CHAPTER 9

Implications for the Future of Human Space Flight

And while many memorials will be built to honor Columbia*'s crew, their greatest memorial will be a vibrant space program with new missions carried out by a new generation of brave explorers.*

– Remarks by Vice President Richard B. Cheney, Memorial Ceremony at the National Cathedral, February 6, 2003

The report up to this point has been a look backward: a single accident with multiple causes, both physical and organizational. In this chapter, the Board looks to the future. We take the insights gained in investigating the loss of *Columbia* and her crew and seek to apply them to this nation's continuing journey into space. We divide our discussion into three timeframes: 1) short-term, NASA's return to flight after the *Columbia* accident; 2) mid-term, what is needed to continue flying the Shuttle fleet until a replacement means for human access to space and for other Shuttle capabilities is available; and 3) long-term, future directions for the U.S. in space. The objective in each case is for this country to maintain a human presence in space, but with enhanced safety of flight.

In this report we have documented numerous indications that NASA's safety performance has been lacking. But even correcting all those shortcomings, it should be understood, will not eliminate risk. All flight entails some measure of risk, and this has been the case since before the days of the Wright Brothers. Furthermore, the risk is not distributed evenly over the course of the flight. It is greater by far at the beginning and end than during the middle.

This concentration of risk at the endpoints of flight is particularly true for crew-carrying space missions. The Shuttle Program has now suffered two accidents, one just over a minute after takeoff and the other about 16 minutes before landing. The laws of physics make it extraordinarily difficult to reach Earth orbit and return safely. Using existing technology, orbital flight is accomplished only by harnessing a chemical reaction that converts vast amounts of stored energy into speed. There is great risk in placing human beings atop a machine that stores and then burns millions of pounds of dangerous propellants. Equally risky is having humans then ride the machine back to Earth while it dissipates the orbital speed by converting the energy into heat, much like a meteor entering Earth's atmosphere. No alternatives to this pathway to space are available or even on the horizon, so we must set our sights on managing this risky process using the most advanced and versatile techniques at our disposal.

Columbia *launches as STS-107 on January 16, 2003.*

Because of the dangers of ascent and re-entry, because of the hostility of the space environment, and because we are still relative newcomers to this realm, operation of the Shuttle and indeed all human spaceflight must be viewed as a developmental activity. It is still far from a routine, operational undertaking. Throughout the *Columbia* accident investigation, the Board has commented on the widespread but erroneous perception of the Space Shuttle as somehow comparable to civil or military air transport. They are not comparable; the inherent risks of spaceflight are vastly higher, and our experience level with spaceflight is vastly lower. If Shuttle operations came to be viewed as routine, it was, at least in part, thanks to the skill and dedication of those involved in the program. They have made it look easy, though in fact it never was. The Board urges NASA leadership, the architects of U.S. space policy, and the American people to adopt a realistic understanding of the risks and rewards of venturing into space.

9.1 Near-Term: Return to Flight

The Board supports return to flight for the Space Shuttle at the earliest date consistent with an overriding consideration: safety. The recognition of human spaceflight as a developmental activity requires a shift in focus from operations and meeting schedules to a concern for the risks involved. Necessary measures include:

- Identifying risks by looking relentlessly for the next eroding O-ring, the next falling foam; obtaining better data, analyzing and spotting trends.
- Mitigating risks by stopping the failure at its source; when a failure does occur, improving the ability to tolerate it; repairing the damage on a timely basis.
- Decoupling unforeseen events from the loss of crew and vehicle.
- Exploring all options for survival, such as provisions for crew escape systems and safe havens.
- Barring unwarranted departures from design standards, and adjusting standards only under the most rigorous, safety-driven process.

The Board has recommended improvements that are needed before the Shuttle Program returns to flight, as well as other measures to be adopted over the longer term – what might be considered "continuing to fly" recommendations. To ensure implementation of these longer-term recommendations, the Board makes the following recommendation, which should be included in the requirements for return-to-flight:

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.

