Part Two

Why The Accident Occurred

Many accident investigations do not go far enough. They identify the technical cause of the accident, and then connect it to a variant of "operator error" – the line worker who forgot to insert the bolt, the engineer who miscalculated the stress, or the manager who made the wrong decision. But this is seldom the entire issue. When the determinations of the causal chain are limited to the technical flaw and individual failure, typically the actions taken to prevent a similar event in the future are also limited: fix the technical problem and replace or retrain the individual responsible. Putting these corrections in place leads to another mistake – the belief that the problem is solved. The Board did not want to make these errors.

Attempting to manage high-risk technologies while minimizing failures is an extraordinary challenge. By their nature, these complex technologies are intricate, with many interrelated parts. Standing alone, the components may be well understood and have failure modes that can be anticipated. Yet when these components are integrated into a larger system, unanticipated interactions can occur that lead to catastrophic outcomes. The risk of these complex systems is increased when they are produced and operated by complex organizations that also break down in unanticipated ways.

In our view, the NASA organizational culture had as much to do with this accident as the foam. Organizational culture refers to the basic values, norms, beliefs, and practices that characterize the functioning of an institution. At the most basic level, organizational culture defines the assumptions that employees make as they carry out their work. It is a powerful force that can persist through reorganizations and the change of key personnel. It can be a positive or a negative force.

In a report dealing with nuclear wastes, the National Research Council quoted Alvin Weinberg's classic statement about the "Faustian bargain" that nuclear scientists made with society. "The price that we demand of society for this magical energy source is both a vigilance and a longevity of our social institutions that we are quite unaccustomed to." This is also true of the space program. At NASA's urging, the nation committed to building an amazing, if compromised, vehicle called the Space Shuttle. When the agency did this, it accepted the bargain to operate and maintain the vehicle in the safest possible way. The Board is not convinced that NASA has completely lived up to the bargain, or that Congress and the Administration has provided the funding and support necessary for NASA to do so. This situation needs to be addressed – if the nation intends to keep conducting human space flight, it needs to live up to its part of the bargain.

Part Two of this report examines NASA's organizational, historical, and cultural factors, as well as how these factors contributed to the accident. As in Part One, this part begins with history. Chapter 5 examines the post-*Challenger* history of NASA and its Human Space Flight Program. This includes reviewing the budget as well as organizational and management history, such as shifting management systems and locations. Chapter 6 documents management performance related to *Columbia* to establish events analyzed in later chapters. The chapter reviews the foam strikes, intense schedule pressure driven by an artificial requirement to deliver Node 2 to the International Space Station by a certain date, and NASA management's handling of concerns regarding *Columbia* during the STS-107 mission.

In Chapter 7, the Board presents its views of how high-risk activities should be managed, and lists the characteristics of institutions that emphasize high-reliability results over economic efficiency or strict adherence to a schedule. This chapter measures the Space Shuttle Program's organizational and management practices against these principles and finds them wanting. Chapter 7 defines the organizational cause and offers recommendations. Chapter 8 draws from the previous chapters on history, budgets, culture, organization, and safety practices, and analyzes how all these factors contributed to this accident. This chapter captures the Board's views of the need to adjust management to enhance safety margins in Shuttle operations, and reaffirms the Board's position that without these changes, we have no confidence that other "corrective actions" will improve the safety of Shuttle operations. The changes we recommend will be difficult to accomplish – and will be internally resisted.

CHAPTER 5

From *Challenger* to *Columbia*

The Board is convinced that the factors that led to the *Columbia* accident go well beyond the physical mechanisms discussed in Chapter 3. The causal roots of the accident can also be traced, in part, to the turbulent post-Cold War policy environment in which NASA functioned during most of the years between the destruction of *Challenger* and the loss of *Columbia*. The end of the Cold War in the late 1980s meant that the most important political underpinning of NASA's Human Space Flight Program – U.S.-Soviet space competition – was lost, with no equally strong political objective to replace it. No longer able to justify its projects with the kind of urgency that the superpower struggle had provided, the agency could not obtain budget increases through the 1990s. Rather than adjust its ambitions to this new state of affairs, NASA continued to push an ambitious agenda of space science and exploration, including a costly Space Station Program.

If NASA wanted to carry out that agenda, its only recourse, given its budget allocation, was to become more efficient, accomplishing more at less cost. The search for cost reductions led top NASA leaders over the past decade to downsize the Shuttle workforce, outsource various Shuttle Program responsibilities – including safety oversight – and consider eventual privatization of the Space Shuttle Program. The program's budget was reduced by 40 percent in purchasing power over the past decade and repeatedly raided to make up for Space Station cost overruns, even as the Program maintained a launch schedule in which the Shuttle, a developmental vehicle, was used in an operational mode. In addition, the uncertainty of top policymakers in the White House, Congress, and NASA as to how long the Shuttle would fly before being replaced resulted in the delay of upgrades needed to make the Shuttle safer and to extend its service life.

The Space Shuttle Program has been transformed since the late 1980s implementation of post-*Challenger* management changes in ways that raise questions, addressed here and in later chapters of Part Two, about NASA's ability to safely operate the Space Shuttle. While it would be inaccurate to say that NASA managed the Space Shuttle Program at the time of the *Columbia* accident in the same manner it did prior to *Challenger*, there are unfortunate similarities between the agency's performance and safety practices in both periods.

5.1 THE *CHALLENGER* ACCIDENT AND ITS AFTERMATH

The inherently vulnerable design of the Space Shuttle, described in Chapter 1, was a product of policy and technological compromises made at the time of its approval in 1972. That approval process also produced unreasonable expectations, even myths, about the Shuttle's future performance that NASA tried futilely to fulfill as the Shuttle became "operational" in 1982. At first, NASA was able to maintain the image of the Shuttle as an operational vehicle. During its early years of operation, the Shuttle launched satellites, performed on-orbit research, and even took members of Congress into orbit. At the beginning of 1986, the goal of "routine access to space" established by President Ronald Reagan in 1982 was ostensibly being achieved. That appearance soon proved illusory. On the cold morning of January 28, 1986, the Shuttle *Challenger* broke apart 73 seconds into its climb towards orbit. On board were Francis R. Scobee, Michael J. Smith, Ellison S. Onizuka, Judith A. Resnick, Ronald E. McNair, Sharon Christa McAuliffe, and Gregory B. Jarvis. All perished.

Rogers Commission

On February 3, 1986, President Reagan created the Presidential Commission on the Space Shuttle Challenger Accident, which soon became known as the Rogers Commission after its chairman, former Secretary of State William Rogers. The Commission's report, issued on June 6, 1986, concluded that the loss of *Challenger* was caused by a failure of the joint and seal between the two lower segments of the right Solid Rocket Booster. Hot gases blew past a rubber O-ring in the joint, leading to a structural failure and the explosive burn-

ing of the Shuttle's hydrogen fuel. While the Rogers Commission identified the failure of the Solid Rocket Booster joint and seal as the physical cause of the accident, it also noted a number of NASA management failures that contributed to the catastrophe.

The Rogers Commission concluded "the decision to launch the *Challenger* was flawed." Communication failures, incomplete and misleading information, and poor management judgments all figured in a decision-making process that permitted, in the words of the Commission, "internal flight safety problems to bypass key Shuttle managers." As a result, if those making the launch decision "had known all the facts, it is highly unlikely that they would have decided to launch." Far from meticulously guarding against potential problems, the Commission found that NASA had required "a contractor to prove that it was not safe to launch, rather than proving it was safe."[1]

The Commission also found that NASA had missed warning signs of the impending accident. When the joint began behaving in unexpected ways, neither NASA nor the Solid Rocket Motor manufacturer Morton-Thiokol adequately tested the joint to determine the source of the deviations from specifications or developed a solution to them, even though the problems frequently recurred. Nor did they respond to internal warnings about the faulty seal. Instead, Morton-Thiokol and NASA management came to see the problems as an acceptable flight risk – a violation of a design requirement that could be tolerated.[2]

During this period of increasing uncertainty about the joint's performance, the Commission found that NASA's safety system had been "silent." Of the management, organizational, and communication failures that contributed to the accident, four related to faults within the safety system, including "a lack of problem reporting requirements, inadequate trend analysis, misrepresentation of criticality, and lack of involvement in critical discussions."[3] The checks and balances the safety system was meant to provide were not working.

Still another factor influenced the decisions that led to the accident. The Rogers Commission noted that the Shuttle's increasing flight rate in the mid-1980s created schedule pressure, including the compression of training schedules, a shortage of spare parts, and the focusing of resources on near-term problems. NASA managers "may have forgotten–partly because of past success, partly because of their own well-nurtured image of the program–that the Shuttle was still in a research and development phase."[4]

The *Challenger* accident had profound effects on the U.S. space program. On August 15, 1986, President Reagan announced that "NASA will no longer be in the business of launching private satellites." The accident ended Air Force and intelligence community reliance on the Shuttle to launch national security payloads, prompted the decision to abandon the yet-to-be-opened Shuttle launch site at Vandenberg Air Force Base, and forced the development of improved expendable launch vehicles.[6] A 1992 White House advisory committee concluded that the recovery from the *Challenger* disaster cost the country $12 billion, which included the cost of building the replacement Orbiter *Endeavour*.[7]

It took NASA 32 months after the *Challenger* accident to redesign and requalify the Solid Rocket Booster and to return the Shuttle to flight. The first post-accident flight was launched on September 29, 1988. As the Shuttle returned to flight, NASA Associate Administrator for Space Flight

Selected Rogers Commission Recommendations

- "The faulty Solid Rocket Motor joint and seal must be changed. This could be a new design eliminating the joint or a redesign of the current joint and seal. No design options should be prematurely precluded because of schedule, cost or reliance on existing hardware. All Solid Rocket Motor joints should satisfy the following:
  - "The joints should be fully understood, tested and verified."
  - "The certification of the new design should include:
    - Tests which duplicate the actual launch configuration as closely as possible.
    - Tests over the full range of operating conditions, including temperature."
- "Full consideration should be given to conducting static firings of the exact flight configuration in a vertical attitude."
- "The Shuttle Program Structure should be reviewed. The project managers for the various elements of the Shuttle program felt more accountable to their center management than to the Shuttle program organization."
- "NASA should encourage the transition of qualified astronauts into agency management positions."
- "NASA should establish an Office of Safety, Reliability and Quality Assurance to be headed by an Associate Administrator, reporting directly to the NASA Administrator. It would have direct authority for safety, reliability, and quality assurance throughout the agency. The office should be assigned the work force to ensure adequate oversight of its functions and should be independent of other NASA functional and program responsibilities."
- "NASA should establish an STS Safety Advisory Panel reporting to the STS Program Manager. The charter of this panel should include Shuttle operational issues, launch commit criteria, flight rules, flight readiness and risk management."
- "The Commission found that Marshall Space Flight Center project managers, because of a tendency at Marshall to management isolation, failed to provide full and timely information bearing on the safety of flight 51-L [the *Challenger* mission] to other vital elements of Shuttle program management … NASA should take energetic steps to eliminate this tendency at Marshall Space Flight Center, whether by changes of personnel, organization, indoctrination or all three."
- "The nation's reliance on the Shuttle as its principal space launch capability created a relentless pressure on NASA to increase the flight rate … NASA must establish a flight rate that is consistent with its resources."[5]

Richard Truly commented, "We will always have to treat it [the Shuttle] like an R&D test program, even many years into the future. I don't think calling it operational fooled anybody within the program … It was a signal to the public that shouldn't have been sent."[8]

The Shuttle Program After Return to Flight

After the Rogers Commission report was issued, NASA made many of the organizational changes the Commission recommended. The space agency moved management of the Space Shuttle Program from the Johnson Space Center to NASA Headquarters in Washington, D.C. The intent of this change was to create a management structure "resembling that of the Apollo program, with the aim of preventing communication deficiencies that contributed to the *Challenger* accident."[9] NASA also established an Office of Safety, Reliability, and Quality Assurance at its Headquarters, though that office was not given the "direct authority" over all of NASA's safety operations as the Rogers Commission had recommended. Rather, NASA human space flight centers each retained their own safety organization reporting to the Center Director.

