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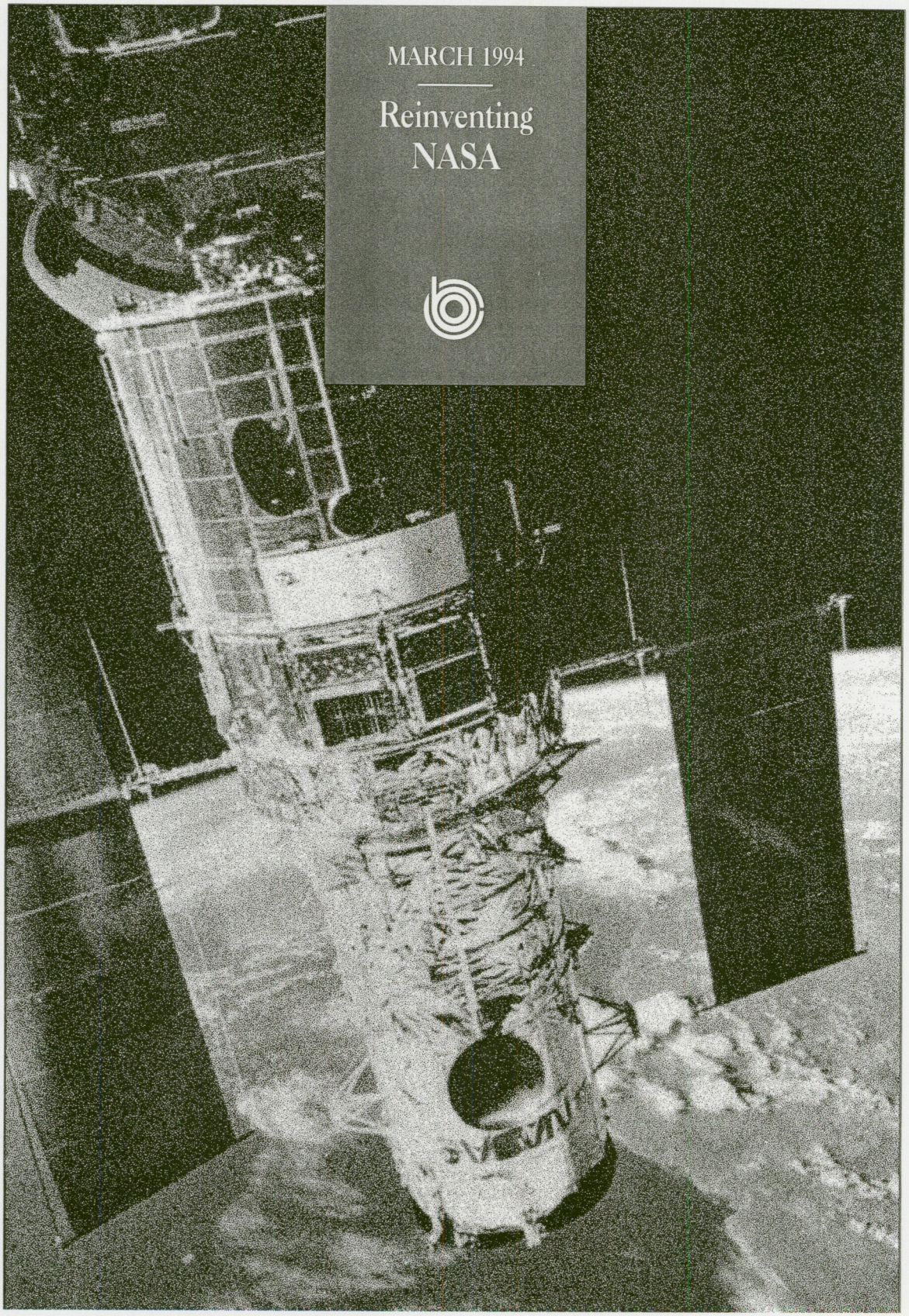
Reinventing NASA



REINVENTING NASA

The Congress of the United States
Congressional Budget Office

NOTES

Unless otherwise indicated, all years are fiscal years.

Cover photo of the Hubble Space Telescope is courtesy of the National Aeronautics and Space Administration.

Preface

The National Aeronautics and Space Administration (NASA) is confronting the difficult task of squeezing a program that it anticipated would cost about $95 billion for five years into a budget plan allowing just over $70 billion. This study, which was prepared for the House Committee on Science, Space, and Technology, evaluates NASA's strategy for coping with the expectation of lower funding in the future and develops a set of illustrative alternatives that would reduce the scope of NASA's mission. In keeping with the mandate of the Congressional Budget Office (CBO) to provide objective analysis, the study makes no recommendation.

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Summary

The National Aeronautics and Space Administration (NASA) is confronting the difficult task of reinventing its program within the confines of a dramatically lower five-year budget plan. The agency has chosen a two-pronged strategy: maintaining the broad structure of its program while marginally adjusting its content by stretching out, scaling down, and canceling some of its projects; and buying more program with its appropriation by doing business more efficiently. This study examines that strategy and a set of alternatives that would focus NASA's program more tightly on one or another of its three major traditional objectives--piloted exploration of space, the generation of new scientific knowledge, or the development of space and aeronautical technology--under an annual budget of no more than $14.3 billion.

The analysis concludes that improving the way NASA conducts its business--buying more for less--is unlikely to produce significant budgetary savings in the next five years. A disproportionate share of the burden of living with lower budgets is likely to involve adjustments to the content of NASA's program--buying less for less. If so, the distinguishing characteristics of that program (high fixed costs for projects with long operational lives), coupled with the agency's tendency to underestimate the cost of its projects, increase the risk that NASA's strategy will lead to greatly reduced productivity in the form of deferred, diminished, or even lost benefits.