The complete list of the Board's recommendations can be found in Chapter 11.

9.2 Mid-Term: Continuing to Fly

It is the view of the Board that the present Shuttle is not inherently unsafe. However, the observations and recommendations in this report are needed to make the vehicle safe enough to operate in the coming years. In order to continue operating the Shuttle for another decade or even more, which the Human Space Flight Program may find necessary, these significant measures must be taken:

- Implement all the recommendations listed in Part One of this report that were not already accomplished as part of the return-to-flight reforms.
- Institute all the organizational and cultural changes called for in Part Two of this report.
- Undertake complete recertification of the Shuttle, as detailed in the discussion and recommendation below.

The urgency of these recommendations derives, at least in part, from the likely pattern of what is to come. In the near term, the recent memory of the *Columbia* accident will motivate the entire NASA organization to scrupulous attention to detail and vigorous efforts to resolve elusive technical problems. That energy will inevitably dissipate over time. This decline in vigilance is a characteristic of many large organizations, and it has been demonstrated in NASA's own history. As reported in Part Two of this report, the Human Space Flight Program has at times compromised safety because of its organizational problems and cultural traits. That is the reason, in order to prevent the return of bad habits over time, that the Board makes the recommendations in Part Two calling for changes in the organization and culture of the Human Space Flight Program. These changes will take more time and effort than would be reasonable to expect prior to return to flight.

Through its recommendations in Part Two, the Board has urged that NASA's Human Space Flight Program adopt the characteristics observed in high-reliability organizations. One is separating technical authority from the functions of managing schedules and cost. Another is an independent Safety and Mission Assurance organization. The third is the capability for effective systems integration. Perhaps even more challenging than these organizational changes are the cultural changes required. Within NASA, the cultural impediments to safe and effective Shuttle operations are real and substantial, as documented extensively in this report. The Board's view is that cultural problems are unlikely to be corrected without top-level leadership. Such leadership will have to rid the system of practices and patterns that have been validated simply because they have been around so long. Examples include: the tendency to keep knowledge of problems contained within a Center or program; making technical decisions without in-depth, peer-reviewed technical analysis; and an unofficial hierarchy or caste system created by placing excessive power in one office. Such factors interfere with open communication, impede the sharing of lessons learned, cause duplication and unnecessary expenditure of resources, prompt resistance to external advice, and create a burden for managers, among other undesirable outcomes. Collectively, these undesirable characteristics threaten safety.

Unlike return-to-flight recommendations, the Board's management and cultural recommendations will take longer to implement, and the responses must be fine-tuned and adjusted during implementation. The question of how to follow up on NASA's implementation of these more subtle, but equally important recommendations remains unanswered. The Board is aware that response to these recommendations will be difficult to initiate, and they will encounter some degree of institutional resistance. Nevertheless, in the Board's view, they are so critical to safer operation of the Shuttle fleet that they must be carried out completely. Since NASA is an independent agency answerable only to the White House and Congress, the ultimate responsibility for enforcement of the recommended corrective actions must reside with those governmental authorities.

Recertification

Recertification is a process to ensure flight safety when a vehicle's actual utilization exceeds its original design life; such a baseline examination is essential to certify that vehicle for continued use, in the case of the Shuttle to 2020 and possibly beyond. This report addresses recertification as a mid-term issue.

Measured by their 20 or more missions per Orbiter, the Shuttle fleet is young, but by chronological age – 10 to 20 years each – it is old. The Board's discovery of mass loss in RCC panels, the deferral of investigation into signs of metal corrosion, and the deferral of upgrades all strongly suggest that a policy is needed requiring a complete recertification of the Space Shuttle. This recertification must be rigorous and comprehensive at every level (i.e., material, component, subsystem, and system); the higher the level, the more critical the integration of lower-level components. A post-*Challenger*, 10-year review was conducted, but it lacked this kind of rigor, comprehensiveness and, most importantly, integration at the subsystem and system levels.