In the almost 15 years between the return to flight and the loss of *Columbia*, the Shuttle was again being used on a regular basis to conduct space-based research, and, in line with NASA's original 1969 vision, to build and service a space station. The Shuttle flew 87 missions during this period, compared to 24 before *Challenger.* Highlights from these missions include the 1990 launch, 1993 repair, and 1999 and 2002 servicing of the Hubble Space Telescope; the launch of several major planetary probes; a number of Shuttle-Spacelab missions devoted to scientific research; nine missions to rendezvous with the Russian space station *Mir*; the return of former Mercury astronaut Senator John Glenn to orbit in October 1998; and the launch of the first U.S. elements of the International Space Station.

After the *Challenger* accident, the Shuttle was no longer described as "operational" in the same sense as commercial aircraft. Nevertheless, NASA continued planning as if the Shuttle could be readied for launch at or near whatever date was set. Tying the Shuttle closely to International Space Station needs, such as crew rotation, added to the urgency of maintaining a predictable launch schedule. The Shuttle is currently the only means to launch the already-built European, Japanese, and remaining U.S. modules needed to complete Station assembly and to carry and return most experiments and on-orbit supplies.[10] Even after three occasions when technical problems grounded the Shuttle fleet for a month or more, NASA continued to assume that the Shuttle could regularly and predictably service the Station. In recent years, this coupling between the Station and Shuttle has become the primary driver of the Shuttle launch schedule. Whenever a Shuttle launch is delayed, it impacts Station assembly and operations.

In September 2001, testimony on the Shuttle's achievements during the preceding decade by NASA's then-Deputy Associate Administrator for Space Flight William Readdy indicated the assumptions under which NASA was operating during that period:

> *The Space Shuttle has made dramatic improvements in the capabilities, operations and safety of the system. The payload-to-orbit performance of the Space Shuttle has been significantly improved – by over 70 percent to the Space Station. The safety of the Space Shuttle has also been dramatically improved by reducing risk by more than a factor of five. In addition, the operability of the system has been significantly improved, with five minute launch windows – which would not have been attempted a decade ago – now becoming routine. This record of success is a testament to the quality and dedication of the Space Shuttle management team and workforce, both civil servants and contractors.*[11]

5.2 The NASA Human Space Flight Culture

Though NASA underwent many management reforms in the wake of the *Challenger* accident and appointed new directors at the Johnson, Marshall, and Kennedy centers, the agency's powerful human space flight culture remained intact, as did many institutional practices, even if in a modified form. As a close observer of NASA's organizational culture has observed, "Cultural norms tend to be fairly resilient … The norms bounce back into shape after being stretched or bent. Beliefs held in common throughout the organization resist alteration."[12] This culture, as will become clear across the chapters of Part Two of this report, acted over time to resist externally imposed change. By the eve of the *Columbia* accident, institutional practices that were in effect at the time of the *Challenger* accident – such as inadequate concern over deviations from expected performance, a silent safety program, and schedule pressure – had returned to NASA.

Organizational Culture

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.

The human space flight culture within NASA originated in the Cold War environment. The space agency itself was created in 1958 as a response to the Soviet launch of S*putnik,* the first artificial Earth satellite. In 1961, President John F. Kennedy charged the new space agency with the task of reaching the moon before the end of the decade, and asked Congress and the American people to commit the immense resources for doing so, even though at the time NASA had only accumulated 15 minutes of human space flight experience. With its efforts linked to U.S.-Soviet competition for global leadership, there was a sense in the NASA workforce that the agency was engaged in a historic struggle central to the nation's agenda.

The Apollo era created at NASA an exceptional "can-do" culture marked by tenacity in the face of seemingly impossible challenges. This culture valued the interaction among

research and testing, hands-on engineering experience, and a dependence on the exceptional quality of the its workforce and leadership that provided in-house technical capability to oversee the work of contractors. The culture also accepted risk and failure as inevitable aspects of operating in space, even as it held as its highest value attention to detail in order to lower the chances of failure.

The dramatic Apollo 11 lunar landing in July 1969 fixed NASA's achievements in the national consciousness, and in history. However, the numerous accolades in the wake of the moon landing also helped reinforce the NASA staff's faith in their organizational culture. Apollo successes created the powerful image of the space agency as a "perfect place," as "the best organization that human beings could create to accomplish selected goals."[13] During Apollo, NASA was in many respects a highly successful organization capable of achieving seemingly impossible feats. The continuing image of NASA as a "perfect place" in the years after Apollo left NASA employees unable to recognize that NASA never had been, and still was not, perfect, nor was it as symbolically important in the continuing Cold War struggle as it had been for its first decade of existence. NASA personnel maintained a vision of their agency that was rooted in the glories of an earlier time, even as the world, and thus the context within which the space agency operated, changed around them.

As a result, NASA's human space flight culture never fully adapted to the Space Shuttle Program, with its goal of routine access to space rather than further exploration beyond low-Earth orbit. The Apollo-era organizational culture came to be in tension with the more bureaucratic space agency of the 1970s, whose focus turned from designing new spacecraft at any expense to repetitively flying a reusable vehicle on an ever-tightening budget. This trend toward bureaucracy and the associated increased reliance on contracting necessitated more effective communications and more extensive safety oversight processes than had been in place during the Apollo era, but the Rogers Commission found that such features were lacking.

In the aftermath of the *Challenger* accident, these contradictory forces prompted a resistance to externally imposed changes and an attempt to maintain the internal belief that NASA was still a "perfect place," alone in its ability to execute a program of human space flight. Within NASA centers, as Human Space Flight Program managers strove to maintain their view of the organization, they lost their ability to accept criticism, leading them to reject the recommendations of many boards and blue-ribbon panels, the Rogers Commission among them.

External criticism and doubt, rather than spurring NASA to change for the better, instead reinforced the will to "impose the party line vision on the environment, not to reconsider it," according to one authority on organizational behavior. This in turn led to "flawed decision making, self deception, introversion and a diminished curiosity about the world outside the perfect place."[14] The NASA human space flight culture the Board found during its investigation manifested many of these characteristics, in particular a self-confidence about NASA possessing unique knowledge about how to safely launch people into space.[15] As will be discussed later in this chapter, as well as in Chapters 6, 7, and 8, the Board views this cultural resistance as a fundamental impediment to NASA's effective organizational performance.

5.3 An Agency Trying to Do Too Much With Too Little

A strong indicator of the priority the national political leadership assigns to a federally funded activity is its budget. By that criterion, NASA's space activities have not been high on the list of national priorities over the past three decades (see Figure 5.3-1). After a peak during the Apollo program, when NASA's budget was almost four percent of the federal budget, NASA's budget since the early 1970s has hovered at one percent of federal spending or less.

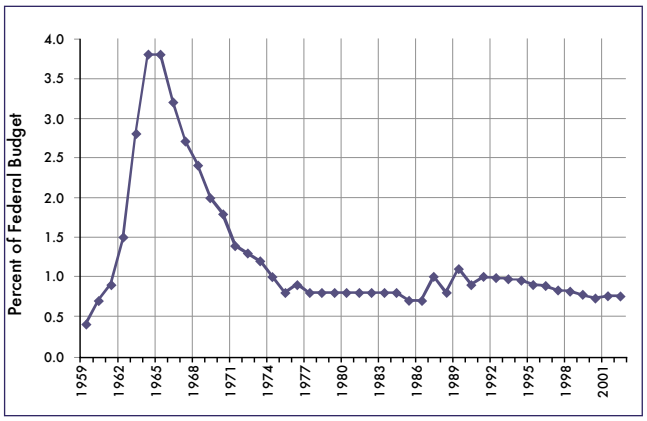

Figure 5.3-1. NASA budget as a percentage of the Federal budget. (Source: NASA History Office)

Particularly in recent years, as the national leadership has confronted the challenging task of allocating scarce public resources across many competing demands, NASA has had difficulty obtaining a budget allocation adequate to its continuing ambitions. In 1990, the White House chartered a blue-ribbon committee chaired by aerospace executive Norman Augustine to conduct a sweeping review of NASA and its programs in response to Shuttle problems and the flawed mirror on the Hubble Space Telescope.[16] The review found that NASA's budget was inadequate for all the programs the agency was executing, saying that "NASA is currently over committed in terms of program obligations relative to resources available–in short, it is trying to do too much, and allowing too little margin for the unexpected."[17] "A reinvigorated space program," the Augustine committee went on to say, "will require real growth in the NASA budget of approximately 10 percent per year (through the year 2000) reaching a peak spending level of about $30 billion per year (in constant 1990 dollars) by about the year 2000." Translated into the actual dollars of Fiscal Year 2000, that recommendation would have meant a NASA budget of over $40 billion; the actual NASA budget for that year was $13.6 billion.[18]

During the past decade, neither the White House nor Congress has been interested in "a reinvigorated space program." Instead, the goal has been a program that would continue to

produce valuable scientific and symbolic payoffs for the nation without a need for increased budgets. Recent budget allocations reflect this continuing policy reality. Between 1993 and 2002, the government's discretionary spending grew in purchasing power by more than 25 percent, defense spending by 15 percent, and non-defense spending by 40 percent (see Figure 5.3-2). NASA's budget, in comparison, showed little change, going from $14.31 billion in Fiscal Year 1993 to a low of $13.6 billion in Fiscal Year 2000, and increasing to $14.87 billion in Fiscal Year 2002. This represented a loss of 13 percent in purchasing power over the decade (see Figure 5.3-3).[19]

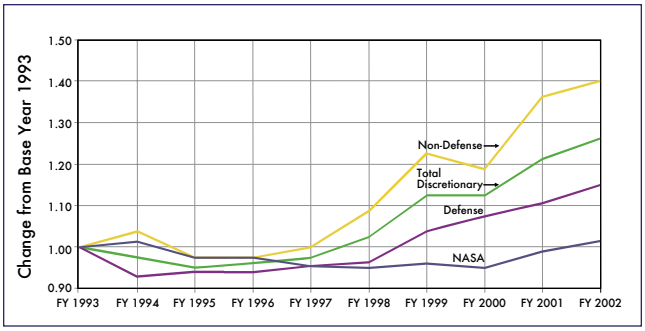

Figure 5.3-2. Changes in Federal spending from 1993 through 2002. (Source: NASA Office of Legislative Affairs)

Fiscal Year	Real Dollars (in millions)	Constant Dollars (in FY 2002 millions)
1965	5,250	24,696
1975	3,229	10,079
1985	7,573	11,643
1993	14,310	17,060
1994	14,570	16,965
1995	13,854	15,790
1996	13,884	15,489
1997	13,709	14,994
1998	13,648	14,641
1999	13,653	14,443
2000	13,601	14,202
2001	14,230	14,559
2002	14,868	14,868
2003	15,335	NA
2004	(requested) 15,255	NA

Figure 5.3-3. NASA Budget. (Source: NASA and Office of Management and Budget)

The lack of top-level interest in the space program led a 2002 review of the U.S. aerospace sector to observe that "a sense of lethargy has affected the space industry and community. Instead of the excitement and exuberance that dominated our early ventures into space, we at times seem almost apologetic about our continued investments in the space program."[20]

What the Experts Have Said

Warnings of a Shuttle Accident

"Shuttle reliability is uncertain, but has been estimated to range between 97 and 99 percent. If the Shuttle reliability is 98 percent, there would be a 50-50 chance of losing an Orbiter within 34 flights … The probability of maintaining at least three Orbiters in the Shuttle fleet declines to less than 50 percent after flight 113."[21]

-The Office of Technology Assessment, 1989

"And although it is a subject that meets with reluctance to open discussion, and has therefore too often been relegated to silence, the statistical evidence indicates that we are likely to lose another Space Shuttle in the next several years … probably before the planned Space Station is completely established on orbit. This would seem to be the weak link of the civil space program – unpleasant to recognize, involving all the uncertainties of statistics, and difficult to resolve."

