8.0 Organizational Structure

CAIB Report Executive Summary, p9:
This report discusses the attributes of an organization that could more safely and reliably operate the inherently risky Space Shuttle, but does not provide a detailed organizational prescription. Among those attributes are: a robust and independent program technical authority that has complete control over specifications and requirements, and waivers to them; an independent safety assurance organization with line authority over all levels of safety oversight; and an organizational culture that reflects the best characteristics of a learning organization.

NASA's safety and engineering organizations lack authority and independence.

Agency-wide Themes

- NASA must ensure systematic checks-and-balances are in place.
- NASA must implement independent safety and technical organizations.
- Roles and responsibilities must be clearly defined and widely understood.

8.1 Introduction

The organizational structure category embodies the NASA organizational configuration, both formal and informal, and its impact on the execution of the Agency's mission and programs. While organizational structure as a discipline can be explored from many perspectives, the dimensions explored in this section deal with structural characteristics to ensure safety, sound decision making and risk management practices, effective lines of communication, clear roles of authority, accountability, responsibility and the implementation of an independent technical authority that employs systematic checks-and-balances.

8.2 Category R-O-F Summary

Overall there were three recommendations, no observations, and 10 findings that the Diaz Team determined had broad NASA applicability to Organizational Structure. Table 21 shows these 13 R-O-Fs in brief summary statement form, along with brief discussion points on NASA applicability. Three themes emerge from these discussion points as shown above.

8.3 Discussion

The core themes of the recommendations and findings deal with the structural/organizational checks-and-balances of technical and safety decisions and the associated mitigation of program risks. The "checks-and-balances" term has been used broadly throughout NASA to describe the principle of multiple avenues to independently reach key technical and operational decisions relating to program safety and mission success. The term "checks" usually implies a seconding of responsibility in reviewing or making program decisions. The term "balances" typically means the appropriate spread of authority among multiple organizational elements. As highlighted by CAIB Board Chairman Admiral Gehman in testimony to Congress, NASA appeared to be "ill-served by an imperfect system of checks-and-balances." In the Shuttle case, it was observed by the CAIB that engineering specialists could not effectively offer independent and balanced views because their position in the organizational structure was embedded in the program. In another example, the checks of the safety office had inadequate resources, even though, according to Gehman, the "safety office was, on paper, perfect."

With a clear mandate to address the "ill-perfect" and under-resourced check-and-balance system within NASA, the CAIB recommended an Independent Technical Engineering Authority (ITEA) be created as a new key structural component within NASA for the Space Shuttle Program. The specific authority and responsibilities of that ITEA must be developed in accordance with the CAIB (CAIB R7.5-1). The CAIB also recommended that the NASA Headquarters Office of Safety and Mission Assurance should have a direct line authority over the entire Space Shuttle Program safety organization and should be independently resourced (CAIB R7.5-2). The Diaz Team concluded that these concepts could be effectively applied to provide independent engineering and safety across all NASA programs. Therefore, the Team recommends that an independent technical engineering authority concept be implemented for all programs. All programs will benefit from an independent engineering authority to ensure that technical standards are being met. This approach will also provide all programs with appropriate processes and channels to ensure that any waivers of requirements and technical standards are done so only with the review and approval of an appropriate engineering authority.

The adopted organization concept must, at a minimum, develop and maintain, and be the sole waiver-granting authority for all technical standards; conduct trend and risk analyses and own the failure mode, effects analyses and hazard reporting systems; and decide what is and what is not an anomalous event. All projects and programs will benefit from these functions being consistently applied. This approach creates the system of checks-and-balances to ensure sound and knowledge-based decision-making. NASA will develop specific structural relationships among the Program Offices, the NASA Engineering and Safety Center (NESC), and future ITEA implementations to facilitate communication, reduce program safety risks, and assure mission success.

The feedback from Safety and Mission Success Week reinforced the Diaz Team assessment:

» NASA should look to eliminate or modify organizational distinctions that create divisions within the Agency, which potentially foster competition rather than collaboration.

» Clearly define roles, responsibilities, and accountability starting with the role of the Agency/Center, then on down, to describe strategically what we want to do, who will do it, and who is responsible for what.

ORGANIZATIONAL STRUCTURE

NASA's safety and engineering organizations lack authority and independence

CAIB Statements

The failure to convey the urgency of engineering concerns was caused, at least in part, by organizational structure and spheres of authority. C7, p192

NASA structure changed as roles and responsibilities were transferred to contractors, which increased the dependence on the private sector for safety functions and risk assessment while simultaneously reducing the in-house capability to spot safety issues. C8, p202

The fact that Headquarters, Center, and Program functions are rolled-up into one position is an example of how a carefully designed oversight process has been circumvented and made susceptible to conflicts of interest. This organizational construct is unnecessarily bureaucratic and defeats NASA's stated objective of providing an independent safety function. C7, p186

The evidence that supports the organizational causes also led the Board to conclude that NASA's current organization, which combines in the Shuttle Program all authority and responsibility for schedule, cost, manifest, safety, technical requirements, and waivers to technical requirements, is not an effective check-and-balance to achieve safety and mission assurance. C7, p192

Response

Learning	Recommendations	Observations	Findings
Broadly Applicable	3	0	10
Actions	1	0	3

Reinforcement/Feedback

Safety & Mission Success Week Statements from NASA Workforce

Organizations must be structured to provide a more effective balance between program schedule/cost management and technical review authority.

Additional restructuring of the independence of Safety and Mission Assurance is critical. The creation of the NESC is not sufficient.

We should look to eliminate or modify organizational distinctions that create divisions within the Agency, which potentially foster competition rather than collaboration.

Many employees expressed concern about "complex organizational structures that create opportunities for conflicting direction which can compromise safety and mission success."

DIAZ TEAM FINAL REPORT → **IMPLEMENTATION PLAN**

» Have our leadership thoroughly evaluate the system of safety and mission success with regard to the plethora of organizations having responsibility for overseeing the safety and quality of work performed with the express intent of making it simpler, safer, and higher quality/reliability while reducing the overlapping responsibilities.
» Organizations must be structured to provide a more effective balance between program schedule/cost management and technical review authority.

The CAIB R-O-Fs also addressed the complexities of NASA as an organization and the real and perceived barriers that exist which inhibit communication and effective decision-making. While the CAIB was not prescriptive in its approach, it offered the Diaz Team insights regarding the organizational characteristics NASA should strive to achieve. These include:

- Effective teamwork exists across boundaries with strong communication links.
- People deliver results, not tasks.
- Every member of the workforce is empowered and willing to offer alternate points of view.
- Organizational functions are well defined and understood.
- Roles of authority, accountability, and responsibility are precisely defined and widely understood.

An effective organizational structure that implements NASA strategies and programs, while minimizing built-in barriers, is appropriate and necessary. The organization must foster the sharing of knowledge and data and facilitate communication based upon a consistency of information and knowledge structures.

The structure of an organization should help clarify roles and responsibilities of individual employees, work groups, and leadership. The Diaz Team is not prescribing one organizational structure over another, but the Team believes for NASA to succeed with any new organization, every member of the workforce should be able to answer three basic questions:

- Do you know where you fit into the organizational structure?
- Do you know whom you report to, and who reports to you?
- Do you know your responsibility, authority, and accountability?

If NASA's workforce cannot answer these three basic questions, the organization is dysfunctional and ultimately the entire organization will suffer.

Poor organizational structure can cause highly talented and skilled people to fail. Pushing people to work harder or replacing a few managers will not change the cultural biases within NASA's organizational structure.

Organizational structure alone does not create a healthy organizational environment. Effective organizational leadership and discipline are necessary. During Safety and Mission Success Week, individuals highlighted several organizational issues of concern across NASA Centers that need to be addressed. These included ensuring positions are filled with qualified people, clarifying roles and responsibilities with clear lines of authority, holding people accountable, facilitating effective communication and decision-making, and increasing the level of technical expertise. The solutions to many of these issues require a multi-faceted approach, incorporating organizational structure changes, process changes, and changes in management and career development practices.

It is essential that we also promote an understanding of program interdependencies and implications of management decisions across programs. Appropriate communications channels across organizational elements will help prevent creation of isolated islands of information. Developing process-oriented models and information systems, as well as engineering capabilities and tools to facilitate effective sharing of information and data across programs will also greatly enhance collaboration and improve communication and decision-making NASA-wide.

All elements of NASA's organizational structure involve the management and accounting of resources. With the implementation of full-cost accounting in the Agency, it is important that NASA employees and contractors comprehend the implications of this method of accounting within programs. Full cost accounting will provide metrics that have not previously been available. The use of these metrics must be integrated into a technical-cost-schedule integrated system. Full cost accounting principles are part of a disciplined organizational management approach, but if used without a balanced consideration of technical, schedule, and strategic concerns the management system will be degraded.

In summary, a healthy organizational structure is a solid foundation to help enable our people to succeed. NASA now has the opportunity to examine its organizational structure and redesign or create new organizational elements that are inherently healthier and succeed in creating the proper checks-and-balances and chains of accountability to enable effective communication and decision-making. Through effective and disciplined organizational leadership, NASA can increase safety, manage risk, and achieve program and mission success throughout the Agency.

In addition to the actions in the Diaz Team Matrix that address each R-O-F, the Diaz Team has one goal addressing the Organizational Structure category, as shown in Table 20.

Table 20. The Diaz Team developed one goal for Organizational Structure.

Organizational Structure – Diaz Team Goal
The Agency should complete its current NASA-wide assessment and establish independent technical authority.

Table 21. The Diaz Team determined that three Recommendations and 10 Findings could be included in the Organizational Structure Category, resulting in four actions.

Diaz Team #	CAIB #	CAIB Report Recommendations and Pertinent Factors	Diaz Team Discussion	Action #	Responsibility
R23	R7.5-1	Establish Independent Technical and Engineering Authority	All programs can benefit from independent authority	9	Q
R24	R7.5-2	HQ S&MA have direct line authority over Shuttle safety	Independent safety organization for all major programs	9	Q
R26	R9.1-1	Prepare detailed plan for ITEA, safety office, integration office	Create orderly transition process	9	Q
F57	F6.1-2	Foam shedding safety concerns evolved to "in family"	Independent organization should review deviations	27	AE
F61	F6.1-6	Debris shedding classified as In-Flight Anomaly	Independent organization should review deviations	27	AE
F68	F6.2-2	Shuttle and ISS intertwining increase scheduling complexity	Manage programs from an Agency-wide perspective	31	AE
F105	F7.1-1	NASA has struggled to achieve viable safety programs	Audit staffing practices and workforce management	9	Q
F107	F7.4-2	S&MA dependent on program for funding	Need to identify conflicts of interest and dependencies	9	Q
F109	F7.4-4	System safety engineering separated from mainstream	Review Agency-wide integration of safety engineering	9	Q
F111	F7.4-6	Shuttle Integration Office does not handle Orbiter	Clear organizational responsibilities needed	37	AE
F113	F7.4-8	Foam responsibilities inconsistent within Integration office	Programs need clear authority and responsibilities	37	AE
F117	F7.4-12	Dependence of SR&QA limits ability to report problems	Identify internal conflicts of interest	9	Q
F118	F7.4-13	Conflicting roles and responsibilities in safety program	Identify internal conflicts of interest	9	Q

9.0 Risk Management

CAIB Report Chapter 1, p25:
As the investigation continued, it revealed a NASA culture that had gradually begun to accept escalating risk, and a NASA safety program that was largely silent and ineffective.

NASA fails to account for program risk.

Agency-wide Themes

- NASA must establish a consistent set of risk assessment tools, applied in a uniform way, across all programs.
- NASA management must have a clear understanding of safety requirements and risks associated with key decisions.
- NASA must stop accepting increasing levels of risk without understanding the total program risk.

9.1 Introduction

This section looks at key issues of risk management and the lessons that can be drawn from the loss of *Columbia*. Included in risk management are NASA's safety programs for its human-rated missions, industrial safety, public safety, and assessing and evaluating risks for successful implementation of all NASA programs.

A fundamental tenet of NASA programs, displayed throughout all field Centers and contractor facilities, is safety and mission assurance. Stellar safety records, such as in the Navy Nuclear Reactor Program, involve applying the most modern risk management techniques to a complex system that must operate over a wide environmental range successfully for many years. Yet, for all its decades of efforts managing inherently risky spaceflight activities, NASA's organization and risk management processes failed in the losses of *Challenger* and *Columbia*. Ultimately, the CAIB found a Shuttle Program history of increasing risk.

