NASA Case Study *MSFC-CS1008-1*
By Lizette Kummer and Jennifer Stevens *Rev. 12/12/16*

In the Hot Seat: STS-115 Lightning Strike Stand Down Debate

'There is no way the PIC's could have seen any current' was the gist of Mike Griffin's assessment. Griffin was the NASA Administrator at the time. The buck stopped at his desk. Holding a napkin out to Pat Lampton, Griffin showed Lampton the calculations he'd made over dinner that predicted that the Pyrotechnic Initiator Controllers (PIC's) at the base of the Space Shuttle Solid Rocket Boosters (SRBs) were fine. A lightning strike the day before, the worst ever experienced with a Space Shuttle on the launch pad, caused a halt to the launch count down as technicians, engineers, and managers scrambled identify any damage to the launch system.

SRB technicians and engineers assessed the data against their Lightning Strike Re-Test Requirements, determining that all but one of the requirements could be checked if they resumed the countdown. For the one remaining requirement, testing the integrity of the PIC's would require 96 hours to set up, test, and reassemble. The engineers were convinced that there was no way to do calculations to show the PIC's were okay. The only option was to stand down.

It was SRB Deputy Project Manager (PM) Pat Lampton's responsibility to decide what the SRB project position needed to be to certify that their hardware was safe to fly. He had to communicate that decision to the Mission Management Team (MMT) as a Go or No Go position to resume the count down. If the answer was Go they could still meet a delayed, but acceptable launch schedule. If the answer was No Go, rescheduling the launch would be a grueling shuffling of hardware, personnel, and mission timelines to accommodate Russian missions to the Space Station, supplies for the launch, and personnel manning launch operations. On top of that, Hurricane Ernesto was spinning off the coast of Florida, threatening the need for the Shuttle to roll back to the hangar if they waited too long.

Ordinary and Extraordinary Delays

Space Transportation System (STS)-115 held crew and cargo bound for the International Space Station (ISS). Following an acceptable Flight Readiness Review (FRR) ending August 15, 2006, the STS-115 mission was scheduled to launch on Sunday, August 27. After a 2 ½ year program stand down following the loss of Space Shuttle Columbia in 2003, and subsequent Return to Flight (RTF) launches of STS-114 and -121, STS-115 was poised to be the first "ordinary" Shuttle launch since the accident.

Before Columbia, the Space Shuttle Program (SSP) had established a mission manifest, a time line of launch date targets, to complete the International Space Station construction by 2010. Schedule delay from the Columbia accident resulted in a more aggressive schedule to still meet the 2010 completion date. Russian Soyuz (crewed) and Progress (cargo) missions bound for the ISS had inflexible launch dates that NASA had to schedule around. Launch windows to the ISS were also constrained by the location of the ISS relative to the launch site and other technicalities of orbital dynamics. Weather conditions were of significant concern. Significantly, strong winds from a hurricane or tropical storm would mean the vehicle would have to be rolled back to the Vehicle Assembly Building (VAB) for protection. Hurricane Ernesto presented such a danger.

Shuttle operations required the terminal launch countdown to start several days before launch. In the countdown, there are built in "holds" where the clock stops to accomplish planned work or poll the various elements to determine their Go-No Go launch status. If Go, the clock starts ticking again. Some vehicle systems have time-dependent expiration of their certification. If delayed long enough, those systems have to be rechecked, and sometimes replaced (such as batteries). The clock for the certification expirations doesn't stop for planned or unplanned holds. The lightning strike was an unplanned hold, and the certification criteria for the PIC's had been exceeded.

Stormy Weather

Preparation work on STS-115 was proceeding on Friday, August 25, but was halted after noon for a severe thunderstorm – not an uncommon occurrence at KSC. In fact, the rollout to Launch Pad 39B was delayed for two days at the end of July because a storm near KSC could have generated lightning, which if it hit the Orbiter, could have caused "immeasurable damage".[1]

At approximately 1:49 PM, the largest recorded lightning strike to date struck directly to the launch pad. Pouring rain obscured camera lenses, so it was unclear exactly where the lightning hit. The pad has lightning rods to protect sensitive systems, but lightning doesn't strike in clean, singular pathways. Electrical current follows the path of least resistance, and can jump

[1] Wikipedia, STS-115, https://en.wikipedia.org/wiki/STS-115 , accessed 4/29/16

unpredictably to other objects in the vicinity of the strike. At the time of the strike, the Orbiter was powered on and the SRB systems were off.