-The Augustine Committee, 1990

Shuttle as Developmental Vehicle

"Shuttle is also a complex system that has yet to demonstrate an ability to adhere to a fixed schedule"

-The Augustine Committee, 1990

NASA Human Space Flight Culture

"NASA has not been sufficiently responsive to valid criticism and the need for change."[22]

-The Augustine Committee, 1990

Faced with this budget situation, NASA had the choice of either eliminating major programs or achieving greater efficiencies while maintaining its existing agenda. Agency leaders chose to attempt the latter. They continued to develop the space station, continued robotic planetary and scientific missions, and continued Shuttle-based missions for both scientific and symbolic purposes. In 1994 they took on the responsibility for developing an advanced technology launch vehicle in partnership with the private sector. They tried to do this by becoming more efficient. "Faster, better, cheaper" became the NASA slogan of the 1990s.[23]

The flat budget at NASA particularly affected the human space flight enterprise. During the decade before the *Columbia* accident, NASA rebalanced the share of its budget allocated to human space flight from 48 percent of agency funding in Fiscal Year 1991 to 38 percent in Fiscal Year 1999, with the remainder going mainly to other science and technology efforts. On NASA's fixed budget, that meant

Earmarks

Pressure on NASA's budget has come not only from the White House, but also from the Congress. In recent years there has been an increasing tendency for the Congress to add "earmarks" – congressional additions to the NASA budget request that reflect targeted Members' interests. These earmarks come out of already-appropriated funds, reducing the amounts available for the original tasks. For example, as Congress considered NASA's Fiscal Year 2002 appropriation, the NASA Administrator told the House Appropriations subcommittee with jurisdiction over the NASA budget that the agency was "extremely concerned regarding the magnitude and number of congressional earmarks" in the House and Senate versions of the NASA appropriations bill.[24] He noted "the total number of House and Senate earmarks … is approximately 140 separate items, an increase of nearly 50 percent over FY 2001." These earmarks reflected "an increasing fraction of items that circumvent the peer review process, or involve construction or other objectives that have no relation to NASA mission objectives." The potential Fiscal Year 2002 earmarks represented "a net total of $540 million in reductions to ongoing NASA programs to fund this extremely large number of earmarks."[25]

the Space Shuttle and the International Space Station were competing for decreasing resources. In addition, at least $650 million of NASA's human space flight budget was used to purchase Russian hardware and services related to U.S.-Russian space cooperation. This initiative was largely driven by the Clinton Administration's foreign policy and national security objectives of supporting the administration of Boris Yeltsin and halting the proliferation of nuclear weapons and the means to deliver them.

Space Shuttle Program Budget Patterns

For the past 30 years, the Space Shuttle Program has been NASA's single most expensive activity, and of all NASA's efforts, that program has been hardest hit by the budget constraints of the past decade. Given the high priority assigned after 1993 to completing the costly International Space Station, NASA managers have had little choice but to attempt to reduce the costs of operating the Space Shuttle. This left little funding for Shuttle improvements. The squeeze on the Shuttle budget was even more severe after the Office of Management and Budget in 1994 insisted that any cost overruns in the International Space Station budget be made up from within the budget allocation for human space flight, rather than from the agency's budget as a whole. The Shuttle was the only other large program within that budget category.

Figures 5.3-4 and 5.3-5 show the trajectory of the Shuttle budget over the past decade. In Fiscal Year 1993, the outgoing Bush administration requested $4.128 billion for the Space Shuttle Program; five years later, the Clinton Administration request was for $2.977 billion, a 27 percent reduction. By Fiscal Year 2003, the budget request had increased to $3.208 billion, still a 22 percent reduction from a decade earlier. With inflation taken into account, over the past decade, there has been a reduction of approximately 40 percent in the purchasing power of the program's budget, compared to a reduction of 13 percent in the NASA budget overall.

Fiscal Year	*President's Request to Congress*	*Congressional Appropriation*	*Change*	*NASA Operating Plan**	*Change*
1993	4,128.0	4,078.0	-50.0	4,052.9	-25.1
1994	4,196.1	3,778.7	-417.4**	3,772.3	-6.4
1995	3,324.0	3,155.1	-168.9	3,155.1	0.0
1996	3,231.8	3,178.8	-53.0	3,143.8	-35.0
1997	3,150.9	3,150.9	0.0	2,960.9	-190.0
1998	2,977.8	2,927.8	-50.0	2,912.8	-15.0
1999	3,059.0	3,028.0	-31.0	2,998.3	-29.7
2000	2,986.2	3,011.2	+25.0	2,984.4	-26.8
2001	3,165.7	3,125.7	-40.0	3,118.8	-6.9
2002	3,283.8	3,278.8	-5.0	3,270.0	-8.9
2003	3,208.0	3,252.8	+44.8		

Figure 5.3-4. Space Shuttle Program Budget (in millions of dollars). (Source: NASA Office of Space Flight)
** NASA's operating plan is the means for adjusting congressional appropriations among various activities during the fiscal year as changing circumstances dictate. These changes must be approved by NASA's appropriation subcommittees before they can be put into effect.*
***This reduction primarily reflects the congressional cancellation of the Advanced Solid Rocket Motor Program*

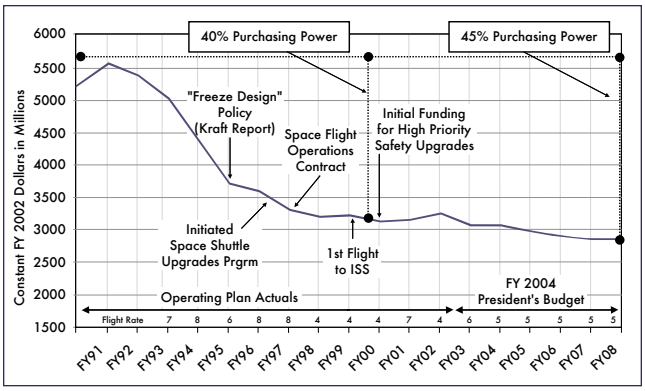

Figure 5.3-5. NASA budget as a percentage of the Federal budget from 1991 to 2008. (Source: NASA Office of Space Flight)

This budget squeeze also came at a time when the Space Shuttle Program exhibited a trait common to most aging systems: increased costs due to greater maintenance requirements, a declining second- and third-tier contractor support base, and deteriorating infrastructure. Maintaining the Shuttle was becoming more expensive at a time when Shuttle budgets were decreasing or being held constant. Only in the last few years have those budgets begun a gradual increase.

As Figure 5.3-5 indicates, most of the steep reductions in the Shuttle budget date back to the first half of the 1990s. In the second half of the decade, the White House Office of Management and Budget and NASA Headquarters held the Shuttle budget relatively level by deferring substantial funding for Shuttle upgrades and infrastructure improvements, while keeping pressure on NASA to limit increases in operating costs.

5.4 Turbulence in NASA Hits the Space Shuttle Program

In 1992 the White House replaced NASA Administrator Richard Truly with aerospace executive Daniel S. Goldin, a self-proclaimed "agent of change" who held office from April 1, 1992, to November 17, 2001 (in the process becoming the longest-serving NASA Administrator). Seeing "space exploration (manned and unmanned) as NASA's principal purpose with Mars as a destiny," as one management scholar observed, and favoring "administrative transformation" of NASA, Goldin engineered "not one or two policy changes, but a torrent of changes. This was not evolutionary change, but radical or discontinuous change."[26] His tenure at NASA was one of continuous turmoil, to which the Space Shuttle Program was not immune.

Of course, turbulence does not necessarily degrade organizational performance. In some cases, it accompanies productive change, and that is what Goldin hoped to achieve. He believed in the management approach advocated by W. Edwards Deming, who had developed a series of widely acclaimed management principles based on his work in Japan during the "economic miracle" of the 1980s. Goldin attempted to apply some of those principles to NASA, including the notion that a corporate headquarters should not attempt to exert bureaucratic control over a complex organization, but rather set strategic directions and provide operating units with the authority and resources needed to pursue those directions. Another Deming principle was that checks and balances in an organization were unnecessary

Congressional Budget Reductions

In most years, Congress appropriates slightly less for the Space Shuttle Program than the President requested; in some cases, these reductions have been requested by NASA during the final stages of budget deliberations. After its budget was passed by Congress, NASA further reduced the Shuttle budget in the agency's operating plan–the plan by which NASA actually allocates its appropriated budget during the fiscal year to react to changing program needs. These released funds were allocated to other activities, both within the human space flight program and in other parts of the agency. Changes in recent years include:

Fiscal Year 1997
- NASA transferred $190 million to International Space Station (ISS).

Fiscal Year 1998
- At NASA's request, Congress transferred $50 million to ISS.
- NASA transferred $15 million to ISS.

Fiscal Year 1999
- At NASA's request, Congress reduced Shuttle $31 million so NASA could fund other requirements.
- NASA reduced Shuttle $32 million by deferring two flights; funds transferred to ISS.
- NASA added $2.3 million from ISS to previous NASA request.

Fiscal Year 2000
- Congress added $25 million to Shuttle budget for upgrades and transferred $25 million from operations to upgrades.
- NASA reduced Shuttle $11.5 million per government-wide rescission requirement and transferred $15.3 million to ISS.

Fiscal Year 2001
- At NASA's request, Congress reduced Shuttle budget by $40 million to fund Mars initiative.
- NASA reduced Shuttle $6.9 million per rescission requirement.

Fiscal Year 2002
- Congress reduced Shuttle budget $50 million to reflect cancellation of electric Auxiliary Power Unit and added $20 million for Shuttle upgrades and $25 million for Vehicle Assembly Building repairs.
- NASA transferred $7.6 million to fund Headquarters requirements and cut $1.2 million per rescission requirement.

[Source: Marcia Smith, Congressional Research Service, Presentation at CAIB Public Hearing, June 12, 2003]

and sometimes counterproductive, and those carrying out the work should bear primary responsibility for its quality. It is arguable whether these business principles can readily be applied to a government agency operating under civil service rules and in a politicized environment. Nevertheless, Goldin sought to implement them throughout his tenure.[27]

Goldin made many positive changes in his decade at NASA. By bringing Russia into the Space Station partnership in 1993, Goldin developed a new post-Cold War rationale for the agency while managing to save a program that was politically faltering. The International Space Station became NASA's premier program, with the Shuttle serving in a supporting role. Goldin was also instrumental in gaining acceptance of the "faster, better, cheaper"[28] approach to the planning of robotic missions and downsizing "an agency that was considered bloated and bureaucratic when he took it over."[29]

Goldin described himself as "sharp-edged" and could often be blunt. He rejected the criticism that he was sacrificing safety in the name of efficiency. In 1994 he told an audience at the Jet Propulsion Laboratory, "When I ask for the budget to be cut, I'm told it's going to impact safety on the Space Shuttle … I think that's a bunch of crap."[30]

One of Goldin's high-priority objectives was to decrease involvement of the NASA engineering workforce with the Space Shuttle Program and thereby free up those skills for finishing the space station and beginning work on his preferred objective–human exploration of Mars. Such a shift would return NASA to its exploratory mission. He was often at odds with those who continued to focus on the centrality of the Shuttle to NASA's future.