An alternative to the current course would be to focus the agency's efforts on narrower objectives. Projects in the emphasized areas would then have adequate budgets, and the chances would be greater that NASA would deliver a productive program--one that produces benefits as promised in a timely way. This strategic alternative would explicitly forgo other benefits that NASA's program might deliver, but it would save the costs of pursuing them in cases in which the risk of failure was high.

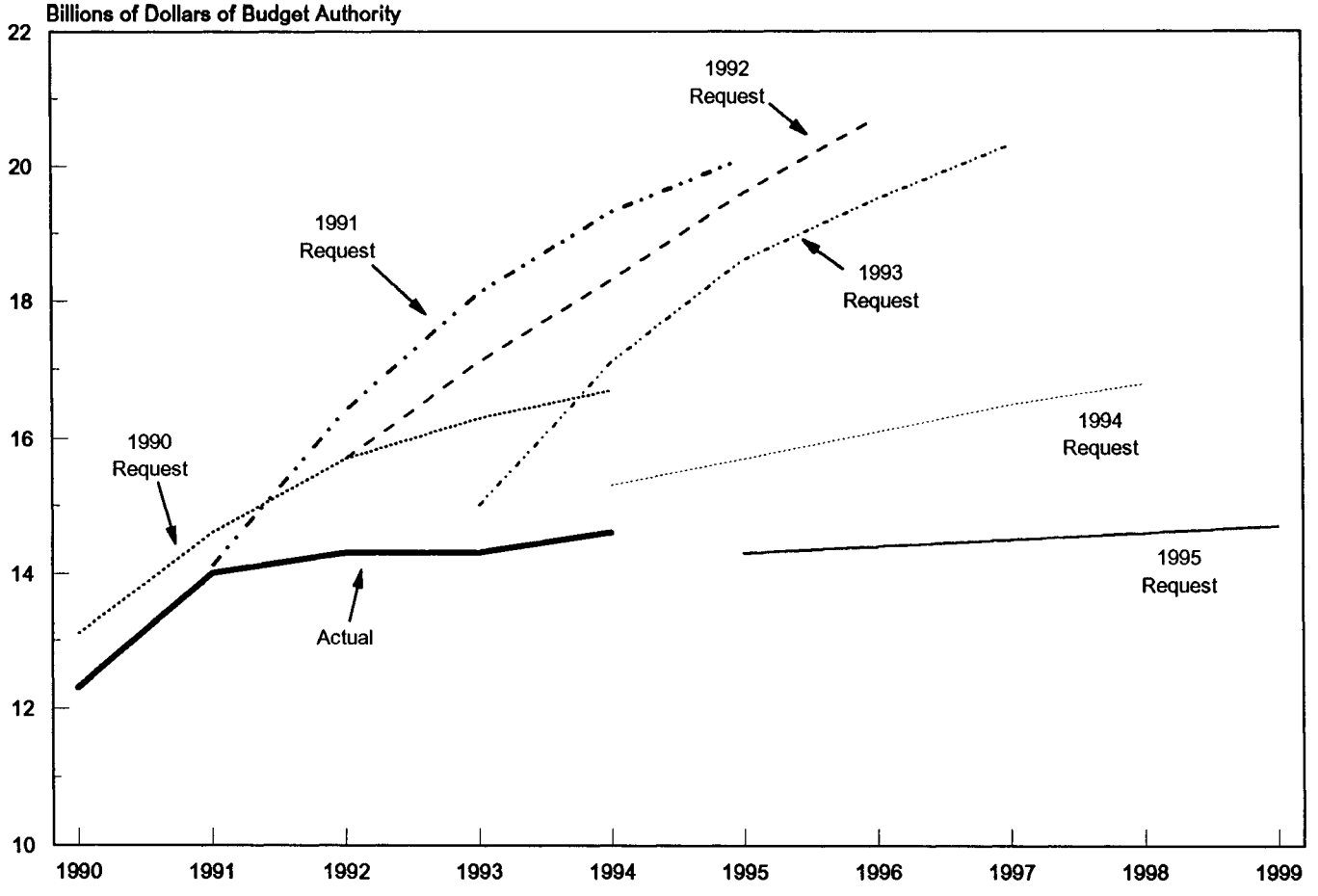
NASA's Program and Budget

Since the mid-1980s, NASA's program has required consistent growth in its out-year budgets, even after adjusting for inflation. By itself, a program plan that requires real increases in funding need not evoke criticism. But in today's environment of fiscal restraint, NASA's plan has generated criticism because of the agency's recurring problems in estimating the costs of its program and because of shortfalls in the performance of some of its major projects.

Concerns about the cost of the NASA program increased after 1990, when the Budget Enforcement Act (BEA) required a tightening of all domestic discretionary spending. As the BEA's caps on spending began to bind, the Congress significantly lowered NASA's budget from the level requested by President Bush for 1992 and 1993. In 1992, the budget request for NASA was $15.8 billion, but the Congress appropriated only $14.3 billion. In 1993, the agency's appropriation was again $14.3 billion, $700 million below the Administration's request of $15 billion.

In this context, the Clinton Administration's proposal to slow the growth in NASA's budget by $16 billion over the 1994-1998 period represented a significant change (see Summary Figure 1). Nevertheless, the Congress voted a smaller appropriation than the Administration's request for 1994: it reduced the Administration's figure of $15.2 billion by $700 million to $14.6 billion. The second Clinton budget proposal for 1995 through 1999

Summary Figure 1.
Five-Year Budget Requests of the National Aeronautics and Space Administration, 1990-1995
(In billions of dollars of budget authority)



SOURCE: Congressional Budget Office based on *Budget of the United States Government* (various years) and 1993 projections from the NASA Comptroller's Office.

flattens NASA's funding even more and for the first time in 21 years requests less for NASA in the coming budget year ($14.3 billion for 1995) than was provided in the current year ($14.6 billion).