Where did the increasing risks come from? According to the CAIB, the answer lies in the traits of the Shuttle Program's organizational culture that "accepted escalating risk" and a "safety program that was largely silent and ineffective." Among them were years of management decisions made under the duress of resource constraints, combined with shifting priorities and schedule pressures. Another included the mischaracterization of the Shuttle as an operational rather than a developmental vehicle. Organizational safety practices emerged that were detrimental, including reliance on past success as a substitute for sound engineering practices, ineffective communication of critical safety information, and a decision-making process that operated outside the organization's rules. The CAIB recommendations and findings in the risk management area and the Safety and Mission Success Week responses from the workforce provide a clear picture of the issues and challenges NASA faces in managing future risks.

9.2 Category R-O-F Summary

Overall there were four recommendations, two observations, and 12 findings that the Diaz Team determined had broad NASA applicability to Risk Management. This is the largest number of R-O-Fs assigned to any one Diaz Team category. Table 23 shows these 18 R-O-Fs in brief summary statement form, along with brief discussion points on NASA applicability. Three themes emerge from these discussion points as highlighted in the bullet points above.

9.3 Discussion

The first risk management theme that stands out is the necessity to set uniform standards and assessment methodologies across all programs. The CAIB clearly saw discrepancies in safety standards Agency-wide as evidenced by the different micrometeoroid and orbital debris safety standards between the Shuttle and ISS programs. Additionally, these standards were treated by managers as being guidelines rather than requirements. For the Shuttle Program, the CAIB R-O-Fs also highlighted the lack of risk assessment independence and integration; no one was taking a systematic view of risk.

Another major theme embodied in the CAIB Report was management's understanding of the risks associated with key decisions. Systematically, resource constraints and schedule pressures clouded management decisions. Safety factors on hardware were not maintained. Adequate replacement spares did not exist for key components. When combined with a safety office that was not independently resourced, the Shuttle's ability to manage risk and conduct safe operations was fundamentally imperiled. To address this issue, one of the CAIB recommendations specifically called for NASA to "adopt and maintain a Shuttle flight schedule that is consistent with available resources." The Board clearly understood that deadlines are an important management tool; however, the message to NASA was that deadlines must be systematically evaluated from a risk standpoint to determine acceptability of schedules. Safety and Mission Success Week responses clearly agreed with this critical issue. One input noted that independent assessments should be alert to the consequences of schedule pressures on technical decisions affecting safety and mission success, as well as program success in infrastructure or nontechnical areas.

As for resources, the Board noted that adequate resources and independent assessments are critical to risk management and decision-making. Agency-wide, NASA can look at its programs to determine whether independent organizations are properly resourced and sufficiently independent. Acquisition approaches for spares and contractor support also require understanding of risks. A Safety and Mission Success Week response clearly articulated this issue by stating that risk-based acquisition management

RISK MANAGEMENT

CAIB REPORT

NASA fails to account for program risk

CAIB Statements

It is the Board's view that, in retrospect, the increased complexity of a Shuttle designed to be all things to all people created inherently greater risks than if more realistic technical goals had been set at the start. C1, p23.

As the investigation continued, it revealed a NASA culture that had gradually begun to accept escalating risk, and a NASA safety program that was largely silent and ineffective. C1, p25.

When a program agrees to spend less money or accelerate a schedule beyond what the engineers and program managers think is reasonable, a small amount of overall risk is added. These little pieces of risk add up until managers are no longer aware of the total program risk, and are, in fact, gambling. Little by little, NASA was accepting more and more risk in order to stay on schedule. C6, p139

Organizations that successfully operate high-risk technologies have a major characteristic in common: they place a premium on safety and reliability by structuring their programs so that technical and safety engineering organizations own the process of determining, maintaining, and waiving technical requirements…. C7, p184

Response

Learning	Recommendations	Observations	Findings
Broadly Applicable	4	2	12
Actions	4	2	5

Reinforcement/Feedback

Safety & Mission Success Week Statements from NASA Workforce

"Normalization of Deviance" by relying on past success instead of an inquisitive perspective backed by sound engineering analysis, compromises NASA's ability to anticipate (and mitigate) what can go wrong with our systems and missions.

Risk-based acquisition management must be re-emphasized as a fundamental tool for ensuring that acquisition approaches enhance the likelihood of mission safety and success.

Independent assessments should be alert for 'normalization of deviance' in processes and organizations and consequences of schedule pressures on technical decisions affecting safety or mission success.

Some employees do perceive our environment as "breeding 'normalization of deviance,'" a contributing accident factor cited in the CAIB report. This stems from projects accepting greater levels of mission risk, including delivering systems that do not meet their original performance goals. Under the pressure of circumstances, people come to accept "good enough" instead of specified performance.

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must be re-emphasized as a fundamental tool for ensuring that acquisition approaches enhance the likelihood of mission and safety success.

The third major theme of Risk Management within the CAIB findings applies to the incremental and insidious growth of risk in programs. As described above, the lack of uniformity in risk assessment standards, combined with decisions under schedule and resource constraints, led to added overall risk. As stated in the CAIB Report, "These little pieces of risk add up until managers are no longer aware of the total program risk, and are, in fact, gambling." The findings of the CAIB provide lessons that NASA can utilize across its programs to improve its risk management practices.

One finding suggests NASA look outside its own organization, such as the Air Force, for valuable risk management lessons that can be applied to its programs. Others suggest logical and systematic risk assessment methodologies be used across the Agency. Finally, proper organizational structure is necessary for placing a premium on safety and reliability. This includes safety and engineering organizations owning the process of determining, maintaining, and waiving technical requirements.

The CAIB defined the set of circumstances and traits that led to a NASA organizational culture of accepting increasing risk as "Normalization of Deviance." This is a term used as a social construct by the author of *The* Challenger *Launch Decision*, Dr. Diane Vaughan, a Boston College Professor. The NASA workforce expounded on this cultural theme during Safety and Mission Success Week with inputs agreeing that there were clearly other examples within their experience of "Normalization of Deviance." The feedback suggested this stems from projects accepting greater levels of mission risk, including delivering systems that do not meet their original performance goals. Under the pressure of circumstances, some individuals may accept "good enough" instead of specified performance. Comprehensive actions across NASA in managing risks will assure a high level of safety and mission success.

Agency-wide, a consistent set of risk assessment tools, applied in a uniform way, will help assure mission success. The CAIB recommendation to provide the National Imagery and Mapping Agency (NIMA) – now known as the National Geospatial-Intelligence Agency (NGA) – imaging of the Orbiter as a standard operating procedure, has its roots in managing the risk of each Shuttle mission with the best data and information available. When applied throughout NASA, all programs would be served by having the best information available by which to make decisions that could impact safety and mission success.

The feedback from Safety and Mission Success Week reinforced the Diaz Team assessment:

» Missions and programs are being driven by budget and schedule and a 'faster, better, cheaper' philosophy. Cost and schedule pressures have surpassed technical quality as the drivers for decision making for projects.
» As in the CAIB Report, Center employees expressed concern over our "can do" attitude, which "goes too far and becomes arrogance, leaving us blind to external information." It tempts us to accept greater risk than may be reasonable or responsible.

In addition to the actions in the Diaz Team Matrix that address each R-O-F, the Diaz Team has one goal addressing the Risk Management category, as shown in Table 22.

Table 22. The Diaz Team developed one goal for Risk Management.

Risk Management – Diaz Team Goal
The Agency should identify a set of risk management processes and tools which can be applied across all programs which recognize the diversity with respect to risk tolerance.

Table 23. The Diaz Team determined that four Recommendations, two Observations, and 12 Findings could be included in the Risk Management Category resulting in 11 actions.

Diaz Team #	CAIB #	CAIB Report Recommendations and Pertinent Factors	Diaz Team Discussion	Action #	Responsible
R12	R3.8-1	Obtain sufficient spare Reinforced Carbon-Carbon panels	Assure adequacy of hardware for safe decision-making	3	AE
R17	R4.2-4	Shuttle to be operated with same micrometeroid safety as ISS	Need same risk standards and assessment methodologies	5	Q
R19	R6.2-1	Adopt flight schedule consistent with available resources	Schedule with underlying rationale and risk assessment	6	AE
R21	R6.3-2	Establish MOU with NIMA for imaging orbiter	The need to use national assets to assess spacecraft health applies to many programs.	8	G
O1	O10.1-1	Develop public risk acceptance policy for launch and re-entry	NASA should continue to develop public risk policies	11	Q
O25	O10.10-1	Reinstate safety factor of 1.4 for attach rings	All programs need consistent design factors to manage risk	16	AE
F12	F3.3-3	Only periodic visual and touch tests on accepted RCC	Appropriate in-service inspection for high-risk areas	20	AE
F35	F3.8-5	Inadequate number of spare RCC panels in program	Programs need robust supply chains with detailed logistics	22	AE
F53	F4.2-16	Shuttle and ISS had different margin criteria for MMOD	Risk determination needs uniform application across Agency	5	Q
F65	F6.1-10	Failure to perform adequate trend analysis on foam losses	Anomalies must be captured and evaluated for risk mitigation	29	AE
F108	F7.4-3	No progress in integrated and independent Shuttle risk	Uniform risk assessment standards across programs needed	36	Q
F110	F7.4-5	No risk information from a systematic view across Shuttle	Uniform risk assessment standards across programs needed	36	Q
F119	F10.1-1	*Columbia* breakup had potential to cause public casualties	NASA should continue to develop public risk policies	11	Q
F120	F10.1-2	Lack of public casualties from *Columbia* expected outcome	Programs need to factor in public risk analysis in planning	11	Q
F121	F10.1-3	US space flights have flawless public safety record	Logical risk assessments for safety should be used	11	Q
F122	F10.1-4	Launch range public safety standards less than one in million	NASA recognizes safety requirements	11	Q
F123	F10.1-5	Public safety standards not followed for Orbiter re-entry	NASA recognizes safety requirements	11	Q
F127	F10.4-1	Shuttle industrial safety programs are in good health	Continuous review of health of industrial safety program needed	40	Q

10.0 Summary and Next Steps

CAIB Report Chapter 5, p9:
Organizational culture refers to the basic values, norms, beliefs, and practices that characterize the functioning of a particular institution. At the most basic level, organizational culture defines the assumptions that employees make as they carry out their work; it defines "the way we do things here." An organization's culture is a powerful force that persists through reorganizations and the departure of key personnel.

10.1 Summary

In summary, the CAIB Report includes significant technical and non-technical R-O-Fs, which NASA leaders must adhere to in order to help the Agency move forward to meet the challenges of the future. The Diaz Team realizes that, in some respects, the most challenging changes will be those which pertain to culture, or those which are the non-technical R-O-Fs noted in the CAIB Report.

The Team knows that the organizational changes recommended in the CAIB Report will require sustained planning and implementation over time to achieve the desired future the CAIB and NASA foresee. When making cultural change, large organizations such as NASA need to assure that, throughout the change process, the organization's core values are both relied on and sustained. The Team believes these core values will help the Agency's leaders take on the serious challenges ahead, which should yield improved safety, performance excellence, and mission success.

The proposed actions in the Diaz Team Report are based on culture-related issues identified by NASA leadership and the workforce in the areas of: leadership, learning, communication, processes and rules, technical capabilities, organizational structure, and risk management. The Team believes this systemic approach to cultural change at this critical juncture of the Agency's history will yield a NASA culture that is significantly more responsive and prepared for the promising opportunities of the American space program's future.

The seven Diaz Team goals are shown in Table 24. In order to gain a more thorough understanding of the Diaz Team's determinations, detailed examination of the entire Diaz Team Matrix and its 40 actions (Appendix A) and the tables in each of the foregoing chapters is critical.

NASA indeed stands at a crossroads. One path is a continuation of the course that allowed the *Challenger* and *Columbia* accidents to occur. The new path of change may be difficult, particularly at the start, and sometimes the goal is not always in sight. But the rewards for walking this path are far greater than those the old path could ever offer us.