Initial Shuttle Workforce Reductions

With NASA leadership choosing to maintain existing programs within a no-growth budget, Goldin's "faster, better, cheaper" motto became the agency's slogan of the 1990s.[31] NASA leaders, however, had little maneuvering room in which to achieve efficiency gains. Attempts by NASA Headquarters to shift functions or to close one of the three human space flight centers were met with strong resistance from the Centers themselves, the aerospace firms they used as contractors, and the congressional delegations of the states in which the Centers were located. This alliance resembles the classic "iron triangle" of bureaucratic politics, a conservative coalition of bureaucrats, interest groups, and congressional subcommittees working together to promote their common interests.[32]

With Center infrastructure off-limits, this left the Space Shuttle budget as an obvious target for cuts. Because the Shuttle required a large "standing army" of workers to

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Total Workforce	30,091	27,538	25,346	23,625	19,476	18,654	18,068	17,851	18,012	17,462
Total Civil Service Workforce	3,781	3,324	2,959	2,596	2,195	1,954	1,777	1,786	1,759	1,718
JSC	1,330	1,304	1,248	1,076	958	841	800	798	794	738
KSC	1,373	1,104	1,018	932	788	691	613	626	614	615
MSFC	874	791	576	523	401	379	328	336	327	337
Stennis/Dryden	84	64	55	32	29	27	26	16	14	16
Headquarters	120	61	62	32	20	16	10	10	10	12
Total Contractor Workforce	26,310	24,214	22,387	21,029	17,281	16,700	16,291	16,065	16,253	15,744
JSC	7,487	6,805	5,887	5,442	*10,556	10,525	10,733	10,854	11,414	11,445
KSC	9,173	8,177	7,691	7,208	539	511	430	436	439	408
MSFC	9,298	8,635	8,210	7,837	5,650	5,312	4,799	4,444	4,197	3,695
Stennis/Dryden	267	523	529	505	536	453	329	331	203	196
Headquarters	85	74	70	37	0	0	0	0	0	0

Figure 5.4-1. Space Shuttle Program workforce. [Source: NASA Office of Space Flight]
** Because Johnson Space Center manages the Space Flight Operations Contract, all United Space Alliance employees are counted as working for Johnson.*

keep it flying, reducing the size of the Shuttle workforce became the primary means by which top leaders lowered the Shuttle's operating costs. These personnel reduction efforts started early in the decade and continued through most of the 1990s. They created substantial uncertainty and tension within the Shuttle workforce, as well as the transitional difficulties inherent in any large-scale workforce reassignment.

In early 1991, even before Goldin assumed office and less than three years after the Shuttle had returned to flight after the *Challenger* accident, NASA announced a goal of saving three to five percent per year in the Shuttle budget over five years. This move was in reaction to a perception that the agency had overreacted to the Rogers Commission recommendations – for example, the notion that the many layers of safety inspections involved in preparing a Shuttle for flight had created a bloated and costly safety program.

From 1991 to 1994, NASA was able to cut Shuttle operating costs by 21 percent. Contractor personnel working on the Shuttle declined from 28,394 to 22,387 in these three years, and NASA Shuttle staff decreased from 4,031 to 2,959.[33] Figure 5.4-1 shows the changes in Space Shuttle workforce over the past decade. A 1994 National Academy of Public Administration review found that these cuts were achieved primarily through "operational and organizational efficiencies and consolidations, with resultant reductions in staffing levels and other actions which do not significantly impact basic program content or capabilities."[34]

NASA considered additional staff cuts in late 1994 and early 1995 as a way of further reducing the Space Shuttle Program budget. In early 1995, as the national leadership focused its attention on balancing the federal budget, the projected five-year Shuttle budget requirements exceeded by $2.5 billion the budget that was likely to be approved by the White House Office of Management and Budget.[35] Despite its already significant progress in reducing costs, NASA had to make further workforce cuts.

Anticipating this impending need, a 1994-1995 NASA "Functional Workforce Review" concluded that removing an additional 5,900 people from the NASA and contractor Shuttle workforce – just under 13 percent of the total – could be done without compromising safety.[36] These personnel cuts were made in Fiscal Years 1996 and 1997. By the end of 1997, the NASA Shuttle civilian workforce numbered 2,195, and the contractor workforce 17,281.

Shifting Shuttle Management Arrangements

Workforce reductions were not the only modifications to the Shuttle Program in the middle of the decade. In keeping with Goldin's philosophy that Headquarters should concern itself primarily with strategic issues, in February 1996 Johnson Space Center was designated as "lead center" for the Space Shuttle Program, a role it held prior to the *Challenger* accident. This shift was part of a general move of all program management responsibilities from NASA Headquarters to the agency's field centers. Among other things, this change meant that Johnson Space Center managers would have authority over the funding and management of Shuttle activities at the Marshall and Kennedy Centers. Johnson and Marshall had been rivals since the days of Apollo, and long-term Marshall employees and managers did not easily accept the return of Johnson to this lead role.

The shift of Space Shuttle Program management to Johnson was worrisome to some. The head of the Space Shuttle Program at NASA Headquarters, Bryan O'Connor, argued that transfer of the management function to the Johnson Space Center would return the Shuttle Program management to the flawed structure that was in place before the *Challenger* accident. "It is a safety issue," he said, "we ran it that way [with program management at Headquarters, as recommended by the Rogers Commission] for 10 years without a mishap and I didn't see any reason why we should go back to the way we operated in the pre-*Challenger* days."[37] Goldin gave O'Connor several opportunities to present his arguments against a transfer of management responsibility, but ultimately decided to proceed. O'Connor felt he had no choice but to resign.[38] (O'Connor returned to NASA in 2002 as Associate Administrator for Safety and Mission Assurance.)

In January 1996, Goldin appointed as Johnson's director his close advisor, George W.S. Abbey. Abbey, a space program veteran, was a firm believer in the values of the original human space flight culture, and as he assumed the directorship, he set about recreating as many of the positive features of that culture as possible. For example, he and Goldin initiated, as a way for young engineers to get hands-on experience, an in-house X-38 development program as a prototype for a space station crew rescue vehicle. Abbey was a powerful leader, who through the rest of the decade exerted substantial control over all aspects of Johnson Space Center operations, including the Space Shuttle Program.

Space Flight Operations Contract

By the middle of the decade, spurred on by Vice President Al Gore's "reinventing government" initiative, the goal of balancing the federal budget, and the views of a Republican-led House of Representatives, managers throughout the government sought new ways of making public sector programs more efficient and less costly. One method considered was transferring significant government operations and responsibilities to the private sector, or "privatization." NASA led the way toward privatization, serving as an example to other government agencies.

In keeping with his philosophy that NASA should focus on its research-and-development role, Goldin wanted to remove NASA employees from the repetitive operations of various systems, including the Space Shuttle. Giving primary responsibility for Space Shuttle operations to the private sector was therefore consistent with White House and congressional priorities and attractive to Goldin on its own terms. Beginning in 1994, NASA considered the feasibility of consolidating many of the numerous Shuttle operations contracts under a single prime contractor. At that time, the Space Shuttle Program was managing 86 separate contracts held by 56 different firms. Top NASA managers thought that consolidating these contracts could reduce the amount of redundant overhead, both for NASA and for the contractors

themselves. They also wanted to explore whether there were functions being carried out by NASA that could be more effectively and inexpensively carried out by the private sector.

An advisory committee headed by early space flight veteran Christopher Kraft recommended such a step in its March 1995 report, which became known as the "Kraft Report."[39] (The report characterized the Space Shuttle in a way that the Board judges to be at odds with the realities of the Shuttle Program).

The report made the following findings and recommendations:

- "The Shuttle has become a mature and reliable system … about as safe as today's technology will provide."
- "Given the maturity of the vehicle, a change to a new mode of management with considerably less NASA oversight is possible at this time."
- "Many inefficiencies and difficulties in the current Shuttle Program can be attributed to the diffuse and fragmented NASA and contractor structure. Numerous contractors exist supporting various program elements, resulting in ambiguous lines of communication and diffused responsibilities."
- NASA should "consolidate operations under a single-business entity."
- "The program remains in a quasi-development mode and yearly costs remain higher than required," and NASA should "freeze the current vehicle configuration, minimizing future modifications, with such modifications delivered in block updates. Future block updates should implement modifications required to make the vehicle more re-usable and operational."
- NASA should "restructure and reduce the overall Safety, Reliability, and Quality Assurance elements – without reducing safety."[40]

When he released his committee's report, Kraft said that "if NASA wants to make more substantive gains in terms of efficiency, cost savings and better service to its customers, we think it's imperative they act on these recommendations … And we believe that these savings are real, achievable, and can be accomplished with no impact to the safe and successful operation of the Shuttle system."[41]

Although the Kraft Report stressed that the dramatic changes it recommended could be made without compromising safety, there was considerable dissent about this claim. NASA's Aerospace Safety Advisory Panel – independent, but often not very influential – was particularly critical. In May 1995, the Panel noted that "the assumption [in the Kraft Report] that the Space Shuttle systems are now 'mature' smacks of a complacency which may lead to serious mishaps. The fact is that the Space Shuttle may never be mature enough to totally freeze the design." The Panel also noted that "the report dismisses the concerns of many credible sources by labeling honest reservations and the people who have made them as being partners in an unneeded 'safety shield' conspiracy. Since only one more accident would kill the program and destroy far more than the spacecraft, it is extremely callous" to make such an accusation.[42]

The notion that NASA would further reduce the number of civil servants working on the Shuttle Program prompted senior Kennedy Space Center engineer José Garcia to send to President Bill Clinton on August 25, 1995, a letter that stated, "The biggest threat to the safety of the crew since the Challenger disaster is presently underway at NASA." Garcia's particular concern was NASA's "efforts to delete the 'checks and balances' system of processing Shuttles as a way of saving money … Historically NASA has employed two engineering teams at KSC, one contractor and one government, to cross check each other and prevent catastrophic errors … although this technique is expensive, it is effective, and it is the single most important factor that sets the Shuttle's success above that of any other launch vehicle … Anyone who doesn't have a hidden agenda or fear of losing his job would admit that you can't delete NASA's checks and balances system of Shuttle processing without affecting the safety of the Shuttle and crew."[43]

NASA leaders accepted the advice of the Kraft Report and in August 1995 solicited industry bids for the assignment of Shuttle prime contractor. In response, Lockheed Martin and Rockwell, the two major Space Shuttle operations contractors, formed a limited liability corporation, with each firm a 50 percent owner, to compete for what was called the Space Flight Operations Contract. The new corporation would be known as United Space Alliance.

In November 1995, NASA awarded the operations contract to United Space Alliance on a sole source basis. (When Boeing bought Rockwell's aerospace group in December 1996, it also took over Rockwell's 50 percent ownership of United Space Alliance.) The company was responsible for 61 percent of the Shuttle operations contracts. Some in Congress were skeptical that safety could be maintained under the new arrangement, which transferred significant NASA responsibilities to the private sector. Despite these concerns, Congress ultimately accepted the reasoning behind the contract.[44] NASA then spent much of 1996 negotiating the contract's terms and conditions with United Space Alliance.

The Space Flight Operations Contract was designed to reward United Space Alliance for performance successes and penalize its performance failures. Before being eligible for any performance fees, United Space Alliance would have to meet a series of safety "gates," which were intended to ensure that safety remained the top priority in Shuttle operations. The contract also rewarded any cost reductions that United Space Alliance was able to achieve, with NASA taking 65 percent of any savings and United Space Alliance 35 percent.[45]

NASA and United Space Alliance formally signed the Space Flight Operations Contract on October 1, 1996. Initially, only the major Lockheed Martin and Rockwell Shuttle contracts and a smaller Allied Signal Unisys contract were transferred to United Space Alliance. The initial contractual period was six years, from October 1996 to September 2002. NASA exercised an option for a two-year extension in 2002, and another two-year option exists. The total value of the contract through the current extension is estimated at $12.8 billion. United Space Alliance currently has approximately 10,000 employees.

Space Flight Operations Contract

The Space Flight Operations Contract has two major areas of innovation:

- It replaced the previous "cost-plus" contracts (in which a firm was paid for the costs of its activity plus a negotiated profit) with a complex contract structure that included performance-based and cost reduction incentives. Performance measures include safety, launch readiness, on-time launch, Solid Rocket Booster recovery, proper orbital insertion, and successful landing.
- It gave additional responsibilities for Shuttle operation, including safety and other inspections and integration of the various elements of the Shuttle system, to United Space Alliance. Many of those responsibilities were previously within the purview of NASA employees.

Under the Space Flight Operations Contract, United Space Alliance had overall responsibility for processing selected Shuttle hardware, including:

- Inspecting and modifying the Orbiters
- Installing the Space Shuttle Main Engines on the Orbiters
- Assembling the sections that make up the Solid Rocket Boosters
- Attaching the External Tank to the Solid Rocket Boosters, and then the Orbiter to the External Tank
- Recovering expended Solid Rocket boosters

In addition to processing Shuttle hardware, United Space Alliance is responsible for mission design and planning, astronaut and flight controller training, design and integration of flight software, payload integration, flight operations, launch and recovery operations, vehicle-sustaining engineering, flight crew equipment processing, and operation and maintenance of Shuttle-specific facilities such as the Vehicle Assembly Building, the Orbiter Processing Facility, and the launch pads. United Space Alliance also provides spare parts for the Orbiters, maintains Shuttle flight simulators, and provides tools and supplies, including consumables such as food, for Shuttle missions.

