Volume II
Appendix D:

Columbia Accident Investigation Board Reports Cited in This Report

SUPPLEMENT TO THE COLUMBIA ACCIDENT INVESTIGATION BOARD REPORT

by Brigadier General Duane Deal, Board Member

with appreciation to Dr. Jim Hallock, Dr. John Logsdon, Dr. Doug Osheroff, and Dr. Sally Ride for their valuable inputs and editing.

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Supplement to The Columbia Accident Investigation Board Report

Err on the side of providing too much rather than too little information in the aftermath of a mistake or failure.

-Strock, Reagan on Leadership[1]

FOREWORD: PREVENTING "THE NEXT ACCIDENT"

The Columbia Accident Investigation Board report is a powerful document. It goes far beyond any previous accident report in the scope and manner with which it tackles a multitude of complex and daunting subjects previously unaddressed. In extensive detail and often in blunt language, it coveys the intricacies of the physical cause of the Columbia tragedy, and places equal weight on the organizational cause. The Board and its staff of professional investigators who produced this landmark report represent the best our nation has to offer--dedicated men and women brought together from many walks of life by an international tragedy, united with a common purpose, and driven to produce a product of substance and worth to the human space flight program. Additionally, its lessons go far beyond the Space Shuttle Program; indeed, the lessons learned are applicable to any large organization, particularly to those operating complex, risky, or aging systems.

This supplement is not written to refute any portion of that report. The Board report contains data, analysis, and conclusions which combine to write a prescription for NASA to recover not only in returning the Space Shuttle safely to the vacuum of space, but also to address NASA's sporadic organizational morass. If NASA will accept this prescription and take the "medicine" prescribed, we may be optimistic regarding the program's future; if, however, NASA settles back into its previous mindset of saying, "Thanks for your contribution to human space flight," summarily ignoring what it chooses to ignore, the outlook is bleak for the future of the program.

The Board report already contains many findings and recommendations. We have confidence that the recommendations carrying a "Return to Flight" annotation will be addressed and fixed prior to the Shuttle launching again. My confidence diminishes somewhat with recommendations that stand alone, not annotated as return-to-flight. In light of the reaction to past studies--even those following the Challenger disaster--my confidence disappears when we offer NASA items only as "observations"--when Board members and investigators considered them significant--and trust NASA to address each one of them. History shows that NASA often ignores strong recommendations; without a culture change, it is overly optimistic to believe NASA will tackle something relegated to an "observation" when it has a record of ignoring recommendations.

When the original members of the Board first spoke via telecon on February 1st, hours after the accident, and when we first assembled at Barksdale Air Force Base the evening of February 2nd, we were presented with the original board charter. While that charter and the Board itself have expanded since then, the basic charge to the original Board was to (1) determine the cause of the loss of the Columbia and her crew, and (2) prevent recurrences--what we termed "the next accident" waiting to happen.

The Board report goes into great depth examining the physical cause of the accident—"the foam did it" … poorly designed, inconsistently manufactured, and inadequately tested, the foam is no longer an accident waiting to happen. The report then goes into a fascinating look at NASA's organizational culture and the pattern of breakdowns that have cost the lives of 14 astronauts.

With the preceding in mind, this supplement is presented to augment the Board report and its condensed list of recommendations. It is written from the perspective of one who's presided or participated in a dozen space and aircraft accidents, who fears the report has bypassed some items that could prevent "the next accident" from occurring—the "next" O-ring or the "next" bipod ramp.

As much or more than that rationale, this comes from the perspective of one who in the course of the investigation has interviewed those in high/medium/low management levels, and also those with hands on equipment "getting their hands dirty." If *they* express concerns, and those concerns are consistent throughout the workforce, those concerns regarding what could cause the next accident if not fixed *must* be heeded.

> *A primary task in taking a company from good to great is to create a culture wherein people have a tremendous opportunity to be heard and, ultimately, for the truth to be heard.*
>
> -Collins, Good to Great[2]

> *In this view [of adaptive leadership], getting people to clarify what matters most, in what balance, with what trade-offs, becomes a central task.*
>
> -Heifetz, Leadership Without Easy Answers[3]

Because of our conviction in the course of the investigation that we should do our very best to prevent the next accident, we must not miss an opportunity to fix something we know about that could cause that next accident and possibly deaths; indeed, we would be negligent to not to do so.

