# CHALLENGER

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Recently, I was asked by John Shannon, the current Space Shuttle Program Manager, to comment on my experiences, best practices, and lessons learned as a former Space Shuttle program manager. This project is part of a broader knowledge capture and retention initiative being conducted by the NASA Johnson Space Center in an "oral history" format.

One of the questions posed was to comment on some of the most memorable moments of my time as a Space Shuttle program manager. Without question, the top two of these were the launch of Challenger on STS-51L on January 28, 1986, and the launch of Discovery on STS-26 on September 29, 1988.

## Background

The tragic launch and loss of Challenger occurred over 22 years ago. 73 seconds into flight the right hand Solid Rocket Booster (SRB) broke away from the External Tank (ET) as a result of a burn-through in its aft most case to case joint and the Space Shuttle vehicle disintegrated resulting in the total loss of the vehicle and crew. The events leading up to that launch are still vivid in my mind and deeply trouble me to this day, as I know they always will. This paper is not about what occurred during the countdown leading up to the launch – those facts and events were thoroughly investigated and documented by the Rogers Commission. Rather, what I can never come to closure with is how we, as a launch team, and I, as one of the leaders of that team, allowed the launch to occur. While the Rogers investigation was thorough, except for my specific testimony at the time, no one then or since has asked me to tell my story of how it happened. So, now, here it is.

I must start by pointing out that, from my perspective at the time, the STS-51L Mission Management Team was a strong, seasoned group of individuals with twenty four Space Shuttle launches behind them and many years of Space Shuttle development experience prior to that. We all knew each other well and there was a feeling of confidence and respect across the team. The only relatively new member of the Space Shuttle management team was Stanley Reinartz, the MSFC Space Shuttle Projects Manager. That role had been previously been filled by Robert Lindstrom, who had retired in August, 1985. Jesse Moore had replaced James Abrahamson as Associate Administrator for Space Flight in the

Spring of 1984 and I had transitioned from JSC Orbiter Project Manager to National Space Transportation System Program Manager in August, 1985.

I felt confident in my role as Manager, National Space Transportation System (NSTS), responsible for Space Shuttle program integration. While this was a program-wide scope of activity, I reported to the Director of the Johnson Space Center in Houston rather than the Associate Administrator for Space Flight at NASA Headquarters. Earlier in the development program there had also been a Space Shuttle Program Director at NASA Headquarters, situated organizationally between the Associate Administrator and the JSC NSTS Program Manager, but that office had been vacant for a number of years and Space Shuttle program integration was managed by JSC as part of the NASA "lead center" approach for multi-center program management which was in vogue at the time.

The confidence I mention has its basis in my years leading the development of the Orbiter avionics and flight software, which actually control the entire space shuttle flight vehicle, my time as Skylab Deputy Program Manager, Apollo Program Office Deputy Manager, and as NSTS Deputy Program Manager. Subsequently, I had served as Orbiter Project Manager during 15 Space Shuttle launches (STS-5 through STS-51-F) and as Manager, NSTS during 5 Space Shuttle launches (STS-51-I through STS-61C). I had played a major role in the Space Shuttle Flight Readiness Reviews which I felt were conducted in a thorough and comprehensive manner. At that time, I believed I was one of the most knowledgeable people in the program on details across the entire Space Shuttle system.

When I became the Space Shuttle Level 2 Program Manager at JSC in August, 1985, this was a highly intense period of activity for the Program. During 1985, the Space Shuttle team was working at a pace of 12 Shuttle launches per year (10 launches plus two launch attempt delays). This pace was planned to continue and accelerate, building to a flight rate of 16 per year by the end of 1986. A flight rate of 16 required having as many as 22 flights in the planning stage. In addition, major activity was underway to bring two additional new major Space Shuttle capabilities on line during the first half of 1986 – the Shuttle Centaur upper stage and the Vandenberg AFB west coast Shuttle launch facility. I sensed that achieving this schedule was a top priority agency goal.

From my start in August 1985 through early January 1986 we conducted five successful Space Shuttle launches. During that same period, Level 1 and 2 program management had also been engaged in the flight readiness firing for the first flight of the Orbiter Atlantis, and a series of major program reviews for the Shuttle/Centaur and for the Vandenberg launch site. In spite of these reviews, there were still a number of major unresolved program flight safety issues with the Shuttle/Centaur, which was scheduled to launch two planetary missions on the Space Shuttle during the first half of 1986. And there was also a major issue with the effectiveness of the launch pad engine exhaust ducts at Vandenberg which seriously threatened its readiness for its first Shuttle launch in mid 1986.

STS-61C (Columbia)

To discuss the events during the STS-51L countdown on January 26, 27 and 28, I need to start several weeks earlier. STS-51L was not the only launch in January of 1986. STS-61C launched on January 12, 1986, on its seventh scheduled attempt (crew installed in cockpit for five). This was a tortuous series of launch attempts which started on December 19, 1985. In particular, I'd like to discuss the attempt for January 10. At the Mission Management Team (MMT) meeting the night before, the weather had been predicted to be marginal, at best, for launch the following day but the MMT elected to proceed with the count. On launch morning, the weather was significantly worse than predicted and the launch was scrubbed at T-45 minutes in a downpour. During that period, it appeared that the MMT members were feeling some frustration regarding the repeated launch delays, many of which seemed to result from conditions which could have been avoided by better advanced planning and scrutiny (see my memorandum "STS 61-C Launch, January 14, 1986"). In particular, I sensed that they felt almost foolish about having gone ahead with the countdown for January 10 which led to a rather predictable weather scrub the following day.

During these launch attempts and earlier program problems, the media had become increasingly critical of NASA's performance. Articles have been written subsequently on the topic of whether the media "goaded NASA into the Challenger launch". I will say unequivocally today, as I would have said in 1986, that the media could never goad NASA into making any decision regarding a launch. Having said that, I believe such continuous negative scrutiny, to the point of ridicule in the case of the STS-61C events, does have a tangible effect on the mood and atmosphere of the conduct of the Mission Management Team activities.

STS-51L (Challenger)

When the STS-61C mission was finally complete, Sunday, January 26, 1986, was chosen for the launch of STS-51L. Those of us who were members of the Mission Management Team who were not already in Florida, flew in on the morning of Saturday, January 25, for a regular L-1 day meeting that afternoon. The L-1 day meeting convened at 11 AM, and, as I recall there were no significant technical matters brought forward relating to proceeding with the launch. Towards the end of the meeting the projected weather conditions for launch on the following day were presented and discussed. The forecast was for a weather front to move into the area from the Northwest with clouds and heavy rain predicted by Sunday, January 26, at launch time. It was agreed that the MMT would convene later that evening to further assess the weather projections just prior to External Tank (ET) loading.