Under the Space Flight Operations Contract, NASA has the following responsibilities and roles:

- Maintaining ownership of the Shuttles and all other assets of the Shuttle program
- Providing to United Space Alliance the Space Shuttle Main Engines, the External Tanks, and the Redesigned Solid Rocket Motor segments for assembly into the Solid Rocket Boosters
- Managing the overall process of ensuring Shuttle safety
- Developing requirements for major upgrades to all assets
- Participating in the planning of Shuttle missions, the directing of launches, and the execution of flights
- Performing surveillance and audits and obtaining technical insight into contractor activities
- Deciding if and when to "commit to flight" for each mission[46]

The contract provided for additional consolidation and then privatization, when all remaining Shuttle operations would be transferred from NASA. Phase 2, scheduled for 1998-2000, called for the transfer of Johnson Space Center-managed flight software and flight crew equipment contracts and the Marshall Space Center-managed contracts for the External Tank, Space Shuttle Main Engine, Reusable Solid Rocket Motor, and Solid Rocket Booster.

However, Marshall and its contractors, with the concurrence of the Space Shuttle Program Office at Johnson Space Center, successfully resisted the transfer of its contracts. Therefore, the Space Flight Operations Contract's initial efficiency and integrated management goals have not been achieved.

The major annual savings resulting from the Space Flight Operations Contract, which in 1996 were touted to be some $500 million to $1 billion per year by the early 2000s, have not materialized. These projections assumed that by 2002, NASA would have put all Shuttle contracts under the auspices of United Space Alliance, and would be moving toward Shuttle privatization. Although the Space Flight Operations Contract has not been as successful in achieving cost efficiencies as its proponents hoped, it has reduced some Shuttle operating costs and other expenses. By one estimate, in its first six years the contract has saved NASA a total of more than $1 billion.[47]

Privatizing the Space Shuttle

To its proponents, the Space Flight Operations Contract was only a beginning. In October 1997, United Space Alliance submitted to the Space Shuttle Program Office a contractually required plan for privatizing the Shuttle, which the program did not accept. But the notion of Shuttle privatization lingered at NASA Headquarters and in Congress, where some members advocated a greater private sector role in the space program. Congress passed the Commercial Space Act of 1998, which directed the NASA Administrator to "plan for the eventual privatization of the Space Shuttle Program."[48]

By August 2001, NASA Headquarters prepared for White House consideration a "Privatization White Paper" that called for transferring all Shuttle hardware, pilot and commander astronauts, and launch and operations teams to a private operator.[49] In September 2001, Space Shuttle Program Manager Ron Dittemore released his report on a "Concept of Privatization of the Space Shuttle Program,"[50] which argued that for the Space Shuttle "to remain safe and viable, it is necessary to merge the required NASA and contractor skill bases" into a single private organization that would manage human space flight. This perspective reflected Dittemore's belief that the split of responsibilities between NASA and United Space Alliance was not optimal, and that it was unlikely that NASA would ever recapture the Shuttle responsibilities that were transferred in the Space Flight Operations Contract.

Dittemore's plan recommended transferring 700 to 900 NASA employees to the private organization, including:

- Astronauts, including the flight crew members who operate the Shuttle

- Program and project management, including Space Shuttle Main Engine, External Tank, Redesigned Solid Rocket Booster, and Extravehicular Activity
- Mission operations, including flight directors and flight controllers
- Ground operations and processing, including launch director, process engineering, and flow management
- Responsibility for safety and mission assurance

After such a shift occurred, according to the Dittemore plan, "the primary role for NASA in Space Shuttle operations … will be to provide an SMA [Safety and Mission Assurance] independent assessment … utilizing audit and surveillance techniques."[51]

With a change in NASA Administrators at the end of 2001 and the new Bush Administration's emphasis on "competitive sourcing" of government operations, the notion of wholesale privatization of the Space Shuttle was replaced with an examination of the feasibility of both public- and private-sector Program management. This competitive sourcing was under examination at the time of the *Columbia* accident.

Workforce Transformation and the End of Downsizing

Workforce reductions instituted by Administrator Goldin as he attempted to redefine the agency's mission and its overall organization also added to the turbulence of his reign. In the 1990s, the overall NASA workforce was reduced by 25 percent through normal attrition, early retirements, and buyouts – cash bonuses for leaving NASA employment. NASA operated under a hiring freeze for most of the decade, making it difficult to bring in new or younger people. Figure 5.4-2 shows the downsizing of the overall NASA workforce during this period as well as the associated shrinkage in NASA's technical workforce.

NASA Headquarters was particularly affected by workforce reductions. More than half its employees left or were transferred in parallel with the 1996 transfer of program management responsibilities back to the NASA centers. The Space Shuttle Program bore more than its share of Headquarters personnel cuts. Headquarters civil service staff working on the Space Shuttle Program went from 120 in 1993 to 12 in 2003.

While the overall workforce at the NASA Centers involved in human space flight was not as radically reduced, the combination of the general workforce reduction and the introduction of the Space Flight Operations Contract significantly impacted the Centers' Space Shuttle Program civil service staff. Johnson Space Center went from 1,330 in 1993 to 738 in 2002; Marshall Space Flight Center, from 874 to 337; and Kennedy Space Center from 1,373 to 615. Kennedy Director Roy Bridges argued that personnel cuts were too deep, and threatened to resign unless the downsizing of his civil service workforce, particularly those involved with safety issues, was reversed.[52]

By the end of the decade, NASA realized that staff reductions had gone too far. By early 2000, internal and external

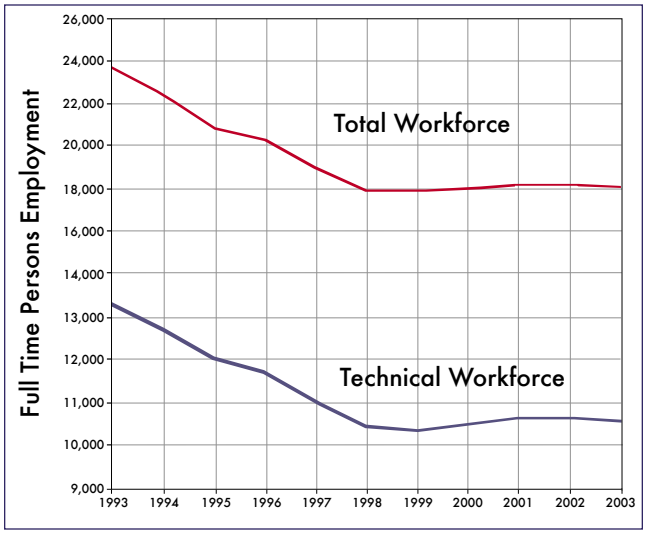

Figure 5.4-2. Downsizing of the overall NASA workforce and the NASA technical workforce.

studies convinced NASA leaders that the workforce needed to be revitalized. These studies noted that "five years of buyouts and downsizing have led to serious skill imbalances and an overtaxed core workforce. As more employees have departed, the workload and stress [on those] remaining have increased, with a corresponding increase in the potential for impacts to operational capacity and safety." [53] NASA announced that NASA workforce downsizing would stop short of the 17,500 target, and that its human space flight centers would immediately hire several hundred workers.

5.5 When to Replace the Space Shuttle?

In addition to budget pressures, workforce reductions, management changes, and the transfer of government functions to the private sector, the Space Shuttle Program was beset during the past decade by uncertainty about when the Shuttle might be replaced. National policy has vacillated between treating the Shuttle as a "going out of business" program and anticipating two or more decades of Shuttle use. As a result, limited and inconsistent investments have been made in Shuttle upgrades and in revitalizing the infrastructure to support the continued use of the Shuttle.

Even before the 1986 *Challenger* accident, when and how to replace the Space Shuttle with a second generation reusable launch vehicle was a topic of discussion among space policy leaders. In January 1986, the congressionally chartered National Commission on Space expressed the need for a Shuttle replacement, suggesting that "the Shuttle fleet will become obsolescent by the turn of the century."[54] Shortly after the *Challenger* accident (but not as a reaction to it), President Reagan announced his approval of "the new Orient Express" (see Figure 5.5-1). This reusable launch vehicle, later known as the National Aerospace Plane, "could, by the end of the decade, take off from Dulles Airport, accelerate up to 25 times the speed of sound attaining low-Earth orbit, or fly to Tokyo within two hours."[55] This goal proved too ambitious, particularly without substantial

funding. In 1992, after a $1.7 billion government investment, the National Aerospace Plane project was cancelled.

This pattern – optimistic pronouncements about a revolutionary Shuttle replacement followed by insufficient government investment, and then program cancellation due to technical difficulties – was repeated again in the 1990s.

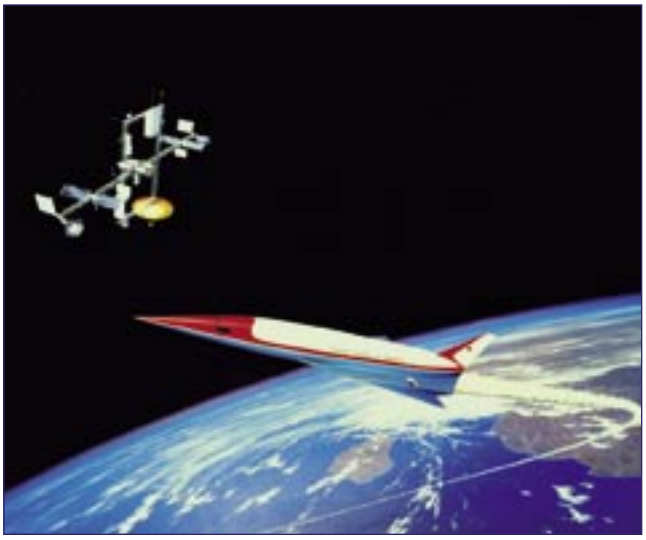

Figure 5.5-1. A 1986 artist's conception of the National Aerospace Plane on a mission to the Space Station.

In 1994, NASA listed alternatives for access to space through 2030.

- Upgrade the Space Shuttle to enable flights through 2030
- Develop a new expendable launcher
- Replace the Space Shuttle with a "leapfrog" next-generation advanced technology system that would achieve order-of-magnitude improvements in the cost effectiveness of space transportation.[56]

Figure 5.5-2. The VentureStar was intended to replace the Space Shuttle based on technology developed for the X-33.

Reflecting its leadership's preference for bold initiatives, NASA chose the third alternative. With White House support,[57] NASA began the X-33 project in 1996 as a joint effort with Lockheed Martin. NASA also initiated the less ambitious X-34 project with Orbital Sciences Corporation. At the time, the future of commercial space launches was bright, and political sentiment in the White House and Congress encouraged an increasing reliance on private-sector solutions for limiting government expenditures. In this context, these unprecedented joint projects appeared less risky than they actually were. The hope was that NASA could replace the Shuttle through private investments, without significant government spending.

Both the X-33 and X-34 incorporated new technologies. The X-33 was to demonstrate the feasibility of an aerospike engine, new Thermal Protection Systems, and composite rather than metal propellant tanks. These radically new technologies were in turn to become the basis for a new orbital vehicle called VentureStar™ that could replace the Space Shuttle by 2006 (see Figure 5.5-2). The X-33 and X-34 ran into technical problems and never flew. In 2001, after spending $1.3 billion, NASA abandoned both projects.

In all three projects – National Aerospace Plane, X-33, and X-34 – national leaders had set ambitious goals in response to NASA's ambitious proposals. These programs relied on the invention of revolutionary technology, had run into major technical problems, and had been denied the funds needed to overcome these problems – assuming they could be solved. NASA had spent nearly 15 years and several billion dollars, and yet had made no meaningful progress toward a Space Shuttle replacement.