ADDRESSING ITEMS ALREADY IN THE REPORT … WHY?

Why suggest modifications to items already present in the Board report? History reveals NASA has repeatedly demonstrated a lack of regard for outside studies and their findings. Chapter 5 of the Board report contains a 2-page chart conveying that during the course of the Board investigation, more than 50 separate post-Challenger reports were examined for various topics; Appendix D.18 recounts what was found, what was recommended, and NASA's response to findings and recommendations--if any. Board members had these findings and responses available as a benchmark for their lines of investigation to compare to NASA's current programs. Additionally, Dennis Jenkins, a Board Investigator and noted space and aviation author, compiled an exhaustive 300-page study of every Aerospace Safety Advisory Panel report; that study is also in Appendix D.18

Despite this extensive look at the past, many items in the report were characterized as less than recommendations. The introduction to Chapter 10 of the Board report, "Other Significant Observations," says:

> *The significant issues listed in this chapter are potentially serious matters that should be addressed by NASA because they fall into the category of "weak signals" that could be indications of future problems.*

In my view, given the reality of NASA's past record with such issues, a sterner and more effective wording would have been:

> *The significant issues listed in this chapter are serious matters that must be addressed by NASA because they fall into the category of "strong signals" that are indications of present and future problems.*

While much of the following is contained in the Board report, it is repeated here together with related views that were not included in the body of the report.

These portions of the report are included to reflect the concern that the Board report addresses micrometeorites that we can't predict or prevent with a Board recommendation, but allows things we can see and can prevent--and can predict an outcome--to remain as "NASA-ignorable observations." Items such as corrosion, the SRB attach rings, the hold-down cable, and the Kennedy Space Center quality assurance program deserve focused attention, as do ATK Thiokol security, the Michoud Assembly Facility (MAF) quality program, MAF security, crew cabin insulation, and other findings/recommendations. In my view, we have not done our best to "prevent the next accident" regarding things we've seen with our own eyes, and that individuals ranging from technicians to engineers have conveyed to us directly and via interviews and documentation.

QUALITY ASSURANCE

Part of preventing the next accident lies in a strong quality program; while you can't inspect quality into a product, the Shuttle Independent Assessment Team, an internal Kennedy Space Center report, and other past reports spotlight what a weak program can potentially cost. Also, as human error has been implicated in 60-80% of accidents in aviation and other complex systems, a solid quality program may be the last measure of checks and balances in a complex system such as the space Shuttle.[4]

Unresponsive Management

> *You need an established system for ongoing checks designed to spot expected as well as unexpected safety problems … Non-HROs [Non-High Reliability Organizations] reject early warning signs of quality degradation.*
>
> -Roberts, "High Reliability Organizations"[5]

Interviews and documentation provided by technicians, inspectors, and engineers revealed that when Quality Assurance Specialist (QAS) inputs are made to improve processes or equipment, regarding issues from safety to discrepancies of out-of-specification items, Kennedy's quality management support is inconsistent.

Quality Assurance Specialists have found they must occasionally go around their management and elevate concerns using the NASA Safety Reporting System. In turn, the NASA Safety Reporting System has been responsive and validated concerns that local management would not. The KSC quality program management is perceived as unresponsive to inspector concerns and inputs toward improvement.

Staffing Levels

Adequate staffing levels remain a concern expressed by today's workforce and previous reports, including a February 17, 1999, letter to multiple levels of NASA management from John Young, dean of the astronaut corps. NASA Mission Assurance leadership reported that while the number of Quality Assurance Specialists may be adequate, with additional staff, workers would not have to wait for an inspector to close out a job, and would be available for additional quality-related pursuits. One of the more common reasons that quality engineers cited for declining to add government inspections at Kennedy Space Center was indeed inadequate personnel—a poor excuse for not adding inspections deemed as necessary. Likewise, Marshall's Mission Assurance staff and the Michoud Defense Contract Management Agency (DCMA) staff also appear short of people for their workload. Columbia Accident Investigation Board recommendations to evaluate Quality Program Requirements Documents should drive decisions on additional staffing; in the interim, staffing to current authorizations with qualified people should be expedited.

