goes around the room" to poll each subsystem for a GO/NO-GO decision. If the subsystem is in good working order, the responsible controller calls for a GO, but if there is a problem in a subsystem, the responsible controller's call is NO GO, and the flight director holds or aborts the event.[2]

Space shuttle flight controllers work relatively brief periods, especially compared to their International Space Station (ISS) counterparts: the several minutes of ascent, the few days the vehicle is in orbit, and reentry. The duration of operations for space shuttle flight controllers is short and time-critical. A failure on a critical phase of the shuttle flight could leave flight controllers little time for decision making, so it is essential that they respond quickly to mitigate potential failures. The controller's ability to send commands to the shuttle for system reconfigurations is limited; if a reconfiguration is needed, then the desired

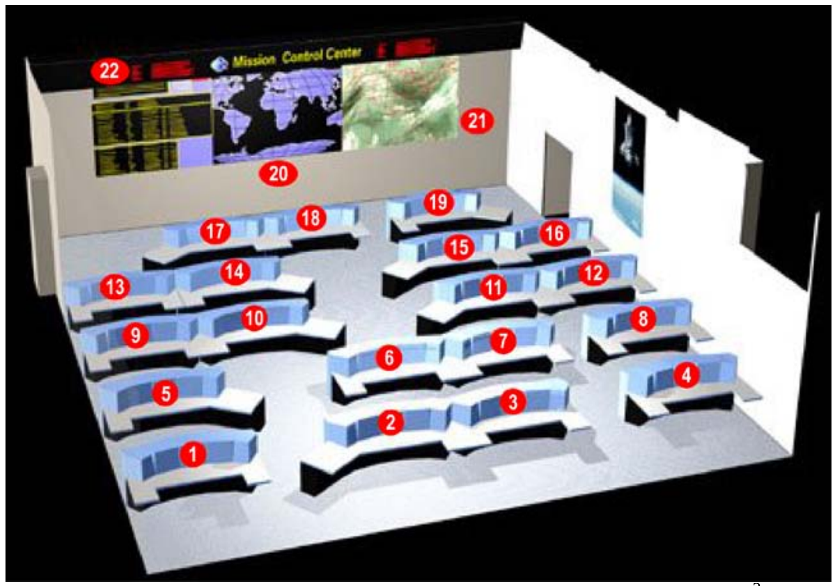

Figure 1:Console locations in the MCC are identified by number. [3]

1. Public Affairs Officer (PAO)
2. Mission Operations Directorate Manager (MOD)
3. Booster Systems Engineer (BOOSTER) and External Vehicle Activity Officer (EVA)
4. Surgeon (SURGEON)
5. Integrated Communications Officer (INCO)
6. Flight Director (FLIGHT)
7. Spacecraft Communicator (CAPCOM)
8. Payload Deployment and Retrieval System (PDRS)
9. Data Processing System Engineer (DPS)
10. Assembly and Checkout Officer (ACO)
11. Flight Activities Officer (FAO)
12. Electrical, Environmental, and Consumables Manager (EECOM)
13. Propulsion Engineer (PROP)
14. Guidance, Navigation, and Controls Systems Engineer (GNC)
15. Maintenance, Mechanical, Arm, and Crew Systems (MMACS)
16. Electrical Generation and Illumination Engineer (EGIL)
17. Flight Dynamics Officer (FDO) and Trajectory Officer (TRAJ)
18. Guidance and Procedures Officer (GPO) or Rendezvous (RNDZ)
19. Ground Controller (GC)
20. Worldmap Screen
21. TV Screen
22. Mission Clocks/Telemetry Data

Image courtesy of the National Aeronautics and Space Administration.

configuration is relayed via the subsystem controller to the spacecraft communicator (CAPCOM) and then to the shuttle crew.

Flight controllers feel very responsible for the success of the mission and for the lives of the astronauts under their watch. There is a phrase often heard in the FCR: “Always be aware that suddenly and unexpectedly we may find ourselves in a role where our performance has ultimate consequences.”