In the event of a lightning strike to the pad, certain contingencies in the countdown sequence, documented in the Operational Maintenance Requirements and Specifications Document (ORMSD), require that systems be evaluated to determine if they have sustained any damage. Ground crews began to do a pad walk down after the storm subsided as required. Spaceflight Now reported, "The spike in the shuttle electrical system was very small and within allowable limits. But no such spikes were expected, .. prompting engineers to question whether it might have caused any problems. At the same time, telemetry indicated a spike in the circuitry associated with a pyrotechnic device that releases a hydrogen vent arm from the side of the shuttle's external tank at liftoff. Engineers inspecting the pad later reported a burning smell in the area of the gaseous hydrogen vent arm, but no obvious signs of damage were seen."[2]

The launch was delayed for 24 hours by LeRoy Cain, the MMT chairman and KSC director of shuttle integration, so that engineers and technicians could inspect the systems and perform any tests or analyses required. The MMT was scheduled to convene at 4:00 PM on Saturday, August 26 to discuss each element's status and readiness to resume the countdown.

Figure 1 The only imagery of the lightning strike at Launch Pad 39B on 25 August 2006 with STS-115 on the pad

Hot Seats

PIC Your Failure

Pyrotechnic Initiator Controllers (PIC's) are used during separation sequences to set off the pyrotechnic charges that sever certain components connecting shuttle elements to each other or the launch pad. If a component fails to sever, unexpected forces can be relayed between still-connected components, causing catastrophic damage or putting the vehicle off its planned flight path. The damage could result in loss of mission, loss of hardware, or loss of life. Pyrotechnic systems must operate.

SRB PIC's were located in the aft skirt at the base of the launch vehicle. Eight large bolt-like studs held the entire Space Shuttle vehicle to launch pad through the hold down posts, secured with frangible nuts. Six seconds after the Space Shuttle Main Engines (SSMEs) ignited and at the moment the solid rocket motors ignited, pyrotechnic charges were activated, shearing the nuts in half, and liberating the vehicle from the pad. If one of the charges did not blow, one or more of

[2] Harwood, William, Lightning delays Atlantis launch a day, Spaceflight Now https://www.spaceflightnow.com/shuttle/sts115/060826delay/, accessed 21 June 2016

the eight studs would not let go. At that point, Lampton worried, they "didn't know if that would make a difference, or if the vehicle would head to Daytona Beach."

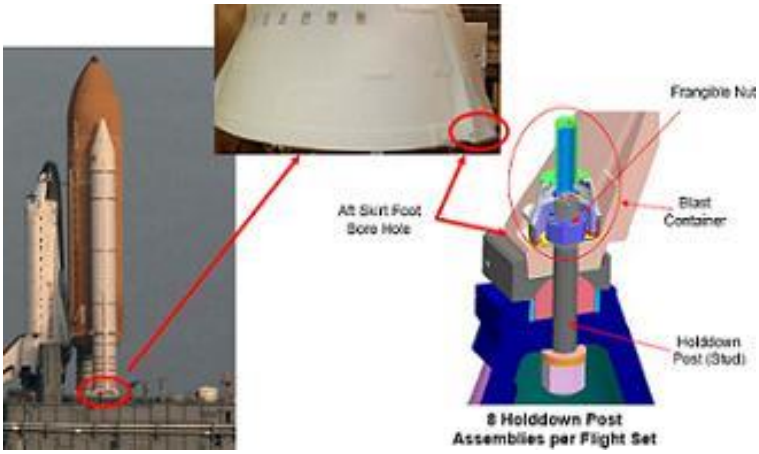

Figure 2 Space Shuttle Hold Down Post Location; Aft Skirt attach point; and Hold Down Post Components
Photo and graphic credit: NASA

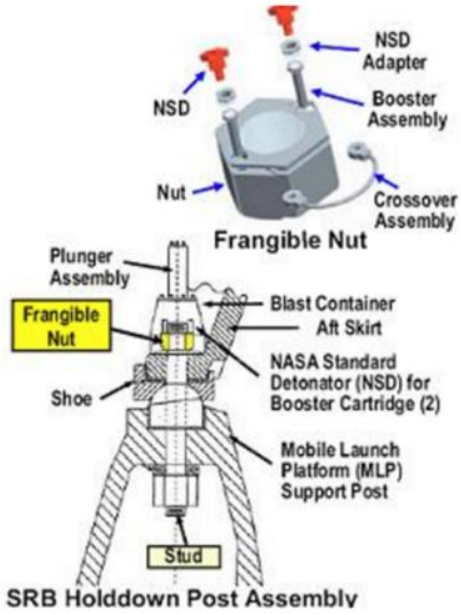

Figure 3 Cross section of the Hold Down Post showing the Detonation Charges Initiated by the PICS, which are located inside the Aft Skirt; Graphic credit: NASA