The MMT included the chairman, Jesse Moore, Associate Administrator for Space Flight "level 1"; me, NSTS Program Manager (JSC) "level 2"; and each of the Space Shuttle Project Managers from the NASA centers "level 3". Project managers or representatives from each of the major Space Shuttle prime contractors "level 4" were also generally in attendance but "voted" through their level 3 NASA counterparts. Center directors William Lucas, MSFC, and Richard Smith, KSC, were present and were included as strong "voting" members as was Dr. Walter C. Williams. Walt was a man who was serving as

a consultant to the NASA Administrator following a long and highly respected career in leading NASA aeronautics and space flight programs and in NASA senior management. To this day, I have immense respect for Walt and at that time I was very pleased to have him included in this forum. As a point of interest, my records indicate that William Graham, acting NASA Administrator, may also have been present at the 9:30 PM MMT, although I believe that was the only one he ever attended.

During this era of Space Shuttle operations it was more or less standard procedure to proceed with the countdown, load propellants in the External Tank, and hope for the best at launch time if there was any possibility that acceptable weather might prevail. This was the case even though a later launch scrub in the terminal count would cause extra expense including ET loading and subsequent off loading and extra workload for the KSC launch team. However, in this case the situation which I discussed previously of the January 10 STS-61C launch attempt, where the weather forecast at L-1 had been similar and had led to a scrub the following day, seemed to have an effect on the MMT assembled at 9:30 PM on January 25 to determine whether to proceed with the STS-51L count. There was a strong consensus to not proceed and to hold for a launch attempt with more favorable odds on the following day (Monday). As history records, on Sunday morning the weather front had slowed over night as it approached the KSC area and the weather appeared to be good for launch at what would have been the intended launch time. However, we had already passed up that opportunity.

The L-1 day Mission Management Team convened again in the early afternoon of Sunday, January 26. Again, there were no technical issues, the weather forecast was favorable for Monday and the MMT authorized the countdown to proceed.

On Monday, January 27, ET tanking proceeded smoothly, the flight crew proceeded to the launch pad and were assisted into the spacecraft. All seemed to be going well up to the time of hatch closure, where upon, several events which initially appeared easily resolvable, caused a series of extended holds. These “simple difficulties” were highly reminiscent of the many difficulties which had occurred during the launch attempts for STS 61C which I previously referred to. First, final latching of the hatch could not be confirmed by instrumentation. After several attempts, a procedure using the flight crew to inspect the condition of the latches on the inside of the hatch was developed and employed to successfully resolve that issue. Next, one of three bolts holding the external hatch positioning tool, or “hatch handle”, could not be extracted to permit the tool to be removed for launch and appeared to have stripped threads.

It was decided to attempt to remove the offending bolt by using a battery powered drill, but it took a long time for the necessary drill to reach the launch pad and after it arrived its battery was not sufficiently charged to complete the job. More batteries were sent for, but after considerable time none were sufficient to complete the task at hand. Finally, an AC powered drill was attempted to be used but it, also, was not successful. As a last resort, approval was given to remove the bolt with a hack saw which finally enabled the bolt and hatch tool to be removed. These efforts, in total, caused an approximate 2 ½ hour delay in the countdown. During that time the winds had risen and were now in violation of the crosswind limits for an RTLS abort landing at the Space Shuttle landing facility at KSC.

These conditions showed no likelihood of improvement and shortly after noon the launch attempt was terminated.

Final L-1 Day Meeting

Early that same afternoon, the L-1 Mission Management Team assembled once again to consider a launch attempt for the following day, Tuesday, January 28. At this meeting, the events of the launch attempt earlier in the day were discussed and then each project was polled for status to support launch the following day. Once again, there were no outstanding technical problems but when the weather forecast was presented, in my view, everything changed. The weather projection was for the offending winds of that day to die down but to be followed a strong cold front moving into the area overnight which would drop the temperatures at the launch pad to as low as 23 deg. F. Temperatures were predicted to return above 31 deg. F the following morning prior to the projected time of launch and this would meet the existing Space Shuttle Space mission rule criteria for launch temperature. Upon hearing this prediction, I felt an immediate, strong feeling of apprehension regarding unknowns of what the unprecedented low temperatures could mean for the Space Shuttle. Much to my surprise, however, the discussion proceeded normally and as it progressed it seemed apparent that no one else in the room was particularly alarmed. MMT members clearly felt that this situation should simply be thoroughly reviewed and assessed. Following some general discussion, the L-1 day meeting was suspended with each project being asked to go and review their elements for any potential impacts with respect to the projected temperature profile.

A few hours later the L-1 day meeting reconvened. Each space shuttle project was asked to report on any impacts from the projected temperature profile and all indicated they had no major issues. The Orbiter and the SRB each had several issues with system components which would either exceed their low temperature limits or require alternate heater utilization profiles during the countdown. None of these were presented or viewed as constraints to launch and could be acceptably managed. There were no changes to the weather projections for the following day. After some additional discussion, the chairman, Jess Moore, polled the L-1 day team as to whether they would recommend proceeding with plans to launch on January 28. I remember to this day that immediately the first two people to speak were Bill Lucas and Walt Williams who both strongly advocated proceeding. Everyone else, including me, subsequently voted to proceed, setting the stage for the events of that evening and January 28, 1986.

The launch decision process at that time generally assumed that following the L-1 day review major launch policy issues had been dealt with and further management activity would transition later in the countdown to the Launch Control Center itself where key program managers would be assembled “on console” in the firing room. In fact, two major situations developed over the evening of January 27 which had major potential impact for launch success and which were never dealt with collectively by the Mission Management Team. I will refer to these subjects as I proceed as “SRB o-rings” and “ice on the launch complex”.