Table 1. Mission Operations Control Room Team: Roles and Responsibilities During Flight.[3]

Role	Console Label	Position (cf Fig. 1)*	Responsibility
Assembly and Checkout Officer	ACO	10	Develops ISS assembly, activation and checkout operations, including the responsibility for any required integrated procedures. Coordinates these activities in real-time. Coordinates payload and transfer operations. Responsible for ISS visiting vehicle systems integration, safety, and all docked operations, including transfer operations, plans, procedures, and systems commanding and telemetry.ACO was formerly known as PAYLOADS.
Booster Systems Engineer	BOOSTER	3	Monitors and evaluates performance of propulsion-related aspects of the launch vehicle during prelaunch and ascent, including the main engines and solid rocket boosters.
Data Processing System Engineer	DPS	9	Responsible for data processing systems in a space flight. Monitors the onboard general-purpose computers , flight-critical launch and payload data buses, the multi-function electronic display system, solid-state mass memory units, flight-critical and payload multiplexer/de-multiplexer units, master timing unit, backup flight control units, and system-level software. The space shuttle general-purpose computers are a critical subsystem, and the vehicle cannot fly without them.
Electrical, Environmental, and Consumables Manager	EECOM	12	Maintains atmospheric pressure control and revitalization systems, cooling systems (air, water, and freon), and supply/waste water system. EECOM's critical function is to maintain the systems, such as atmosphere and thermal control, that keep the crew alive.
Electrical Generation and Illumination Engineer	EGIL	16	Monitors cryogenic levels for the fuel cells, electrical generation, and distribution systems on the spacecraft, as well as vehicle lighting. This is a portion of the job was formerly done by EECOM.
Extravehicular Activity Officer	EVA		Responsible for all spacesuit and spacewalking–related tasks, equipment, and plans when the EVA takes place from the shuttle. The EVA officer shares a console with BOOSTER. EVA uses the console during the orbit phase of the flight.
Flight Activities Officer	FAO	11	Coordinates implementation of the flight plan and develops alternate and flight plans, as required. Provides the capability to transfer data (text, graphics, and video) between a ground PC network and the orbiter laptops.
Flight Director	FLIGHT	6	Provides overall management and authority for flight execution. Responsible for the detailed control of the mission, from prelaunch until post landing.
Flight Dynamics Officer	FDO	17	Responsible for the flight path of the space shuttle, both atmospheric and orbital. Monitors vehicle performance during the powered flight phase and assesses abort modes, calculates orbital maneuvers and resulting trajectories, and monitors vehicle flight profile and energy levels during re-entry. The FDO and TRAJ share a console in the MCC.