For NASA to embark on the new pathway, some fundamental reforms must be instituted. These are encompassed by the 40 Diaz Team actions and seven goals identified in the Report. The essence of these can be captured in three overarching reforms:

- NASA must assure that appropriate checks and balances are in place to develop and operate its missions safely, and must undertake the organizational changes necessary to make this happen. The organizational structure should help clarify roles and responsibilities of individual employees, work groups and leadership. Every member of the workforce must know his or her position in the organization and all must know their authority, responsibility and accountability for assuring mission success. The entire workforce must also be aware of and understand the rules.
- NASA must enhance communications at all levels with a focus on fostering diversity of viewpoints and eliminating fear of retribution. A communications culture must be established with formal communications procedures to ensure effective communications flow up and down the chain of command and across organizational lines. Communications channels should be sufficiently flexible to support, encourage, and objectively evaluate all viewpoints, ensuring sound decision-making practices.
- NASA must focus on the ways it is managing risk. Safety, mission success and program performance must not be the product of schedule and budget pressures alone. Technological and workforce factors must be considered in program planning and decision-making as well. A critical role of leadership is to ensure there is an appropriate balance between requirements, resources and risk. NASA must assure that the workforce has the appropriate processes, tools and technical capabilities to accomplish this.

10.2 Next Steps

It should be noted the NASA Administrator asked the Team in its charter to identify broadly applicable R-O-Fs in the CAIB Report, recommend actions to address those R-O-Fs, and submit a Report documenting its conclusions and recommendations to the NASA Deputy Administrator. The responsibility for preparing implementation plans to accomplish the 40 "specific actions" in the Diaz Team Matrix was given to the appropriate NASA Headquarters organizations. The responsibility for accomplishing the seven "Diaz Team Goals" is not identified in this Report. However, it is anticipated that the NASA Deputy Administrator will provide direction to the development of all implementation plans. It is recommended that all the implementation plans prepared in response to the CAIB Report (i.e. RTF, CTF, Next Generation Vehicle, Diaz Team and Aircraft Operations) be placed under configuration control, and any intent to establish other implementation plans be subject to approval by the Deputy Administrator. It is further anticipated that NASA will implement the appropriate systems to coordinate and track the progress of their implementation.

The Diaz Team suggests that NASA should periodically review and measure the progress of all implementation activities in response to the CAIB Report. It is suggested that this assessment be conducted six months after the release of the Diaz Team Report, and annually thereafter. The Diaz Team, or some subset thereof, could perform this assessment.

Table 24. Diaz Team Goals

Leadership	The Agency should assess whether program management and budget formulation processes are adequate to assure there is an appropriate balance of requirements, resources, and risk to ensure safety and mission success.
Learning	The Agency should identify an appropriate approach for the future development of a knowledge management system and infrastructure to assure knowledge retention and lessons learned.
Communication	The Agency should continue the dialog that it began with the NASA workforce during Safety and Mission Success Week.
Processes and Rules	The Agency should conduct a review of its approach to maintaining and managing rules.
Technical Capabilities	The Agency should develop guidelines and metrics for assessing and maintaining its core competencies, including those associated with in-house work.
Organizational Structure	The Agency should complete its current NASA-wide assessment and establish independent technical authority.
Risk Management	The Agency should identify a set of risk management processes and tools which can be applied across all programs which recognize the diversity with respect to risk tolerance.

Appendix A The Diaz Team Matrix

1. The CAIB Report listed 29 recommendations, 27 observations, and 137 findings for a total of 193. From the 193 R-O-Fs, the Diaz Team selected 85 that they believe are broadly applicable across all of NASA.

2. The 85 broadly applicable R-O-Fs resulted in 40 specific actions. Each action is comprised of multiple tasks and has a NASA Headquarters code assigned with primary responsibility for preparing an action plan that will lead to an implementation plan. The responsible NASA Headquarters code will coordinate with other organizations as necessary to accomplish this. The responsible codes are:

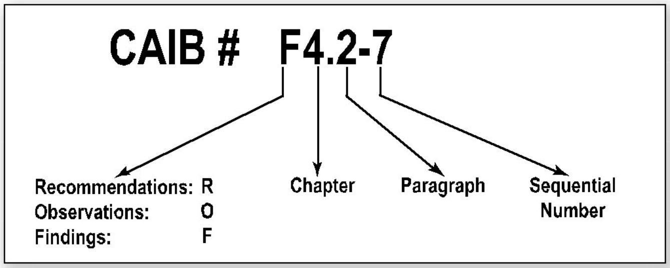
   a. Code AE – Chief Engineer
   b. Code F – Human Resources
   c. Code G – General Council
   d. Code H – Procurement
   e. Code J – Management Systems
   f. Code Q – Safety and Mission Assurance
   g. Code X – Security Management and Safeguards

3. The Diaz Team numbered each of the R-O-Fs with a unique identifier as shown below:

   a. Recommendations: R1 through R29
   b. Observations: O1 through O27
   c. Findings: F1 through F137

4. Each Specific Action is numbered sequentially 1 through 40.

5. The CAIB Report used the schema shown below to identify each R-O-F.



Diaz Team #	CAIB #	CAIB Report Recommendations and Pertinent Factors	BA*	Diaz Summary Discussion	Specific Action	Category
R1	R3.2-1	Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris-shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank. [RTF]				
R2	R3.3-1	Develop and implement a comprehensive inspection plan to determine the structural integrity of all Reinforced Carbon-Carbon system components. This inspection plan should take advantage of advanced non-destructive inspection technology. [RTF]				
R3	R3.3-2	Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes. [RTF]				
R4	R3.3-3	To the extent possible, increase the Orbiter's ability to successfully re-enter the Earth's atmosphere with minor leading edge structural sub-system damage.				
R5	R3.3-4	In order to understand the true material characteristics of Reinforced Carbon-Carbon components, develop a comprehensive database of flown Reinforced Carbon-Carbon material characteristics by destructive testing and evaluation.				
R6	R3.3-5	Improve the maintenance of launch pad structures to minimize the leaching of zinc primer onto Reinforced Carbon-Carbon components.				
R7	R3.4-1	Upgrade the imaging system to be capable of providing a minimum of three useful views of the Space Shuttle from liftoff to at least Solid Rocket Booster separation, along any expected ascent azimuth. The operational status of these	Y	While the CAIB Report focuses on the Space Shuttle Program and a specific area of risk, all programs need to identify the critical means for monitoring their systems and ensure that the data is collected, observed, and	1) Review/develop current policy or guidance that assures critical event data is collected, observed and analyzed. a. Review/develop a standard for program development strategy	Processes & Rules

* Broadly Applicable

Diaz Team #	CAIB #	CAIB Report Recommendations and Pertinent Factors	BA*	Diaz Summary Discussion	Specific Action	Category
		assets should be included in the Launch Commit Criteria for future launches. Consider using ships or aircraft to provide additional views of the Shuttle during ascent. [RTF]		analyzed. Without the information, there may be no means of identifying potential incipient failures that could lead to mission degradation, failure, or loss.	based on the program focus of R&D versus operational system or infrastructure that focuses on the comprehensive assessment of program management, technical, and operational risks. b. Review/develop a process to determine appropriate means for observing the program at all phases where risks have been identified along with a means of observing, collecting, trending, archiving, and analyzing data. c. Review/develop a process for program reviews that would ensure that any changes, degradation or improvement, in a relied-upon system, cannot be accomplished without the concurrence of programs. Responsibility: Code AE	
R8	R3.4-2	Provide a capability to obtain and downlink high-resolution images of the External Tank after it separates. [RTF]	Y	Following the rationale for R3.4-1, this capability needs to be available for all phases of the program's execution, especially during times of major program events. Otherwise problem resolutions may be based on guesses or theories as opposed to hard data.	2) Develop a standard for comprehensive program risk management and observable data collection for all phases of program development, test, operation, and enhancement to be used for program management, improvement, anomaly/disaster reconstruction. a. Similar to the Cost Analysis Resource Document (CARD), develop a process for a continuously updated and maintained program document that details the plan for management of program data and ongoing anomaly resolution activities and closeout results. b. Develop a process for periodic independent program review and assessment that validates risk	Processes & Rules

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					areas and comprehensive monitoring/management based on this standard. Responsibility: Code AE	
R9	R3.4-3	Provide a capability to obtain and downlink high-resolution images of the underside of the Orbiter wing leading edge and forward section of both wings' Thermal Protection System. [RTF]				
R10	R3.6-1	The Modular Auxiliary Data System instrumentation and sensor suite on each Orbiter should be maintained and updated to include current sensor and data acquisition technologies.				
R11	R3.6-2	The Modular Auxiliary Data System should be redesigned to include engineering performance and vehicle health information, and have the ability to be reconfigured during flight in order to allow certain data to be recorded, telemetered, or both, as needs change.				
R12	R3.8-1	Obtain sufficient spare Reinforced Carbon-Carbon panel assemblies and associated support components to ensure that decisions related to Reinforced Carbon-Carbon maintenance are made on the basis of component specifications, free of external pressures relating to schedules, costs, or other considerations.	Y	All programs, whether they are aerospace missions or supporting infrastructure, should make decisions on the use of hardware without finding it necessary to compromise on safety or quality in the face of programmatic pressures. Every program risk assessment should include consideration of the adequacy of hardware development quantities and schedule to assure mission success.	3) Review current policy, criteria, and contractual guidance regarding supply chain, sparing, and obsolescence policy. a. Identify whether program is operational and amenable to Life Cycle Cost (LCC) analysis; identify if program provides mission support and supports critical mission operations. b. Identify best practices across other federal agencies and commercial companies for supply chain management for R&D versus operations programs (for which an LCC analysis is applicable). c. Develop standards and criteria for tracking degradation of capabilities (especially for mission critical support items),	Risk Management

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					managing obsolescence, re-supply, and refurbishment for supply chain definition and management. d. Incorporate any new policies, criteria or guidance into the risk analysis process. e. Develop standards for program recertification based on obsolescence and other decision criteria such as service life extension. <u>Responsibility</u>: Code AE	
R13	R3.8-2	Develop, validate, and maintain physics-based computer models to evaluate Thermal Protection System damage from debris impacts. These tools should provide realistic and timely estimates of any impact damage from possible debris from any source that may ultimately impact the Orbiter. Establish impact damage thresholds that trigger responsive corrective action, such as on-orbit inspection and repair, when indicated.	Y	All programs should produce, maintain, and validate models to assess the state of their systems and components. These models should be continually updated and validated against experimental and operational data to determine appropriate courses of action and repair. The value of the models should be assessed with respect to their ability to support decision making in a timely way so as not to lead the decision maker to a conflict between costly action versus effective action in the interest of safety or mission success.	4) Develop a standard for the development, documentation, and operation of models and simulations. a. Identify best practices to ensure that knowledge of operations is captured in the user interfaces (e.g. users are not able to enter parameters that are out of bounds). b. Develop process for tool verification and validation, certification, reverification, revalidation, and recertification based on operational data and trending. c. Develop standard for documentation, configuration management, and quality assurance. d. Identify any training or certification requirements to ensure proper operational capabilities. e. Provide a plan for tool management, maintenance, and obsolescence consistent with modeling/simulation environments and the aging or	Technical Capabilities

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					changing of the modeled platform or system. f. Develop a process for user feedback when results appear unrealistic or defy explanation. Responsibility: Code AE	
R14	R4.2-1	Test and qualify the flight hardware bolt catchers. [RTF]				
R15	R4.2-2	As part of the Shuttle Service Life Extension Program and potential 40-year service life, develop a state-of-the-art means to inspect all Orbiter wiring, including that which is inaccessible.				
R16	R4.2-3	Require that at least two employees attend all final closeouts and intertank area hand-spraying procedures. [RTF]				
R17	R4.2-4	Require the Space Shuttle to be operated with the same degree of safety for micrometeoroid and orbital debris as the degree of safety calculated for the International Space Station. Change the micrometeoroid and orbital debris safety criteria from guidelines to requirements.	Y	All programs should adopt the same standards for risk acceptance and adopt common methodologies for risk assessment. Programs should look for innovative solutions to risk mitigation including use and support of other agency (e.g., DoD) resources.	5) Review current policies associated with the uniform application of risk acceptance for orbital operations. a. Identify institutional standards for requirements for debris avoidance and protection. b. Review liaison responsibility with the Air Force for debris tracking and NASA funding support (as required) with Code Q. Responsibility: Code Q	Risk Management
R18	R4.2-5	Kennedy Space Center Quality Assurance and United Space Alliance must return to the straightforward, industry-standard definition of "Foreign Object Debris" and eliminate any alternate or statistically deceptive definitions like "processing debris." [RTF]				
R19	R6.2-1	Adopt and maintain a Shuttle flight schedule that is consistent with available resources. Although schedule deadlines are an important management tool, those	Y	It has been noted that schedules are sometimes established without an underlying rationale and assessment of risk. As a result, programs across	6) Develop a standard for program development strategy based on the program focus of R&D versus operational system or	Risk Management