SRB O-Rings

Following the L-1 day meeting, until I reported to the Firing Room at 5 am the next morning, the only flight related item that was brought to my attention was via a telephone call to my hotel at approximately 11 pm from Larry Molloy, the Solid Rocket Booster (SRB) Project Manager at MSFC. Larry called to say that the SRB recovery ships were having trouble holding their proper position in the rough sea conditions off shore. Larry felt that this would likely cause problems in recovering the SRB's following launch with the potential loss of some hardware such as drogue and main parachutes, nose cones and frustums. The SRB's and associated equipment were routinely recovered for reuse and Larry was in touch with me because loss of some of this equipment would likely result in additional financial costs to the program. In perspective, additional launch delays also result in significant additional program costs and I told Larry that that it was my intention to proceed with the launch as planned. Of more significant importance, however, is that during this telephone conversation Larry never mentioned the extensive telecons that had occurred between Thiokol and MSFC earlier that evening on temperature effects on SRB o-ring seals and whether they could commit to fly the following day.

The details of the deliberations between Thiokol engineering and management and MSFC on the evening of January 27, following the earlier L-1 day reviews, have been covered in detail in the proceedings of the Rogers Commission and have been broadly analyzed and debated in numerous subsequent articles and books. I have nothing to add here regarding those deliberations except to say that I was totally unaware that these meetings and discussions had even occurred until they were brought to light several weeks following the Challenger accident in a Rogers Commission hearing at KSC. A number of people analyzing the Challenger accident have written that they find it hard to believe that senior Space Shuttle program managers were not aware of the concerns brought forward by the Thiokol engineers and the subsequent decision to proceed by Thiokol and MSFC management as was testified to the Rogers Commission. I find this extremely hard to believe, as well, but it is, in fact, the case. Jesse Moore and I sat shoulder to shoulder with Bill Lucas, the MSFC Director, and Stan Reinartz, the MSFC Space Shuttle Projects Manager, on console in the firing room for approximately 5 hours leading up to the launch of Challenger and no aspect of these deliberations was ever discussed or even mentioned. It would never have occurred to me that concerns of such a critical flight risk nature, such as these which the MSFC team had dealt with, would not be brought to full program management attention by any program team member.

In the early days following the accident a Mishap Review Board was convened at KSC under Jess Moore. This forum was made up of key members of the L-1 day Mission Management Team including Dick Smith, Bill Lucas, Walt Williams, Jim Harrington and me. The team was augmented by additional project and KSC support and data analysis people as appropriate. This team met daily for several weeks until it was replaced at Rogers Commission request by the independent NASA STS 51-L Interim Investigation Team led by J. R. Thompson. During the first several days of the Moore review there was no strong suspect for the cause of the accident, many possibilities were being considered and there was no discussion to uniquely implicate the SRB's. The deliberations by Thiokol and MSFC the evening

before the launch were never mentioned, much less put on the table as indicating a possible cause of the accident. Only by Thursday afternoon, when launch and in flight photography became available, did the SRB field joints emerge as a probable cause of the failure that had led to the accident.

In the reviews by the Rogers Commission following the accident and in subsequent independent assessments, there was much analyses and debate regarding the history and implications of o-ring erosion on flights in the Shuttle program prior to STS-51L. The level 2 program was aware that a number of nozzle and case joint o-ring and blow by flight anomalies had occurred and were continuing to be addressed technically by MSFC and Thiokol. However, following the earliest occurrences, these were regularly waived as reportable flight anomalies by Larry Mulloy, the MSFC level 3 project manager, as "repeats of conditions that had already been accepted for flight" and "within their experience base". Hence, as these conditions continued to occur during 1984-1985, they were brought forward to the program Flight Readiness Reviews (FRR's) for information only and were not presented or discussed in detail as serious concerns or constraints to launch.

I had been unaware that in 1983 NASA level 2 had approved a directive which eliminated project reporting requirements on most flight safety problems, flight schedule problems and problem trends (see the Rogers Commission report, Volume 1, page 154). Orbiter problems, under my jurisdiction, had continued to be fully reported at the FRR's. While the limited MSFC treatment of o-ring problems at the FRR's may have been consistent with this updated guidance, it was in no way what I had expected and assumed was being covered in the FRR's with respect to flight safety. To me, the FRR process was the primary method for senior program management to stay on top of critical program problems and safety related issues and if such issues existed I assumed they would be discussed in our meetings. Further, the fact that level 1 had also reclassified the criticality of SRB joints from criticality 1R to criticality 1 on March 28, 1983 seems to me to still require anomalies associated with them to be discussed in detail at each FRR, irrespective of the above mentioned change in reporting policy.

As the post accident analyses and findings progressed, I learned how extensive and serious the concerns and deliberations had been at Thiokol and MSFC regarding SRB nozzle, case and igniter joint seal and blow by anomalies that had occurred over the year and a half prior to STS-51L. In August 1985, a critical review had been held for NASA Headquarters by MSFC and Thiokol to address these issues. The review had been intended for Jesse Moore but he was not present and it was chaired by Michael Weeks. In spite of the serious nature of the findings presented, Thiokol recommended that it was safe to continue to fly. A number of corrective actions were brought forward for immediate consideration and Headquarters agreed to funding reallocations to support efforts leading to a redesign of the SRB case joints. The Level 2 NSTS Program Office in Houston was not notified of or included in this meeting and no one from JSC, not even someone from the astronaut office, was in attendance. Further, the SRB redesign funding agreements reached did not flow through the normal Level 2 PRCB program approval channels. The fact that Headquarters and MSFC did not seek to include the Level 2 Program in these deliberations reflects a serious breakdown in the official NSTS Program management and communications process, a breakdown that I believe continued up to and including the events surrounding the launch of Challenger. In their subsequent findings, the Rogers Commission stated that

the o-ring history presented in this August 1985 meeting "was sufficiently detailed to require corrective action prior to the next flight".

Although I took over as NSTS Program Manager at about the time this Headquarters meeting on the SRB took place, I do not recall that either of my predecessors, Glynn Lunney nor Richard Kohrs, who became my deputy, had been aware of the degree of concern that existed in the Thiokol and MSFC engineering communities regarding the SRB joint/seal flight anomalies and the related flight safety implications. To a large degree, I expect, this also was due to the reporting requirements change discussed above and the effects that this had on what was reported to them in the FRR's which they had chaired. I had been a direct participant in these earlier FRR's as well, as the JSC Orbiter Project Manager.

Ice on the Launch Complex

I believe that the basis for the ice issue was brought forward toward the end of the final L-1 day meeting. KSC stated that as the countdown proceeded into the evening they would have to implement special procedures to protect the water systems on the launch complex from freezing. KSC indicated that they had such procedures for this and it was not discussed as a significant issue.