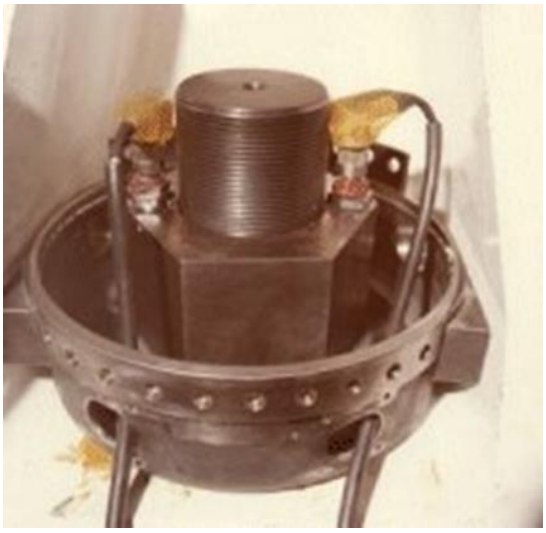

Figure 5 Frangible Nut on the Hold Down Post with PIC lines attached Photo credit: NASA

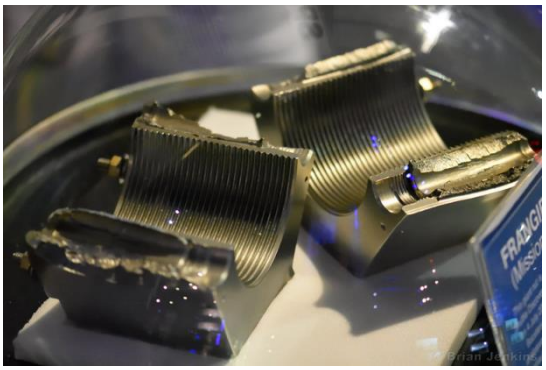

Figure 4 Frangible Nut after pyrotechnic severance Photo credit: NASA

Contention in the MMT

As soon as the lightning strike hit, newly named SRB Deputy Project Manager Pat Lampton, worked with his engineering team to assess the requirements described in the OMRSD and the probable health status of the boosters. Out of the required health tests for Booster, seventeen are for pyrotechnics. Sixteen of them could be conducted during in the current stand down. One of the seventeen OMRS requirements for testing the integrity of the PIC's would require 96 hours to set up, test, and reassemble. Video imagery was indeterminate. The booster systems were powered off, meaning they had no sensors operating to determine the health of the components.

The strike "might have affected circuitry that fires the explosive charges used during booster ignition and separation"[3], which may also have affected the booster's self-destruct system. Consolidating the information, the SRB Chief Engineer and engineers recommended a No Go vote. The only option for assuring crew safety, according to the engineers, was to stand down and perform the required test.

As the MMT convened around 4:00 PM Saturday, August 26 to discuss the potential impact of the lightning strike on all the elements (project offices, ground ops, weather, integration, etc.) were Go for launch except SRB. Representing the Booster Project on the MMT, Pat explained they did not have sufficient data to ensure the PIC's were operational. Other elements of the Shuttle had similar issues, but had determined they could test the health of their systems in existing planned system checks in the normal countdown procedure. Orbiter Project felt that since the Orbiter was powered on, they had sufficient sensor data to indicate that their systems were not affected by the lightning strike. SRB had no such data. Discussion challenging the validity of the SRB OMRS requirement and their engineering assessment ensued.

According to Wayne Hale, such challenges were typical and valid MMT discussions. Pat repeated the No Go justification – simply, they did not have sufficient information to indicate that their system was not affected by the lightning strike, that the system was critical for the safe operation of the vehicle, and that the test was required to determine the integrity of the PIC lines. He could not justify writing a "waiver" to the requirement based on ungrounded analysis. He needed data. Lampton recalled that the challenges to the validity of the requirement and to the engineering assessment was intense. MMT members expressed opinions about the unreasonableness of the test. Hale even questioned the requirement. Lampton held the SRB position and explained the reasoning in detail. Several, including NASA Administrator Mike Griffin, ran simple engineering calculations, convincing themselves that electrical current could not have gotten to the aft skirts, much less penetrated them and affected the PIC's.