Grade Levels

Grade factors also enter the equation, in two respects. First, the KSC Mission Assurance chiefs are at a lower grade than the Chief Engineer or Launch Director. This organizational structure may cause pressure in resolving conflicting priorities between respective organizations. KSC should review the position description and make adjustments to establish parity in leadership and influence. Second, a review of other NASA center quality assurance specialist staffing and grades revealed that Kennedy is the only NASA center evaluated that has Quality Assurance Specialist grades set at GS-11—other centers have Quality Assurance Specialist grades set at GS-12. An evaluation of this disparity should determine whether those grades are appropriate.

Inspector Qualifications

Examples surfaced where individuals with no previous aviation, space, technical, or inspection background had been selected as Quality Assurance Specialists and were making NASA final inspections. While most inspectors had extensive aviation and/or related military experience, such hiring practices indicate a need to consistently specify and stringently observe job qualifications for new hires that spell out proper criteria for applicants.

Employee Training

Workers expressed concerns over the type and amount of training they received. A common theme expressed by 67 percent of those interviewed regards the lack of formal training, particularly for quality engineers, process analysts, and quality assurance specialists of both NASA and DCMA. Instead of formal training, most is simply on-the-job training. Where available, some training is provided in classrooms conducted by and for contractor employees, and numerous examples were provided where a contractor technician had to provide training to the inspector who would be evaluating the technician's work. Quality Program management must work with the rest of NASA (and perhaps with the Department of Defense) to develop training programs for its quality program personnel. These views were expressed predominantly at KSC and the Michoud Assembly Facility. (NOTE: Board report observation O10.4-3 addresses Kennedy training, but not MAF or NASA-wide interest.)

Providing Necessary Tools

Irritants preventing inspectors from performing undistracted were discovered at Kennedy: Quality inspectors experienced difficulty and delays in attaining the tools they needed to do their work per specifications. Some purchased their own equipment, leading to concerns about configuration management of the equipment used in final inspections.

Government Inspections

The existing list of NASA Mission Assurance oversight inspections was based on a point-in-time engineering risk assessment with limited application of quality analysis and sampling techniques to determine the scope and frequency of inspections. Tasks were retained for government oversight on the basis of criticality, not process or quality assurance. By comparison, Marshall Mission Assurance retained government oversight options during its government inspections reduction by moving all the former Government Mandatory Inspection Points (GMIPs) into a new category, Surveillance Opportunities. These Surveillance Opportunities are no longer considered mandatory inspection points, but remain an optional area for Mission Assurance inspection. The MSFC Mission Assurance system includes feedback and closed loop systems to use in trend analysis and in development of future Mission Assurance tasks designed to improve quality. Mission Assurance-observed events that result in a Verbal Corrective Action Report are included in this tracking system, and are used to tailor surveillance or government inspections. ATK Thiokol goes further and calls the Mission Assurance shop with a 15-minute warning when a Surveillance Opportunity is occurring, but by agreement, will not wait for the inspector in order to maintain job flow.

Quality Program Surveillance

> *Discovering these vulnerabilities and making them visible to the organization is crucial if we are to anticipate future failures and institute change to head them off.*
>
> -Woods and Cook,
> "Nine Steps to Move Forward from Error"[6]

In contrast to other NASA and contractor locations—where inspectors conduct unscheduled evaluations and observations--Quality Assurance Specialist surveillance is essentially nonexistent at Kennedy, despite reports that document organizational inconsistency within the NASA quality assurance construct. For example, the 2000 Space Shuttle Independent Assessment Team report echoed the Rogers Commission report with a lengthy discussion of the need for organizational independence and a strong presence. [7] "The Shuttle Independent Assessment Team believes strongly that an independent, visible Safety and Mission Assurance function is vital to the safe operation and maintenance of the Shuttle. The Shuttle program and its "one strike and you're out" environment is unlike most other defense or commercial industries. As a consequence, it is believed the industry trend toward reducing Safety and Mission Assurance oversight and functions is inappropriate for the Shuttle."[8] Among the Assessment Team's recommendations was a strong suggestion to restore surveillance.[9] This is consistent with the testimony of numerous Mission Assurance inspectors, technicians, and engineers to the Columbia Accident Investigation Board. Further, this surveillance should include concurrent inspections (for oversight of the contractor Mission Assurance function), and sequential or no-notice evaluations to improve "oversight by spontaneity."