To adapt to the new budgetary realities, NASA has chosen to adjust the content of its program marginally and improve its efficiency. If successful, this strategy would permit the agency to pursue simultaneously objectives in piloted spaceflight, space science (using robotic spacecraft), and aeronautics and space technology useful to both the public sector and private aerospace industries. At stake are the benefits of NASA's projects in these areas--for example, new knowledge about the universe or progress toward the piloted exploration of Mars. Such benefits are directly observable but difficult to measure and value. Most research on the effects of past NASA spending and the benefits of its program does not substantiate the claim that the choices among program objectives or funding levels for NASA will have significant implications for the U.S. economy.

The Risks of Marginal Adjustment

A part of NASA's strategy to adapt to new budget realities is to delay, scale back, and cancel some projects but maintain the overall structure of the program that the agency has sought to establish since the early 1980s. That structure includes developing and operating piloted spacecraft (the space shuttle and the space station), developing and operating robotic spacecraft (for example, the Earth Observation System and the Hubble Space Telescope), and making continued advances in rocket and satellite, aeronautical, and other systems and technologies necessary to support the nation's public and private aerospace activities. Essential characteristics of NASA's current program heighten the risks of the strategy of marginal adjustment. Moreover, long-standing concerns about the productivity of NASA's overall program will intensify as a strategy of marginal adjustment is pursued.

High fixed costs and support for long-term mission operations and data analysis in order to realize benefits are two characteristics of many of NASA's projects that complicate a strategy of marginal adjustment. High fixed costs imply that relatively large cuts in the activities of a program produce only small budgetary savings. For example, cutting the space shuttle's annual rate of flights by 25 percent (two flights of the normally scheduled eight) reduces the operating costs of the shuttle system by less than 5 percent. Similarly, reducing the funding necessary to operate space science missions and analyze the data they produce can inflict a disproportionately high cost in lost benefits, which lowers the return on NASA's substantial past investment in spacecraft and facilities.

NASA's strong tendency to underestimate the cost of its projects is a third characteristic that compounds the risk of the agency's marginal adjustment strategy. Extensive documentation compiled by the General Accounting Office (GAO) and the Institute for Defense Analysis attests to NASA's poor record in this regard. The prospect that large numbers of projects in NASA's program will cost more than anticipated complicates decisions about which programs to downgrade, delay, or cancel, and further increases the possibility that the benefits of NASA's work will be deferred, decreased, or lost.

Concerns about the content and worth of NASA's program might well arise even if cost and budgetary problems were not evident, but those concerns are strengthened by the adjustments that NASA is making in the content of its program to reduce its budgetary requirements. First is the question of people in space. On the one hand, supporters of piloted spaceflight and human exploration are unhappy with the slow pace of these activities. On the other hand, critics argue that NASA's decision to spend more than 50 percent of its budget on piloted spaceflight crowds out more worthy science and technology projects.

A second content issue is that NASA's science program is dominated by projects that critics label as too big, too expensive, and too long-lived. For example, the Hubble Space Telescope cost billions of dollars to build and operate; the life span of the project, from the beginning of development to the end of operations, is expected to be at least 20 years. Critics contend that "cheaper, better, quicker" missions are preferable: although such missions are less ambitious than recent large projects, more of them can be supported, and they inflict a lower cost in lost scientific benefits if they fail.

Third, the content of NASA's program has been criticized as unresponsive to the economic challenges facing the nation. This viewpoint calls for more emphasis on projects to increase private productivity--for example, research and development supporting U.S. aircraft, rocket, and satellite manufacturers.

Changing the Way NASA Does Business and Reducing Program Costs

Changing the way NASA does business, the second part of the agency's strategy to adapt to lower budgets, may offer improvements in program management and technical performance and some reduc-

tions in costs. But the associated budgetary savings are uncertain and unlikely to be realized in the near term. Accordingly, the first element of NASA's strategy to adapt to lower budgets in the future--making adjustments in the content of its program--will have to bear more of the burden of lowering costs. The Congressional Budget Office (CBO) has reviewed six types of proposals for improving the way NASA conducts its business.

Ongoing Management Reforms

Proposals for reforming NASA's management emphasize better planning, uniform and more centralized review of projects, improved cost estimating independent of program advocates, and development of measures of contractor and program performance. If successful, the proposals could allow the agency to control its costs better, but the effects of the proposals are more likely to be felt in the future because improved management and planning will influence new programs more than current ones. Making a success of these efforts will require a steadfastness among NASA's leaders not always evident in the past. For example, funds for planning projects carefully early in their life cycle have been cut in difficult budgetary times, despite the acknowledgment by senior management that such funds are necessary to avoid future problems.

Ongoing Procurement Reform

NASA proposes three major changes in its procurement process: modifying the agency's procedures for incentive contracting, placing more weight on a contractor's past performance when awarding new contracts, and streamlining midrange procurement (purchases between $25,000 and $500,000).

Formal evaluations of the Department of Defense's (DoD's) use of incentive contracting suggest that incentives helped to hold down growth in the costs of developing strategic missile systems and satellites. Because NASA has long practiced incentive contracting, the changes currently being considered are unlikely to lower costs significantly. But NASA may be able to improve its technical results by basing a contractor's incentive fees more on the performance of finished systems than on meeting interim schedules and cost goals, and emphasizing a contractor's past performance when awarding new business.

