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

Synopsis:

This paper will summarize the thirty-year history of Space Shuttle operations from the perspective of training in NASA Johnson Space Center's Mission Control Center. If will focus on training and development of flight controllers and instructors, and how training practices have evolved over the years as flight experience was gained, new technologies developed, as programmatic needs changed, and as the shuttle program is ending.

Abstract:
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. As the space shuttle program ends in 2011, a review of how training for STS-1 was conducted compared to STS-134 will show multiple changes in training of shuttle flight controller over a thirty year period. This paper will additionally give an overview of a flight control team's makeup and responsibilities during a flight, and details on how those teams have been trained certified over the life span of the space shuttle.

The training methods for developing flight controllers have evolved significantly over the last thirty years, while the core goals and competencies have remained the same. In addition, the facilities and tools used in the control center have evolved. These changes have been driven by many factors including lessons learned, technology, shuttle accidents, shifts in risk posture, and generational differences.

A primary method used for training Space Shuttle flight control teams is by running mission simulations of the orbit, ascent, and entry phases, to truly "train like you fly." The reader will learn what it is like to perform a simulation as a shuttle flight controller. Finally, the paper will reflect on the lessons learned in training for the shuttle program, and how those could be applied to future human spaceflight endeavors.

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ABSTRACT

Operation of human spaceflight systems is extremely complex; therefore, effective training and certification of operations personnel are critical for mission success. The Mission Control Center (MCC-H), at NASA's Lyndon B. Johnson Space Center in Houston, Texas, manages mission operations for the Space Transportation System program, including training and certification of the astronauts and flight control teams. As the space shuttle program ends in 2011, a comparison of STS-1 with STS-134 shows multiple changes shuttle flight controller training over a 30-year period. An overview of a flight control team's makeup and responsibilities during a flight, and details on how those teams have been trained and certified, also reveal important changes over the life span of the space shuttle. The training methods for developing flight controllers have evolved significantly over the last thirty years, while the core goals and competencies have remained the same. In addition, the facilities and tools used in the control center have evolved. These changes have been driven by many factors, including lessons learned, technology, shuttle accidents, shifts in risk posture, and generational differences. A primary method used for training space shuttle flight control teams is mission simulations of the orbit, ascent, and entry phases, a practice that fully aligns the mission operations training with NASA's "train like you fly, fly like you train" approach. A review of space shuttle training program lessons learned suggests how they could be applied to future human spaceflight endeavors.

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Christie Bertels earned a B.S. in Aerospace Engineering from the University of Kansas in 2000, and has over ten years of human spaceflight operations experience. Ms. Bertels began her career in the JSC Mission Operations Directorate as a flight controller and astronaut instructor for the International Space Station (ISS), specializing in mechanical and maintenance systems operations. In this role, she supported flight hardware test and integration, developed operational techniques and products, developed training courses, supported real-time flight operations in Mission Control Center-Houston, and was her team's lead for the STS-114/LF1 Return to Flight mission following the Space Shuttle Columbia accident. She also spent 3 years working at the German Space Agency's Columbus Control Center in Munich, Germany, where she was operations lead for the Astrolab mission, and performed payload-systems integration and planning during real-time ISS operations. Recently, Ms. Bertels returned to NASA JSC to work in the Mission Operation Directorate's Constellation Systems Integration group, and completed a rotational assignment in the ISS Training Lead group. Her current duties include operations and program integration for the Flight Director Office, and working as an ISS Capsule Communicator (CapCom) in Mission Control.

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INTRODUCTION

For 30 years, NASA's Space Transportation System (STS), also known as the shuttle program, has been the United States' launch vehicle for the human spaceflight program. With the last shuttle launch on July 8, 2011, and with NASA exploring alternatives for future launch vehicles, 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 is 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 of the attitude control system, power, propulsion, thermal, attitude dynamics, orbital operations and other subsystem disciplines (NASA 2006). 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 these 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"). This paper provides a review of training methods and simulations developed over the 30-year shuttle program, as well as related lessons learned, that can help NASA plan for the next era of human spaceflight.