In 2000**,** as the agency ran into increasing problems with the X-33, NASA initiated the Space Launch Initiative, a $4.5 billion multi-year effort to develop new space launch technologies. By 2002, after spending nearly $800 million, NASA again changed course. The Space Launch Initiative failed to find technologies that could revolutionize space launch, forcing NASA to shift its focus to an Orbital Space Plane, developed with existing technology, that would complement the Shuttle by carrying crew, but not cargo, to and from orbit. Under a new Integrated Space Transportation Plan, the Shuttle might continue to fly until 2020 or beyond. (See Section 5.6 for a discussion of this plan.)

As a result of the haphazard policy process that created these still-born developmental programs, the uncertainty over Shuttle replacement persisted. Between 1986 and 2002, the planned replacement date for the Space Shuttle was consistent only in its inconsistency: it changed from 2002 to 2006 to 2012, and before the *Columbia* accident, to 2020 or later.

Safety Concerns and Upgrading the Space Shuttle

This shifting date for Shuttle replacement has severely complicated decisions on how to invest in Shuttle Program upgrades. More often than not, investments in upgrades were delayed or deferred on the assumption they would be a waste of money if the Shuttle were to be retired in the near future (see Figure 5.5-3).

Past Reports Reviewed

During the course of the investigation, more than 50 past reports regarding NASA and the Space Shuttle Program were reviewed. The principal purpose of these reviews was to note what factors that reports examined, what findings were made, and what response, if any, NASA may have made to the findings. Board members then used these findings and responses as a benchmark during their investigation to compare to NASA's current programs. In addition to an extensive 300-page examination of every Aerospace Safety Advisory Panel report (see Appendix D.18), the reports listed on the accompanying chart were examined for specific factors related to the investigation. A complete listing of those past reports' findings, plus the full text of the reports, is contained in Appendix D.18.

Report Reviewed	*Topic Examined*								
	Infrastructure	*Communications*	*Contracts*	*Risk Management*	*Quality Assurance*	*Safety Programs*	*Maintenance*	*Security*	*Workforce Issues*
Rogers Commission Report – 1986	•	•	•	•	•	•	•		
STS-29R Prelaunch Assessment – 1989				•					
"Augustine Report" – 1990		•	•	•			•		•
Paté-Cornell Report – 1990				•	•				
"Aldridge Report" – 1992				•					
GAO: NASA Infrastructure – 1996	•								•
GAO: NASA Workforce Reductions – 1996	•								•
Super Light Weight Tank Independent Assessment – 1997				•	•				
Process Readiness Review – 1998				•			•		•
S&MA Ground Operations Report – 1998					•				
GAO: NASA Management Challenges – 1999		•	•	•					
Independent Assessment JS-9047 – 1999				•					
Independent Assessment JS-9059 – 1999				•					
Independent Assessment JS-9078 – 1999		•					•		
Independent Assessment JS-9083 – 1999					•				
S&MA Ground Operations Report – 1999					•	•			
Space Shuttle Independent Assessment Team – 1999			•	•		•	•		•
Space Shuttle Ground Operations Report – 1999						•			
Space Shuttle Program (SSP) Annual Report – 1999						•			

	Infrastructure	Communications	Contracts	Risk Management	Quality Assurance	Safety Programs	Maintenance	Security	Workforce Issues
GAO: Human Capital & Safety – 2000						•			
Independent Assessment JS-0032 – 2000					•				
Independent Assessment JS-0034 – 2000	•								
Independent Assessment JS-0045 – 2000					•				
IG Audit Report 00-039 – 2000			•						
NASA Independent Assessment Team – 2000		•		•	•	•			•
Space Shuttle Program Annual Report – 2000	•		•	•		•			
ASAP Report – 2001	•		•	•		•	•	•	•
GAO: NASA Critical Areas – 2001				•					
GAO: Space Shuttle Safety – 2001									•
Independent Assessment JS-1014 – 2001		•		•	•	•			
Independent Assessment JS-1024 – 2001		•			•				•
Independent Assessment KS-0003 – 2001		•			•				•
Independent Assessment KS-1001 – 2001			•	•			•		
Workforce Survey-KSC – 2001				•	•				
Space Shuttle Program Annual Report – 2001		•		•					
SSP Processing Independent Assessment – 2001				•	•	•			•
ASAP Report – 2002	•		•	•	•	•			•
GAO: Lessons Learned Process – 2002		•							
Independent Assessment KS-1002 – 2002					•				
Selected NASA Lessons Learned – 1992-2002		•		•	•	•	•		•
NASA/Navy Benchmarking Exchange – 2002		•	•	•		•			•
Space Shuttle Program Annual Report – 2002	•			•		•			•
ASAP Leading Indicators – 2003		•		•		•			
NASA Quality Management System – 2003					•				
QAS Tiger Team Report – 2003					•				
Shuttle Business Environment – 2003			•						

Fiscal Year	Upgrades
1994	$454.5
1995	$247.2
1996	$224.5
1997	$215.9
1998	$206.7
1999	$175.2
2000	$239.1
2001	$289.3
2002	$379.5
2003	$347.5

Figure 5.5-3. Shuttle Upgrade Budgets (in millions of dollars). (Source: NASA)

In 1995, for instance, the Kraft Report embraced the principle that NASA should "freeze the design" of the Shuttle and defer upgrades due to the vehicle's "mature" status and the need for NASA to "concentrate scarce resources on developing potential replacements for the Shuttle."[58] NASA subsequently halted a number of planned upgrades, only to reverse course a year later to "take advantage of technologies to improve Shuttle safety and the need for a robust Space Shuttle to assemble the ISS."[59]

In a June 1999 letter to the White House, NASA Administrator Daniel Goldin declared that the nation faced a "Space Launch Crisis." He reported on a NASA review of Shuttle safety that indicated the budget for Shuttle upgrades in Fiscal year 2000 was "inadequate to accommodate upgrades necessary to yield significant safety improvements."[60] After two "close calls" during STS-93 in July 1999 Goldin also chartered a Shuttle Independent Assessment Team (SIAT) chaired by Harry McDonald, Director of NASA Ames Research Center. Among the team's findings, reported in March 2000:[61]

- "Over the course of the Shuttle Program … processes, procedures and training have continuously been improved and implemented to make the system safer. The SIAT has a major concern … that this critical feature of the Shuttle Program is being eroded." The major factor leading to this concern "is the reduction in allocated resources and appropriate staff … There are important technical areas that are 'one-deep.' " Also, "the SIAT feels strongly that workforce augmentation must be realized principally with NASA personnel rather than with contractor personnel."
- The SIAT was concerned with "success-engendered safety optimism … The SSP must rigorously guard against the tendency to accept risk solely because of prior success."
- "The SIAT was very concerned with what it perceived as Risk Management process erosion created by the desire to reduce costs … The SIAT feels strongly that NASA Safety and Mission Assurance should be restored to its previous role of an independent oversight body, and not be simply a 'safety auditor.' "
- "The size and complexity of the Shuttle system and of NASA/contractor relationships place extreme importance on understanding, communication, and information handling … Communication of problems and concerns upward to the SSP from the 'floor' also appeared to leave room for improvement."[62]

The Shuttle Independent Assessment Team report also stated that the Shuttle "clearly cannot be thought of as 'operational' in the usual sense. Extensive maintenance, major amounts of 'touch labor' and a high degree of skill and expertise will always be required." However, "the workforce has received a conflicting message due to the emphasis on achieving cost and staff reductions, and the pressures placed on increasing scheduled flights as a result of the Space Station."[63]

Responding to NASA's concern that the Shuttle required safety-related upgrades, the President's proposed NASA budget for Fiscal Year 2001 proposed a "safety upgrades initiative." That initiative had a short life span. In its Fiscal Year 2002 budget request, NASA proposed to spend $1.836 billion on Shuttle upgrades over five years. A year later, the Fiscal Year 2003 request contained a plan to spend $1.220 billion – a 34 percent reduction. The reductions were primarily a response to rising Shuttle operating costs and the need to stay within a fixed Shuttle budget. Cost growth in Shuttle operations forced NASA to "use funds intended for Space Shuttle safety upgrades to address operational, supportability, obsolescence, and infrastructure needs."[64]

At its March 2001 meeting, NASA's Space Flight Advisory Committee advised that "the Space Shuttle Program must make larger, more substantial safety upgrades than currently planned … a budget on the order of three times the budget currently allotted for improving the Shuttle systems" was needed.[65] Later that year, five Senators complained that "the Shuttle program is being penalized, despite its outstanding performance, in order to conform to a budget strategy that is dangerously inadequate to ensure safety in America's human space flight program."[66] (See Chapter 7 for additional discussion of Shuttle safety upgrades.)

Deteriorating Shuttle Infrastructure

The same ambiguity about investing in Shuttle upgrades has also affected the maintenance of Shuttle Program ground infrastructure, much of which dates to Project Apollo and 1970s Shuttle Program construction. Figure 5.5-4 depicts the age of the Shuttle's infrastructure as of 2000. Most ground infrastructure was not built for such a protracted lifespan. Maintaining infrastructure has been particularly difficult at Kennedy Space Center, where it is constantly exposed to a salt water environment.

Board investigators have identified deteriorating infrastructure associated with the launch pads, Vehicle Assembly Building, and the crawler transporter. Figures 5.5-5 and 5.5-6 depict some of this deterioration. For example, NASA has installed nets, and even an entire sub-roof, inside the Vehicle Assembly Building to prevent concrete from the building's ceiling from hitting the Orbiter and Shuttle stack. In addition, the corrosion-control challenge results in zinc primer

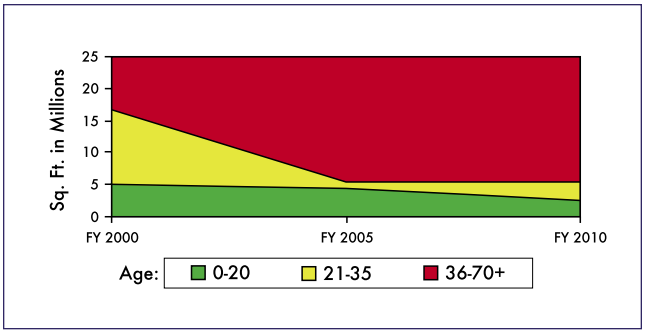

Figure 5.5-4. Age of the Space Shuttle infrastructure. (Source: Connie Milton to Space Flight Advisory Council, 2000.

on certain launch pad areas being exposed to the elements. When rain falls on these areas, it carries away zinc, runs onto the leading edge of the Orbiter's wings, and causes pinholes in the Reinforced Carbon-Carbon panels (see Chapter 3).

In 2000, NASA identified 100 infrastructure items that demanded immediate attention. NASA briefed the Space Flight Advisory Committee on this "Infrastructure Revitalization" initiative in November of that year. The Committee concluded that "deteriorating infrastructure is a serious, major problem," and, upon touring several Kennedy Space Center facilities, declared them "in deplorable condition."[67] NASA subsequently submitted a request to the White House Office of Management and Budget during Fiscal Year 2002 budget deliberations for $600 million to fund the infrastructure initiative. No funding was approved.

In Fiscal Year 2002, Congress added $25 million to NASA's budget for Vehicle Assembly Building repairs. NASA has reallocated limited funds from the Shuttle budget to pressing infrastructure repairs, and intends to take an integrated look at infrastructure as part of its new Shuttle Service Life Extension Program. Nonetheless, like Space Shuttle upgrades, infrastructure revitalization has been mired by the uncertainty surrounding the Shuttle Program's lifetime. Considering that the Shuttle will likely be flying for many years to come, NASA, the White House, and Congress alike now face the specter of having to deal with years of infrastructure neglect.

5.6 A Change in NASA Leadership

Daniel Goldin left NASA in November 2001 after more than nine years as Administrator. The White House chose Sean O'Keefe, the Deputy Director of the White House Office of Management and Budget, as his replacement. O'Keefe stated as he took office that he was not a "rocket scientist," but rather that his expertise was in the management of large government programs. His appointment was an explicit acknowledgement by the new Bush administration that NASA's primary problems were managerial and financial.