NASA spent only 13 percent of its 1992 funding for procurement under contracts covered by its Mid-Range Procurement Initiative. Thus, even an extremely successful reform effort that reduced costs by 5 percent would save only about $85 million annually. The initiative might yield additional savings by decreasing the number of NASA employees needed in the procurement area. However, increased productivity in procurement activities is more likely to allow the agency to make do with a smaller increase in personnel for that area than was recently recommended by examiners for both the executive branch and the Congress.

A New Relationship with the Private Sector

The possible relationships between NASA and the private sector span a wide range. At one extreme is NASA's traditional mode of acquisition, which is characterized by extensive and direct involvement of the government in all phases of activity. At the other extreme is purchasing data and services provided by private firms that are wholly responsible for the design, production, launch, and operation of the spacecraft necessary to provide those products. Among the candidates for purchases on commercial terms are NASA's communications satellites or the services they provide, data needed for research on the global climate, and launch services for small scientific payloads.

The vision that underlies suggestions to buy more on commercial terms emphasizes two points. First, the aerospace industry can produce the technically sophisticated products that NASA needs more cheaply without government supervision than with that oversight. Second, NASA has a self-defeating tendency to drive up the cost of the hardware it buys in the traditional manner through excessive oversight, overly detailed design specifications, and too many contract changes.

Similar concerns have been raised about the defense acquisition process. A 1993 study by the Defense Science Board, for example, argues that DoD's acquisition costs could be reduced by as much as 20 percent, largely by applying commercial practices. That conclusion should be treated as tentative, however, because it is based on a small number of cases and expert judgment. The board used those factors to develop rules of thumb that it then extrapolated to the entire defense budget. In addition, the study concluded that the savings it projected were likely to accrue only after five years of determined reform, a point as applicable to NASA as to DoD.

Purchasing on commercial terms has drawbacks and limitations. In some cases, the government's potential savings from commercial purchasing may be offset by the higher relative costs of private financing and insurance, which are included in the prices that the government pays for commercial products and services. In other cases, the substantial risk involved in developing the new technologies necessary for some NASA programs makes commercial purchasing inappropriate. Finally, the risk of loss of human life in piloted spaceflight may preclude applying the more hands-off government position typical of commercial purchasing to those programs.

Streamlining

Proposals for streamlining overlap with the call for NASA to buy more on commercial terms. They focus on increasing the authority and responsibility of program managers and prime contractors by loosening procurement and acquisitions regulations and decreasing the role of NASA's field centers in program management.

Advocates of streamlining NASA's procurement process point to two examples to support their case: classified military space projects and the recent experience of the Strategic Defense Initiative Organization (SDIO). Yet no public studies have shown that the universe of classified military projects has demonstrated superior cost, schedule, and technical outcomes compared with NASA or open military acquisitions. The SDIO claim also seems unsupported by serious analysis. Moreover, regarding the federal acquisitions regulations in particular, the General Accounting Office's "High-Risk Series" review of NASA's contract management found that the agency has often failed to comply fully with procurement requirements. That failure has led NASA's field centers to approve contract changes without adequate technical evaluation and to allow unpriced contract changes to persist. Such factors have contributed to cost overruns and unsatisfactory performance.

New Cooperative Ventures

The Cold War prevented NASA from taking full advantage of joint ventures with the U.S. military or with foreign governments. Now that that conflict has ended, many observers have suggested that NASA could increase its productivity by entering into new cooperative efforts. The agency has taken up that suggestion and is aggressively pursuing new international cooperation in piloted spaceflight with the Russian Space Agency. The Administration is also examining the prospect of integrating NASA's Earth observation efforts with the polar satellite programs of DoD and the National Oceanic and Atmospheric Administration.

The major focus of the new cooperation with Russia is to develop and subsequently operate a space station, an effort that carries both risks and rewards. The evolving and preliminary plan for the new international station would restore some of the capability lost in the earlier redesign and virtually all of the lost schedule. The costs of the venture would be lower than those estimated for Freedom (an earlier design) and would not exceed the $2.1 billion cap that the Administration has placed on annual spending for the station for the next five years. Whether the current estimates of costs hold up will not be known until late summer 1994, when final contracts with the prime contractor, Boeing, are expected. Integrating U.S. and Russian hardware, computer software, and operating procedures could prove difficult, however. In addition, political tensions could always stop the project in its tracks, forcing NASA to either cancel the station (and lose the chance of a return on its past investment) or redesign the program yet again.

Total Quality Management

Total quality management (TQM) is a managerial philosophy whose objective is to achieve customer satisfaction through continuous improvement of production processes. Customer satisfaction and the positive performance indicators that go with it are achieved by committed managers and empowered employees seeking to continuously improve their products by applying empirical data and analysis to production processes. First adopted by private manufacturing firms in Japan, the approach spread to private manufacturers in the United States in the late 1970s, achieved wide acceptance in the 1980s, and by late in that decade was being adopted by large parts of the federal government. Although TQM originated in manufacturing, it has spread to the service sector, where it has gradually won adherents.

NASA was one of the first federal agencies to adopt TQM during the late 1980s. According to a 1992 GAO survey, eight NASA installations employing roughly 20,000 people have adopted TQM. GAO asked respondents to place themselves in one of five phases of TQM. Four of the NASA installations placed themselves in the second phase, "just getting started"; three in the third phase, "implementation"; and one in the fourth phase, "achieving results." (The first phase is "deciding whether to implement TQM," and the final phase is "institutionalization.")

The GAO survey reported two sets of results: external organizational performance--the implementing agency's assessment of its relationships with its customers--and internal operating conditions. For NASA installations and for a larger survey sample of more than 2,200 other federal installations, self-reported improvement was correlated with progress along GAO's five-phase scale. Those improvements included reductions in costs, although GAO did not report the size of the reductions or the categories of effort in which they occurred.