TRAINING PRE-CHALLENGER

Evolving Processes: from Workbooks to Simulations

NASA began space shuttle flight controller training in the late 1970s, even 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 (Case 1989). 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 (R. Dittemore, personal communication, April 4, 2011). 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 weekly hardware and software changes. 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 (W. Hale, personal communication, May 10, 2011). Participants in these simulations involved staffed consoles that were connected to a vehicle simulator.

The simulations executed a piece of the mission timeline, procedures, and 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 (NASA 1988). The ascent and entry phases of flight require more training time because there is little time to make real-time decisions during these flight phases. In comparison, the orbit phase allows more time to make decisions because there is more time to look at potential failures or anomalies. As a result, less intense training is required for the orbit phase.

Unlike today, there was no software to assist in decision making (R. Dittemore, personal communication, April 4, 2011). 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. 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 (T. Ceccacci, personal communication, May 11, 2011).

From the beginning, instructors developed simulations to "stretch" the console operators' knowledge and to identify weaknesses in procedures, 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 (W. Hale, personal communication, May 10, 2011). 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.

These simulations also uncovered issues that vehicle testing and certification had missed. For example, in an April 19, 1999 simulation, the Back Up Flight (BFS) software 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, and simulation data validated this change. Failures were welcome, 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 (R. Dittemore, personal communication, April 4, 2011).

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 (Torres 2002). Additionally, the mission manifest had grown, and more certified individuals were needed in a variety of positions to support multiple missions.

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 (T. Ceccacci, personal communication, May 11, 2011).

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 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 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, they would move to front control room (FCR) positions, responsible for appropriately integrating their systems' requirements with other system operators (NASA 1988). Additionally, the FCR position was responsible for providing a plan, operational changes, and recommendations to the Flight Director (T. Ceccacci, personal communication, May 11, 2011)..

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 (R. Dittemore, personal communication, April 4, 2011).

TRAINING IMPROVEMENTS IN THE 1990s

There were many catalysts for change in the shuttle operations environment: lessons learned from experience and adjusted practices 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 every aspect of shuttle operations.

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 phases, procedures, and flight rules. Additional flight rules were written and procedures were revised, with the result that the simulations became more complex. The review period 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 (T.Ceccacci, personal communication, May 11, 2011). Additional desktop computers were also added to the MCC to augment display data (Figure 1).

Figure 1. 1980s-era MCC

The transition to a new MCC facility (Figure 2) occurred in the mid 1990s. The control center provided new hardware and software, with an increase in the number of available displays, communication resources, data availability, playback, and data charting. Communication panels changed from back lighted mechanical push buttons to programmable touch screens (NASA 1988). Display capability was greatly increased. Instead of data from a few screens,

each flight controller could access many software programs showing data. This additional data insight made failure diagnosis much easier.

Figure 2. Current MCC

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 failure recognition. The FCT was also used to train multiple operations personnel as if they were working in the mission control room together (Cooper 1987).

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 and systems knowledge certification requirements continued to expand as more became known about the system, with increased complexity of procedures and rules. 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 (R. Dittemore, personal communication, April 4, 2011.

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. This conclusion is based on historical data collected by the Mission Operations Directorate; Table 1 shows examples of these data for the mid-1990s through 2007. One can see a significant increase in simulations needed to certify from the early dates in each table until the last input in each table. The factors mentioned above may have been factors as well. The amount of time spent by personnel in training was deemed to be a problem for staffing future missions. Recommendations were made and implemented, but the training time was not affected.

After the Columbia Accident

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 items were not approved or were not 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

Table 1. Simulations required to certify one flight controller in each of several groups (1995–2007)

Year Certification Completed	Number of Simulations					
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
1995		22				
1996	40					
1997		17	31			
1998	74	66				37
1999		39	74		31	38
2000		85		33	47	48
2001	41		66	45		22
2002	21	46		69	107	50
2003		43	23			
2004	181	119	60		123	
2005	157		44			
2006			40	55		58
2007			68	57		

teams trained more, then they would be better prepared to handle a problem that occurred during the mission (W. Hale, personal communication, May 10, 2011).