> *Over the years, these organizations [HROs] have learned that there are particular kinds of error, often quite minor, that can escalate rapidly into major, system-threatening failures.*

-Reason, Managing the Risks of Organizational Accidents[10]

> *In discussing such reliable organizations, it's emphasized that, "The people in these organizations … are driven to use a proactive, preventive decision making strategy. Analysis and search come before as well as after errors … [and] encourage:*
> - *initiative to identify flaws in SOPs and nominate and validate changes in those that prove to be inadequate;*
> - *error avoidance without stifling initiative or (creating) operator rigidity ….*

-LaPorte and Consolini, in Reason's Managing the Risks of Organizational Accidents[11]

The Mission Assurance function of United Space Alliance (and other NASA contractors) samples a large amount of its workload and processes. The relatively minimal Kennedy Mission Assurance samples of Alliance work is informal, and results are currently documented only in the Safety & Mission Assurance Reporting Tool database, which is used as a quality problem-tracking tool to help Mission Assurance identify trends and focus its approach to oversight and insight. Problems revealed by the sampling inspections or from the informal Reporting Tool database can be communicated to United Space Alliance through its Quality Control Assessment Tool (QCAT) system, but there is no contractual requirement for United Space Alliance to respond or even take corrective action. The Space Shuttle Processing Independent Assessment Report of 2001 noted succinctly: "Process surveillance as it exists today is not accomplishing its desired goals nor is it a true measure of the health of the work processes, as was its original stated objective."[12] Even in 2003, the Board found this is still true. To achieve greater effectiveness, sample-based inspections should include all aspects of production, and emphasis should go beyond "command performance" (announced and scheduled) inspections to validate United Space Alliance quality inspection results.

KSC Quality Assurance Specialist Position Descriptions —what the specialists are hired to do and tasks against which they are evaluated--actually require independent surveillance of contractor activity. However, KSC Quality Assurance Specialist surveillance is essentially nonexistent, as the Kennedy quality program manager actively discourages Quality Assurance Specialist unscheduled hardware surveillance. Testimony revealed that the manager actually threatened those who had conducted such activity, even after a Quality Assurance Specialist had found equipment marked "ground test only" installed on an Orbiter.

In an attempt to meet position description requirements and the basics of a solid surveillance program, a thorough surveillance program concept was developed by KSC Quality Assurance Specialists, presented, and accepted as "needed" by Space Shuttle Program management. However, rather than adapting it for Kennedy, this concept was never implemented, and Space Shuttle Program management was never informed of that decision. Ignoring surveillance--a Position Description requirement and a basic tenet of quality operations--is setting the stage for reliance upon "diving catches" referred to by the Space Shuttle Independent Assessment Team report.

> *Some HROs design in redundancy to ensure that there are several ways to catch problems before they become catastrophes. U.S. Navy aircraft carrier operations are characterized by much human redundancy in oversight of operations to make sure nothing is missed that can potentially turn into an accident.*

-Roberts and Brea, Must Accidents Happen? Lessons from High Reliability Organizations[13]

Findings:

- Kennedy Space Center's current government mandatory inspection process is both inadequate and difficult to expand even incrementally, inhibiting the ability of quality assurance to respond to an aging system, changing workforce dynamics, and process improvement initiatives.
- The Quality Planning Requirements Document, which defines inspection conditions, was originally well formulated; however, there is no requirement that it be routinely reviewed and updated as applicable.
- KSC has a separate Mission Assurance office working directly for each program, a separate Safety, Health, and Independent Assessment office under the center director, and separate quality engineers under each program. Integration of the quality program would be much better served if these were consolidated under one Mission Assurance office reporting to the center director.
- Past reports (such as the 1986 Rogers Commission, 2000 Shuttle Independent Assessment Team report, and 2003 internal Kennedy Tiger Team) affirmed the need for a strong and independent quality program, though the quality program management at Kennedy took an opposite tack.
- NASA's Kennedy Space Center Quality Assurance Program discrepancy-tracking program is inadequate

to nonexistent. Robust as recently as three years ago, KSC no longer has a "closed loop" system, where discrepancies and their remedies make a full circle back to the person who detected the discrepancy, and in turn to others across the system who may help prevent or detect similar discrepancies.