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		deadlines must be regularly evaluated to ensure that any additional risk incurred to meet the schedule is recognized, understood, and acceptable. [RTF]		NASA may not be using schedules as management tools but as concrete dates for performance. NASA needs to continually reevaluate program risk as to whether it is acceptable given NASA policy and standards. This is applicable across all NASA programs whether they be R&D, mission related, or infrastructure.	infrastructure that focuses on the comprehensive assessment of program management, technical, and operational risks; all of these factors must be incorporated into the development of an integrated program schedule. a. Expand upon independent program reviews (Independent Assessments, Independent and Implementation Reviews) that require re-review when any interim major milestone slips to determine the impact on mission completion schedule and cost risk. Responsibility: Code AE	
R20	R6.3-1	Implement an expanded training program in which the Mission Management Team faces potential crew and vehicle safety contingencies beyond launch and ascent. These contingencies should involve potential loss of Shuttle or crew, contain numerous uncertainties and unknowns, and require the Mission Management Team to assemble and interact with support organizations across NASA/Contractor lines and in various locations. [RTF]	Y	All programs should have robust training programs that allow personnel to practice both likely and unlikely failure scenarios to prepare them for contingency management. Simulations should be a routine part of training. This will reduce the potential response shock and enable more effective problem resolution and personnel innovation at multiple organizational levels.	7) Review current policies associated with developing emergency procedures and operational contingencies and associated training and certification. a. After review of policies, conduct an audit of no less than three programs to determine compliance. The training curricula should be for systems, and programs that have requirements for operational support. These systems would be on orbit, flight, underwater, human testing, and any other system or program that requires any type of emergency procedures. b. If required, rewrite the policies to comply with the CAIB recommendation as a minimum. The rewritten policies should go beyond the CAIB recommendation if the minimum	Learning

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					is not sufficient to affect the changes needed. c. Upon Code AE review of the policies associated with emergency procedures and operational contingencies, and changes made as necessary in a revision to NASA Policy Directive (NPD) 3410, appropriately communicate to Center Directors and Center training officers for compliance. Responsibility: Code AE	
R21	R6.3-2	Modify the Memorandum of Agreement with the National Imagery and Mapping Agency to make the imaging of each Shuttle flight while on orbit a standard requirement. [RTF]	Y	The need to use national assets to assess spacecraft health applies to many programs.	8) Review the current Memorandum of Agreement (MOA) with the National Imagery and Mapping Agency, which is now called the National Geospatial-Intelligence Agency (NGA). a. Expand the MOA to include programs other than Shuttle. b. Ensure that the proper security clearances are maintained for access to classified data. See F6.3-20 Responsibility: Code G	Risk Management
R22	R6.4-1	For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities available when near to or docked at the International Space Station. For non-Station missions, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible				

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		range of damage scenarios. Accomplish an on-orbit Thermal Protection System inspection, using appropriate assets and capabilities, early in all missions. The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an International Space Station mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking. [RTF]				
R23	R7.5-1	Establish an independent Technical Engineering Authority that is responsible for technical requirements and all waivers to them, and will build a disciplined, systematic approach to identifying, analyzing, and controlling hazards throughout the life cycle of the Shuttle System. The independent technical authority does the following as a minimum: • Develop and maintain technical standards for all Space Shuttle Program projects and elements • Be the sole waiver-granting authority for all technical standards • Conduct trend and risk analysis at the sub-system, system, and enterprise levels • Own the failure mode, effects analysis and hazard reporting systems • Conduct integrated hazard analysis • Decide what is and is not an anomalous event • Independently verify launch readiness • Approve the provisions of the	Y	All programs should have the benefit of an independent engineering authority to ensure that technical standards are being met. No programs should have the ability to waive technical standards or compromise a standard without the review and approval of an appropriate engineering authority. All projects and programs should conduct risk analysis consistent with Agency policy regarding risk management. All Centers should have the capability in either their engineering or Safety and Mission Assurance (SMA) organizations to perform and or review failure modes and effects analysis, and hazard analysis. For manned and unmanned flights and launches, Centers should establish flight, mission, or launch readiness certification processes that include verification by the independent engineering and SMA organizations. Independence is defined as both organizational (outside the operations, project or program structure) as well as financial (funding allocation decisions made or approved) at the first organizational level that owns both the operation, project or program and the center engineering and SMA	9) Develop plans for implementing an Independent Technical Engineering Authority (ITEA) of the scope envisioned by the CAIB. a. Develop organizational approaches that assure independence of Safety, Reliability, and Quality Assurance (SR&QA) activities and organizations. b. Implement the ITEA organization. Responsibility: Code Q	Organizational Structure

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		recertification program called for in Recommendation R9.1-1 The Technical Engineering Authority should be funded directly from NASA Headquarters, and should have no connection to or responsibility for schedule or program cost.		organizations.		
R24	R7.5-2	NASA Headquarters Office of Safety and Mission Assurance should have direct line authority over the entire Space Shuttle Program safety organization and should be independently resourced.	Y	All programs having an impact on operational safety should have the benefit of an independent safety organization for assurance. This approach supplements the in-line safety, quality, reliability and mission assurance efforts by providing independence from any perceived conflicts due to program budgets and schedules. This is important across all programs, including infrastructure programs that could have a direct or indirect impact on space vehicle mission success and safety. The establishment of the NASA Engineering and Safety Center (NESC) as an enhancement to the agency's independent safety capability is noted and endorsed. As in R7.5-1, independence is defined as both organizational and financial with respect to the activity being served by the assurance team.	Same as R7.5-1	Organizational Structure
R25	R7.5-3	Reorganize the Space Shuttle Integration Office to make it capable of integrating all elements of the Space Shuttle Program, including the Orbiter.				
R26	R9.1-1	Prepare a detailed plan for defining, establishing, transitioning, and implementing an Independent Technical Engineering Authority, independent safety program, and a reorganized Space Shuttle Integration Office as described in R7.5-1, R7.5-2, and R7.5-3. In addition, NASA should submit annual reports to Congress, as part of the budget review process, on its implementation activities.	Y	NASA should address the formation of these organizations subject to R7.5-1. The process should allow for an orderly transition to avoid any unintended consequence in the process.	Same as R7.5-1	Organizational Structure

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		[RTF]				
R27	R9.2-1	Prior to operating the Shuttle beyond 2010, develop and conduct a vehicle recertification at the material, component, subsystem, and system levels. Recertification requirements should be included in the Service Life Extension Program.				
R28	R10.3-1	Develop an interim program of closeout photographs for all critical sub-systems that differ from engineering drawings. Digitize the closeout photograph system so that images are immediately available for on-orbit troubleshooting. [RTF]	Y	All programs should maintain a log and photographic record of all critical sub system modifications and their engineering drawings to ensure real-time access to the latest configurations for configuration management and problem resolution. This will help reduce the time and cost to reconstruct the current system configuration whether it be on orbit, in a ground station, or in a laboratory.	10) Review current policies and capabilities associated with configuration control, closeout photographs, and engineering drawings. Determine if the policies if implemented, meet the intent of the CAIB recommendation. a. After review of policies, conduct an audit of no less than three programs to determine compliance. If the programs are compliant, determine if the methods used are adequate. b. If required, rewrite the policies to comply with the CAIB recommendation as a minimum. The rewritten policies should go beyond the CAIB recommendation if the minimum is not sufficient to affect the changes needed. Responsibility: Code AE	Technical Capabilities
R29	R10.3-2	Provide adequate resources for a long-term program to upgrade the Shuttle engineering drawing system including: • Reviewing drawings for accuracy • Converting all drawings to a computer-aided drafting system • Incorporating engineering changes	Y	Accurate, comprehensive, up-to-date engineering drawings should be maintained for all programs. All programs should have adequate resources to maintain a drawing system that is Computer-Aided Design (CAD) based and can incorporate engineering changes.	Same as R10.3-1	Technical Capabilities

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O1	O10.1-1	NASA should develop and implement a public risk acceptability policy for launch and re-entry of space vehicles and unmanned aircraft.	Y	The FAA and DoD both have policies that require public risk analyses for programs under their purview. NASA does and should continue to do this as well if there is any issue of public risk through launch or reentry of a vehicle, over-flight of an aerodynamic test vehicle, or handling/transportation of material that could lead to public risk.	11) Review current policies associated with public risk on launch, overflight, end of life reenentry of previously manned or robotic spacecraft, and recovery of any NASA asset as well as the handling and transportation of hazardous materials. Determine if the policies, if implemented, meet the intent of the CAIB recommendation. a. NASA should consider Federal and commercial best practices with respect to public risk management to determine if any policies and practices are applicable and transferable to NASA. b. After Review of Policies, conduct an audit of no less than three programs to determine compliance. If the programs are compliant, determine if the methods used are adequate. c. If required, rewrite the policies to comply with the CAIB recommendation as a minimum. The rewritten policies should go beyond the CAIB recommendation if the minimum is not sufficient to affect the changes needed. Responsibility: Code Q	Risk Management
O2	O10.1-2	NASA should develop and implement a plan to mitigate the risk that Shuttle flights pose to the general public.				
O3	O10.1-3	NASA should study the debris recovered from *Columbia* to facilitate realistic estimates of the risk to the public during Orbiter re-entry.				

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O4	O10.2-1	Future crewed-vehicle requirements should incorporate the knowledge gained from the *Challenger* and *Columbia* accidents in assessing the feasibility of vehicles that could ensure crew survival even if the vehicle is destroyed.				
O5	O10.4-1	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.				
O6	O10.4-2	Kennedy Space Center's Quality Assurance programs should be consolidated under one Mission Assurance office, which reports to the Center Director.				
O7	O10.4-3	Kennedy Space Center quality assurance management must work with NASA and perhaps the Department of Defense to develop training programs for its personnel.				
O8	O10.4-4	Kennedy Space Center should examine which areas of International Organization for Standardization 9000/9001 truly apply to a 20-year-old research and development system like the Space Shuttle.	Y	NASA programs should assess whether programs are operational or inherently R&D and then determine the applicability of standardization and certification processes.	12) Review current initiatives for International Standards Organization (ISO) and Software Engineering Institute Capabilities Maturity Model (SEI CMM) across the agency to determine if they are meeting the objectives of NASA and are cost and operationally effective. a. Develop a policy that is NASA wide on the use of initiatives like ISO and SEI CMM. Responsibility: Code AE	Processes & Rules
O9	O10.5-1	Quality and Engineering review of work documents for STS-114 should be accomplished using statistical sampling to ensure that a representative sample is	Y	Program audits and random checks of documentation, subject to the rigors of statistical significance, are advised including feedback to those appropriate.	13) Review current policies program and technical audits across NASA. Determine if the policies if implemented meet the	Processes & Rules

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		evaluated and adequate feedback is communicated to resolve documentation problems.			intent of the CAIB recommendation. a. Conduct an audit of no less than three programs using statistical sampling techniques. b. Compile the results: develop a recommendation on conducting routine and random audits of all NASA programs, to include adequate feedback to those responsible for resolving problems. c. Develop or rewrite a policy for conducting audits. <u>Responsibility</u>: Code AE	
O10	O10.5-2	NASA should implement United Space Alliance's suggestions for process improvement, which recommend including a statistical sampling of all future paperwork to identify recurring problems and implement corrective actions.				
O11	O10.5-3	NASA needs an oversight process to statistically sample the work performed and documented by United Space Alliance technicians to ensure process control, compliance, and consistency.	Y	All NASA oversight processes should include statistical sampling of performed work and statistical data analysis to assure integrity of processes and hardware.	Same as O10.5-1	Processes & Rules
O12	O10.6-1	The Space Shuttle Program Office must make every effort to achieve greater stability, consistency, and predictability in Orbiter Major Modification planning, scheduling, and work standards (particularly in the number of modi-fications). Endless changes create unnecessary turmoil and can adversely impact quality and safety.				
O13	O10.6-2	NASA and United Space Alliance managers must understand workforce and infrastructure requirements, match them against capabilities, and take actions to avoid exceeding thresholds.	Y	All NASA managers must maintain a constant awareness of workforce and facility requirements and match them against capabilities and take action when exceeding thresholds.	14) Identify policies associated with workforce and infrastructure/ facilities management and obsolescence. a. Conduct an agency-wide audit of infrastructure backlog	Leadership