By the time O'Keefe arrived, NASA managers had come to recognize that 1990s funding reductions for the Space Shuttle Program had resulted in an excessively fragile program, and also realized that a Space Shuttle replacement was not on the horizon. In 2002, with these issues in mind, O'Keefe made a number of changes to the Space Shuttle Program. He transferred management of both the Space Shuttle Program and the International Space Station from Johnson Space Center to NASA Headquarters. O'Keefe also began considering whether to expand the Space Flight Operations Contract to cover additional Space Shuttle elements, or to pursue "competitive sourcing," a Bush administration initiative that encouraged government agencies to compete with the private sector for management responsibilities of publicly funded activities. To research whether competitive sourcing would be a viable approach for the Space Shuttle Program, NASA chartered the Space Shuttle Competitive Sourcing Task Force through the RAND Corporation, a federally funded think tank. In its report, the Task Force recognized the many obstacles to transferring the Space Shuttle to non-NASA management, primarily NASA's reticence to relinquish control, but concluded that "NASA must pursue competitive sourcing in one form or another."[68]

NASA began a "Strategic Management of Human Capital" initiative to ensure the quality of the future NASA workforce. The goal is to address the various external and internal challenges that NASA faces as it tries to ensure an appropriate mix and depth of skills for future program requirements. A number of aspects to its Strategic Human Capital Plan require legislative approval and are currently before the Congress.

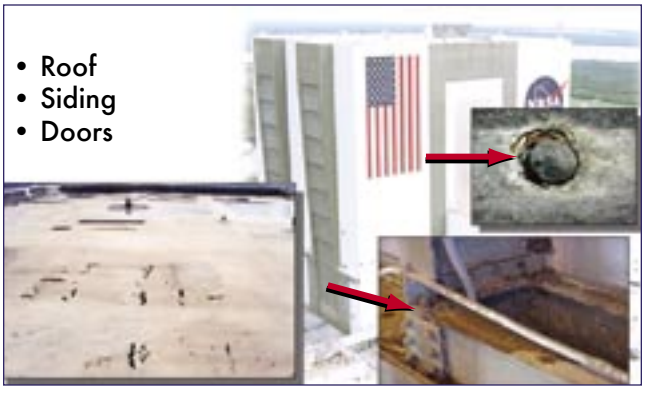

Figure 5.5-5 and 5.5-6. Examples of the seriously deteriorating infrastructure used to support the Space Shuttle Program. At left is Launch Complex 39A, and at right is the Vehicle Assembly building, both at the Kennedy Space Center.

The new NASA leadership also began to compare Space Shuttle program practices with the practices of similar high-technology, high-risk enterprises. The Navy nuclear submarine program was the first enterprise selected for comparative analysis. An interim report on this "benchmarking" effort was presented to NASA in December 2002.[69]

In November 2002, NASA made a fundamental change in strategy. In what was called the Integrated Space Transportation Plan (see Figure 5.6-1), NASA shifted money from the Space Launch Initiative to the Space Shuttle and International Space Station programs. The plan also introduced the Orbital Space Plane as a complement to the Shuttle for the immediate future. Under this strategy, the Shuttle is to fly through at least 2010, when a decision will be made on how long to extend Shuttle operations – possibly through 2020 or even beyond.

As a step in implementing the plan, NASA included $281.4 million in its Fiscal Year 2004 budget submission to begin a Shuttle Service Life Extension Program,[70] which NASA describes as a "strategic and proactive program designed to keep the Space Shuttle flying safely and efficiently." The program includes "high priority projects for safety, supportability, and infrastructure" in order to "combat obsolescence of vehicle, ground systems, and facilities."[71]

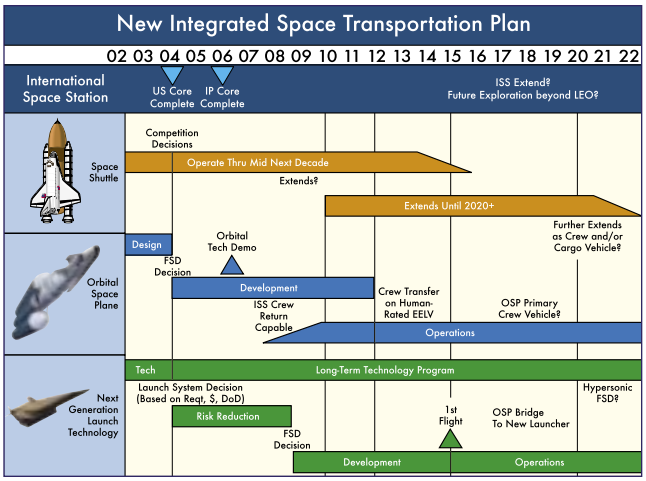

Figure 5.6-1. The Integrated Space Transportation Plan.

5.7 The Return of Schedule Pressure

The International Space Station has been the centerpiece of NASA's human space flight program in the 1990s. In several instances, funds for the Shuttle Program have paid for various International Space Station items. The Space Station has also affected the Space Shuttle Program schedule. By the time the functional cargo block *Zarya,* the Space Station's first element, was launched from the Baikonur Cosmodrome in Kazakhstan in November 1998, the Space Station was two years behind schedule. The launch of STS-88, the first of many Shuttle missions assigned to station assembly, followed a month later. Another four assembly missions in 1999 and 2000 readied the station for its first permanent crew, Expedition 1, which arrived in late 2000.

When the Bush Administration came to the White House in January 2001, the International Space Station program was $4 billion over its projected budget. The Administration's Fiscal Year 2002 budget, released in February 2001, declared that the International Space Station would be limited to a "U.S Core Complete" configuration, a reduced design that could accommodate only three crew members. The last step in completing the U.S. portion of this configuration would be the addition of the Italian-supplied but U.S.-owned "Node 2," which would allow Europe and Japan to connect their laboratory modules to the Station. Launching Node 2 and thereby finishing "core complete" configuration became an important political and programmatic milestone (see Figure 5.7-1).

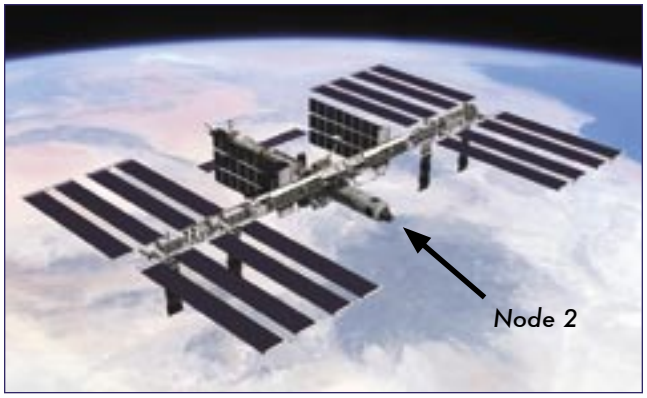

Figure 5.7-1. The "Core Complete" configuration of the International Space Station.

During congressional testimony in May of 2001, Sean O'Keefe, who was then Deputy Director of the White House Office of Management and Budget, presented the Administration's plan to bring International Space Station costs under control. The plan outlined a reduction in assembly and logistics flights to reach "core complete" configuration from 36 to 30. It also recommended redirecting about $1 billion in funding by canceling U.S. elements not yet completed, such as the habitation module and the X-38 Crew Return Vehicle. The X-38 would have allowed emergency evacuation and landing capability for a seven-member station crew. Without it, the crew was limited to three, the number that could fit into a Russian Soyuz crew rescue vehicle.

In his remarks, O'Keefe stated:

> *NASA's degree of success in gaining control of cost growth on Space Station will not only dictate the capabilities that the Station will provide, but will send a strong signal about the ability of NASA's Human Space Flight program to effectively manage large development programs. NASA's credibility with the Administration and the Congress for delivering on what is promised and the longer-term implications that such credibility may have on the future of Human Space Flight hang in the balance.*[72]

At the request of the White House Office of Management and Budget, in July 2001 NASA Administrator Dan Goldin

formed an International Space Station Management and Cost Evaluation Task Force. The International Space Station Management and Cost Evaluation Task Force was to assist NASA in identifying the reforms needed to restore the Station Program's fiscal and management credibility.

While the primary focus of the Task Force was on the Space Station Program management, its November 2001 report issued a general condemnation of how NASA, and particularly Johnson Space Center, had managed the International Space Station, and by implication, NASA's overall human space flight effort. [73] The report noted "existing deficiencies in management structure, institutional culture, cost estimating, and program control," and that "the institutional needs of the [human space flight] Centers are driving the Program, rather than Program requirements being served by the Centers." The Task Force suggested that as a cost control measure, the Space Shuttle be limited to four flights per year and that NASA revise the station crew rotation period to six months. The cost savings that would result from eliminating flights could be used to offset cost overruns.

NASA accepted a reduced flight rate. The Space Shuttle Program office concluded that, based on a rate of four flights a year, Node 2 could be launched by February 19, 2004.

In testimony before the House Committee on Science on November 7, 2001, Task Force Chairman Thomas Young identified what became known as a "performance gate." He suggested that over the next two years, NASA should plan and implement a credible "core complete" program. In Fall 2003, "an assessment would be made concerning the ISS program performance and NASA's credibility. If satisfactory, resource needs would be assessed and an [ISS] 'end state' that realized the science potential would become the baseline. If unsatisfactory, the core complete program would become the 'end state.' "[74]

Testifying the same day, Office of Management and Budget Deputy Director Sean O'Keefe indicated the Administration's agreement with the planned performance gate:

> *The concept presented by the task force of a decision gate in two years that could lead to an end state other than the U.S. core complete Station is an innovative approach, and one the Administration will adopt. It calls for NASA to make the necessary management reforms to successfully build the core complete Station and operate it within the $8.3 billion available through FY 2006 plus other human space flight resources … If NASA fails to meet the standards, then an end-state beyond core complete is not an option. The strategy places the burden of proof on NASA performance to ensure that NASA fully implements the needed reforms.*[75]

Mr. O'Keefe added in closing:

> *A most important next step – one on which the success of all these reforms hinges – is to provide new leadership for NASA and its Human Space Flight activities. NASA has been well-served by Dan Goldin. New leadership is now necessary to continue moving the ball down the field with the goal line in sight. The Administration recognizes the importance of getting the right leaders in place as soon as possible, and I am personally engaged in making sure that this happens.*

A week later, Sean O'Keefe was nominated by President Bush as the new NASA Administrator.

To meet the new flight schedule, in 2002 NASA revised its Shuttle manifest, calling for a docking adaptor to be installed in *Columbia* after the STS-107 mission so that it could make an October 2003 flight to the International Space Station. *Columbia* was not optimal for Station flights – the Orbiter could not carry enough payload – but it was assigned to this flight because *Discovery* was scheduled for 18 months of major maintenance. To ensure adequate Shuttle availability for the February 2004 Node 2 launch date, *Columbia* would fly an International Space Station resupply mission.

The White House and Congress had put the International Space Station Program, the Space Shuttle Program, and indeed NASA on probation. NASA had to prove it could meet schedules within cost, or risk halting Space Station construction at core complete – a configuration far short of what NASA anticipated. The new NASA management viewed the achievement of an on-schedule Node 2 launch as an endorsement of its successful approach to Shuttle and Station Programs. Any suggestions that it would be difficult to meet that launch date were brushed aside.

This insistence on a fixed launch schedule was worrisome. The International Space Station Management and Cost Evaluation Task Force, in particular, was concerned with the emphasis on a specific launch date. It noted in its 2002 review of progress toward meeting its recommendations that "significant progress has been made in nearly all aspects of the ISS Program," but that there was "significant risk with the Node 2 (February '04) schedule."[76]

By November 2002, NASA had flown 16 Space Shuttle missions dedicated to Station assembly and crew rotation. Five crews had lived onboard the Station, the last four of them delivered via Space Shuttles. As the Station had grown, so had the complexity of the missions required to complete it. With the International Space Station assembly more than half complete, the Station and Shuttle programs had become irreversibly linked. Any problems with or perturbations to the planned schedule of one program reverberated through both programs. For the Shuttle program, this meant that the conduct of all missions, even non-Station missions like STS-107, would have an impact on the Node 2 launch date.