- Efforts by Kennedy Space Center quality management to move its workforce toward a "hands-off, eyes-off" approach to quality assurance are cause for alarm.
- Evidence underscored the need to expand government inspections, the need for increased surveillance, and a lack of communication between NASA centers and contractors regarding the disposition of "ground test only" components.
- Witness testimony and documentation submitted by witnesses revealed items that had been annotated "Fly as is," without proper disposition by the Material Review Board prior to flight, leading to a concern about a growing acceptability of risk at the Center level.
- KSC quality management discourages inspectors from rejecting contractor work; instead, it insists on working with the contractor to fix things in the process of the work being accomplished, versus rejecting it and returning for a re-evaluation only after it is fixed.
- The NASA Safety Reporting System was viewed as credible, and was effectively used to validate concerns that local management would not.
- Though most inspectors had extensive aviation and/or related military experience, there are examples where some individuals with no previous aviation, space, technical, or inspection background had been selected as Quality Assurance Specialists, and were making NASA final inspections for human space flight components.
- Following the 2000 Shuttle Independent Assessment Team report, some 35 new inspectors were added at Kennedy Space Center; however, most of that increase has eroded through retirements, promotions, departures, and one death.
- A review of other NASA center Quality Assurance Specialist staffing and grades revealed that Kennedy Space Center is the only NASA center evaluated that has Quality Assurance Specialist grades set at GS-11—other centers have Quality Assurance Specialist grades set at GS-12.
- No formal NASA Kennedy Space Center training exists in the quality program for its quality engineers, process analysts, and quality assurance specialists.
- NASA-KSC Quality Assurance Specialist Position Descriptions require independent surveillance of contractor activity. However, Quality Assurance Specialist surveillance is discouraged and essentially nonexistent at Kennedy Space Center.
- Through extensive interviews at the Michoud Assembly Facility (MAF)--technicians to managers--plus an extensive review of work documents, we conclude that the MAF Quality Program Requirements Document (alternatively, the Mandatory Inspection Points document) is in need of review, for few believe it covers all of the critical items that government inspectors should be reviewing, and that it may force redundant or non-value added inspections.

Recommendations:

- (NOTE: This item is currently Observation 10.4-1 in the Board report. Due to the potential gravity of this item, it is urged this become a return-to-flight Recommendation.) Perform an independently led, bottom-up review of the Kennedy Space Center Quality Planning Requirements Document to address the entire quality assurance program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections. Suggested Government Mandatory Inspection Point (GMIP) additions should be treated by higher review levels as justifying why they should not be added, versus making the lower levels justify why they should be added. Any GMIPs suggested for removal need concurrence of those in the chain of approval, including responsible engineers.
- (NOTE: Like the preceding item, this item is currently a subset of Observation 10.4-1 in the Board report; while it is urged this become a Recommendation, it does not need to be characterized as a return-to-flight recommendation) Kennedy Space Center must develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program reflects the evolving nature of the Shuttle system and mission flow changes. At a minimum, this process should document and consider equally inputs from engineering, technicians, inspectors, analysts, contractors, and Problem Reporting and Corrective Action to adapt the following year's program.
- NASA Safety and Mission Assurance should establish a process inspection program to provide a valid evaluation of contractor daily operations, while in process, using statistically-driven sampling. Inspections should include all aspects of production, including training records, worker certification, etc., as well as Foreign Object Damage prevention. NASA should also add all process inspection findings to its tracking programs.
- The KSC quality program must emphasize forecasting and filling personnel vacancies with qualified candidates to help reduce overtime and allow inspectors to accomplish their position description requirements (i.e., more than the inspectors performing government inspections only, to include expanding into completing surveillance inspections).
- Job qualifications for new quality program hires must spell out criteria for applicants, and must be closely screened to ensure the selected applicants have backgrounds that ensure that NASA can conduct the most professional and thorough inspections possible.
- MSFC should perform an independently-led bottom-up review of the Michoud Quality Planning Requirements Document to address the quality program and its administration. This review should include development of a responsive system to add or delete government mandatory inspections. Suggested Government Mandatory Inspection Point (GMIP) additions should be treated by higher review levels as justifying why they should not be added, versus making the lower levels justify

why they should be added. Any GMIPs suggested for removal should need concurrence of those in the chain of approval, including responsible engineers.