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					maintenance and repair; identify which programs they support, and whether they have mission critical functions. b. Conduct an audit of no less than three programs using available cost and staffing levels to determine if the programs are balancing the available workforce and infrastructure against capabilities and schedules. Determine if the programs are using any type of scheduling, or workforce allocation tools. c. Determine if existing tools such as the workforce planning and analysis website, the Agency competency management system, and the Agency master planning/infrastructure tools can be used to improve workforce and infrastructure planning. d. Compile the results of above; develop a recommendation(s). e. If required, develop policy (linkage) between workforce planning and infrastructure tools/policies and the set of minimum thresholds that shall be met. Responsibility: Code J	
O14	O10.6-3	NASA should continue to work with the U.S. Air Force, particularly in areas of program management that deal with aging systems, service life extension, planning and scheduling, workforce management, training, and quality assurance.	Y	Other organizations with similar and dissimilar research and development and large systems operational experience have best practices and lessons learned that could be of value to NASA program management.	15) Form a workgroup to benchmark best practices from Federal agencies (e.g., DoD, FAA, DOE), and commercial industries. a. Compile the results; establish a permanent working group to address common issues, and a senior leadership group to oversee its functioning.	Leadership

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					b. Develop or rewrite policies that implement these best practices. Responsibility: Code AE	
O15	O10.6-4	The Space Shuttle Program Office must determine how it will effectively meet the challenges of inspecting and maintaining an aging Orbiter fleet before lengthening Orbiter Major Maintenance intervals.				
O16	O10.7-1	Additional and recurring evaluation of corrosion damage should include non-destructive analysis of the potential impacts on structural integrity.				
O17	O10.7-2	Long-term corrosion detection should be a funding priority.				
O18	O10.7-3	Develop non-destructive evaluation inspections to find hidden corrosion.				
O19	O10.7-4	Inspection requirements for corrosion due to environmental exposure should first establish corrosion rates for Orbiter-specific environments, materials, and structural configurations. Consider applying Air Force corrosion prevention programs to the Orbiter.				
O20	O10.8-1	Teflon (material) and Molybdenum Disulfide (lubricant) should not be used in the carrier panel bolt assembly.				
O21	O10.8-2	Galvanic coupling between aluminum and steel alloys must be mitigated.				
O22	O10.8-3	The use of Room Temperature Vulcanizing 560 and Koropon should be reviewed.				
O23	O10.8-4	Assuring the continued presence of compressive stresses in A-286 bolts should be part of their acceptance and qualification procedures.				
O24	O10.9-1	NASA should consider a redesign of the system, such as adding a cross-strapping cable, or conduct advanced testing for intermittent failure.				
O25	O10.10-1	NASA should reinstate a safety factor of 1.4 for the Attachment Rings—which	Y	Design and safety factors have been developed by many engineering and	16) Review current policies and waivers on safety factors.	Risk Management

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		invalidates the use of ring serial numbers 16 and 15 in their present state—and replace all deficient material in the Attachment Rings.		manufacturing organizations with a broad base of underlying test and supporting data.	a. Conduct an audit of no less than three programs. Determine if the programs are using a 1.4 safety factor, and what waivers have been granted. b. Compile the results and develop a recommendation. c. If required, develop or rewrite a policy for minimum safety factors, and associated waivers. Responsibility: Code AE	
O26	O10.11-1	Assess NASA and contractor equipment to determine if an upgrade will provide the reliability and accuracy needed to maintain the Shuttle through 2020. Plan an aggressive certification program for replaced items so that new equipment can be put into operation as soon as possible.				
O27	O10.12-1	NASA should implement an agency-wide strategy for leadership and management training that provides a more consistent and integrated approach to career development. This strategy should identify the management and leadership skills, abilities, and experiences required for each level of advancement. NASA should continue to expand its leadership development partnerships with the Department of Defense and other external organizations.	Y	Succession planning, leadership training, and personnel enrichment are standard business practices in many organizations including NASA. Review and continuous improvement through benchmarking with other organizations is advised. Opportunities to expand NASA leadership perspectives by participation in external leadership programs should be encouraged throughout the agency.	17) Review current training strategy/policies on management, leadership, and exchange programs used by government and commercial industry (including NASA contractors) for best practices. a. Identify programs, both federal and commercial, for professional enrichment. b. Review/develop standards for advancement in grade based on leadership skills, technical abilities, and operational experience. c. Develop a recommendation for new or improved training programs that address leadership. d. Develop or rewrite the strategy/policy for leadership and management training. Responsibility: Code F	Leadership

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F1	F3.2-1	NASA does not fully understand the mechanisms that cause foam loss on almost all flights from larger areas of foam coverage and from areas that are sculpted by hand.				
F2	F3.2-2	There are no qualified non-destructive evaluation techniques for the as-installed foam to determine the characteristics of the foam before flight.	Y	Programs need to have sufficient testing methodologies to determine that design requirements are met and that product performance is verified prior to NASA acceptance.	18) Review current policy, criteria, and contractual guidance regarding government acceptance. a. Identify best practices across other federal agencies and commercial companies. b. Develop standards for acceptance testing and performance verification. c. Develop and specify suitable inspection techniques for all critical manufacturing processes. Responsibility: Code H	Technical Capabilities
F3	F3.2-3	Foam loss from an External Tank is unrelated to the tank's age and to its total pre-launch exposure to the elements. Therefore, the foam loss on STS-107 is unrelated to either the age or exposure of External Tank 93 before launch.				
F4	F3.2-4	The Board found no indications of negligence in the application of the External Tank Thermal Protection System.				
F5	F3.2-5	The Board found instances of left bipod ramp shedding on launch that NASA was not aware of, bringing the total known left bipod ramp shedding events to 7 out of 72 missions for which imagery of the launch or External Tank separation is available.	Y	Adequate development of root cause determination requires that there be a detailed understanding of whether a failure is an anomaly or systemic.	19) Review procedures for anomaly identification and characterization. a. Develop a protocol to assess the review of past performance to determine the incidence of identical or related anomalies. b. Develop an escalation procedure based on mission criticality. c. Develop closeout process for root cause determination and anomaly mitigation.	Processes & Rules

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					Responsibility: Code Q	
F6	F3.2-6	Subsurface defects were found during the dissection of three bipod foam ramps, suggesting that similar defects were likely present in the left bipod ramp of External Tank 93 used on STS-107.				
F7	F3.2-7	Foam loss occurred on more than 80 percent of the 79 missions for which imagery was available to confirm or rule out foam loss.	Y	Trend analysis needs to be correlated with program requirements for determination of anomalous or systematic problems.	See F3.2-5.	Processes & Rules
F8	F3.2-8	Thirty percent of all missions lacked sufficient imagery to determine if foam had been lost.	Y	Anomalies cannot be addressed if they are not observed. This spans all NASA programs.	See F3.2-5 and R3.4-1.	Processes & Rules
F9	F3.2-9	Analysis of numerous separate variables indicated that none could be identified as the sole initiating factor of bipod foam loss. The Board therefore concludes that a combination of several factors resulted in bipod foam loss.				
F10	F3.3-1	The original design specifications required the RCC components to have essentially no impact resistance.				
F11	F3.3-2	Current inspection techniques are not adequate to assess structural integrity of the RCC components.	Y	Acceptance programs must be well defined and robust.	See F3.2-2	Technical Capabilities
F12	F3.3-3	After manufacturer's acceptance non-destructive evaluation, only periodic visual and touch tests are conducted.	Y	NASA needs to ensure appropriate In-Service Inspection activities are taking place for high-risk areas of repetitive missions.	20) Review current policy for obsolescence determination, system maintenance, and adherence to manufacturer's warranty. a. Identify life-cycle management and inspection practices at other select federal agencies and commercial enterprises. b. Develop standards for nondestructive evaluations of systems and maintenance standards to ensure that performance is not degraded below acceptance levels. c. Develop standards defining	Risk Management

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					robust supply chains to ensure that component availability does not compromise maintenance standards. Responsibility: Code AE	
F13	F3.3-4	RCC components are weakened by mass loss caused by oxidation within the substrate, which accumulates with age. The extent of oxidation is not directly measurable, and the resulting mission life reduction is developed analytically.				
F14	F3.3-5	To date, only two flown RCC panels, having achieved 15 and 19 missions, have been destructively tested to determine actual loss of strength due to oxidation.				
F15	F3.3-6	Contamination from zinc leaching from a primer under the paint topcoat on the launch pad structure increases the opportunities for localized oxidation.				
F16	F3.4-1	Photographic evidence during ascent indicates the projectile that struck the Orbiter was the left bipod ramp foam.				
F17	F3.4-2	The same photographic evidence, confirmed by independent analysis, indicates the projectile struck the underside of the leading edge of the left wing in the vicinity of RCC panels 6 through 9 or the tiles directly behind, with a velocity of approximately 775 feet per second.				
F18	F3.4-3	There is a requirement to obtain and downlink on-board engineering quality imaging from the Shuttle during launch and ascent.	Y	Anomalies can occur during all phases of a mission or operation but cannot be adequately resolved without an ability to observe the performance and communicate the information.	21) Identify methods used by other test organizations to perform remote system testing and anomaly resolution. a. Develop a practice and standard for the determination of baseline observables and telemetry for anomaly sampling, resolution, and detection. b. Perform a comparison of data requirements against available	Technical Capabilities

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					sensor and communications capabilities. c. Identify shortfalls and mitigation requirements in communications architecture to mitigate shortfalls, if possible. d. Develop communications protocols and escalation procedures for anomaly resolution. e. Develop notification procedures for up/down escalation chain and horizontal communications integration. Responsibility: Code AE	
F19	F3.4-4	The current long-range camera assets on the Kennedy Space Center and Eastern Range do not provide best possible engineering data during Space Shuttle ascents.	Y	Observation capabilities for anomaly detection need to have the appropriate resolution and data rates for information gathering and transfer.	See F3.4-3	Technical Capabilities
F20	F3.4-5	Evaluation of STS-107 debris impact was hampered by lack of high resolution, high speed cameras (temporal and spatial imagery data).	Y	Observation of anomalies whether it be on the Space Shuttle, a deep space probe, a ground system, etc… cannot be accomplished without a calculation of the requirements for resolution and sampling	See F3.4-3	Technical Capabilities
F21	F3.4-6	Despite the lack of high quality visual evidence, the information available about the foam impact during the mission was adequate to determine its effect on both the thermal tiles and RCC.				
F22	F3.5-1	The object seen on orbit with *Columbia* on Flight Day 2 through 4 matches the radar cross-section and area-to-mass measurements of an RCC panel fragment.				
F23	F3.5-2	Though the Board could not positively identify the Flight Day 2 object, the U.S. Air Force exclusionary test and analysis processes reduced the potential Flight Day 2 candidates to an RCC panel				

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		fragment.				
F24	F3.6-1	The de-orbit burn and re-entry flight path were normal until just before Loss of Signal.				
F25	F3.6-2	*Columbia* re-entered the atmosphere with a pre-existing breach in the left wing.				
F26	F3.6-3	Data from the Modular Auxiliary Data System recorder indicates the location of the breach was in the RCC panels on the left wing leading edge.				
F27	F3.6-4	Abnormal heating events preceded abnormal aerodynamic events by several minutes.				
F28	F3.6-5	By the time data indicating problems was telemetered to Mission Control Center, the Orbiter had already suffered damage from which it could not recover.				
F29	F3.7-1	Multiple indications from the debris analysis establish the point of heat intrusion as RCC panel 8-left.				
F30	F3.7-2	The recovery of debris from the ground and its reconstruction was critical to understanding the accident scenario.				
F31	F3.8-1	The impact test program demonstrated that foam can cause a wide range of impact damage, from cracks to a 16- by 17-inch hole.				
F32	F3.8-2	The wing leading edge Reinforced Carbon-Carbon composite material and associated support hardware are remarkably tough and have impact capabilities that far exceed the minimal impact resistance specified in their original design requirements. Nevertheless, these tests demonstrate that this inherent toughness can be exceeded by impacts representative of those that occurred during *Columbia*'s ascent.				
F33	F3.8-3	The response of the wing leading edge to impacts is complex and can vary greatly, depending on the location of the impact, projectile mass, orientation, composition,				