Role	Console Label	Position (cf Fig. 1)*	Responsibility
Ground Controller	GC	19	Directs maintenance and operation activities affecting MCC hardware, software, and support facilities. Coordinates spaceflight tracking and data network. CoordinatesTracking and Data Relay Satellite System with Goddard Space Flight Center.
Guidance and Procedures Officer	GPO	18	Depending on the phase of flight the mission is in, position 18 is either staffed by GPO (a specialist in the procedures related to flight or RNDZ (a specialist in orbital rendezvous procedures). GPO is responsible for monitoring the Shuttle guidance and navigation as well as execution of crew procedures, particularly for ascent abort situations.
Guidance, Navigation, and Controls Systems Engineer	GNC	14	Responsible for operating and monitoring the sensor system, which includes navigation sensors and associated software. Responsible for flight control system hardware and software, which includes aero and reaction control system controls, digital autopilots, main engines, solid rocket boosters, and orbital maneuvering system thrust vector control with associated software.
Integrated Communications Officer	INCO	5	Responsible for all data, voice and video communications systems. Monitors the configuration of in-flight communications and instrumentation systems. Monitors the telemetry link between the vehicle and the ground. Oversees the uplink command and control processes. This position evolved directly from the Apollo program Integrated Communications Officer role.
Maintenance, Mechanical, Arm, and Crew Systems	MMACS	15	Responsible for space shuttle structural and mechanical systems. Monitors auxiliary power units and hydraulic systems. Manages payload bay door, external tank umbilical door, vent door, radiator deploy/stow, Ku-band antenna deploy/stow, and payload retention latch operations, landing gear/deceleration systems (landing gear deploy, tires, brakes/antiskid, and drag chute deploy).Monitors the orbiter docking system. Tracks use of onboard crew hardware and in-flight equipment maintenance. This represents aportion of the job formerly done by EECOM, with additional responsibilities added by the specific requirements of space shuttle operations. The MMACS officer serves as the point of contact for PDRS, BOOSTER, and EVA during periods in a mission when these positions do not require constant staffing.
Mission Operations Directorate Manager	MOD	2	Serves as an upper management interface to the flight operations team.
Payload Deployment and Retrieval System	PDRS	8	Responsible for space shuttle remote manipulator system, also known as "robot arm."
Propulsion Engineer	PROP	13	Manages the reaction control thrusters and orbital maneuvering engines during all phases of flight. Monitors fuel usage and propellant tank status. Calculates optimal sequences for thruster firings.
Public Affairs Officer	PAO	1	Serves as a liaison between the public information media and the flight operations team.

Role	Console Label	Position (cf Fig. 1)*	Responsibility
Rendezvous	RNDZ	18	Depending on the phase of flight the mission is in, position 18 is either staffed by GPO (a specialist in the procedures related to flight or RNDZ (a specialist in orbital rendezvous procedures). RNDZ is.responsible for activities such as trajectory operations related to the rendezvous and docking/capture with another spacecraft, including the Mir space station, ISS, and satellites such as the Hubble Space Telescope.
Spacecraft Communicator	CAPCOM	7	Provides air-to-ground communication between the flight crew members and ground support team. Ensures that ground recommendations regarding vehicle maintenance and control are transmitted clearly and appropriately to the crew.
Surgeon	SURGEON	4	Provides real-time medical consultation on issues related to flight crew member health and safety.
Trajectory Officer	TRAJ	17	Assists the FDO during time-critical operations. Maintains the various processors that help determine the shuttle's current and potential trajectories. A controller who wants to become a flight dynamics officer must first be certified as a trajectory officer. The FDO and TRAJ share a console in the MCC.

* Note: Mission Clocks/Telemetry Data (22 in Figure 1), TV Screen (21), World Map Screen (20), are not flight controller positions

III. Training Pre-Challenger

A. Evolving Processes: From Workbooks to Simulations

NASA began space shuttle flight controller training in the late 1970s, years before the first shuttle launch. This training involved a variety of tasks intended to build vehicle system expertise and core flight control skills, which had evolved from previous human spaceflight programs such as Gemini and Apollo.[4] Because the shuttle design was not yet stable, shuttle operations practices were evolving rapidly, and flight controllers by necessity developed the operations documentation as they learned the systems. Early training primarily involved reading workbooks on different systems and pieces of hardware. Occasionally a flight controller would research a piece of hardware and present the findings to the group as a lecture. Office time was spent studying and working on operational documents to help the flight controller prepare for simulations.[‡] Additionally, flight controllers developed and reviewed crew procedures, flight rules, system drawings, and malfunction procedures; these documents in turn became the primary training materials used in simulations. Flight controllers supported operations boards, project meetings, and program meetings. They coordinated, reviewed, and dispositioned the many hardware and software changes that occurred on a weekly basis. As basic console operations were established, console positions identified, and support positions staffed, the simulations revealed weaknesses in console operations that had to be fixed. Every day required attention to changes and preparation for future simulations.