In 2002, this reality, and the events of the months that would follow, began to place additional schedule pressures on the Space Shuttle Program. Those pressures are discussed in Section 6.2.

5.8 Conclusion

Over the last decade, the Space Shuttle Program has operated in a challenging and often turbulent environment. As

discussed in this chapter, there were at least three major contributing factors to that environment:

- Throughout the decade, the Shuttle Program has had to function within an increasingly constrained budget. Both the Shuttle budget and workforce have been reduced by over 40 percent during the past decade. The White House, Congress, and NASA leadership exerted constant pressure to reduce or at least freeze operating costs. As a result, there was little margin in the budget to deal with unexpected technical problems or make Shuttle improvements.

- The Shuttle was mischaracterized by the 1995 Kraft Report as "a mature and reliable system … about as safe as today's technology will provide." Based on this mischaracterization, NASA believed that it could turn increased responsibilities for Shuttle operations over to a single prime contractor and reduce its direct involvement in ensuring safe Shuttle operations, instead monitoring contractor performance from a more detached position. NASA also believed that it could use the "mature" Shuttle to carry out operational missions without continually focusing engineering attention on understanding the mission-by-mission anomalies inherent in a developmental vehicle.

- In the 1990s, the planned date for replacing the Shuttle shifted from 2006 to 2012 and then to 2015 or later. Given the uncertainty regarding the Shuttle's service life, there has been policy and budgetary ambivalence on investing in the vehicle. Only in the past year has NASA begun to provide the resources needed to sustain extended Shuttle operations. Previously, safety and support upgrades were delayed or deferred, and Shuttle infrastructure was allowed to deteriorate.

The Board observes that this is hardly an environment in which those responsible for safe operation of the Shuttle can function without being influenced by external pressures. It is to the credit of Space Shuttle managers and the Shuttle workforce that the vehicle was able to achieve its program objectives for as long as it did.

An examination of the Shuttle Program's history from *Challenger* to *Columbia* raises the question: Did the Space Shuttle Program budgets constrained by the White House and Congress threaten safe Shuttle operations? There is no straightforward answer. In 1994, an analysis of the Shuttle budget concluded that reductions made in the early 1990s represented a "healthy tightening up" of the program.[77] Certainly those in the Office of Management and Budget and in NASA's congressional authorization and appropriations subcommittees thought they were providing enough resources to operate the Shuttle safely, while also taking into account the expected Shuttle lifetime and the many other demands on the Federal budget. NASA Headquarters agreed, at least until Administrator Goldin declared a "space launch crisis" in June 1999 and asked that additional resources for safety upgrades be added to the NASA budget. By 2001, however, one experienced observer of the space program described the Shuttle workforce as "The Few, the Tired," and suggested that "a decade of downsizing and budget tightening has left NASA exploring the universe with a less experienced staff and older equipment."[78]

It is the Board's view that this latter statement is an accurate depiction of the Space Shuttle Program at the time of STS-107. The Program was operating too close to too many margins. The Board also finds that recent modest increases in the Shuttle Program's budget are necessary and overdue steps toward providing the resources to sustain the program for its now-extended lifetime. Similarly, NASA has recently recognized that providing an adequately sized and appropriately trained workforce is critical to the agency's future success.

An examination of the Program's management changes also leads to the question: Did turmoil in the management structure contribute to the accident? The Board found no evidence that the transition from many Space Shuttle contractors to a partial consolidation of contracts under a single firm has by itself introduced additional technical risk into the Space Shuttle Program. The transfer of responsibilities that has accompanied the Space Flight Operations Contract has, however, complicated an already complex Program structure and created barriers to effective communication. Designating the Johnson Space Center as the "lead center" for the Space Shuttle Program did resurrect some of the Center rivalries and communication difficulties that existed before the *Challenger* accident. The specific ways in which this complexity and lack of an integrated approach to Shuttle management impinged on NASA's performance during and before the flight of STS-107 are discussed in Chapters 6 and 7.

As the 21st century began, NASA's deeply ingrained human space flight culture – one that has evolved over 30 years as the basis for a more conservative, less technically and organizationally capable organization than the Apollo-era NASA – remained strong enough to resist external pressures for adaptation and change. At the time of the launch of STS-107, NASA retained too many negative (and also many positive) aspects of its traditional culture: "flawed decision making, self deception, introversion and a diminished curiosity about the world outside the perfect place."[79] These characteristics were reflected in NASA's less than stellar performance before and during the STS-107 mission, which is described in the following chapters.

ENDNOTES FOR CHAPTER 5

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 of the Presidential Commission on the Space Shuttle Challenger Accident*, June 6, 1986, (Washington: Government Printing Office, 1986), Vol. I, p. 82, 118.

2 *Report of the Presidential Commission*, Vol. I, p. 48.

3 *Report of the Presidential Commission*, Vol. I, p. 52.

4 *Report of the Presidential Commission*, Vol. I, pp. 164-165.

5 *Report of the Presidential Commission*, Vol. I, pp. 198-201.

6 *Report of The National Commission for the Review of the National Reconnaissance Office: The NRO at the Crossroads,* November 2000, p. 66. Roger Guillemette, "Vandenberg: Space Shuttle Launch and Landing Site, Part 1," *Spaceflight*, October 1994, pp. 354-357, and Roger Guillemette, "Vandenberg: Space Shuttle Launch and Landing Site, Part 2," *Spaceflight*, November 1994, pp. 378-381; Dennis R. Jenkins, *Space Shuttle: The History of the National Space Transportation System – The First 100 Missions* (Cape Canaveral, FL, Specialty Press, 2001), pp. 467-476.

7 Vice President's Space Policy Advisory Board, *A Post Cold War Assessment of U.S. Space Policy*, December 1992, p. 6.

8 Quoted in John M. Logsdon, "Return to Flight: Richard H. Truly and the Recovery from the *Challenger* Accident," in Pamela E. Mack, editor, *From Engineering to Big Science: The NACA and NASA Collier Trophy Research Project Winners*, NASA SP-4219 (Washington: Government Printing Office, 1998), p. 363.

9 *Aviation Week & Space Technology*, November 10, 1986, p. 30.

10 There are proposals for using other U.S. systems, in development but not yet ready for flight, to provide an alternate U.S. means of station access. These "Alternate Access to Space" proposals have not been evaluated by the Board.

11 Testimony of William F. Readdy to the Subcommittee on Science, Technology and Space, U.S. Senate, September 6, 2001.

12 Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore: The Johns Hopkins University Press, 1993), p. 24.

13 Garry D. Brewer, "Perfect Places: NASA as an Idealized Institution," in Radford Byerly, Jr., ed., *Space Policy Reconsidered* (Boulder, CO: Westview Press, 1989), p. 158. Brewer, when he wrote these words, was a professor of organizational behavior at Yale University with no prior exposure to NASA. For first-hand discussions of NASA's Apollo-era organizational culture, see Christopher Kraft, *Flight: My Life in Mission Control* (New York: E.P. Dutton, 2001); Gene Kranz, *Failure is Not an Option: Mission Control from Mercury to Apollo 13* (New York: Simon & Schuster, 2000); and Thomas J. Kelly, *Moon Lander: How We Developed the Apollo Lunar Module* (Washington: Smithsonian Institution Press, 2001).

14 Brewer, "Perfect Places," pp. 159-165.

15 As NASA human space flight personnel began to become closely involved with their counterparts in the Russian space program after 1992, there was grudging acceptance that Russian human space flight personnel were also skilled in their work, although they carried it out rather differently than did NASA.

16 Bush administration space policy is discussed in Dan Quayle, *Standing Firm: A Vice-Presidential Memoir* (New York: Harper Collins, 1994), pp. 185-190.

17 *Report of the Advisory Committee on the Future of the U.S. Space Program*, December 1990. The quotes are from p. 2 of the report's executive summary.

18 *Report of the Advisory Committee on the Future of the U.S. Space Program*. Measured in terms of total national spending, the report's recommendations would have returned NASA spending to 0.38 percent of U.S. Gross Domestic Product – a level of investment not seen since 1969.

19 For Fiscal Years 1965-2002 in Real and Constant Dollars, see NASA, "Space Activities of the U.S. Government – in Millions of Real Year Dollars," and "Space Activities of the U.S. Government – Adjusted for Inflation," in *Aeronautics and Space Report of the President – Fiscal Year 2002 Activity*, forthcoming. For Fiscal Years 2003-2004 in Real Dollars, see Office of Management and Budget, "Outlays By Agency: 1962-2008," in Historical Budget of the United States Government, Fiscal Year 2004, (Washington: Government Printing Office, 2003), pp. 70-75.

20 Commission on the Future of the U.S. Aerospace Industry, *Final Report*, November 18, 2002, p. 3-1.

21 U.S. Congress, Office of Technology Assessment, "Shuttle Fleet Attrition if Orbiter Recovery Reliability is 98 Percent," August 1989, p. 6. From: *Round Trip to Orbit: Human Space Flight Alternatives: Special Report*, OTS-ISC-419.

22 *Report of the Advisory Committee on the Future of the U.S. Space Program*.

23 Howard E. McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore: The Johns Hopkins University Press, 2001).

24 Letter from Daniel Goldin to Representative James T. Walsh, October 4, 2001. CAIB document CAB065-01630169.

25 Ibid.

26 W. Henry Lambright, *Transforming Government: Dan Goldin and the Remaking of NASA* (Washington: Price Waterhouse Coopers Endowment for the Business of Government, March 2001), pp. 12; 27-29.

27 Deming's management philosophy was not the only new notion that Goldin attempted to apply to NASA. He was also an advocate of the "Total Quality Management" approach and other modern management schemes. Trying to adapt to these various management theories was a source of some stress.

28 For a discussion of Goldin's approach, see Howard McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore: The Johns Hopkins University Press, 2001). It is worth noting that while the "faster, better, cheaper" approach led to many more NASA robotic missions being launched after 1992, not all of those missions were successful. In particular, there were two embarrassing failures of Mars missions in 1999.

29 Lambright, *Transforming Government*, provides an early but comprehensive evaluation of the Goldin record. The quote is from p. 28.

30 Goldin is quoted in Bill Harwood, "Pace of Cuts Fuels Concerns About Shuttle," *Space News*, December 19-25, 1994, p. 1.

31 McCurdy, *Faster, Better, Cheaper*.

[32] For two recent works that apply the "Iron Triangle" concept to other policy areas, see Randall B. Ripley and Grace A. Franklin, *Congress, the Bureaucracy and Public Policy,* 5th Edition, (Pacific Grove, CA: Brooks/Cole Publishing Company, 1991); and Paul C. Light, *Forging Legislation: The Politics of Veterans Reform,* (New York: W. W. Norton, 1992).

[33] Information obtained from Anna Henderson, NASA Office of Space Flight, to e-mail to John Logsdon, June 13, 2003.

[34] National Academy of Public Administration, *A Review of the Space Shuttle Costs, Reduction Goals, and Procedures*, December 1994, pp. 3-5. CAIB document CAB026-0313.

[35] Presentation to NASA Advisory Council by Stephen Oswald, Acting Director, Space Shuttle Requirements, "Space Flight Operations Contract (SFOC) Acquisition Status," April 23, 1996. CAIB document CTF064-1369.

[36] Bryan D. O'Connor, Status Briefing to NASA Administrator, "Space Shuttle Functional Workforce Review," February 14, 1995. CAIB document CAB015-0400.

[37] Ralph Vartabedian, "Ex-NASA Chief Hits Flight Safety," *Houston Chronicle*, March 7, 1996.

[38] Kathy Sawyer, "NASA Space Shuttle Director Resigns," *Washington Post*, February 3, 1996, p. A3. See also "Take this Job and Shuttle It: Why NASA's Space Shuttle Chief Quit," *Final Frontier*, July/August 1996, pp. 16-17; "NASA Alters Its Management, Philosophy," *Space News*, February 12-18, 1996, p. 3.

[39] *Report of the Space Shuttle Management Independent Review Team,* February 1995.

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