The next time I heard of the issue was at approximately 5 AM on launch morning when I plugged into my console in the firing room. At that time, KSC management was receiving a detailed report from the ice team at the pad regarding the amount of ice that had built up on the fixed service structure (FSS) over night as water system spigots had been allowed to drain to prevent systems from freezing. The team at the launch pad seemed quite alarmed and it was not clear that these conditions would be acceptable for launch. As the countdown proceeded, the conditions were regularly reviewed by leaders of the KSC launch team in the LCC and members of the ice team at the pad and with each report the assessment became more positive as to the acceptability of proceeding to launch. Never the less, those of us gathered in the program management area of the firing room considered this to be a most serious issue and it was agreed that I would lead an off console Program level meeting to further evaluate the situation.

At approximately 9 AM, I met with senior representatives from each of the Space Shuttle projects in a conference room in the firing room. Not all of the project managers were in attendance as some of them had critical responsibilities on console at this late point in the countdown. However, each of the attendees was well known to me and had the full backing to represent his/her respective project. The issue of the ice buildup on the launch complex and the forecast for conditions at launch time were presented in detail by KSC. The issue primarily being discussed was whether at ignition or in the initial seconds after liftoff the launch dynamics would cause ice to break loose from the FSS and impact the Orbiter, which potentially could cause serious damage to the Orbiter's thermal protection tiles. After extensive discussion, I polled the projects for recommendations as to whether to proceed with the launch.

By that point in the count, KSC felt that conditions were acceptable to proceed. They had reported that the most significant ice buildup was on the north and west sides of the FSS, away from the Orbiter. Horace Lamberth, KSC Director of Shuttle Engineering stated that their calculations showed that falling ice would not impact the Orbiter and recommended, a "Go". Richard Colonna, JSC Manager for STS Orbiter and GFE Projects, also voted to proceed. I also questioned the Mission Evaluation Room (MER) team in Houston which had been following the problem. The MER stated that they had also done calculations that showed that ice falling from the FSS would not impact the Orbiter. Tom Moser, JSC Director of Engineering, a man for whom I had significant respect, was the spokesman for the MER and they recommended a "go".

Two key people from Rockwell International, prime contractor for the Orbiter and for Space Shuttle Integration, were in the meeting; Robert Glayser, RI Orbiter Project Manager and Marty Cioffoletti , RI Shuttle Integration Project Manager. I knew and respected each of these men who I had worked with extensively over the years. At this point in the meeting, although they were sitting at the side of the room and not at the table, each of them spoke up expressing their concerns that while they did not disagree with the KSC and JSC analyses, these conditions constituted additional risk to the success of the launch. My problem was that everyone in the room, and probably the entire LCC, would agree with them and that was why we were holding the meeting in the first place. Thus, I pressed them for a specific recommendation on whether they felt we should proceed. As we continued to talk, Bob and Marty seemed to back off somewhat on the degree of additional risk they felt we were being exposed to and they would not offer a firm recommendation. I also must point out that I was aware that Rockwell engineering and technical management was well represented for mission support in the Mission Evaluation Room in Houston and at the RI Mission Support Room in Downey, CA and, therefore, would have been a party to the MER "go" recommendation.

No other comments or recommendations with respect to concerns for proceeding were offered by the large group assembled. I could not feel that the RI concerns should override the positive go that I had received from each of the other organizations represented in the meeting and that I, now, personally agreed with. However, I was concerned that in the ensuing time since the return of the ice team from the pad, conditions might have changed. Thus, I asked for an additional ice inspection to be performed as close to launch as possible to include assessment of any significant change in icing conditions and to remove any additional ice from the MLP deck and the sound suppression water troughs. I then closed the meeting and went back and reported the results, including the Rockwell reservations, to Jess Moore and the other senior management in the Firing Room including Phil Culbertson, the NASA General Manager. My recommendation to Jess was that we proceed unless the ice team identified a significant change in the launch pad condition.

During the remainder of the countdown, several additional holds were called to provide for more ice inspections as temperatures continued to rise. Lift off occurred close to noon and by that time all ice had been removed from the sound suppression water troughs below the launch vehicle and the Mobile Launch Platform (MLP) deck, temperatures were well above freezing and there was significant melting occurring on the launch complex. During the launch no falling ice impacted the Orbiter.

In the Rogers investigations following the accident several other issues related to the ice and cold were brought out. There was a concern brought forward that ice had been a factor on the walkways on the FSS leading to the Orbiter and, more seriously, on the walkway leading to the crew escape baskets on the far side of the FSS which were there for use by the crew in the event of a time critical emergency late in the countdown. Whether the ice team discussed these issues with KSC management I do not know, but they were not brought up in any of my discussions within the LCC. Further, the launch support personnel who assisted the crew out to and into the spacecraft, to my knowledge, did not raise this as a significant issue.

Concerns about Ice falling from the FSS to the MLP at engine ignition and potentially leading to rebound or engine aspiration anomalies also were brought forward in the hearings. There was never a focused discussion on such issues in our preflight LCC discussions.

In the days following the accident, it was reported that an ice team member on the pad had, by chance, measured much lower temperatures, on the order of 8 deg. F, on the lower portions of the right hand SRB with an infrared instrument. These instruments were normally employed for the purpose of evaluating ice conditions on the External Tank. Such an SRB measurement was not part of the prescribed plan and to my knowledge this information was not brought forward at the time to any management, and specifically, not those in the LCC. Thus, it had no bearing on either the SRB or ice prelaunch deliberations. Subsequently, analyses by KSC showed these readings had not been taken in an effective manner and were not accurate.

Other Possible Launch Decision Factors

Two other possible launch decision factors were extensively debated by analysts during and subsequent to the post launch hearings. I have already mentioned potential media impact on the launch decision and state again that the media could never cause NASA to make a launch decision it otherwise would not choose to make. The second, political pressure from Washington, was also extensively debated with respect to the timing of the President's State of the Union speech, the fact that Christa McAuliffe, a school teacher, was to be onboard and the critical timing of this mission in conjunction with other missions and activities to investigate the arrival of Halley's comet only several months away. From my perspective, I had no contact or pressure from anyone on these subjects, nor did I witness or hear of any. If any such pressure was felt by Jess Moore it was not apparent and only he could comment further, although I had heard it previously rumored that Jess had received criticism for scrubs on several prior launches.