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		and the material properties of the panel assembly, making analytic predictions of damage to RCC assemblies a challenge.[17]				
F34	F3.8-4	Testing indicates the RCC panels and T-seals have much higher impact resistance than the design specifications call for.				
F35	F3.8-5	NASA has an inadequate number of spare Reinforced Carbon-Carbon panel assemblies.	Y	Programs should develop robust supply chains based on detailed analysis of logistics requirements and failure analyses.	22) Review current policy, criteria, and contractual guidance regarding supply chain, sparing, and obsolescence policy. a. Identify whether program is operational and amenable to LCC analysis. b. Identify best practices across other federal agencies and commercial companies for supply chain management for R&D versus operations programs (for which an LCC analysis is applicable). c. Develop standards and criteria for managing obsolescence, re-supply, and refurbishment for supply chain definition and management. <u>Responsibility</u>: Code AE	Risk Management
F36	F3.8-6	NASA's current tools, including the CRATER model, are inadequate to evaluate Orbiter Thermal Protection System damage from debris impacts during pre-launch, on-orbit, and post-launch activity.	Y	Same as R3.8-2	See R3.8-2	Technical Capabilities
F37	F3.8-7	The bipod ramp foam debris critically damaged the leading edge of *Columbia*'s left wing.				
F38	F4.2-1	The certification of the bolt catchers flown on STS-107 was accomplished by extrapolating analysis done on similar but not identical bolt catchers in original testing. No testing of flight hardware was performed.	Y	Historically there have been instances of inappropriate application of similarity as the criterion for hardware verification. The Agency should strengthen its instruction in the use of similarity as a verification method.	23) Develop a standard for the modeling and testing (both destructive and nondestructive) of system components and assemblies. a. Identify best practices to ensure	Technical Capabilities

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					that knowledge of operations and trend data is captured and incorporated into test procedures. b. Develop process for component test verification, validation, certification, reverification, revalidation, and recertification based on operational data and trending against component and assembly design specifications. c. Develop escalation process for communicating results of critical mission importance. d. Develop process for incorporation of test data into supply chain management process. Responsibility: Code AE	
F39	F4.2-2	Board-directed testing of a small sample size demonstrated that the "as-flown" bolt catchers do not have the required 1.4 margin of safety.	Y	Periodic testing of program subassemblies and components should occur to determine whether or not design specifications have been compromised; this data is valid in supporting supply chain analyses.	See F4.2-1	Technical Capabilities
F40	F4.2-3	Quality assurance processes for bolt catchers (a Criticality 1 subsystem) were not adequate to assure contract compliance or product adequacy.				
F41	F4.2-4	An unknown metal object was seen separating from the stack during Solid Rocket Booster separation during six Space Shuttle missions. These objects were not identified, but were characterized as of little to no concern.	Y	Unknown anomalies should be considered a problem unless proven otherwise.	24) Identify clear chains of command in a program including responsibility, accountability, and authority for issue communications. a. Develop escalation process for communicating information of critical mission importance. b. Develop communications process up/down escalation path, which also considers horizontal communications integration and informal channels of input.	Communication

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					c. Develop independent conflict resolution process for anomaly mediation and resolution, as required. Responsibility: Code AE	
F42	F4.2-5	Based on the extensive wiring inspections, maintenance, and modifications prior to STS-107, analysis of sensor/wiring failure signatures, and the alignment of the signatures with thermal intrusion into the wing, the Board found no evidence that Kapton wiring problems caused or contributed to this accident.				
F43	F4.2-6	Crushed foam does not appear to have contributed to the loss of the bipod foam ramp off the External Tank during the ascent of STS-107.				
F44	F4.2-7	The hypergolic spill was not a factor in this accident.				
F45	F4.2-8	Space weather was not a factor in this accident.				
F46	F4.2-9	A "rough wing" was not a factor in this accident.				
F47	F4.2-10	The Board concludes that training and on-orbit considerations were not factors in this accident.				
F48	F4.2-11	The payloads *Columbia* carried were not a factor in this accident.				
F49	F4.2-12	The Board found no evidence that willful damage was a factor in this accident.				
F50	F4.2-13	Two close-out processes at the Michoud Assembly Facility are currently able to be performed by a single person.				
F51	F4.2-14	Photographs of every close out activity are not routinely taken.	Y	Best practices from commercial aviation and nuclear power plants are applicable to NASA operations to provide complete documentation if necessary.	25) Identify programs of similar nature with applicable practices for such activities as closeout photographs, program documentation and configuration management to NASA operational and R&D initiatives.	Technical Capabilities

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					a. Develop program case studies of best practices for analysis of problems, solutions, and results from applicable programs. b. Develop standards based on researched best practices for NASA operational and R&D programs. c. Develop publications and continued training to ensure the dissemination of information to NASA and contractor personnel. d. Update and expand as necessary. Responsibility: Code AE	
F52	F4.2-15	There is little evidence that *Columbia* encountered either micrometeoroids or orbital debris on this flight.				
F53	F4.2-16	The Board found markedly different criteria for margins of micrometeoroid and orbital debris safety between the International Space Station and the Shuttle.	Y	Risk determination needs to be uniformly applied across NASA. Programs should have standards for risk acceptance.	See R4.2-4	Risk Management
F54	F4.2-17	Based on a thorough investigation of maintenance records and interviews with maintenance personnel, the Board found no errors during *Columbia*'s most recent Orbiter Major Modification that contributed to the accident.				
F55	F4.2-18	Since 2001, Kennedy Space Center has used a non-standard approach to define foreign object debris. The industry standard term "Foreign Object Damage" has been divided into two categories, one of which is much more permissive.				
F56	F6.1-1	NASA has not followed its own rules and requirements on foam-shedding. Although the agency continuously worked on the foam-shedding problem, the debris impact requirements have not been met on any mission.	Y	Independent audits need to be conducted to identify any deviations from adherence to specifications.	26) Review a minimum of three programs to determine if they are "Following the Rules." a. Conduct an awareness campaign on the need to "follow the rules" for requirements imposed by	Processes & Rules

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					programs. b. Rewrite policy or practice if required. Responsibility: Code AE	
F57	F6.1-2	Foam-shedding, which had initially raised serious safety concerns, evolved into "in-family" or "no safety-of-flight" events or were deemed an "accepted risk."	Y	An independent organization should identify deviations from program requirements. Unless a requirement is determined as an over-specification and formally waived, any deviation from a design requirement should not be relegated to a lower status. Program Managers should be careful to avoid "normalization of deviance."	27) Develop a standard and process for independent review of all program requirements and operational constraints for consistency and identify all program waivers. a. Conduct an analysis of the history of program anomalies and resolution actions and identify all changes in status consistent with the normalization of deviance. b. Develop course of action to reconcile any deficiencies and refocus on root cause analysis, and anomaly resolution as it relates directly to program requirements. c. Develop a plan for periodic, independent program reviews. Responsibility: Code AE	Organizational Structure
F58	F6.1-3	Five of the seven bipod ramp events occurred on missions flown by *Columbia*, a seemingly high number. This observation is likely due to Columbia having been equipped with umbilical cameras earlier than other Orbiters.				
F59	F6.1-4	There is lack of effective processes for feedback or integration among project elements in the resolution of In-Flight Anomalies.	Y	NASA has many large and complex programs that likely have similar communications and organizational problems. Feedback mechanisms and processes should be established for all programs to ensure that in-flight anomalies are resolved.	28) Develop a clear process for management chain of command and communications within a program and among government organizations and program management/contractor interfaces for anomaly request and resolution. a. Develop streamlined and rapid escalation process for	Leadership

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					communicating information of critical mission importance b. Develop communications process up/down escalation path, which also provides for horizontal and informal communications integration. c. Develop independent conflict resolution process for anomaly mediation and resolution that would stop "normalization of deviance". d. Develop a website and hotline for the reporting of program concerns for third parties. Appropriate escalation procedures need to be determined for timely notification. e. Provide training and assistance if needed. Responsibility: Code AE	
F60	F6.1-5	Foam bipod debris-shedding incidents on STS-52 and STS-62 were undetected at the time they occurred, and were not discovered until the Board directed NASA to examine External Tank separation images more closely.				
F61	F6.1-6	Foam bipod debris-shedding events were classified as In-Flight Anomalies up until STS-112, which was the first known bipod foam-shedding event not classified as an In-Flight Anomaly.	Y	An independent organization should identify all deviations from program requirements. Unless a requirement is determined as an over-specification and formally waived, any deviation from a design requirement should not be relegated to a lower status.	See F6.1-2	Organizational Structure
F62	F6.1-7	The STS-112 assignment for the External Tank Project to "identify the cause and corrective action of the bipod ramp foam loss event" was not due until after the planned launch of STS-113, and then slipped to after the launch of STS-107.				
F63	F6.1-8	No External Tank configuration changes				

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		were made after the bipod foam loss on STS-112.				
F64	F6.1-9	Although it is sometimes possible to obtain imagery of night launches because of light provided by the Solid Rocket Motor plume, no imagery was obtained for STS-113.				
F65	F6.1-10	NASA failed to adequately perform trend analysis on foam losses. This greatly hampered the agency's ability to make informed decisions about foam losses.	Y	All anomalies must be captured, well documented and researched to determine if they represent unique or systemic problems.	29) Develop a standard and process for anomaly identification, trending, classification, tracking, and resolution management. a. Develop a process for root cause analysis, resolution, and documentation. b. Perform at least 3 program audits to assure compliance with standards. c. Develop a standard for the periodic independent review of this process. Responsibility: Code AE	Risk Management
F66	F6.1-11	Despite the constant shedding of foam, the Shuttle Program did little to harden the Orbiter against foam impacts through upgrades to the Thermal Protection System. Without impact resistance and strength requirements that are calibrated to the energy of debris likely to impact the Orbiter, certification of new Thermal Protection System tile will not adequately address the threat posed by debris.				
F67	F6.2-1	NASA Headquarters' focus was on the Node 2 launch date, February 19, 2004.	Y	Executive management's decisions will benefit from a better understanding of program milestones and associated changing risks before casting schedules in stone. They should not force decisions to be schedule-driven without understanding the implications.	30) Expand upon the process for independent program reviews (Independent Assessments, Independent Implementation Reviews, and Non-Advocate Reviews) that require re-review when any interim major milestone slips to determine the impact on mission completion schedule and cost risk.	Leadership

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					Responsibility: Code AE	
F68	F6.2-2	The intertwined nature of the Space Shuttle and Space Station programs significantly increased the complexity of the schedule and made meeting the schedule far more challenging.	Y	NASA programs should be managed with an Agency-wide system and operational optimization perspective. This applies to both operational and infrastructure programs.	31) Perform a comprehensive assessment of major program interdependencies. a. Analyze the data from the Integrated Financial Management Program (IFMP) to cross check this analysis in terms of perception and reality. b. Develop an assessment of the full cost implications of individual program requirements changes on other programs to ensure that cost- effective decisions are the result. c. Identify cross-programmatic dependencies and cross-programmatic risk factors. d. Each program should identify its own interdependencies, which are recognized in the program plans and risk assessments. e. Reevaluate individual program requirements based on this analysis. Responsibility: Code AE	Organizational Structure
F69	F6.2-3	The capabilities of the system were being stretched to the limit to support the schedule. Projections into 2003 showed stress on vehicle processing at the Kennedy Space Center, on flight controller training at Johnson Space Center, and on Space Station crew rotation schedules. Effects of this stress included neglecting flight controller recertification requirements, extending crew rotation schedules, and adding incremental risk by scheduling additional Orbiter movements at Kennedy.	Y	NASA needs to audit its staffing practices and workforce management practices in terms of surge and certifications. Data needs to be provided to executive management regarding personnel burnout, loss of certifications, errors, etc., so that executives can make appropriate determinations.	32) Develop a clear process for management chain of command for program management. a. Identify clear requirements for advancement or reassignment to positions in terms of required training and skill, not simply meeting minimum qualification standards. b. Develop a standard for the application of overtime and surge duration based on demonstrated industry best practices for other Federal agencies and similar commercial enterprises.	Leadership