MMT discussions can be very aggressive in questioning analysis, requirements, and conclusions presented. Challenging engineering rationale is healthy and necessary to ensure issues are well vetted. The scrutiny can be intense. Wayne Hale, then SSP Program Manager, stated it this way, "There is always some back and forth. ..In the old days, maybe, they ha[d gone to the extent] of what would be considered brow beating, but not this time." After Columbia, Hale had ordered MMT members to undergo an intense series of training to address CAIB concerns of communication disconnects. But, Hale recalled, "[there was still an attitude that] it's a mature system, we've operated it for 20 years, we'll get no new surprises."

Hale noted that "some of the senior management was trained under former Marshall Space Flight Center Director Bill Lucas. Lucas had said, 'MSFC will never hold up a launch'… That was his attitude at the time of Challenger… Lucas was famous for that statement." Hale continued, "Before Columbia, you really had to present clear and present danger to stop the train

[3] Harwood, William, Solid rocket booster tests could be ordered, Spaceflight Now, https://www.spaceflightnow.com/shuttle/sts115/060826srbtest/, accessed 23 June 2016

in those old days." After Columbia, Hale generalized, "they had really toned it down; they had to keep it civil. Columbia was always on their mind. They tried to never issue waivers and deviations." Still, many mangers raised in the old system felt, from their personal engineering judgment, that the lightning strike was not close enough to the aft skirt to have affected that system. Lampton commented that the MMT Chair, Leroy Cain, kept repeating "You can't fly because you don't have data that says you meet the requirement", but that the logic of the statement didn't seem to make sense to him given the evidence. All the other Elements were Go for launch, why not SRB? After several hours, Cain called a recess for dinner.

Necessary Breaks

During the break, Lampton recalls that Bryan O'Connor, the head of Safety and Mission Assurance (S&MA) approached him and told him, "If you're No Go, I'm No Go." O'Connor and Chris Scolese, then NASA Chief Engineer, sat at Cain's left at the table, and would be the last MMT members to register their Go/No Go vote.[4] The show of support renewed the new Deputy PM's commitment to the engineering recommendation.

After dinner, Griffin handed Lampton the famous napkin with the simple Faraday cage calculations showing that the potential for effects to the PIC's were unlikely. "Yes, we've all done that calculation in high school physics, but what are your assumptions?", Lampton recalls responding. How did he know lightning only hit at the top of the service mast where the lightning rod was? How did he know it didn't jump to the boosters? What was the voltage or current at the different locations? It wasn't that they couldn't do physics calculation. They didn't have justifiable numbers to put into the calculations.

Engineering Operations

For the most part, everyone sitting at the table was an engineer of some sort. They had the same engineering training. However, there was a difference, Hale recalls, in the perspective about Go/No Go decisions. Hale, Cain, and Deputy SS PM John Shannon were all "Ops" guys. "It's always about the clock in Operations", said Hale. "Engineering is more tradition, more deliberative." Hale also suggested that some people, such as Griffin and himself, didn't need a lot of data in order to make a decision. Their challenge was in having the patience to "allow other people to catch up." As a former flight director, Hale was always mindful of the limitation of food, water, and timing of operations on the ISS. Deliberation is not as useful in the mission operations directorate (MOD) as it is in Engineering.

[4] In the FRR for the flight before STS-115, STS-121, Both Scolese and O'Connor registered a dissenting opinion (we No Go) for the flight. At that FRR, Mike Griffin overrode the No Go recommendation, and approved going for launch. The circumstance in that case was different. The External Tank (ET) felt they couldn't analytically predict that foam would not fall off the ET. Scolese and O'Connor could not certify that the Orbiter would not be hit, and if it were hit, they could not accept the responsibility for the loss of the Orbiter. Contingency measures were in place to rescue the crew, but the Orbiter would be lost, at a high dollar cost to the program. Only Griffin had the authority to risk losing such an expensive piece of hardware, and its attendant capability.

Although it is typical to challenge the validity of requirements, persistent questioning throughout the night became an increasingly unproductive discussion. Robert Wright, the United Space Alliance avionics lead, with decades of experience with PIC's stood near the wall behind Lampton. Wright had written and approved the OMRS requirements and knew the system thoroughly. As he stood silently behind Lampton throughout the night, arms folded across his chest, he watched and waited to see what Lampton would do. Lampton saw him there. Lampton held his ground.