Even if NASA's adoption of TQM is ultimately successful, it is unlikely to lower the cost of the agency's program or to have a significant budgetary impact, at least in the next several years. The private sector's experience with TQM indicates that it is most effective when consistently practiced over a long period and when improved quality precedes reduced costs. The federal experience with TQM, including NASA's, is relatively limited. These findings should create skepticism about claims that immediate cost savings will follow the decision to employ TQM.

Alternative Programs for NASA

An alternative to NASA's strategy of adjusting to lower future budgets is to narrow substantially the focus of the agency's activities. If NASA's problem is trying to do too much with too few dollars, one solution is to do less. Narrowing NASA's focus directly addresses the issues of cost and program content and might even provide more opportunities for effective reform of the way NASA does business. By explicitly forgoing some benefits, budget costs could be reduced. Moreover, the likelihood would be increased that NASA could actually achieve results and obtain benefits in the areas in which its resources were concentrated.

CBO has developed and evaluated three alternatives to NASA's current program, each of which illustrates the option of a more focused strategy. Each emphasizes one of the three major objectives that NASA historically has pursued, although no alternative is a specific proposal of NASA's critics. The annual budgetary cost of each alternative is $14.3 billion or less, ranging from a program focused on piloted spaceflight for the full $14.3 billion to a program emphasizing technological development and robotic space science for $7.0 billion. The budgetary cost of each of the programs ranges downward from the current level of funding because of the national emphasis on deficit reduction and the prospect of diminishing returns to dramatically larger investments in programs with more limited objectives than the current one. The budgetary costs of the second and third alternatives are presented as point estimates. Actual costs could vary as much as a $1 billion above or below the estimates.

The three alternatives presented here are broad outlines that might be better viewed as end points in a process of adjustment rather than starting points. They neither include strategies for transition from the current program, nor do they take account of transition costs. The three alternatives are:

- **A program that emphasizes piloted spaceflight at a sustained budget of $14.3 billion annually.** To fund this option, plans for robotic space science would be cut. This alternative concentrates on the space station program and on new technology to support future piloted exploration of the solar system. It would fund the space station program at a higher level to ensure its timely completion and secure the benefits of the program, including improved relations with Russia. This alternative also responds to the criticism that NASA's current program does not give a high enough priority to future human exploration of the solar system. Spending for space science and technology activities in areas that do not directly support human exploration would be reduced dramatically. Yet the pace of piloted exploration is likely to be slow, as most estimates of the cost of a base on the Moon or a piloted mission to Mars make such activities difficult to afford within a constrained budget.

- **A program that emphasizes robotic space science at a budget of $11 billion a year and includes piloted spaceflight only for scientific purposes--a criterion under which the space station would be canceled.** This alternative emphasizes the creation of new knowledge, including that gained in piloted spaceflight, but it does not support piloted spaceflight for the purposes of improving relations with Russia or preparing for future piloted exploration of the Moon or Mars. This content mix addresses the criticism that NASA's program places too much emphasis on piloted spaceflight when the agency's major contribution is creating new scientific knowledge. This alternative does not directly address the "cheaper, better, quicker" criticism of shuttle-era space science. It should, however, permit experimentation with small satellites within the space science program and the execution of long-planned, large-scale missions.

- **A program budgeted at $7 billion annually that eliminates piloted spaceflight and instead emphasizes robotic space science and developing new technology for both private industry and public missions.** This alternative, which would effectively end the current era of piloted spaceflight by the United States, addresses the criticism that NASA's activities do not contribute to the competitiveness of U.S. industry. The alternative would concentrate resources in areas that are most likely to produce tangible payoffs--technology development directed toward specific industries and space science activities with significant applications value. For example, funding would be available for refurbishing aeronautical facilities, including new wind tunnels, which was included in the President's request for 1994 but dropped from the 1995 plan.

Posing alternatives to NASA's current program and providing estimates of their cost do not solve the problem of valuing what NASA produces. They can, however, illustrate that the balances struck in the current program--between piloted and unpiloted activities or between science missions and the development of new technologies--are neither the only options nor necessarily the best ones for NASA as it attempts to adjust to the lower budgets that it anticipates in the future.

Chapter One

The National Aeronautics and Space Administration in Transition

The Administration's five-year plan for the National Aeronautics and Space Administration (NASA) requires that the agency carry out its program with a nearly flat budget. This prospect marks a significant change for NASA: since the mid-1980s, the agency has planned its program with the expectation of continuous increases in funding. NASA has developed a two-pronged strategy to maintain productivity in the face of its constrained budget outlook. First, the agency is making marginal adjustments to the content of its program by stretching out, scaling down, and even canceling some projects. Second, NASA is seeking to improve the way it does business to get more in return for the money that it spends. This study evaluates NASA's strategy and an alternative one that would radically change the agency's program by emphasizing one or another of the broad objectives that NASA has historically pursued.

NASA bears major responsibility for the nation's space and aeronautics activities. Its most visible efforts are the flights of the piloted space shuttle. It also develops, launches, and operates unpiloted spacecraft whose purpose is to increase knowledge about the Earth, the solar system, and the universe. To accomplish those missions, NASA conducts research and develops supporting technologies for piloted and unpiloted missions alike. The agency also plays a key role in supporting research and providing facilities to meet the nation's civil and military aviation needs.

In 1994, NASA was permitted over 24,000 full-time-equivalent workyears (figured in time spent by federal workers) to accomplish its objectives. Personnel were located at the agency's Washington headquarters and nine major installations, or centers (for example, the Johnson Space Center in Houston). NASA's federal employees bear responsibility for all aspects of the agency's activity, but private industry executes most of NASA's program. The agency's procurements from industry typically total more than 90 percent of its annual spending.