- Michoud should develop and institutionalize a responsive bottom-up system to add to or subtract from Government Inspections in the future, starting with an annual Quality Planning Requirements Document review to ensure the program reflects the evolving nature of the Shuttle system and mission flow changes. Defense Contract Management Agency manpower at Michoud should be refined as an outcome of the QPRD review.
- (NOTE: This item is currently Observation 10.4-4 in the Board report; however to avoid further diluting the quality program focus, it is urged this become a Recommendation.) Kennedy Space Center should examine which areas of ISO 9000/9001 truly apply to a 20-year-old research and development system like the Space Shuttle.

Observations:

- As an outcome of the Quality Program Requirements Document review, manpower refinements may be warranted (for example, should a substantial change in Government Inspections justify additional personnel, adjust the manpower accordingly). While Board recommendations to evaluate quality requirement documents should drive decisions on additional staffing, in the interim, staffing with qualified people to current civil service position allocations should be expedited.
- (NOTE: This item is currently Observation 10.4-3 in the Board report.) NASA-wide quality assurance management must work with the rest of NASA (and perhaps with the Department of Defense) to develop training programs for its quality program personnel.
- An evaluation of the disparity of Quality Assurance Specialist civilian grades at Kennedy Space Center compared to other NASA centers should be accomplished to determine whether the current grade levels are appropriate.

ORBITER CORROSION

Dr. Gebman's draft [a RAND Corporation study's draft released to the NY Times] also says NASA has deferred inspections for corrosion, even though standing water had occasionally been found inside the Atlantis (which is still available to fly) and the Columbia after rainstorms. The Columbia and the Discovery have each had corrosion behind the crew cabin, a spot that is hard to inspect and hard to repair.

At one time, NASA had a "corrosion control board," but the study said it apparently no longer exists.

-Wald, "Report Criticizes NASA and Predicts Further Fatal Accidents"[14]

Section 10.7 of the Board report does a great job of spelling out the dangers of and current NASA efforts to combat the effects of corrosion. The chapter also offers four observations to encourage NASA to continue to further its efforts. However, rather than remain an observation, O10.7-3 should be slightly reworded and become a recommendation:

Recommendation:

- Develop non-destructive evaluation inspections to detect and, as necessary, correct hidden corrosion.

HOLD-DOWN POST CABLE ANOMALY

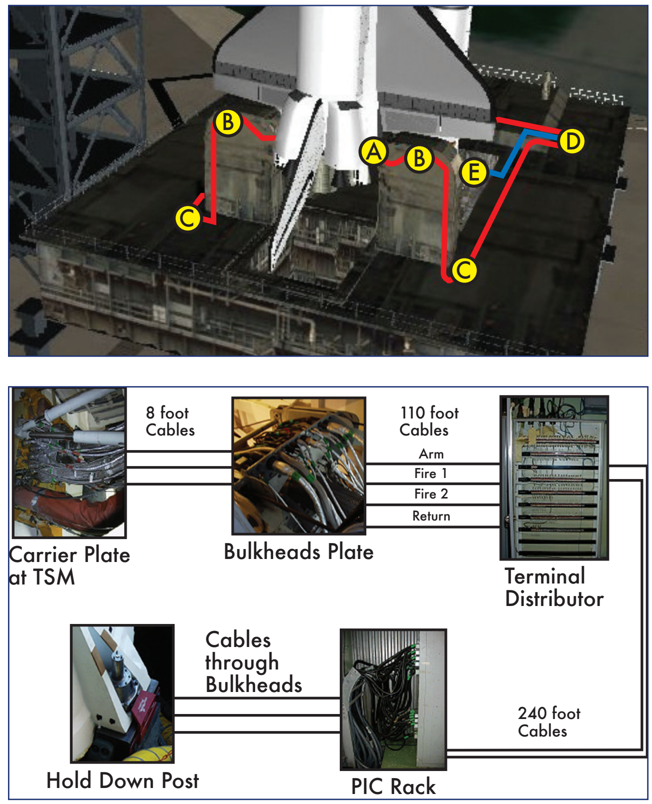

Figure S-1: Hold-Down Post/External Tank Vent Arm Systems diagram with nomenclature below (NOTE: This figure was not included in the final report section 10.9; it is provided here for clarity.)