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					c. Develop a standard for requirements for certifications and a notification method for employee recertification and training. d. Review and modify NASA policies and practices concerning staffing, workforce management, and certifications. e. Conduct an audit of at least three programs for compliance. Responsibility: Code AE	
F70	F6.2-4	The four flights scheduled in the five months from October 2003, to February 2004, would have required a processing effort comparable to the effort immediately before the *Challenger* accident.				
F71	F6.2-5	There was no schedule margin to accommodate unforeseen problems. When flights come in rapid succession, there is no assurance that anomalies on one flight will be identified and appropriately addressed before the next flight.	Y	All programs including those associated with NASA infrastructure should allow adequate schedule margin to accommodate unforeseen problems.	33) Perform an assessment of best industry practices for R&D, completion, and operational programs to assess the management of schedule and cost risk through the development of management reserves. a. Perform an assessment of the planned versus actual time and cost transition across Technology Readiness Levels (TRL) to benchmark NASA performance against other federal agencies. b. Develop a standard associated with program development and planning that incorporates independent reviews. Responsibility: Code AE	Leadership
F72	F6.2-6	The environment of the countdown to Node 2 and the importance of maintaining the schedule may have begun	Y	Minority views and engineering intuition are important sources of information that employees should feel comfortable	See F6.1-4	Leadership

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		to influence managers' decisions, including those made about the STS-112 foam strike.		offering without fear of retribution.		
F73	F6.2-7	During STS-107, Shuttle Program Managers were concerned with the foam strike's possible effect on the launch schedule.				
F74	F6.3-1	The foam strike was first seen by the Intercenter Photo Working Group on the morning of Flight Day Two during the standard review of launch video and high-speed photography. The strike was larger than any seen in the past, and the group was concerned about possible damage to the Orbiter. No conclusive images of the strike existed. One camera that may have provided an additional view was out of focus because of an improperly maintained lens.				
F75	F6.3-2	The Chair of the Intercenter Photo Working Group asked management to begin the process of getting outside imagery to help in damage assessment. This request, the first of three, began its journey through the management hierarchy on Flight Day Two.	Y	Streamlined lines of communication and requests need to be identified for time-critical requirements that may have adverse effects on program success.	See F6.1-4	Leadership
F76	F6.3-3	The Intercenter Photo Working Group distributed its first report, including a digitized video clip and initial assessment of the strike, on Flight Day Two. This information was widely disseminated to NASA and contractor engineers, Shuttle Program managers, and Mission Operations Directorate personnel.				
F77	F6.3-4	Initial estimates of debris size, speed, and origin were remarkably accurate. Initial information available to managers stated that the debris originated in the left bipod area of the External Tank, was quite large, had a high velocity, and struck the underside of the left wing near its leading				

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		edge. The report stated that the debris could have hit the RCC or tile.				
F78	F6.3-5	A Debris Assessment Team began forming on Flight Day Two to analyze the impact. Once the debris strike was categorized as "out of family" by United Space Alliance, contractual obligations led to the Team being Co-Chaired by the cognizant contractor sub-system manager and her NASA counterpart. The team was not designated a Tiger Team by the Mission Evaluation Room or Mission Management Team.				
F79	F6.3-6	Though the Team was clearly reporting its plans (and final results) through the Mission Evaluation Room to the Mission Management Team, no Mission manager appeared to "own" the Team's actions. The Mission Management Team, through the Mission Evaluation Room, provided no direction for team activities, and Shuttle managers did not formally consult the Team's leaders about their progress or interim results.	Y	Best business practices define individual responsibility, accountability, and authority including well-defined chains of command and organized methods for dissent.	See F6.1-4	Leadership
F80	F6.3-7	During an organizational meeting, the Team discussed the uncertainty of the data and the value of on-orbit imagery to "bound" their analysis. In its first official meeting the next day, the Team gave its NASA Co-Chair the action to request imagery of *Columbia* on-orbit.				
F81	F6.3-8	The Team routed its request for imagery through Johnson Space Center's Engineering Directorate rather than through the Mission Evaluation Room to the Mission Management Team to the Flight Dynamics Officer, the channel used during a mission. This routing diluted the urgency of their request. Managers viewed it as a non-critical engineering desire rather than a critical operational need.	Y	Clear lines of reporting within and across organizations need to be identified, documented, rehearsed, and adhered to.	See F6.1-4	Leadership

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F82	F6.3-9	Team members never realized that management's decision against seeking imagery was not intended as a direct or final response to their request.	Y	Feedback systems involved in channels of decision-making need to be developed and adhered to, so that the workforce is aware of the status and rationale of decisions throughout the process.	See F6.1-4	Leadership
F83	F6.3-10	The Team's assessment of possible tile damage was performed using an impact simulation that was well outside CRATER's test database. The Boeing analyst was inexperienced in the use of CRATER and the interpretation of its results. Engineers with extensive Thermal Protection System expertise at Huntington Beach were not actively involved in determining if the CRATER results were properly interpreted.	Y	Same as R3.8-2	See R3.8-2	Technical Capabilities
F84	F6.3-11	Crater initially predicted tile damage deeper than the actual tile depth, but engineers used their judgment to conclude that damage would not penetrate the densified layer of tile. Similarly, RCC damage conclusions were based primarily on judgment and experience rather than analysis.	Y	Personnel need to be adequately trained in model use, limitations, and escalation procedures when issues arise. Engineers, when faced with results that defy "reality checks," should double check the model then raise their concerns.	See R3.8-2	Technical Capabilities
F85	F6.3-12	For a variety of reasons, including management failures, communication breakdowns, inadequate imagery, inappropriate use of assessment tools, and flawed engineering judgments, the damage assessments contained substantial uncertainties.	Y	Many programs across NASA have similar scopes across multiple organizations and likely have similar potential problems.	See F6.1-4	Leadership
F86	F6.3-13	The assumptions (and their uncertainties) used in the analysis were never presented or discussed in full to either the Mission Evaluation Room or the Mission Management Team.				
F87	F6.3-14	While engineers and managers knew the foam could have struck RCC panels; the briefings on the analysis to the Mission Evaluation Room and Mission Management Team did not address RCC damage, and neither Mission Evaluation				

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		Room nor Mission Management Team managers asked about it.				
F88	F6.3-15	There were lapses in leadership and communication that made it difficult for engineers to raise concerns or understand decisions. Management failed to actively engage in the analysis of potential damage caused by the foam strike.	Y	Subject matter experts need to be heard and understood when problems arise that could affect mission success. Communications through viewgraphs does not work and decisions need to be documented and communicated to all parties.	See F6.1-4	Leadership
F89	F6.3-16	Mission Management Team meetings occurred infrequently (five times during a 16 day mission), not every day, as specified in Shuttle Program management rules.	Y	Operations procedures and checklist need to be verified, communicated, and followed for all programs.	See F6.1-1	Processes & Rules
F90	F6.3-17	Shuttle Program Managers entered the mission with the belief, recently reinforced by the STS-113 Flight Readiness Review, that a foam strike is not a safety-of-flight issue.				
F91	F6.3-18	After Program managers learned about the foam strike, their belief that it would not be a problem was confirmed (early, and without analysis) by a trusted expert who was readily accessible and spoke from "experience." No one in management questioned this conclusion.	Y	Experience should not be used to dismiss concerns about safety and mission success without a logical rationale to support the conclusion. NASA needs to instill a practice in which management should prove that a problem is not a problem rather than reversing the burden of proof.	See F6.1-4	Leadership
F92	F6.3-19	Managers asked *"Who's requesting the photos?"* instead of assessing the merits of the request. Management seemed more concerned about the staff following proper channels (even while they were themselves taking informal advice) than they were about the analysis.	Y	There are many programs in NASA that have large organizations with potential problems. Leaders need to develop processes to address the merits of problems rather than the individuals raising the problems.	See F6.1-4	Leadership
F93	F6.3-20	No one in the operational chain of command for STS-107 held a security clearance that would enable them to understand the capabilities and limitations of National imagery resources.	Y	Many programs would benefit from Program Managers holding active clearances. NASA should review clearances agency-wide to determine which are appropriate and should be active to achieve safety and mission success.	34) Determine if NASA needs a central source for maintaining security clearances. a. Develop a list of cleared personnel at all clearance levels, and maintain the list at the appropriate security level. Correlate the organizational	Processes & Rules

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					chain of command for each major program with the clearance list. b. Review the security requirements for each major program, and determine if the number of cleared personnel is sufficient to effectively run the program during normal and crisis/emergency operations. c. Submit requests for additional cleared personnel to meet the delta between current and required. Responsibility: Code X	
F94	F6.3-21	Managers associated with STS-107 began investigating the implications of the foam strike on the launch schedule, and took steps to expedite post-flight analysis.				
F95	F6.3-22	Program managers required engineers to prove that the debris strike created a safety-of-flight issue: that is, engineers had to produce evidence that the system was unsafe rather than prove that it was safe.	Y	There are many programs in NASA that have large hierarchical organizations. However, problems are identified throughout the organizations at every level. Leaders need to develop processes to address the merits of problems regardless of the source within the hierarchy.	See F6.1-4	Leadership
F96	F6.3-23	In both the Mission Evaluation Room and Mission Management Team meetings over the Debris Assessment Team's results, the focus was on the bottom line – was there a safety-of-flight issue, or not? There was little discussion of analysis, assumptions, issues, or ramifications.	Y	Managers need to base critical mission decisions on facts, not intuition. Many programs may be faced with similar situations, in particular where analysis teams are located at dispersed locations. Processes need to be in place to accommodate such circumstances.	See R6.3-1	Learning
F97	F6.3-24	Communication did not flow effectively up to or down from Program managers.	Y	Some NASA programs span multiple Centers and geographic locations, so this problem could be more widespread than the Space Shuttle Program. Communication paths should be clearly documented.	35) Review communications policies and reports. The review will focus on the requirements for formal reporting during normal and emergency/crisis times. For formal reporting during normal operating tempo, the frequency of the reports shall be	Communication

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					determined, and who produces/reviews, and approves these reports. a. After review of policies, conduct an audit of no less than three programs to determine compliance and methods used. If the programs are compliant, determine if the methods used are adequate. b. Rewrite the policy(s) if required. c. Provide training and assistance. Responsibility: Code AE	
F98	F6.3-25	Three independent requests for imagery were initiated.				
F99	F6.3-26	Much of Program Managers' information came through informal channels, which prevented relevant opinion and analysis from reaching decision makers.	Y	Formal reporting paths and chain of command need to be codified, implemented, and rehearsed in all programs, and need to accommodate informal sources of information.	See F6.3-24	Communication
F100	F6.3-27	Program Managers did not actively communicate with the Debris Assessment Team. Partly as a result of this, the Team went through institutional, not mission-related, channels with its request for imagery, and confusion surrounded the origin of imagery requests and their subsequent denial.	Y	Formal reporting paths and chain of command need to be codified, implemented, and rehearsed in all programs, including feedback mechanisms.	See F6.3-24	Communication
F101	F6.3-28	Communication was stifled by the Shuttle Program attempts to find out who had a "mandatory requirement" for imagery.				
F102	F6.3-29	Safety representatives from the appropriate organizations attended meetings of the Debris Assessment Team, Mission Evaluation Room, and Mission Management Team, but were passive, and therefore were not a channel through which to voice concerns or dissenting views.	Y	Rules of engagement and organizational responsibilities should be clearly identified across all programs. Employees should be trained and encouraged to raise issues proactively when their concerns, insights, or knowledge would impact safety and mission success.	See F6.3-24	Communication
F103	F6.4-1	The repair option, while logistically viable using existing materials onboard				