Shuttle flight simulations began approximately 1 year prior to the first launch (as originally scheduled in 1978). However, as the launch was delayed several times, the STS-1 teams had several years and hundreds of hours of simulations prior to the actual launch.[§] Participants in these simulations staffed consoles in the MCC that were connected to a shuttle vehicle simulator. The simulations executed a piece of the mission timeline, and allowed flight controllers to execute procedures, and respond to malfunctions. The malfunctions were inserted by instructors to evaluate flight controller performance.

Ascent and entry teams conducted 6-hour simulations weekly to test the flight controllers on console. Flight phases were defined the same as they are today: The ascent phase of lift begins at liftoff and continues until the vehicle is in a safe low-Earth orbit (LEO) or until an abort landing is achieved. The orbit phase of flight begins after the vehicle is in a safe orbit and lasts until preparation for re-entry back to Earth. The entry phase of flight starts from the in-space de-orbit burn and ends with space shuttle touchdown.[5] The ascent and entry phases of flight require more training time because there is very little time, on the order of seconds, to make real-time decisions. .In comparison, the orbit phase allows more time, on the order of minutes or hours, to make decisions because the

[‡] R. Dittemore, personal communication, April 4, 2011
[§] W. Hale, personal communication, May 10, 2011

vehicle systems are less dynamic and allow more time to analyze failures or anomalies. As a result, less intense training is required for the orbit phase.

Early in the space shuttle program there were no software tools to assist in flight controller decisionmaking.[**] The information available was read from basic: displays of data and "advisory lights" that represented binary information; the operator had to identify and interpret the information quickly. These initial displays were based on Apollo telemetry requirements, and each display provided specific and limited insight to the vehicle systems. Multiple displays (data/plots) were needed to decipher and troubleshoot data. Console operations involved intensive data review, both real time and non–real time. During early missions, real-time telemetry was available for only brief periods of orbit time until the constellation of Tracking and Data Relay Satellites (TDRS) was developed to provide nearly continuous data.[††]

Even in the very early days of shuttle training, instructors developed simulations to "stretch" the console operators' knowledge and to identify weaknesses in procedures, flight rules, and mission plan. Simulations explored the way the flight system truly behaved, which sometimes differed from the original intentions of the spacecraft designers. The degree of difficulty varied depending upon the simulation objectives; operators could not be certified unless they were able to handle the full range of scenarios.[‡‡] The instructors also developed simulations that would stress the hardware and software system to help the team understand how the system would react in specific flight phases. This sometimes differed from the original intentions of the spacecraft designers

These simulations also uncovered issues that vehicle testing and certification had missed. For example, in an April 19, 1999 simulation, Backup Flight Software (BFS) took control of the space shuttle as planned, but an unexpectedly high pitch rate resulted. The vehicle pitched up over 360 degrees before operators could regain control. The simulation was rerun several times and the problem was reproduced. This BFS issue was corrected on the flight vehicles, and simulation data validated this change. Failures were welcome during training, as they indicated that the simulation hardware and software sufficiently stressed the system. "Crashes" were common in early simulations and sometimes the simulation efficacy was questionable. Simulations evolved and became more complex as the systems and software were better understood. As in any integrated system, the software was the most difficult part of the equation, with heavy demands on time, effort, and resources.[§§]

Although simulation schedules varied in the 1970s, simulations were usually held once or twice a week to accommodate the continuous systems development. By 1983, simulations were being held every day because the simulator had been sufficiently developed to handle the rigors of a daily run.[6] Additionally, the mission manifest had grown, and more certified individuals were needed in a variety of positions to support multiple missions.