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 was on a scale of high, medium or low was based on the number of selected failures and actions 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 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. Below in Table 2 are the levels of scenarios/failures that determined the difficulty rating for each simulation.

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

Table 2: Simulation Ranking Information Criteria

Results have shown that these changes have helped decrease certification time over the last few years of the space shuttle program.

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.

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

In the early shuttle program, the skill set 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 operations requirements. Over the life of the shuttle program, there are many examples of individuals who left the Mission Operations Directorate for other jobs. This in most cases was due to a lack of skills needed to perform on console. There are no data to document this, but it is axiomatic in the flight controller working environment.

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

If a flight controller is not receiving the necessary feedback, then he or she do not know how or what to improve. This feedback job 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.

A no-cost solution to the controller feedback issue is to have more group leads or senior flight controllers observing trainees on every other simulation and provide real-time oral feedback. Feedback can be given on a regular basis and bad habits resolved more quickly. In addition, give written feedback within three days after each certification simulation. This has historically not been done by some group leads and would be a role change for that job title.

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 against 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 taking 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 a reasonable opportunity to advance

their careers. In some cases the frustration could cause poor performance in the employee's daily work. These issues might drive away qualified employees. That is not true for all cases; some individuals love the work and are committed to it no matter how long it takes to advance.

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 (Loftin 1989). 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.

Another recommendation is to revert back to certification of individuals who have not seen every failure of a system; 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. However, the data has not been analyzed that addresses the likelihood of success if trainees to not see every failure, so a significant concern is that it could increase the risk that a certified flight controller is not fully qualified. If this recommendation is accepted, 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.

Cost/Certification Time: *In NASA's cost- sensitive environment, money is a huge driver.*

The more simulations that were conducted by the operations organization the more cost the shuttle program incurred. In the years before the Columbia accident, cost conservation was more a concern. After the accident, cost was not the top concern; returning

safely to flight was the top priority of the NASA leadership. Simulations were being run twice a day and during the day and night. Long simulations again were started up. Although these accounted for increased cost, they were viewed as necessary to ensure safety.

As more flights were added to the manifest prior to the shuttle accidents, more people were hired. This created a back log in multiple groups for training. People were waiting their turn to get simulations. One easy way to reduce cost is to reduce personnel. This not a popular topic with many people, but is a valid solution to reduce cost. This could be done by combining groups, which would allow responsibilities to be shared and encourage individuals to learn multiple skill sets, thereby increasing efficiency and reducing costs. In the past MOD has tried this concept. This was done in the early shuttle program with the Avionics console position. A temporary combination of EECOM and EGIL positions was done, but was not made permanent due to the demands placed on the one position. The International Space Station (ISS) console operators have implemented this concept as well for some of their flight controller positions. The results have proven to be effective by reducing staff and positions needed to manned. Private industry has successfully used this approach over the last several years: Companies had to lay off individuals to cut costs, and the remaining workers had to assume additional roles and responsibilities. These leaner companies run much more efficiently and generate larger revenues. While NASA is not interested in revenues, it is very interested in controlling and reducing costs.

The Department of Defense (DoD) has a problem similar to NASA with respect to cost. The DoD budget for fiscal year 2011 was decreased and will most likely be further reduced in FY 2012. However, the cost to operate and launch their solid rocket vehicles increases each year. The training efficiencies identified by NASA for their next-era launch vehicle can benefit DoD and other agencies as well, which will help other agencies keep within increasingly tightened budgets.

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 the1990s' control center 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, it appears that the technology that gives NASA the most capability, flexibility, and lowest cost is 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.

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 can bring unwanted scrutiny, which in turn could result in expensive requirements.

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 is yet to be selected or designed. The uncertain future provides an opportunity

to start over 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 the 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.

ACKNOWLEDGEMENTS

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