Lingering Questions

As I discussed earlier, L-1 day meetings are held as close to picking up the terminal launch countdown as is practical, with the principal objective to give a "go" to proceed with preparations for

External Tank loading. Normally, nothing much changes between completion of the L-1 review and initiation of tanking approximately 10 – 12 hours before launch. Team members are resting, activities at the pad are at a low level and the Mission Management Team never meets collectively, face to face, again. Rather, Team members report to their respective places in the LCC, as appropriate, sometime later in the countdown with the intention of dealing with any new problems on console in real time. In the case of STS-51L, however, this approach was not adequate to bring necessary focus to the real situation at hand. Two major issues had arisen subsequent to the L-1 day deliberations - Thiokol engineering reservations to launch and significant ice accumulation on the launch pad - and these were never addressed collectively by the full Mission Management Team. Why didn't we hold a MMT meeting on the morning of the launch? This quite likely would have brought out the nature of the SRB discussions of the previous evening. Had that happened, I feel certain the launch attempt would have been called off.

I've already discussed the breakdown in program process and communication which had evolved between the Level 2 Program Office and NASA Headquarters and MSFC over joint sealing anomalies in the SRB Project. I believe it reflects a lack of understanding of, and sensitivity to, formal program process control within both Headquarters and MSFC and perhaps JSC, as well. One factor may be that, as I mentioned earlier, Bob Lindstrom had fairly recently retired as the MSFC Space Shuttle Projects Manager. He had been with the Shuttle Program from its early years and had always kept both me and my predecessors well up to speed on all program developments within the MSFC Shuttle projects. Bob definitely was a member of the Space Shuttle program team as well as the MSFC team and he had played a role that Level 2 had grown accustomed to and relied on. While I knew his replacement, Stan Reinartz, quite well from earlier work together on the Skylab Program I realize now that he actually didn't assume the same role of program communicator as Bob had.

Alan McDonald was a senior member of the Thiokol management team at KSC for the launch. In his testimony and comments post flight he affirms that he strongly supported the Thiokol engineering reservations to launch in the meetings/telecons of the evening prior to launch and that he did not concur in the decision by his management to go ahead. I knew Alan quite well and he certainly knew how to reach me either at the hotel the night before or on console the morning of the launch. Why did he not call and alert me to these concerns? It most certainly would have brought higher level program attention to bear on this critical issue.

I also knew Rocco Petrone, President, RI Space Transportation Systems Division, from interacting with him in the Mission Control Center during the Apollo Program when he was the NASA Apollo Program Director. Rocco had been at KSC earlier in the preparations for the STS-51L launch and I was not aware that he had returned to California. In any event, when he became aware of the ice issues on the morning of launch why did he not call me, or if he felt it more appropriate, Jess Moore, to express his concerns? It likely would have made a difference.

There is one question that truly amazes me and that escaped all of us prior to the launch. That is why we so readily accepted the fact that a launch commit criteria which states that ambient temperature must be at or above 31 deg. F at time of launch would cover the case where the ambient

temperature drops to 23 deg. F or below overnight, spends a significant number of hours below freezing and then rises above 31 deg. shortly prior to launch the following day. I have no answer for this one.

STS-26 (Discovery)

Thirty three months later Discovery lifted off on STS-26. During the ensuing time, I had been appointed the Director, NSTS (Space Shuttle Program) at NASA Headquarters, a position which had been vacant for a number of years and was reinstated as a result of the Rogers Commission recommendation to strengthen program management at the Headquarters level. Over those months, I felt the NASA-wide Space Shuttle program team had come together strongly. A significant redesign of the SRB had been implemented which provided for dependable case and nozzle joint performance with multiple levels of redundancy. In addition, I had led a program-wide review of all Space Shuttle systems , not just those directly implicated in the accident, a process I had witnessed George Low follow after the Apollo 1 fire. This had led to my approval of over 400 safety related changes to the Space Shuttle vehicle, flight software and ground support systems. Many of these changes dealt with issues that were well known to the engineering communities involved in the program. Some were limitations/deficiencies which had been recognized during Space Shuttle development and had been waived as acceptable for the first Shuttle flights with the intent to correct them at some later time. In the process, every one of the extensive Space Shuttle program Failure Mode and Effects Analyses had also been re-reviewed in depth and re-baselined.

The combination of the impact of the Challenger accident and these in depth program technical reassessments and changes had caused a predictable amount of additional conservatism and caution across the entire Space Shuttle program community. It had taken much time and effort to get to the point where all concerns had been resolved to the point of launch readiness. In the early hours of September 29, 1988, as the External Tank was being loaded, a large storm moved in to the KSC area with winds, lightning and heavy rain. In spite of the years of meticulous preparations, I felt that the gods might be telling us we were still not yet ready to go. Towards dawn, the weather began to clear and as we passed through T-60 minutes it became apparent that this was the day the Space Shuttle would fly again. Many successful Space Shuttle flights followed in the years ahead.

September 29, 1988, was one of the most proud and momentous days of my long career. Never the less, it can never ease or erase the questions and memories I trouble over from the terrible loss of Challenger and her crew.

Some Perspectives

I conclude that different motives were in play among the various organizations and personalities involved in the Challenger launch decision. While each will purport, and perhaps even believe, that flight safety is their number one focus and will use appropriate flight safety related terminology, flight

safety culture is not in-bred in many organizations the way it is at the Johnson Space Center. Motives and pressures of cost, schedule, politics, organizational independence/arrogance, pleasing one's customer and media interactions also run strong beneath the surface and affect the manner in which people react and perform. A number of these tendencies seem evident in the events leading up to the launch of Challenger. A space flight program manager must be continually aware of such tendencies in human nature and organizational performance and continually attempt to effectively account for them.

In addition to the tragic and unforgettable loss of life, the Challenger accident had, and continues to have, momentous effects on United States and international Space programs. In the near term, it led directly to an unprecedented restructuring of the Space Station Freedom program resulting in extensive redirection, massive delays and huge cost overruns. This was half a dozen years prior to the second massive restructuring of the Space Station under NASA administrator Daniel Goldin, which likely never would have occurred. A strong case can be made that if the Challenger accident had not occurred the Space Station would have flown and become operational a decade earlier than what has transpired, with attendant cost savings and opportunities to expeditiously move forward with future plans and programs. Also, the Shuttle was reined in from its full potential with decisions to move away from DOD and commercial customers, a large, flexible onboard upper stage and west coast launch capability. In the longer term, the play out of these events continues today as NASA struggles to plan for effective Space Station operations without the Space Shuttle while attempting to move forward with a vast new program of human space exploration beyond Earth orbit. The Challenger accident changed the course of history and the nature of both national and international space programs even as these programs continue to evolve in the 21$^{st}$ century. The full impact of the Challenger launch decision is still unfolding.