What Is at Stake?

NASA's total funding for 1993 was $14.3 billion, which constituted less than 1 percent of all federal spending. The agency's budget for research and development (R&D), however, accounted for 5 percent of total national investment in R&D, over 10 percent of federal funding for R&D, and almost 25 percent of nondefense federal funding for R&D.[1] NASA applies these resources to objectives in three major areas: the piloted exploration of space, scientific research on space-related topics, and the development of space and aeronautical technologies for carrying out future public missions in space and for serving the technological needs of private industry. NASA's supporters contend that accomplishment in these areas improves the nation's self-image, enhances its international prestige, furthers certain foreign policy objectives, creates new scientific knowledge, quickens the pace of technological change, and contributes to economic productivity in

1. For total federal and NASA research and development for 1993, see *Budget of the United States Government, Fiscal Year 1994*, pp. 44-45; for total national R&D spending, see National Science Foundation, "U.S. Expenditures on R&D Expected to Increase in 1993," *SRS Data Brief*, September 24, 1993.

the aerospace industries and perhaps, indirectly, in the larger economy. Ultimately, it is these contributions that are at stake when decisions are made about NASA's program or budget or when questions arise about how well the agency manages its resources.

The Agency's Objectives and Their Value

Although the objectives of the NASA program are easily listed, measuring progress toward those goals and valuing that progress in dollar terms have proved to be extremely difficult.[2] The lack of objective evaluation leaves substantial room for equally supportable but very different opinions about the appropriate mix of activities in NASA's program or the potential benefits from increasing the efficiency of the agency. For example, advocates for continued emphasis on piloted spaceflight place a high value on such activities and attribute to them both past and potential future successes in U.S. foreign policy. Advocates for the agency's space science efforts argue that most of the important benefits that NASA has produced in its 37-year history have been generated by the less than 20 percent of its total budget devoted to scientific enterprises. No objective measure exists to compare these contrasting visions of what NASA has accomplished and the value of its current activities.

This analysis does not solve the problem of how to value NASA's activities. Instead, it emphasizes two points. The first is that the balance that NASA's current program strikes among piloted exploration, space science missions, and technology development is only one of several possible choices. As funds become scarcer, the agency may either rearrange its priorities under the current level of funding or focus on a more limited set of objectives (and accomplish them for less than it now spends).

The second point is that a scaled-down version of NASA's current program plan (the first part of its strategy for dealing with its constrained means) may not be the best use of the agency's resources. Although the benefits of NASA's activities cannot be quantified, common sense suggests that underfunded or poorly planned projects will not accomplish the objectives that ultimately produce the benefits associated with NASA's program. A major question arises about whether the current program can be rationally downsized and avoid the trap of functioning as a level-of-effort enterprise--one that is mired in stretched-out, overbudget projects that do not meet their objectives and fail to deliver their ultimate benefits.

NASA and the Economy

How NASA affects the U.S. economy is likely to consume a large part of any debate about the agency's program. The problems involved in assessing the direct benefits that NASA provides have led some advocates of continued increases in spending for the agency to claim that the indirect influence of NASA's program on the economy is sufficient to justify its cost. The more general issue of what the federal government--and taxpayers--are receiving from their R&D investments has also focused attention on the economic consequences of NASA's spending.

The balance of the evidence does not support higher levels of funding for NASA as a means to increase economywide productivity. In the short term, NASA's spending affects the economy in the same way that other government spending does--and is properly viewed as a cost rather than a benefit of the program (see Box 1). Over the longer term, NASA's contribution to the economy does not appear to be large when measured by the most objective standard. Studies that employ other approaches requiring large measures of judgment by the analyst and examine NASA's contribution within particular markets can be used to bolster the argument that past spending by NASA has led to increased productivity. But for the most part, economists have rejected the argument that would justify NASA's program based on its contribution to the economy.

2. A report by the Office of Technology Assessment, *Federally Funded Research: Decisions for a Decade* (May 1991), discusses the general issues of measuring and valuing the output of R&D agencies. The difficulties in measuring and valuing NASA's output are not unique; similar problems exist in measuring the value of most federally supported R&D efforts.

Box 1.
Short-Term Economic Effects of Spending for the National Aeronautics and Space Administration

NASA's spending does not have a uniquely large short-term effect on the U.S. economy. All federal spending for goods and services tends to stimulate the economy temporarily, increasing growth and employment for a short time (provided that the economy is not already at full employment). Such spending also tends to increase inflation and interest rates.

Under certain conditions, NASA's expenditures could have a slightly larger or smaller short-run effect on the growth of the economy and on employment compared with federal spending overall. For example, if an unusually large proportion of NASA's spending was directed toward industrial sectors or regions of the country that were experiencing much higher unemployment than the nation as a whole, the effects of the spending would be slightly larger, although still temporary. If spending for NASA was concentrated in industries that had a high value added per worker, the effect on employment would be slightly smaller than federal spending overall. On balance, nothing suggests that unique aspects of NASA's spending cause it to affect the economy differently from other types of federal spending for goods and services.