B. Training and Certification Standards

At the beginning of the shuttle program and into the late 1980s, there were no set standards for training or certification. In addition to there being no set standards for training, there was no minimum number of simulations required for certification Controllers studied the systems, developed documentation, and participated in simulations to learn how to operate the shuttle.[***]

The basic qualifications for flight controllers were talent and skill in communication, failure recognition, and leadership, as well as an ability to handle the fast pace and stress of the operations environment. The flight controllers were evaluated on seven main categories. Mission cognizance deals with maintaining "big picture" awareness of the shuttle vehicle configuration and prioritizing discipline activities. Systems knowledge deals with understanding how to maintain and operate the vehicle efficiently with respect to current conditions. Problem recognition and resolution tests the knowledge of the existence of a problem, and the ability to diagnose and develop multiple solution options along with appropriate rationale. Console management testing involves understanding the limits of the console tools and appropriate use during different phases of flight. Communication is evaluated on timeliness of response, clarity, proactivness, and accuracy. Team management involves the trainee's ability to accept or give direction, balance work load, and prioritize team tasks. Attitude/effort assesses the trainee's honesty, how he or she deals with difficult situations, and whether or not full effort is made.

Mission-specific simulations are conducted each flight to allow the crew and flight control teams to practice various parts of the mission timeline before a flight. These mission-specific simulations are very different from generic training simulations. The generic simulations are filled with multiple malfunctions to test and train

** R. Dittemore, personal communication, April 4, 2011
†† T. Ceccacci, personal communication, May 11, 2011
‡‡ W. Hale, personal communication, May 10, 2011
§§ R. Dittemore, personal communication, April 4, 2011
*** T. Ceccacci, personal communication, May 11, 2011

uncertified flight controllers. Initially, flight controllers were trained in generic simulations for "backroom" positions—system-specific experts responsible for the details of their assigned systems. The backroom in the mission control room is called the multi-purpose support room (MPSR). The backroom positions (MPSR) were the training positions used to first introduce the operations principles to new hires and new console operators. The expectation was that as personnel learned more about shuttle operations and attained a MPSR certification, they would then move to front control room (FCR) positions, where operators are responsible for appropriately integrating their systems' requirements with other system operators.[5] Additionally, the FCR position was responsible for providing a plan, operational changes, and recommendations to the Flight Director.[†††]

When a controller finished the training for a certain position, a final evaluation simulation was scheduled. In the final evaluation for certification, the individual was presented with multiple failures and complex situations. The final simulation was a onetime case with more failures than would occur in real time operations or generic simulations. These evaluations were conducted by senior experienced flight controllers. If in the judgment of the senior flight controllers the trainees performed well and met the category objectives listed above, they were considered to be certified. Over time, evaluation criteria were established for certification, and evaluators would formally assess each candidate against these criteria to complete the certification process. Many controllers came up with their own ways to recall information on console. For example, some controllers developed a set of "cue cards" that helped them remember specific flight phase characteristics, timelines, and other critical information. As more and more people developed individual sets, the operations team identified the best cue cards, which were formalized and became part of the training.[‡‡‡]

IV. Training Improvements in the 1990s

Over the years, there were many catalysts for change in the shuttle operations environment, which in turn improved flight controller training: lessons were learned from experience and practices adjusted accordingly; software improvements provided greater details into down linked data from the shuttle; operations moved to a new control center; and the two space shuttle accidents initiated changes in nearly every aspect of shuttle operations.

Figure 2. 1980s-era MCC (Courtesy NASA)

A. After the Challenger Accident

After the Challenger accident in 1987, there was a down period for training simulations. The Challenger accident resulted in an in-depth review of all flight phase operations, procedures, and flight rules to ensure operational rigor. New flight rules were written and procedures were revised, which resulted in simulations becoming more complex. The review period also allowed time for a more formal training process to be formulated. Development started on a training guide, today called the "blue book," and detailed training flows were created. Instructor-led technical classes were created to supplement the workbooks, with topics ranging from hardware to crew procedures. Shuttle onboard software was updated to be more efficient and help with failure scenarios.[§§§] Additional desktop computers were also added to the MCC to augment display data (Figure 2).

Figure 3. Current MCC (Courtesy NASA)

The transition to a new MCC facility (Figure 3) occurred in the mid 1990s. The control center provided modernized hardware and software, with an increase in the number of available displays, communication resources, data availability, playback, and data plotting.