Attachments

1. STS 61-C Launch, Jan. 14, 1986
2. STS 51-L Partial MMT on Orbiter Ice Threat During Launch, Feb. 24, 1986
3. STS 51-L Launch Pad Icing, Apr. 15, 1986

National Aeronautics and
Space Administration

**Lyndon B. Johnson Space Center**
Houston, Texas
77058

NASA

Reply to Attn of: GA-86-001

JAN 14 1986

TO: Distribution

FROM: GA/Manager, National Space Transportation System

SUBJECT: STS 61-C Launch

I would like to congratulate the NSTS team on the successful launch of STS 61-C. It seems to me that this particular flight, which gave the team such a workout in kicking off our CY 1986 flight activity, introduced a particularly large number of "lessons learned" and potential followup actions. In the remainder of this memorandum I will summarize my view of these "lessons" which I believe are really operations efficiency and safety issues for the program. I would also ask that the listed actions be picked up by the Management Integration Office as formal actions to be tracked and reported to the PRCB.

1. The first STS 61-C launch attempt in December 1985 resulted in an automatic LPS hold at T-14 seconds and was subsequently scrubbed for a problem later determined to be an oversensitivity in an SRB HPU electronic control circuit. This was traced to a piece part substitution which introduced a circuit sensitivity characteristic which had been experienced and corrected several years earlier in a similar upgrade of the Orbiter APU control electronics.

ACTION: Review Orbiter formal closeout paperwork for this issue and the process for communicating this problem throughout the NSTS system to identify reasons SRB project did not react appropriately. Recommend process to review similar closeouts to assure full program communication has occurred.

JSC/GA/W. McCarty

2. The launch attempt on Monday, January 6 experienced a problem with a "closed" position talkback on a GSE replenish valve in the tail service mast just after T-5 minutes. The console operator did not immediately call a hold for this situation and attempted a manual workaround procedure which introduced several additional issues into the situation. The first issue to become evident was that main engine oxygen temperatures decreased below redline limits. This situation was determined not to be waiverable and the count was recycled to permit propellant temperature reconditioning. The time required for this activity also necessitated the return to OPS-9 for a full IMU realignment. Subsequent to proceeding with the recycle further data review established that the manual workaround procedure had inadvertently operated the GSE replenish valve and the Orbiter fill and drain valve out of normal sequence

resulting in draining up to 18,000 lbs. of LOX back out of the external tank and drawing a slight negative pressure on the ET LOX tank. Both of these eventualities could have led to serious safety of flight consequences had the team elected to waive the SSME temperature redlines and proceed with launch.

ACTIONS: a. Institute positive monitoring at KSC and HOSC to assure liftoff will not occur with less than the planned ET propellant load or following any negative pressure cycle on the ET that has not had full engineering assessment.

KSC/R. Sieck
MSFC/S. Reinartz

b. Review KSC LPS console operator procedures and console software for off nominal situations. Consider additional launch/flight system training and contingency simulations for operators on critical LPS system consoles.

KSC/R. Sieck

c. Assess criteria which establishes IMU hold time for potential relaxation beyond 90 minutes. Current hold time appears to be based upon a highly conservative set of failure conditions.

JSC/VA/R. Colonna

3. As the recycle proceeded on January 6 it became apparent that much of the available 1 1/2 hour launch window would be required to effect propellant temperature reconditioning and IMU realignment. The JSC payload support team identified several additional options for deployment of the RCA satellite which would allow an additional 30 minutes of launch window. However, coordination of these options with the customer was not successful in the time available and the launch was eventually scrubbed due to launch window closure. Had the 30 minutes been made available a successful launch would quite likely have occurred. By the following day the customer had agreed to the additional options and the 30 minutes were added to the launch window for all subsequent 61-C launch attempts.

ACTIONS: a. Review launch window constraints for all flights at Flight Operations Review or before and bias window availability for maximum launch opportunity. Consider whether secondary payload deploy situations such as possible malfunction of the PAM sunshield should be covered by NASA internal contingency planning rather than by negotiating window constraining mission options with the customers.

JSC/TA/L. Nicholson

b. Arrange for the availability of customer representatives at JSC

with full authority to negotiate launch window adjustments in direct support of the payload support team.

NASA Hqs./C. Lee
JSC/TA/L. Nicholson

4. On Tuesday, January 7 all launch and flight systems functioned satisfactorily during the countdown and KSC weather appeared to be acceptable for both launch and RTLS. TAL weather was no-go, however, at both Moron and Dakar. At Dakar the problem resulted from low visibility due to haze from dust blowing in off the African continent. Discussions were held regarding the possibility of closing the TAL exposure in order to permit launch under these conditions. This would have necessitated extending the RTLS regime by approximately 5 seconds which would require 109% SSME thrust and by flying through a major portion of the 35 second TAL window with zero to minimum launch performance margins. MSFC determined that acceptance testing and turbopump life remaining on the specific engines installed on Columbia would not permit operation at 109% even as a hedge to cover the low probability of an SSME shutdown leading to an abort during this 5-second period. A NASA JSC observer conducted approach observation flights at Dakar throughout the launch window with the hope that visibility would improve with sun angle. However, Dakar visibility degraded as the day wore on and standard weather reports from Moron indicated conditions were deteriorating. At the end of the launch window the mission was scrubbed. It was also noted that in October 1985 when the Syncom satellite was removed from STS 61-C sufficient performance was made available such that the ascent trajectory could have been redesigned to eliminate the need for a TAL abort. This redesign had been reviewed and disapproved based upon team workload priorities which existed at that time.

ACTIONS: a. Determine actions necessary to provide SSME's for all missions which are acceptable for use at 109% to augment abort profiles.

MSFC/S. Reinartz

b. Develop and implement mission design criteria and groundrules which maximize performance allocation toward minimizing TAL abort exposure.