Aviation industry standards offer ample measurable criteria for gauging specific aging characteristics, such as stress and corrosion. The Shuttle Program, by contrast, lacks a closed-loop feedback system and consequently does not take full advantage of all available data to adjust its certification process and maintenance practices. Data sources can include experience with material and component failures, non-conformances (deviations from original specifications) discovered during Orbiter Maintenance Down Periods, Analytical Condition Inspections, and Aging Aircraft studies. Several of the recommendations in this report constitute the basis for a recertification program (such as the call for nondestructive evaluation of RCC components). Chapters 3 and 4 cite instances of waivers and certification of components for flight based on analysis rather than testing. The recertification program should correct all those deficiencies.

Finally, recertification is but one aspect of a Service Life Extension Program that is essential if the Shuttle is to continue operating for another 10 to 20 years. While NASA has such a program, it is in its infancy and needs to be pursued with vigor. The Service Life Extension Program goes beyond the Shuttle itself and addresses critical associated components in equipment, infrastructure, and other areas. Aspects of the program are addressed in Appendix D.15.

The Board makes the following recommendation regarding recertification:

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.

9.3 Long-Term: Future Directions for the U.S. in Space

The Board in its investigation has focused on the physical and organizational causes of the *Columbia* accident and the recommended actions required for future safe Shuttle operation. In the course of that investigation, however, two realities affecting those recommendations have become evident to the Board. One is the lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space. President John Kennedy's 1961 charge to send Americans to the moon and return them safely to Earth "before this decade is out" linked NASA's efforts to core Cold War national interests. Since the 1970s, NASA has not been charged with carrying out a similar high priority mission that would justify the expenditure of resources on a scale equivalent to those allocated for Project Apollo. The result is the agency has found it necessary to gain the support of diverse constituencies. NASA has had to participate in the give and take of the normal political process in order to obtain the resources needed to carry out its programs. NASA has usually failed to receive budgetary support consistent with its ambitions. The result, as noted throughout Part Two of the report, is an organization straining to do too much with too little.

A second reality, following from the lack of a clearly defined long-term space mission, is the lack of sustained government commitment over the past decade to improving U.S. access to space by developing a second-generation space transportation system. Without a compelling reason to do so, successive Administrations and Congresses have not been willing to commit the billions of dollars required to develop such a vehicle. In addition, the space community has proposed to the government the development of vehicles such as the National Aerospace Plane and X-33, which required "leapfrog" advances in technology; those advances have proven to be unachievable. As Apollo 11 Astronaut Buzz Aldrin, one of the members of the recent Commission on the Future of the United States Aerospace Industry, commented in the Commission's November 2002 report, "Attempts at developing breakthrough space transportation systems have proved illusory."[1] The Board believes that the country should plan for future space transportation capabilities without making them dependent on technological breakthroughs.

Lack of a National Vision for Space

In 1969 President Richard Nixon rejected NASA's sweeping vision for a post-Apollo effort that involved full develop-

ment of low-Earth orbit, permanent outposts on the moon, and initial journeys to Mars. Since that rejection, these objectives have reappeared as central elements in many proposals setting forth a long-term vision for the U.S. Space program. In 1986 the National Commission on Space proposed "a pioneering mission for 21st-century America: To lead the exploration and development of the space frontier, advancing science, technology, and enterprise, and building institutions and systems that make accessible vast new resources and support human settlements beyond Earth orbit, from the highlands of the Moon to the plains of Mars."[2] In 1989, on the 20th anniversary of the first lunar landing, President George H.W. Bush proposed a Space Exploration Initiative, calling for "a sustained program of manned exploration of the solar system."[3] Space advocates have been consistent in their call for sending humans beyond low-Earth orbit as the appropriate objective of U.S. space activities. Review committees as diverse as the 1990 Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine, and the 2001 International Space Station Management and Cost Evaluation Task Force have suggested that the primary justification for a space station is to conduct the research required to plan missions to Mars and/or other distant destinations. However, human travel to destinations beyond Earth orbit has not been adopted as a national objective.