The signal to fire the HDP/ETVAS begins in the Main Computers and goes to both of the Master Events Controllers (MECs). (See Figure S-1 for system routing.) MEC 1 communicates this signal to the A system cable, and MEC 2 feeds the B system. The cabling then goes through the Mobile Launch Platform mast to the Pyrotechnics Initiator Controllers (PICs; there are 16 PICs for A and B Hold-Down Posts, and 4 for A and B External Tank Vent Arm Systems); it then goes to each Solid Rocket Booster and Hold Down Post External Tank Vent Arm System. The A system is hard-wired to one of the initiators on each of the four nuts (eight total) that hold the Solid Rocket Booster to the Mobile Launch Platform. The B system cabling is hard-wired to the secondary initiator on each nut. The A and B systems also send a duplicate signal to the External Tank Vent Arm System. Either Master Events Controller will operate if the other or the intervening cabling fails. To verify cabling integrity, a continuity and ohms check is performed before each launch.

A post-launch review of STS-112 indicated that the A-System Hold-Down Post and ETVAS PICs did not discharge. Initial troubleshooting revealed no malfunction, leading to the conclusion that the failure was intermittent. An extensive analysis was initiated, with some 25 different potential fault chains considered as the source of the A-system failure.

Recommendation:

- NASA should evaluate a redesign of the Hold-Down Post Cable, such as adding a cross-strapping cable or utilizing a laser initiator, and consider advanced testing to prevent intermittent failure.

Solid Rocket Booster External Tank Attach Ring

In Chapter 4, the Board noted how NASA's reliance on "analysis" to validate Shuttle components led to the use of flawed bolt catchers. NASA's use of this flawed "analysis" technique is endemic. The Board has found that such analysis was invoked, with potentially disastrous consequences, on the Solid Rocket Booster External Tank Attach Ring. Tests showed that the tensile strength of several of these rings was well below minimum safety requirements. This problem was brought to NASA's attention shortly before the launch of STS-107. To accommodate the launch schedule, the External Tanking Meeting Chair subsequently waived the minimum required safety factor of 1.4 for the Attach Rings (that is, able to withstand NASA-standard 1.4 times the maximum load ever expected in operations). Though NASA has formulated short- and long-term corrections, its long-term plan has not yet been approved by the Space Shuttle Program.

As a result of this finding, the Board issued an observation contained in Section 10.10 of the report. Due to the potential danger of this system experiencing a failure, this observation should become a recommendation.

Recommendation:

- NASA must reinstate a safety factor of 1.4 for the Attach Rings—which invalidates the use of ring serial numbers 15 and 16 in their present state—and replace all deficient material in the Attach Rings.

Other Issues

Leaders should listen and listen and listen. Only through listening can they find out what's really going on. If someone comes in to raise an issue with the leader and the leader does not allow the individual to state the full case and to get emotions out in the open, the leader is likely to understand only a piece of the story and the problem probably will not be solved.

-Smith, Taking Charge[15]

It's extremely important to see the smoke before the barn burns down.

-Creech, The Five Pillars of TQM[16]

Though discussed and submitted by various investigators, the observations that follow did not appear in the Board report. They are offered here to illuminate other aspects of the Space Shuttle Program observed during the course of the investigation.

Crew Survivability

The issues surrounding crew survivability are well covered in Chapter 3 and 10 of the Board report. However, only one observation came from that coverage, and no recommendations, instead deferring to NASA in its long-term evaluation of related issues through the work of the Crew Survivability Working Group. That Group is diligently pursuing improvements to future designs and to today's fleet. One example of a possible improvement to today's fleet is evidence presented to the Board that a small amount of additional insulation or ablative material adhering around the crew cabin (between the inner pressure vessel of the cabin and the outer shell of the Orbiter) might provide the thermal protection needed for the cabin to retain its structural integrity in certain extreme situations. Thus, it seems pertinent to offer a *recommendation* that NASA assess that and other near-term possibilities immediately.