JSC/TA/L. Nicholson

5. Following the January 7 scrub a 48-hour turnaround was planned to permit SSME propellant line ovality checks. During detanking, however, the Orbiter LOX prevalve leading to SSME #2 failed to close properly and an intensive failure investigation ensued resulting in the determination that a temperature probe in the GSE LOX TSM had broken loose and lodged downstream in the prevalve, precluding full closure. The probe was removed and analysis showed that failure had occurred as a result of an inadequate weld. Even though program requirements imply that no components should be installed downstream of the final filters in GSE propellant servicing lines it was determined that several temperature probes did exist downstream of the filter in both the $LO_2$ and $LH_2$ servicing systems. The $LH_2$ probes were removed and

the ports capped and the $LO_2$ probes were replaced with units verified to be of adequate structural integrity. During the investigation, failure modes of the Orbiter prevalve were highlighted including several critical single point failures of the anti-slam elements on the actuator. The current program technical data base specifies that proper Orbiter prevalve closure is required for safe SSME shutdown.

ACTIONS: a. Review adequacy of and rationale for component/filter placement in critical launch complex fluid servicing lines.

JSC/TA/L. Nicholson
JSC/GA/W. McCarty
KSC/R. Sieck

b. Review adequacy of current Space Shuttle main engine shutdown mechanization with respect to flight safety. Provide recommendations as appropriate for additional main engine testing, removal or modification of Orbiter prevalve anti-slam components, and/or SSME modifications as appropriate.

JSC/TA/L. Nicholson
JSC/GA/W. McCarty
MSFC/S. Reinartz
W. Taylor

6. As a result of the failure investigation and corrective action on the Orbiter LOX prevalve the next launch attempt occurred on Friday, January 10, 72 hours after the attempt on January 7. Weather for January 10 at KSC was predicted to be marginal at the MMT on the evening of January 9, however, the mission team elected to proceed with the count. On January 10, weather conditions were significantly worse than predicted with heavy rain and overcast and the launch was scrubbed with 45 minutes remaining in the launch window. The next launch attempt was scheduled for Sunday, January 12, leaving January 11 for the weather to clear and for performing SSME propellant line ovality checks in order to set up consecutive launch opportunities on January 12 and 13 which were both predicted to have good KSC weather.

7. At the MMT on January 11 all launch related elements were reported to be in good shape for January 12 except for TAL weather. Both Moron and Dakar were predicted to be no-go. As a result action was taken to investigate opportunities to optimize TAL weather prediction and to investigate other possible TAL landing locations. It was determined that Runway 10 at Rota would also be acceptable and I-load development was expedited to add this location to the landing site table. Even though Rota is only 40 minutes from Moron it was believed that its location on the coast might provide enough different local weather environment in the event of marginal Moron conditions that proceeding was worthwhile. Also, it was determined that STS 61-C had sufficient performance margin to reach Zaragoza and MECO target development was initiated although it was known that this could not be completed for several days. All other landing sites in the TAL coverage area were reviewed

and found to be unacceptable. Finally, military weather assessment flights and communications back to JSC and KSC were arranged for both Moron and Rota.

ACTIONS: a. Develop and implement mission design criteria and planning to maximize TAL site locations and opportunities for all future flights.

JSC/TA/L. Nicholson
JSC/AM/C. Charlesworth

b. Identify, characterize, and recommend to the program an additional TAL site in the North African area to back-up or replace Dakar which appears to have a persistent winter haze/dust problem.

JSC/TA/L. Nicholson
JSC/AM/C. Charlesworth

c. Develop and implement plans and procedures for appropriate weather flights and direct communications to JSC and KSC for all selected TAL sites for all missions.

JSC/TA/L. Nicholson
JSC/AM/C. Charlesworth

d. Reinstitute Orbiter autoland DTO/flight certification into the near-in STS manifest with the objective of providing auto approach to low ceiling conditions for use with marginal intact abort site weather.

JSC/TA/L. Nicholson
JSC/VA/R. Colonna

8. On Sunday, January 12 weather was clear at KSC and Moron. During the count it was elected not to patch the mass memory to include Rota in the landing site table as patch development had taken longer than expected and potential impacts to the countdown would have been involved in proceeding. STS 61-C lifted off at the opening of the launch window at 6:55 a.m. following a flawless countdown.

In summary, the NSTS program is proud of calling itself "operational." In my view one of the key attributes of an operational program is to be able to safely and consistently launch on time and land on time at the intended landing site. The STS 61-C experience demonstrates that there are avenues for extra margin in this regard throughout the STS system. I would like to encourage the NSTS team to strive to identify and achieve this extra margin in all areas possible. Further, where additional program resources are required to support efforts in this regard I would like to have these resources clearly identified so that the program can undertake aggressive efforts to provide them.

Arnold D. Aldrich

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Lyndon B. Johnson Space Center
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NASA

FEB 24 1986

eply to Attn of

TO: Memorandum for Record

FROM: GA/Manager, National Space Transportation System

SUBJECT: STS 51-L Partial MMT on Orbiter Ice Threat During Launch

At 9 a.m. on January 28, 1986, I requested a meeting in the Launch Control Center (LCC) "Operations Center" room to review the report of the ice inspection team and to specifically assess the threat of ice impact damage to the Orbiter Thermal Protection System (TPS) during launch and ascent. I felt this meeting was necessary prior to final launch commit because of the large amount of ice reported on the launch pad Fixed Service Structure (FSS) resulting from the "Freeze Protection Plan" procedures which had been implemented at the launch complex on the preceeding evening during the terminal countdown. The potential ice impact threat to the orbiter from the external tank was also reviewed. The paragraphs which follow provide a summary of this meeting.

The ice team reported that the flight vehicle (primarily external tank) looked very good with only frost on the H2 tank and H2 feedlines. On the Mobile Launch Platform (MLP) sheet ice had been found in the sound suppression water troughs and it had all been broken up and removed except for a few small pieces which were in troughs furthest away from the vehicle. All troughs had had ice in them except for two on the south side. Some ice was also reported to be on the bottom of the Solid Rocket Booster (SRB) aft skirt, on the MLP deck, and on the Tail Service Mast (TSM). The ice team indicated that they felt that this ice (residual in water troughs, MLP deck, SRB skirt and ET frost) was okay in terms of not being a launch threat to the Orbiter TPS.

On the Fixed Service Structure (FSS) ice existed from facility water drain procedures which had been utilized during the previous evening and from one or more broken water lines. There were varying amounts of ice from the 215 foot level down to the 95 foot level with no ice existing above the 255 foot level. The characteristics of the ice on the FSS were discussed in detail by the ice team indicating that there were large amounts of ice and icicles on the north and west sides of the FSS with the east side (toward the Orbiter) having significantly less.