[†††] T. Ceccacci, personal communication, May 11, 2011
[‡‡‡] R. Dittemore, personal communication, April 4, 2011
[§§§] T.Ceccacci, personal communication, May 11, 2011

Communication panels, which flight controllers used to talk to each other on "voice loops," changed from back-lighted mechanical push buttons to programmable touch screens.[5] Display capability was greatly increased. Instead of viewing data from a few screens, each flight controller could access a variety of software programs to display more data in the optimal configuration. This additional data insight made failure diagnosis much easier.

Training for shuttle flight controllers continued in the previously described manner until the 1990s, when training was formalized to accommodate an influx of shuttle flight controllers. The blue book created for each subsystem streamlined the training process. In addition, new technology was brought into the training process. Computers became more readily available; no longer did five or more people share one computer. Shuttle mock-ups, called single-system trainers (SST), had been created in the early 1980s to help controllers understand what the astronauts were doing as the controllers executed certain procedures. The SSTs contained computer databases with software allowing students to interact with controls and displays like those of a shuttle crew station. This was a significant contribution to training at the time, but it was not until the 1990s that the SST software was made available at the controllers' individual computers. Also in the 1990s, more computer-based training was being introduced to the flight controllers. An additional improvement was creation of a flight controller trainer (FCT), a mini mission control room that could be used to teach system failure recognition prior to entering the simulation environment. The FCT was also used to train multiple operations personnel as if they were working in the mission control room together.[7]

As the shuttle training program matured, it took longer for people to become certified. Over the course of the program, the number of simulations required to certify each person increased steadily. It is unclear why this is so, since one might predict that certification would take less time as shuttle operations practices matured. One possibility is that the problem resolution skills and systems knowledge needed to get certified continued to expand as more became known about the system and complexity of procedures and rules increased. It became very difficult for some systems disciplines to reduce the certification requirements, even after flying the shuttles for 20 years. Some failures were being simulated without full understanding of how the system might perform, as if the shuttle were still in the early stages of development. It is also possible that certification expectations varied by position and even by person, with evaluators for some positions being more determined than others to identify a rigorous set of certification requirements.[****]

B. After the Columbia Accident

When the shuttle program was initiated in 1972, flight controllers needed to be certified quickly to accommodate NASA's original goal of 8 to 12 flights per year. The flight controllers learned a great deal during the first few shuttle flights. The shuttle capabilities and operating characteristics were continually under test. New information was acquired with each launch. Certification time (measured both in the number of simulations completed and in calendar time) was less than what it was in the latter half of the shuttle program.

There were more training program changes after the Columbia accident in 2003. For the 10 years prior to the Columbia accident, the shuttle program budget had been steadily decreasing, with corresponding impacts on all organizations funded by the shuttle program office. Some initiatives for improving operations and training were not approved built due to cost. This situation was created in part because of the space station program. The space station was being built with no increase in the NASA budget, which meant cuts in other agency programs to fund the station. Without the necessary funding, improvements to flight controller training could not be implemented. After the Columbia accident, there were no simulations for several weeks. Once the simulations were started up again, the schedule became very busy. Multiple simulations were being held each day. Long simulations that simulated multiple flight days became more prevalent in training. This increase in simulations was viewed as a way to increase safety by the Columbia accident investigation review board. If the console teams trained more, then they would be better prepared to handle a problem that occurred during themission .[††††]

New standards were established to set simulation difficulty ratings and to define the maximum number of simulations allowed prior to certification, along with a difficulty rating for each simulation. The difficulty rating of the simulations had a scale of high, medium or low, and was based on the number of selected failures and actions required during the simulations. A threshold level was established for each subsystem, based on the historical average number of simulations needed to certify personnel within the previous 5 years. This numerical value is not consistent from group to group. If a console operator did not complete certification within the threshold, his or her group leader could appeal to management for additional simulation opportunities. The management team would then determine the additional number of simulations that would be allocated for the console operator to show

[****] R. Dittemore, personal communication, April 4, 2011
[††††] W. Hale, personal communication, May 10, 2011

improvement before another final certification simulation would be scheduled for the individual. At the end of the simulation, the number of scenarios/failures that occurred during the simulation determined the rating assigned to the simulation. Table 2 specifies the levels of scenarios/failures that determined the difficulty rating for each simulation.