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		Columbia, relied on so many uncertainties that NASA rated this option "high risk."				
F104	F6.4-2	If Program managers were able to unequivocally determine before Flight Day Seven that there was potentially catastrophic damage to the left wing, accelerated processing of *Atlantis* might have provided a window in which *Atlantis* could rendezvous with *Columbia* before *Columbia*'s limited consumables ran out.				
F105	F7.1-1	Throughout its history, NASA has consistently struggled to achieve viable safety programs and adjust them to the constraints and vagaries of changing budgets. Yet, according to multiple high level independent reviews, NASA's safety system has fallen short of the mark.	Y	NASA needs to audit its staffing practices and workforce management practices in terms of surge and certifications. Data needs to be provided to executive management regarding personnel burnout, loss of certifications, errors, etc., so that executives can make appropriate determinations.	See R7.5-2	Organizational Structure
F106	F7.4-1	The Associate Administrator for Safety and Mission Assurance is not responsible for safety and mission assurance execution, as intended by the Rogers Commission, but is responsible for Safety and Mission Assurance policy, advice, coordination, and budgets. This view is consistent with NASA's recent philosophy of management at a strategic level at NASA Headquarters but contrary to the Rogers' Commission recommendation.				
F107	F7.4-2	Safety and Mission Assurance organizations supporting the Shuttle Program are largely dependent upon the Program for funding, which hampers their status as independent advisors.	Y	Programs need to perform assessments to identify potential conflicts of interest that can compromise independence.	See R7.5-2	Organizational Structure
F108	F7.4-3	Over the last two decades, little to no progress has been made toward attaining integrated, independent, and detailed analyses of risk to the Space Shuttle	Y	NASA needs to develop a uniform standard of risk assessment and management and apply it to all of its programs including missions and	36) Review current policies and standards for Risk Assessment to include cost, technical, and schedule risk considerations.	Risk Management

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		system.		infrastructure programs.	a. After review of policies, conduct an audit of no less than three programs to determine compliance and methods used. If the programs are compliant, determine if the methods used are adequate. b. Rewrite the policy(s) if required. c. Develop a standard for Risk Analysis. d. Provide training and assistance. Responsibility: Code Q	
F109	F7.4-4	System safety engineering and management is separated from mainstream engineering, is not vigorous enough to have an impact on system design, and is hidden in the other safety disciplines at NASA Headquarters.	Y	An Agency-wide safety and engineering organization that integrates system safety engineering and management with mainstream engineering should be evaluated.	See R7.5-1	Organizational Structure
F110	F7.4-5	Risk information and data from hazard analyses are not communicated effectively to the risk assessment and mission assurance processes. The Board could not find adequate application of a process, database, or metric analysis tool that took an integrated, systemic view of the entire Space Shuttle system.	Y	NASA needs to develop a uniform standard of risk assessment and management and apply it to all of its programs including missions and infrastructure programs.	See F7.4-3	Risk Management
F111	F7.4-6	The Space Shuttle Systems Integration Office handles all Shuttle systems except the Orbiter. Therefore, it is not a true integration office.	Y	Programs need to have clear organizational responsibilities whether they are geographically dispersed or managed across centers. Programs need to assess their organizations to determine interdependencies and collaborative opportunities that would impact safety and mission success.	37) Review current policies and standards from an organizational structure and responsibility perspective. a. Conduct a comprehensive review of organizational structures across NASA with an emphasis on the organization's ability to do systems integration. b. Rewrite the policy(s) if required. c. Create an organization standard and mandate for program and integration offices. d. Provide training and assistance. Responsibility: Code AE	Organizational Structure

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F112	F7.4-7	When the Integration Office convenes the Integration Control Board, the Orbiter Office usually does not send a representative, and its staff makes verbal inputs only when requested.				
F113	F7.4-8	The Integration office did not have continuous responsibility to integrate responses to bipod foam shedding from various offices. Sometimes the Orbiter Office had responsibility, sometimes the External Tank Office at Marshall Space Flight Center had responsibility, and sometimes the bipod shedding did not result in any designation of an In-Flight Anomaly. Integration did not occur.	Y	Programs must determine clear organizational lines of authority, responsibility, and accountability.	See F7.4-6	Organizational Structure
F114	F7.4-9	NASA information databases such as The Problem Reporting and Corrective Action and the Web Program Compliance Assurance and Status System are marginally effective decision tools.	Y	NASA should assess decision support tool effectiveness for program management, problem identification, and problem resolution.	38) Review current policies and standards for decision support tools. a. Conduct a comprehensive review of all NASA decision support tools, and compile a directory. b. Rewrite the policy(s) if required. c. Create a common standard and mandate for decision support systems across NASA. d. Provide training and development assistance on decision support tools. See F7.4-10/11 Responsibility: Code AE	Learning
F115	F7.4-10	Senior Safety, Reliability & Quality Assurance and element managers do not use the Lessons Learned Information System when making decisions. NASA subsequently does not have a constructive program to use past lessons to educate engineers, managers, astronauts, or safety personnel.	Y	Training programs that leverage case studies and lessons learned capabilities are characteristic of other Federal and commercial organizations and should be adopted by NASA and implemented across the entire Agency as appropriate.	See F7.4-11	Learning
F116	F7.4-11	The Space Shuttle Program has a wealth of data tucked away in multiple databases	Y	NASA should address database commonality and real-time access just as	39) Review current policies and standards for databases and	Learning

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		without a convenient way to integrate and use the data for management, engineering, or safety decisions.		it did for the Integrated Financial Management Program (IFMP).	knowledge sharing. a. Conduct a comprehensive review of all NASA databases, and compile a directory. b. Rewrite the policy(s) if required. c. Create a common standard and mandate for database real-time access across NASA. d. Provide training and development assistance on the database standard and associated real-time access process that is developed. Responsibility: Code AE	
F117	F7.4-12	The dependence of Safety, Reliability & Quality Assurance personnel on Shuttle Program support limits their ability to oversee operations and communicate potential problems throughout the organization.	Y	Programs should identify internal conflicts of interest and address means for mitigation.	See R7.5-2	Organizational Structure
F118	F7.4-13	There are conflicting roles, responsibilities, and guidance in the Space Shuttle safety programs. The Safety & Mission Assurance Pre-Launch Assessment Review process is not recognized by the Space Shuttle Program as a requirement that must be followed (NSTS 22778). Failure to consistently apply the Pre-Launch Assessment Review as a requirements document creates confusion about roles and responsibilities in the NASA safety organization.	Y	Programs should perform periodic audits to identify internal conflicts of interest; process conflicts; and other program operational inconsistencies, roles, and responsibilities and address means for mitigation.	See R7.5-2	Organizational Structure
F119	F10.1-1	The *Columbia* accident demonstrated that Orbiter breakup during re-entry has the potential to cause casualties among the general public.	Y	Same as O10.1-1	See O10.1-1	Risk Management
F120	F10.1-2	Given the best information available to date, a formal risk analysis sponsored by the Board found that the lack of general-public casualties from *Columbia*'s break-up was the expected outcome.	Y	Programs should know all results of risk analyses, regardless of the anticipated outcome, and factor those considerations into safety and mission success planning and contingency management activities.	See O10.1-1	Risk Management

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F121	F10.1-3	The history of U.S. space flight has a flawless public safety record. Since the 1950s, hundreds of space flights have occurred without a single public injury.	Y	Safety should be based on logical risk assessments. Small sample statistics provide for an uninformed development of intuition.	See O10.1-1	Risk Management
F122	F10.1-4	The FAA and U.S. space launch ranges have safety standards designed to ensure that the general public is exposed to less than a one-in-a-million chance of serious injury from the operation of space launch vehicles and unmanned aircraft.	Y	NASA policies recognize requirements for public safety. Those policies should be reviewed and the models used should be continually updated and assessed with respect to value in supporting timely decision making.	See O10.1-1	Risk Management
F123	F10.1-5	NASA did not demonstrably follow public risk acceptability standards during past Orbiter re-entries. NASA efforts are underway to define a national policy for the protection of public safety during all operations involving space launch vehicles.	Y	Same as F10.1-4	See O10.1-1	Risk Management
F124	F10.3-1	The engineering drawing system contains outdated information and is paper-based rather than computer-aided.	Y	Accurate and comprehensive engineering drawings should be maintained for all programs. These drawings must be computer-aided.	See R10.3-1	Technical Capabilities
F125	F10.3-2	The current drawing system cannot quickly portray Shuttle sub-systems for on-orbit troubleshooting.				
F126	F10.3-3	NASA normally uses closeout photographs but lacks a clear system to define which critical sub-systems should have such photographs. The current system does not allow the immediate retrieval of closeout photos.	Y	Standards for taking, organizing, preserving, handling, and managing closeout photographs should be uniformly applied across all of NASA's programs.	See R10.3-1	Technical Capabilities
F127	F10.4-1	Shuttle System industrial safety programs are in good health.	Y	The state of health of all NASA industrial safety programs should be reviewed.	40) Review current policies and regulations on industrial safety programs. a. After review of policies and regulations, conduct an audit of no less than three programs to determine compliance. b. Compile the results; develop a recommendation. c. If required, rewrite the policies to comply with regulations.	Risk Management

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					Responsibility: Code Q	
F128	F10.4-2	The Quality Planning Requirements Document, which defines inspection conditions, was well formulated. However, there is no requirement that it be routinely reviewed.				
F129	F10.4-3	Kennedy Space Center's current government mandatory inspection process is both inadequate and difficult to expand, which inhibits the ability of Quality Assurance to process improvement initiatives.				
F130	F10.4-4	Kennedy's quality assurance system encourages inspectors to allow incorrect work to be corrected without being labeled "rejected." These opportunities hide "rejections," making it impossible to determine how often and on what items frequent rejections and errors occur.				
F131	F10.8-1	The present design and fabrication of the lower carrier panel attachments are inadequate. The bolts can readily pull through the relatively large holes in the box beams.				
F132	F10.8-2	The current design of the box beam in the lower carrier panel assembly exposes the attachment bolts to a rapid exchange of air along the wing, which enables the failure of numerous bolts.				
F133	F10.8-3	Primers and sealants such as Room Temperature Vulcanizing 560 and Koropon may accelerate corrosion, particularly in tight crevices.				
F134	F10.8-4	The negligible compressive stresses that normally occur in A-286 bolts help protect against failure.				
F135	F10.9-1	The Hold-Down Post External Tank Vent Arm System is a Criticality 1R (redundant) system. Before the anomaly on STS-112, and despite the high-criticality factor, the original cabling for this system was used repeatedly until it				

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		was visibly damaged. Replacing these cables after every flight and removing the Kapton will prevent bending and manipulation damage.				
F136	F10.9-2	NASA is unclear about the potential for damage if the system malfunctions, or even if one nut fails to split. Several program managers were asked: What if the A system fails, and a B-system initiator fails simultaneously? The consensus was that the system would continue to burn on the pad or that the Solid Rocket Booster would rip free of the pad, causing potentially catastrophic damage to the Solid Rocket Booster skirt and nozzle maneuvering mechanism. However, they agree that the probability of this is extremely low.				
F137	F10.9-3	With the exception of STS-112's anomaly, numerous bolt hang-ups, and occasional Master Events Controller failures, these systems have a good record. In the early design stages, risk-mitigating options were considered, including strapping with either a wire that crosses over the nut from the A to B side, or with a toggle circuit that sends a signal to the opposite side when either initiator fires. Both options would eliminate the potential of a catastrophic dual failure. However, they could also create new failure potentials that may not reduce overall system risk. Today's test and troubleshooting technology may have improved the ability to test circuits and potentially prevent intermittent failures, but it is not clear if NASA has explored these options.				

* Broadly Applicable

Appendix B Acronyms

CAD	Computer-Aided Design
CAIB	Columbia Accident Investigation Board
CARD	Cost Analysis Resource Document
CFT	Continuing Flight Team
CMM	Capability Maturity Model
CRM	Crew Resource Management
DoD	Department of Defense
DOE	Department of Energy
ET	External Tank
FAA	Federal Aviation Administration
HR	Human Resources
IFMP	Integrated Financial Management Program
ISO	International Standard Organization
ISS	International Space Station
ITEA	Independent Technical Engineering Authority
LCC	Life Cycle Cost
MOA	Memorandum of Agreement
NASA	National Aeronautics and Space Administration
NESC	NASA Engineering and Safety Center
NGA	National Geospatial-Intelligence Agency
NIMA	National Imagery & Mapping Agency
NPD	NASA Policy Directive
NSTS	National Space Transportation System
R&D	Research and Development
RCC	Reinforced Carbon-Carbon
R-O-F	Recommendations, Observations, and Findings
RTF	Return to Flight
SEI	Software Engineering Institute
S&MA	Safety and Mission Assurance
SR&QA	Safety, Reliability, & Quality Assurance
TRL	Technology Readiness Level
USA	United Space Alliance