Recommendation:

To enhance the likelihood of crew survivability, NASA must evaluate the feasibility of improvements to protect the crew cabin of existing Orbiters.

Shiftwork And Overtime

In its Volume 2, Appendix G, on Human Factors Analysis, the Rogers Commission addressed the negative safety impacts of Shiftwork and Overtime. While Chapter 6 of our report addresses schedule pressure magnificently, it does not address directly issues of workforce morale resulting from that pressure. Workers, had they not been stressed by overtime, may have even highlighted items of concern such as foam fragility, and those concerns could have been acknowledged and potentially acted upon. Issues of excess overtime and staffing are worth including in this supplement, particularly as too much overtime is often indicative of too little manning. Indeed, there were some concerns expressed regarding overtime that provide evidence and resurrect "echoes of Challenger," making issues of excess overtime and manning worth including in this supplement:

Findings:

- Workers expressed concern over workflow scheduling. Workflow scheduling in some areas had become so challenging that 69 percent of interviewees related that overtime and its resultant family and workplace stress had become a significant factor in their work environment. Added to that stress, 75 percent related that overtime was not effectively scheduled, often being told on Friday afternoons that overtime would be required over the weekend.
- Workers expressed concern over staffing levels. Using excessive and unpredictable overtime as an indicator,

many employees remained convinced that achieving adequate staffing levels would not only allow adaptation to workflow schedules, but also prevent the stresses that accompany the excessive overtime they found themselves working.

RSRM Segments Shipping Security

Findings:

- When ATK Thiokol completes an order, it transports completed segments to the Corrine, Utah, railhead. The segments are escorted by a host of vehicles on special transporters to the rail spur dedicated to ATK Thiokol that has no common access and is fenced off from public access.
- At the railhead, the segments are cross-loaded onto specially outfitted flatbed rail cars with a hardened enclosure for the booster. At this point the fences are closed and locked, and the booster is left to await delivery of the remaining segments to complete a SRB ship set. This wait time will typically approach 10-12 days.
- During this wait time, ATK Thiokol uses occasional patrols from the main compound and closed circuit TV to maintain vigilance. While theft or destruction of the booster would require heavy lift equipment or a rail engine, it appears to be an unneces-sary vulnerability having such a component exposed without more stringent security.

Recommendation:

- NASA and ATK Thiokol perform a thorough security assessment of the RSRM segment security, from manufacturing to delivery to Kennedy Space Center, identifying vulnerabilities and identifying remedies for such vulnerabilities.

Michoud Assembly Facility Security

Findings:

- The Michoud Assembly Facility has a number of natural and manmade provisions to promote its security.
- Several gaps were noted that bear assessment, to include availability of 4-wheel drive vehicles, night vision goggles, and an assessment of security staffing for the large amount of property which must be covered in the manufacture and transport of the Shuttle External Tank.

Recommendation:

- NASA and Lockheed Martin complete an assessment of the Michoud Assembly Facility security, focusing on items to eliminate vulnerabilities in its current stance.

ENDNOTES FOR THE SUPPLEMENT

The citations that contain a reference to "CAIB document" with CAB or CTF followed by seven to eleven digits, such as CAB001-0010, refer to a document in the Columbia Accident Investigation Board database maintained by the Department of Justice and archived at the National Archives.

1 James M. Strock, Reagan on Leadership, Roseville, CA: Forum, 1998, pg 104.

2 im Collins, Good to Great, New York: Harper Business, 2001, pg 88.

3 Ronald A. Heifetz, Leadership Without Easy Answers, Cambridge, MA: Harvard University Press, 1994, Pg 22.

4 Douglas A. Wiegmann, Institute of Aviation of the University of Illinois, presentation before the Board, May 8, 2003.

5 Karlene H. Roberts, High Reliability Organizations, presentation before the Board, May 7, 2003.

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