Table 2. Simulation ranking information criteria

Simulation Ranking	Number of criteria
Low	0–7 criteria marked
Medium	8–14 criteria marked
High	15 or more criteria marked

V. Lessons Learned and Recommendations

Many factors led to improvements in shuttle operator training: advances in technology, an expanding manifest with concurrent need for more efficient training methods, experience gained from shuttle accidents, and the operations experience gained by completing over one hundred missions. The following are lessons learned that have been identified by the Mission Operations Directorate. The corresponding recommendations are proposed by the authors, based on interviews and discussions with senior operators.

A. Skills: Effective certification requires that individual flight controllers have the appropriate capabilities.

In the early shuttle program, the skill set of a flight controller was evolving along with the maturity of the shuttle itself. It was not unusual for flight controllers to be selected based on engineering capabilities that were not directly applicable to the operations environment. Over the life of the shuttle program, there are many examples of individuals who left the Mission Operations Directorate for other jobs. In many cases certification requirements could not be met because the individual lacked the skills needed to perform on console. There is no data documenting this trend, but it is axiomatic in the flight controller working environment. While it is very difficult, it is important to try to select individuals with the skill set mentioned throughout this paper as early in the hiring and training phase as possible. This will give teams the greatest chance at successfully certifying personnel, and avoid sunken training costs.

B. Feedback: Continuous constructive feedback is essential to flight controller success.

Without receiving the necessary feedback, a flight controller in training does not know what skills need work or how to improve overall performance. This feedback role falls primarily on the group lead, who must make sure that the individual is progressing at the proper rate, and that the employee is receiving the right amount of feedback and encouragement from senior flight controllers as mentors and evaluators.

Recommendation: A no-cost solution to this issue is to have more group leads or senior flight controllers observing trainees on every other simulation and provide real-time oral feedback. Feedback should be given on a regular basis so that bad habits are resolved more quickly. In addition, written feedback should be given within three days after each certification simulation. This practice has historically not been applied in the past.

C. Training Strategy: Training of the flight controllers needs to be done efficiently.

The years of not flying after the Columbia accident contributed to a change in the training strategy. The number of simulations was increased after the accident as a way to ensure more expertise and decision making from the console teams. Additionally, the training strategy required that each flight controller had to see every failure that could occur. This led to issues with scheduling “the right” failures in specific simulations. The simulations are scripted to address a specific test objective that the flight controller has to resolve. Normally there might be one or two failures per system in a noncertification simulation. Scheduling issues contributed as well to the length of time it took to certify. The organization attempted to solve this by creating ranking systems for simulations of high, medium, or low content. Only the high or medium simulations counted towards certification of the individual in the training flow. This approach was started in 2007 and has been in place since that time. The amount of simulations varies on who needs to accomplish certain objectives and what positions need to be certified prior to flight.

Another impact of long certification times is employee morale. Sometimes there would be two or three people waiting in a flow for a turn to get certified. It could take several years to even start participating in simulations. This was frustrating for new hires and trainees right out of college. Then taking a year or longer to get a certification added to the frustration; employees had difficulty seeing an opportunity to advance their careers in a reasonable timeframe. In some cases the frustration could cause poor performance in the employee’s daily work. These issues might drive away qualified employees. Yet that is not true in all cases; some individuals love the work and are committed to it no matter how long it takes to advance.