Production Function Studies. A production function is a mathematical formulation that relates the value of output to the value of inputs. Compared with other approaches (for example, cost-benefit analyses or case studies), production function studies require the analyst to make the fewest assumptions and subjective judgments.[3] The private firm Chase Econometrics Associates prepared two such studies under contract to NASA; the General Accounting Office (GAO) conducted another that evaluated the first Chase study. All of the studies illustrate the issues associated with attempting to discover NASA's contribution to private productivity.[4]

The first Chase study found a substantial contribution by NASA to productivity--indeed, one large enough to explain all of the productivity growth in the U.S. economy over the 1965-1974 period. (The equivalent return on NASA's research and development spending would have been 43 percent.) The GAO critique showed that small changes in the period covered in the estimate or in assumptions about capacity utilization or labor quality reduced the estimate of NASA's contribution to a level indistinguishable from zero.[5] The second Chase report confirmed the GAO finding.[6]

3. At the economywide level, many studies have found a strong relationship between spending for R&D and productivity. But when the contributions to economic growth of private R&D and public R&D are evaluated separately, private spending remains a strong positive factor, and public investment in R&D is not correlated with growth in productivity. See, for example, Frank Lichtenberg, "R&D Investment and International Productivity Difference," Working Paper 4161 (National Bureau of Economic Research, Cambridge, Mass., September 1992), p. 24. The author notes that from the mid-1960s through the late 1980s there was a "*negative*, large, and highly significant" relation between government-funded R&D and output.

4. Michael K. Evans, "The Economic Impact of NASA R&D Spending" (Chase Econometrics Associates, Inc., Washington, D.C., April 1976); General Accounting Office, *NASA Report May Overstate the Economic Benefits of Research and Development Spending* (October 1977); and David M. Cross, "The Economic Impact of NASA R&D Spending: An Update" (Chase Econometrics Associates, Inc., Washington, D.C., March 1980).

5. One of the most frequently quoted estimates of NASA's contribution to economic growth--for every $1 of NASA R&D spending, $9 will be returned to the economy over a roughly 20-year period --relies on a production function approach. (See Midwest Research Institute, *Economic Impact and Technological Progress of NASA Research and Development Expenditures*, vol. 2, *Economic Impacts of NASA R&D Expenditures*, Kansas City, Mo., Midwest Research Institute, 1988, pp. II-2 through II-3.) The study by the Midwest Research Institute makes two debatable assumptions that are unsupported by other research: that NASA's R&D is as productive as the average of all publicly and privately funded R&D, and that NASA's R&D investment falls into the same category of federal R&D as health and agriculture (for which positive returns have been found) rather than into the category with "purely military projects" (for which positive results have not been found). In contrast to the latter assumption, most analysts argue that NASA's activities are similar to those on the defense side of government, exhibiting the same mission orientation and relying on the same contractor base.

6. Another study by the Department of Labor's Bureau of Labor Statistics (*Impact of Government and Private R&D Spending on Factor Productivity in Space Manufacturing*, July 1980) also found no measurable relation between R&D spending by NASA and changes in productivity in industries that are directly affected by NASA procurement.

The conclusion of such studies--that NASA's R&D spending has not had a significant effect on national productivity--is neither surprising nor indicative of a waste of resources. The case can be made that these results fail to capture a positive effect that is actually occurring.[7] The benefits of new products that come from R&D activities are more difficult to assess than the reductions in costs permitted by innovations in production processes. To the extent that all federal R&D and NASA efforts are biased toward innovation in products rather than processes, the contributions from those efforts could be understated.

Other Studies. Cost-benefit analyses (many of them supported by NASA) have been undertaken to determine the effect of the agency's programs on consumers and producers.[8] Studies of this type have characteristically produced large ratios of benefits to costs or large estimates of the benefits from specific innovations generated by NASA funding. These studies have considered innovations that were spun off from NASA's spaceflight and science programs as well as those supported by its general research and technology programs.

Studies of this kind constitute a microeconomic approach that requires the analyst to make numerous assumptions about where the credit for an innovation lies, the period over which benefits should be assessed, conditions of supply and demand in directly affected and related markets, and the possibility that in the absence of the innovation being evaluated an alternative might have been devised. Consequently, cost-benefit studies of past NASA efforts include a large measure of subjective judgment. Nevertheless, the studies demonstrate that placing the contribution of NASA's R&D at zero, a result that could be implied by the production function studies, is probably as mistaken as attributing large parts of past productivity growth in the national economy to NASA's program.

Case studies of NASA's role in influencing the development of three industries--aviation, satellite communications, and materials processing in space--also provide data about the economic effects of NASA's programs. The agency's historical role in the aviation industry is generally viewed as positive;[9] its support of the communications satellite industry is usually but not always assessed as a positive contribution.[10] NASA's more recent attempts to create new industries requiring piloted spaceflight have been failures to date.[11]

A 1992 study employing a historical approach and a large measure of subjective judgment reviewed the concept of the "spin-off"--a product or process developed by NASA for its purposes that finds its way into the larger economy and leads to increased productivity.[12] The spin-off occupies a central place in the mythology of NASA's relation to the private economy and, accordingly, in the argument that secondary economic benefits might justify spending for NASA. The study's critique of spin-offs as an organizing principle for technology

7. Henry R. Hertzfeld, "Measuring the Returns to Space Research and Development," in Joel Greenberg and Henry Hertzfeld, eds., *Space Economics* (Washington, D.C.: American Institute of Aeronautics and Astronautics, 1992), pp. 153-155.

8. See, for example, Mathematica, Inc., *Quantifying the Benefits to the National Economy from Secondary Applications of NASA Technology* (National Aeronautics and Space Administration, March 1976). The study found that NASA's role in four innovations (a computer program used to analyze large structures, integrated circuits, insulation for supercooled materials, and the gas turbine engine--an effort begun by NASA's predecessor in the 1940s) produced $7 billion (in 1974 dollars) in net benefits.

9. David Mowery and Nathan Rosenberg, *Technology and Economic Growth* (New York: Cambridge University Press, 1989), pp. 181-184; and George Eberstadt, "Government Support of the Large Commercial Aircraft Industries of Japan, Europe, and the United States" (Office of Technology Assessment, May 1991), pp. 63-87.