The report of the Augustine Committee commented, "It seems that most Americans do support a viable space program for the nation – but no two individuals seem able to agree upon *what* that space program should be."[4] The Board observes that none of the competing long-term visions for space have found support from the nation's leadership, or indeed among the general public. The U.S. civilian space effort has moved forward for more than 30 years without a guiding vision, and none seems imminent. In the past, this absence of a strategic vision in itself has reflected a policy decision, since there have been many opportunities for national leaders to agree on ambitious goals for space, and none have done so.

The Board does observe that there is one area of agreement among almost all parties interested in the future of U.S. activities in space: *The United States needs improved access for humans to low-Earth orbit as a foundation for whatever directions the nation's space program takes in the future*. In the Board's view, a full national debate on how best to achieve such improved access should take place in parallel with the steps the Board has recommended for returning the Space Shuttle to flight and for keeping it operating safely in coming years. Recommending the content of this debate goes well beyond the Board's mandate, but we believe that the White House, Congress, and NASA should honor the memory of *Columbia*'s crew by reflecting on the nation's future in space and the role of new space transportation capabilities in enabling whatever space goals the nation chooses to pursue.

All members of the Board agree that America's future space efforts must include human presence in Earth orbit, and eventually beyond, as outlined in the current NASA vision. Recognizing the absence of an agreed national mandate cited above, the current NASA strategic plan stresses an approach of investing in "transformational technologies" that will enable the development of capabilities to serve as "stepping stones" for whatever path the nation may decide it wants to pursue in space. While the Board has not reviewed this plan in depth, this approach seems prudent. Absent any long-term statement of what the country wants to accomplish in space, it is difficult to state with any specificity the requirements that should guide major public investments in new capabilities. The Board does believe that NASA and the nation should give more attention to developing a new "concept of operations" for future activities – defining the range of activities the country intends to carry out in space – that could provide more specificity than currently exists. Such a concept does not necessarily require full agreement on a future vision, but it should help identify the capabilities required and prevent the debate from focusing solely on the design of the next vehicle.

Developing a New Space Transportation System

When the Space Shuttle development was approved in 1972, there was a corresponding decision not to fund technologies for space transportation other than those related to the Shuttle. This decision guided policy for more than 20 years, until the National Space Transportation Policy of 1994 assigned NASA the role of developing a next-generation, advanced-technology, single-stage-to-orbit replacement for the Space Shuttle. That decision was flawed for several reasons. Because the United States had not funded a broad portfolio of space transportation technologies for the preceding three decades, there was a limited technology base on which to base the choice of this second-generation system. The technologies chosen for development in 1996, which were embodied in the X-33 demonstrator, proved not yet mature enough for use. Attracted by the notion of a growing private sector market for space transportation, the Clinton Administration hoped this new system could be developed with minimal public investment – the hope was that the private sector would help pay for the development of a Shuttle replacement.

In recent years there has been increasing investment in space transportation technologies, particularly through NASA's Space Launch Initiative effort, begun in 2000. This investment has not yet created a technology base for a second-generation reusable system for carrying people to orbit. Accordingly, in 2002 NASA decided to reorient the Space Launch Initiative to longer-term objectives, and to introduce the concept of an Orbital Space Plane as an interim complement to the Space Shuttle for space station crew-carrying responsibilities. The Integrated Space Transportation Plan also called for using the Space Shuttle for an extended period into the future. The Board has evaluated neither NASA's Integrated Space Transportation Plan nor the detailed requirements of an Orbital Space Plane.