Impasse

At 2:00 AM Sunday morning, after 8 hours of deliberations, Cain called for a recess to the discussion. The discussion was going in circles and no new information or understanding was coming to light. Lampton requested a 7 hour break, hoping to reconvene no earlier than 9:00 AM. Griffin recommended that they reconvene at 7:00 AM – 5 hours from the time they dismissed. Given the driving distance to homes and hotels, Hale intervened, stating they would come back at 10:30 AM. In Hale's view, coming back after 2 hours of sleep could be worse than continuing through the night. The MMT itself would reconvene at 6:00 PM on Sunday night, and Lampton needed to have rationale then, or a final No Go vote.

Although Wayne was not chairing the MMT at that time, he made a command decision to clarify what was needed when everyone came back. Hale summarized the problem back to Pat at 2:00 AM Sunday morning in this way "So what you're saying is, that you have a requirement in the OMRS that you don't have data to satisfy?" Lampton recalled Hale said something like, "Pat doesn't need to know why he has a bad (OMRSD) requirement. Pat needs information so that he can justify why he meets the requirement for the PIC's. When you come back at 10:30, all of you are going to give all the information that you have to SRB so Pat can find the rationale he needs to be able to launch."

STOP AND THINK

What needs to be done when they come back at 10:30 AM in order to have flight rationale by 6:00 PM?

From Lampton's perspective

From Cain's perspective

From Hale's perspective

From Griffin's perspective

The Rest of the Story

At 2:00 AM Hale had asked all members of the management team to exhaust all sources of data and give it to Lampton when they came back later that morning. At 10:30 AM the data started coming in from his booster team, and people from all the other elements. What they found was "reams and reams of imperfect data." Everyone brought data except the ground ops people, who had so much data they couldn't make sense of it all. The E3[5] team (lightning strike experts) came in and explained that a lightning strike occurs in a nanosecond and that the sensors on which the management team (i.e., all the other elements) relied to capture the impact of a lightning strike on their systems were not sensitive enough to capture or measure lightning strike data. The sampling rate was too low to sense a transient that fast.

After about 2 hours, ATK's Cary Ralston came up with an idea for how they could have confidence the PIC's were okay without having to go through the 96-hour PIC test. Ralston's solution involved the 400 thermocouple gages glued to the exterior of the Reusable Solid Rocket Motors (RSRMs), an element integrally tied to the SRB hardware. The off-the-shelf, unshielded, non-de-rated thermocouples arrayed across the outside of the motor to measure hardware temperature are far more sensitive to electrical transient surges than the shielded and de-rated PIC's sheltered inside the thick aft skirt. Before and after the lightning strike all 400 thermocouple sensors were actively working. The logic was that if a lightning strike had impacted the booster then some or all the sensors would not be working. Because the aft skirt is connected to and below the motor, the Booster PIC's were not impacted. Pat did the other 16 health tests on the pyrotechnics and they showed okay. The flight rationale on Boosters would be based on a risk assessment, not testing.

The rationale was vetted through the whole Mission Management Team and up through the agency. Before the MMT reconvened at 6:00 PM on Sunday, August 26, Lampton started briefing various groups on Booster's flight rationale. Lampton commented that David Martin, the SRB PM, gave him advice for building consensus for the rationale. Martin counseled Lampton to talk the rationale through with the engineers such as the E3 members that supported higher level managers. Those managers needed to agree with the rationale before the MMT did. Lampton found this approach to consensus building wise.

Lampton noted that for the Sunday night briefings the SRB flight rationale was based on new data gained that morning, not from the discussion started the day before. The final rationale required the new data and approach. That Sunday morning, said Lampton, "the health of the pyrotechnics [was] not based on the capacitor[6]." Of the relationship of the motors to the booster, Lampton noted, "essentially, the data on the RSRM is canary data, like the canary in the mine. If the data from the thermocouples is okay, then the rest of the booster below that is okay."

[5] Electromagnetic Environmental Effects Team
[6] A capacitor is a component of the pics that would have been compromised by the lightning strike

At 2:00 PM Lampton presented the rationale on a telecon to the Booster PM (Martin), and Engineering and S&MA managers. The phone lines were open, so Pat suspects that other people, such as other MMT members were listening in on their discussion. Pat went through the reasoning on the rationale and got concurrence from Engineering, his PM, and S&MA. At 6:00 PM, Pat presented his new flight rationale to the MMT. The other Elements also presented modified flight rationale; after hearing SRB's assessment and reviewing their own systems' abilities to record the electrical spike from the strike, they recognized their flight rationale for the first go around was incomplete.