Recommendation: One solution would be to use simulation technology at each employee's workstation. Currently there is a Flight Controller Trainer (FCT) available to teach a class, usually once per week per trainee. The FCT is a workstation that is used to introduce malfunctions to new trainees; this amount of FCT usage is not enough to decrease certification time. An interactive software program for the trainee's office workstation might decrease certification time.[8] This software program would model failures, give options for solutions, and show the impact of the solution path selected. This would allow more access and training every day in the office and not require as much time in the control room. The cost to develop the tool is less than the cost of running hundreds of simulation. Time would be needed to develop the tool, but that is available at the end of the shuttle program. Technology is readily available to do this and could be done by private industry. This would help create a working relationship in the private training world.

Recommendation: Revert back to a "skills-based" versus "task-based" certification of individuals, meaning they do not have to see every possible failure of a system, but learn to address various types of malfunctions and know how to systematically approach anomalies. In this approach, a trainee does not need a "check in every box" to be certified—a method that would definitely drive down certification time. While the data has not been analyzed to address the likelihood of success if trainees to not see every failure, this has already been implemented in the International Space Station flight controller training program. If this recommendation is accepted for future vehicles with ascent and entry phases, questions on qualification need to address failure recognition and resolution, and need to prove whether or not the trainee has the skills to support likely failure scenarios. Additionally, the interactive workstation software program discussed above could help cover some of the failures not seen by the individual. This would additionally reduce the cost as associated with many simulations needed by multiple individuals.

D. Technology: The use of technology can aide in the reduction of cost.

Another lesson learned is the degree to which technology development can affect operations. The costs associated with limited data availability in the original shuttle mission control were reduced when flight controllers moved to the new control center in the 1990s with its then state-of-the-art technology. That technology has since become dated and obsolete; in the new space vehicle development era, there are opportunities to explore a variety of mission control room models. Some companies suggest that a trailer filled with computers and operators would be sufficient. Others look to the models used by satellite operations controllers. Another model incorporates the large control rooms and teams used by the shuttle and space station. There are benefits and drawbacks to each of these options. In the current environment, with cost being the greatest driver, the technology that gives NASA the most capability, flexibility, and lowest cost will be the preferred option. Currently, the Mission Operations Directorate is building a new MCC and training System capability to apply state of the art technology and achieve these efficiencies.

Technology is our greatest opportunity to ensure success as we go forward in the space program. It will help reduce cost by eliminating some of the work done today by people—just as it did when the shuttle program transitioned from the old to the new control center. Many commercial companies are trying to find the balance of new technology, minimal operations teams, and small control rooms. While NASA is not-for-profit, the agency can learn from the for-profit companies' efforts to achieve the optimum balance; however, NASA also must learn from history how to balance technology and cost with risk and mission success.

Consider the example of the airline industry in the 1930s. At that time there were many fledging airline carriers being formed. There were no operating standards, and many accidents occurred and people were killed. It was not until 1935, when an airline accident killed a sitting U.S. senator that questions were raised about safety. Eventually operating standards were created and these eventually led to the creation of what we know today as the Federal Aviation Administration. We can see that one accident of importance can change the industry and bring regulations and add process; and, of course, the improvements are likely to add cost and time to production. This happened in the space program after the Challenger and Columbia accidents, and could happen again in the revenue-conscious for-profit environment. One accident from one of the commercial companies could bring unwanted scrutiny, which in turn could result in expensive requirements.

VI. Conclusion

Over the 30-year space shuttle program, NASA has had many opportunities to improve flight controller training and certification. As the shuttle program comes to a close, the replacement vehicle has yet to be selected or designed. The uncertain future provides an opportunity to pause and reevaluate the flight controller training process. A review of the evolving STS certification requirements, the data collected and the lessons learned suggest recommendations that establish a foundation for developing an effective training program for the next space transportation vehicle. Although we do not now know what requirements a new launch vehicle will place on mission operations, the shuttle-related recommendations are likely to be relevant in the post-shuttle environment; in particular, the need to address challenges related to cost is likely to remain.

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