Even so, based on its in-depth examination of the Space Shuttle Program, the Board has reached an inescapable conclusion: *Because of the risks inherent in the original design of the Space Shuttle, because that design was based in many aspects on now-obsolete technologies, and because the Shuttle is now an aging system but still developmental in character, it is in the nation's interest to replace the Shuttle*

as soon as possible as the primary means for transporting humans to and from Earth orbit. At least in the mid-term, that replacement will be some form of what NASA now characterizes as an Orbital Space Plane. The design of the system should give overriding priority to crew safety, rather than trade safety against other performance criteria, such as low cost and reusability, or against advanced space operation capabilities other than crew transfer.

This conclusion implies that whatever design NASA chooses should become the primary means for taking people to and from the International Space Station, not just a complement to the Space Shuttle. And it follows from the same conclusion that there is urgency in choosing that design, after serious review of a "concept of operations" for human space flight, and bringing it into operation as soon as possible. This is likely to require a significant commitment of resources over the next several years. The nation must not shy from making that commitment. The International Space Station is likely to be the major destination for human space travel for the next decade or longer. The Space Shuttle would continue to be used when its unique capabilities are required, both with respect to space station missions such as experiment delivery and retrieval or other logistical missions, and with respect to the few planned missions not traveling to the space station. When cargo can be carried to the space station or other destinations by an expendable launch vehicle, it should be.

However, the Orbital Space Plane is seen by NASA as an interim system for transporting humans to orbit. NASA plans to make continuing investments in "next generation launch technology," with the hope that those investments will enable a decision by the end of this decade on what that next generation launch vehicle should be. This is a worthy goal, and should be pursued. *The Board notes that this approach can only be successful: if it is sustained over the decade; if by the time a decision to develop a new vehicle is made there is a clearer idea of how the new space transportation system fits into the nation's overall plans for space; and if the U.S. government is willing at the time a development decision is made to commit the substantial resources required to implement it*. One of the major problems with the way the Space Shuttle Program was carried out was an *a priori* fixed ceiling on development costs. That approach should not be repeated.

It is the view of the Board that *the previous attempts to develop a replacement vehicle for the aging Shuttle represent a failure of national leadership*. The cause of the failure was continuing to expect major technological advances in that vehicle. With the amount of risk inherent in the Space Shuttle, the first step should be to reach an agreement that the overriding mission of the replacement system is to move humans safely and reliably into and out of Earth orbit. To demand more would be to fall into the same trap as all previous, unsuccessful, efforts. That being said, it seems to the Board that past and future investments in space launch technologies should certainly provide by 2010 or thereabouts the basis for developing a system, significantly improved over one designed 40 years earlier, for carrying humans to orbit and enabling their work in space. Continued U.S. leadership in space is an important national objective. That leadership depends on a willingness to pay the costs of achieving it.

Final Conclusions

The Board's perspective assumes, of course, that the United States wants to retain a continuing capability to send people into space, whether to Earth orbit or beyond. The Board's work over the past seven months has been motivated by the desire to honor the STS-107 crew by understanding the cause of the accident in which they died, and to help the United States and indeed all spacefaring countries to minimize the risks of future loss of lives in the exploration of space. The United States should continue with a Human Space Flight Program consistent with the resolve voiced by President George W. Bush on February 1, 2003: *"Mankind is led into the darkness beyond our world by the inspiration of discovery and the longing to understand. Our journey into space will go on."*

Two proposals – a capsule (above) and a winged vehicle - for the Orbital Space Plane, courtesy of The Boeing Company.

ENDNOTES FOR CHAPTER 9

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

1 *Report on the Commission on the Future of the United States Aerospace Industry*, November 2002, p. 3-3.

2 National Commission on Space, *Pioneering the Space Frontier: An Exciting Vision of Our Next Fifty Years in Space, Report of the National Commission on Space* (Bantam Books, 1986), p. 2.

3 President George H. W. Bush, "Remarks on the 20th Anniversary of the Apollo 11 Moon Landing," Washington, D.C., July 20, 1989.

4 "Report of the Advisory Committee on the Future of the U.S. Space Program," December 1990, p. 2.