Following this discussion the acceptability of the potential ice threat to the Orbiter was reviewed in detail. Mr. Horace Lamberth, KSC Director of Shuttle Engineering, reported that his engineering team had calculated the trajectories for ice falling from the identified areas on the FSS east side with the current projected winds (approximately 10 knots at 300 degrees) and it was their position that none of the falling ice would contact the Orbiter even if the winds were to increase to 15 knots. Mr. Richard Colonna, JSC Orbiter Project Manager, reported that similiar calculations had been performed by the mission evaluation team in Houston and they concurred in this evaluation.

Further, Mr. Colonna stated that even if these calculations were significantly in error only lightweight pieces of ice would be likely to be transported the full distance from the FSS to the Orbiter and that they would contact the Orbiter at oblique angles. Impacts of this type would have a very low probability of causing serious damage to the Orbiter TPS and at most should result in post flight turnaround repairs. During the meeting, I placed a phone call to Mr. Thomas Moser, Director of Engineering at JSC, who was in the Mission Evaluation Room (MER). He confirmed detailed agreement with Mr. Colonna's and Mr. Lamberth's positions and also indicated that he had been in contact with Mr. John Peller, Chief Engineer at Rockwell International Space Transportation System Division, who was in the Mission Support Room (MSR) at Downey with his engineering team.

Following these discussions I asked for a position regarding proceeding with the launch. Mr. Lamberth, Mr. Colonna, and Mr. Moser recommended to proceed. At that time I also polled Mr. Robert Glayser, Orbiter Project Manager for Rockwell International STS Division and Mr. Marty Cioffoletti, Shuttle Integration Project Manager for Rockwell International STS Division. Mr. Glayser stated that while Rockwell did not disagree with the above analysis, they could not give an unqualified go for launch based upon the fact that ice on the FSS was a condition which we had not launched with previously and this posed an additional small but unquantifiable risk. Mr. Glayser did not ask or insist that we not launch and no other comments or recommendations were offered by the large group assembled with respect to concern for proceeding.

At the conclusion of the above review I felt reasonably confident that the launch should proceed. However, I was concerned that in the ensuing time period between the return of the ice team and the subsequent launch conditions at the pad might change. Thus I asked for an additional ice team inspection to be performed as close to launch as possible which would include an assessment of any significant changes in the icing conditions, removal of any fallen ice from the MLP deck and removal of any new ice from the water troughs.

At this point I returned to the Operations Support Room (OSR) where I reviewed the context of this meeting with the Associate Administrator for Space Flight, Mr. Jesse Moore, who was seated with the NASA General Manager, Mr. Philip Culbertson. In that summary, I clearly indicated the qualified position taken by Rockwell International and recommended that the launch proceed unless the additional ice team inspection identified a significant change in launch pad condition.

The report of the ice team following the final launch pad inspection indicated no significant changes although several pieces of ice were swept from the MLP deck and some additional ice was removed from the water troughs.

Arnold D. Aldrich

U.S. Government

# MEMORANDUM

Lyndon B. Johnson Space Center

NASA

| REFER TO: GA-86-039 | DATE APR 15 1986 | INITIATOR GA/ADAldrich:rkd:4/4/86:3658 | ENCL 1 |
|---|---|---|---|

TO: Record

CC

FROM: GA/Manager, National Space Transportation System

SIGNATURE

Arnold D. Aldrich

SUBJ: STS 51-L Launch Pad Icing

Enclosed is a letter which I submitted to the STS 51-L Interim Investigation Team regarding the decision to launch with accumulations of ice on the launch pad and the fixed service structure (FSS). While that memorandum presents a full discussion of the January 28 partial Mission Management Team (MMT) meeting on launch pad icing, my Commission testimony on this subject contained some additional considerations.

The acceptability of the icing conditions on the FSS primarily related to the specific locations on the FSS where the ice had formed. The preponderance of the ice (which has been so widely discussed and shown in photographs) was located on the north and west sides of the FSS where drains had been left open and where there did not appear to be significant credible transport paths to the flight vehicle. Also, ice did not exist on the higher levels of the FSS in any location and thus ice impacts were not expected on critical forward portions of the Orbiter regardless of transport considerations.

In my testimony I also presented rationale for believing the low but possible potential for ice impact to the Orbiter TPS was consistent with a number of earlier situations in the program where precedent had been established to proceed with launches with known low level TPS damage threats. For example, early in OFT there were a number of protuberances and other features on the external tank which caused significant ice to form on almost every launch, and a major program was instituted to change external tank configurations to reduce these threats. This program cost approximately $40 million and took a significant period of time to implement. While that implementation was under way the program continued to fly STS flights with attendant low level Orbiter ice impact risks from ET icing. Also during that same time period, significant TPS damage was experienced from launch pad debris, much of which came from RTV which was applied over the SRB holddown posts. Again a program was instituted to remove pad debris and reduce the amount of RTV on the SRB mounts; however, a number of flights were flown with reduced but not eliminated threats for TPS debris damage before these conditions were fully eliminated from the program.



* U.S. GOVERNMENT PRINTING OFFICE: 1985-659-015/20272

During 1985 a condition was identified where pieces of external tank insulation from the intertank area were found to be breaking loose during ascent and causing TPS damage on the underside of the Orbiter. Near-in and long-range fixes were developed for solving this problem; however, a number of additional tanks were flown with the known potential for some TPS damage on the Orbiter underside from this condition. Also, during OFT the team elected to fly STS-4 following significant hail damage to the Orbiter TPS, and on many flights damage to TPS has been experienced on the Orbiter aft end from the SSME $H_2$ ignitors.

In a number of these previous situations significant technical discussions have occurred prior to proceeding with the various launches, and Rockwell International has frequently taken conservative positions very similar to the one which they took in the partial MMT on January 28.

I would also emphasize that it was and is my belief that the telephone discussions which Mr. Thomas Moser, JSC Director of Engineering and Mr. Richard Colonna, JSC Manager for STS Orbiter and GFE Projects had with Mr. John Peller, Vice President, Engineering, Rockwell International prior to and during the partial MMT had given them a very strong feeling that there was technical agreement on the risks involved with respect to committing to launch with the known launch pad icing conditions.