Ultimately, "the decision was made to postpone the launch for another 24 hours, making the earliest possible launch date [Tuesday] 29 August 2006, still unassured that there was no damage from the lightning strike and taking into account the possible threat from Hurricane Ernesto."[7]

Figure 6 Space Shuttle Atlantis launches on STS-115 September 9, 2006
Photo credit: Scott Andrews, NASA

[7] Wikipedia, STS-115, https://en.wikipedia.org/wiki/STS-115 , accessed 4/29/16

APPENDIX A: Time Line

Thursday, Aug. 24, 2006

Countdown begins (3-day count)

Launch Sunday August 27, 2006 at 4:29 PM EDT (scheduled)

Friday, 25 August 2006, a direct lightning strike hit the lightning rod atop the launch pad

Leaving the L-2 in a storm, lightning struck the Pad Mast

Orbiter was powered on

Booster was powered down

Saturday, August 26, 2006

Pad Walkdown early morning – Team found strong discharge/burnt odor/vent arm PIC

Convene MMT 4:00 PM – to decide go back and bring re-test or flight rationale and plan for retest

Slip flight to Monday, August 28, 2006 4:04 PM EDT

All elements GO except Booster is No Go due to inability to complete OMRSD Lightning Retest requirements – No rationale for waiver

MMT debates rationale until 2:00 AM Sunday morning

Sunday, August 27, 2006

Project teams convene at 10:00 (10:30?) AM

Meet with SRB team and experts from other elements to develop rationale

Developed rationale to waive testing requirements on low likelihood evidence, large pile of imperfect information

Briefed SRB Project Manager at 3:00 PM

Briefed Propulsion Deputy/MSFC Engineering at 4:00 PM

MMT Special Session at 6:00 PM; Wavier rationale developed and briefed

Go for Launch on Tuesday, August 29 pending weather

Monday, August 28, 2006

Weather brief on path of Hurricane Ernesto and decision to roll back for cover

Later: Weather briefing changed to favorable. Ernesto changed direction and headed out to sea. Decision to roll back to pad mid-way between rolling from pad to VAB. Violated speed limits also in rolling back to pad.

Later: Launch scrub because of ECO sensor failure

Later: Launch of STS-115

APPENDIX B: Post-Columbia Procedural Changes

MMT Training

The Columbia Accident Investigation Board (CAIB) observed that the decision making process of the Space Shuttle Program, and especially the MMT, was not thorough enough in vetting engineering issues in time constrained, high consequence settings, such as a launch scrub and turnaround. As the newly named SS Program Manager, having replaced Ron Dittemore, Wayne Hale was responsible for changing the culture. The program had many outside observers, such as the Return to Flight task group, GAO, and even congressional staffers who were looking over their shoulders to make sure they actually made the changes needed. Such changes were identified as contributing to the loss of the Challenger in 1986, and it was obvious that by 2003 the needed changes were not made. Hale stated, "pretty much anything anyone suggested for training, we did. Some of it may have been over the top.. some changes needed, even some not needed."

Changes other than Training

In addition to culture changes regarding the means and methods for vetting flight rationale at the MMT, changes were made to the attitude towards waivers and deviations. The attitude became to try never to issue waivers and deviations.

Hale also suggested that flight operations does attract people who make decisions faster and don't need a lot of data to justify a decision. People like Mike Griffin are "a quick study", others around the table are slower. The quick studies need to allow those who are more deliberative or not as quick time to catch up because you need people to understand the issues. He commented that there would be diversity in the MMT and that MMT members needed to learn how to deal with that and manage the diversity, manage their approaches to satisfy the needs of the diverse perspectives and methods.

Hale had the MMT room at JSC refurbished, making it bigger, with a bigger table, more chairs, audio-video teleconferencing capabilities, and posters hung up around the room to remind MMT members of the consequences of poor decisions made on time versus right decisions made after launch delays. The posters also included a synopsis adopted from the FAA on an error chain, which if broken, can reduce the likelihood of failures. Those posters are contained in Appendix C.

Hale recognized that he, Cain, and John Shannon all shared the same flight operations background, that their thought processes were alike. He deliberately brought in others, like Kim Doering and Lucy Krantz to provide different backgrounds and different perspectives.

Systems Engineering and Integration was greatly changed after Columbia. Before Columbia, it was a "small and unhappy group" because they could not do much. They only had about 10% of the people before Columbia as they did after Columbia.

APPENDIX C: Posters from the MMT Rooms