10. Recent studies of satellite communications and NASA's role in creating that industry do not agree fully about the significance of NASA's activities. Linda Cohen and Roger Noll, "The Applications Technology Satellite Program," in Linda Cohen and Roger Noll, eds., *The Technology Pork Barrel* (Washington, D.C.: Brookings Institution, 1991), pp. 149-178, offer a generally favorable appraisal of NASA's role in the private satellite communications industry, citing the agency's development of satellite technology and its role in providing launch services. A contrasting view is offered in Peter Cunniffe, "Misreading History: Government Intervention in the Development of Commercial Communications Satellites," Report 24 (Program in Science and Technology for International Security, Massachusetts Institute of Technology, Cambridge, Mass., May 1991). The author accepts the importance of NASA's role in providing launch services but finds that most of the significant technical innovations in the industry were privately financed and developed.

11. See Chapter 4 in Congressional Budget Office, *Encouraging Private Investment in Space Activities* (February 1991).

12. John Alic and others, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992).

policy noted that the technology and institutional arrangements necessary for success in the missions of federal agencies were diverging from the characteristics necessary for success in private markets. It concluded that "grandiose projects patterned on the Apollo moon landing or the Strategic Defense Initiative will be increasingly irrelevant to world technological competition."[13] The analysis suggests that, even if spin-offs from NASA's program were important in the past, they are unlikely to be as important in the future. The production systems that NASA requires and those that serve the private market follow different paths.

The Structure of NASA's Program and Budget

In 1994, NASA received $14.6 billion in budget authority, which it allocated as shown in Table 1. Funding for the space shuttle system, including both operations and continuing investment, was the largest single item at $3.8 billion--over 25 percent of NASA's total appropriation. Funding for the space station at $1.9 billion was the next largest single item and accounted for 13 percent of the agency's budget. The space science and applications program, which supports the robotic spacecraft that NASA uses to gather information about the Earth and space, received $3.3 billion in 1994. That funding was concentrated in three areas: physics and astronomy ($1.1 billion), planetary exploration ($650 million), and Earth science ($1.1 billion). NASA allocated $1.4 billion to efforts to advance aeronautics and space technology, with more than 70 percent of the total going to aeronautics. The bulk of NASA's remaining funds were divided among the accounts that pay federal employees and that support the construction of facilities.

Funding Trends During the 1980s

NASA's current funding is about twice the $7.2 billion granted the agency in 1984 but only a small

13. Ibid., pp. 12-13.

Table 1.
Initial Operating Plan for the National Aeronautics and Space Administration, 1994 (In millions of dollars of budget authority)

Category of Spending	Amount
Research and Development	
Space station	1,946
Space transportation capability	663
Space science and applications	
Physics and astronomy	1,068
Planetary exploration	654
Life sciences	188
Microgravity	177
Earth science (Mission to Planet Earth)	1,068
Other[a]	162
Subtotal	3,307
Advanced concepts and technology[b]	433
Aeronautical research and technology	1,007
Transatmospheric research and technology	20
Safety, reliability, and quality assurance	34
Academic programs	86
Tracking and data advanced systems	24
Total	7,529
Space Flight, Control, and Data Communications	
Shuttle production and operations capability	1,035
Shuttle operations	2,744
Space and ground tracking systems	761
Launch services	313
Total	4,853
Construction of Facilities	518
Research and Program Management	1,636
Inspector General	15
Total, All Categories	14,551

SOURCE: Congressional Budget Office based on data from National Aeronautics and Space Administration, "Initial Operating Plan for 1994" (1993).

NOTE: Numbers may not add to totals because of rounding.

a. Includes some spacelab costs for life sciences and microgravity experiments and $50 million for U.S.-Russian cooperative activities.

b. Formerly Space Research and Technology, and Commercial Programs.

increase compared with NASA's 1991 funding level of $13.9 billion. Between 1984 and 1991, the NASA budget increased at an average rate of 9.7 percent annually. Between 1991 and 1994, annual average growth in the agency's budget fell to 1.5 percent.

Traditionally, NASA presents its budget to the Congress as the sum of four major appropriations (see Table 2). (NASA's 1995 budget request includes a change in its appropriations from the traditional accounts shown in Table 2 to a new scheme discussed in Box 2.) The Research and Development category supports development of aeronautics and space technology, and development and operation of both piloted and robotic spacecraft--with the major exception of the space shuttle. Spending for the Research and Development component more than tripled over the past decade, increasing its share of the agency's budget from about 30 percent in 1984 to around 50 percent in 1994.

The increase in NASA's research and development spending was driven by the piloted space station program and large-scale robotic space science projects. In 1984, spending for the space station was less than $100 million spread throughout the agency. By 1994, annual funding had reached $1.9 billion. Large robotic space science missions also contributed to the growth in NASA's research and development spending. In the mid-1980s, spending for physics and astronomy projects (the Hubble Space Telescope and the Compton Gamma Ray Observatory) and spacecraft for planetary exploration (the Galileo probe to Jupiter, the Venus Radar Mapper, and the Mars Observer) accounted for the increase. By the late 1980s and early 1990s, those projects were on the downward sloping tail of their budgetary lives, but spending was on the rise in the Earth science area, primarily for the Earth Observation System (EOS). Under the Bush Administration's 1993 budget plan, the space station and the

Table 2.
Budget of the National Aeronautics and Space Administration, 1984-1994
(In millions of dollars of budget authority)

Category	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Research and Development	2,064	2,468	2,619	3,154	3,255	4,238	5,228	6,024	6,827	7,089	7,529
Space Flight, Control, and Data Communications	3,772	3,594	3,666	6,000	3,806	4,452	4,625	5,124	5,385	5,086	4,854
Construction of Facilities	156	158	138	169	178	282	411	498	531	525	518
Research and Program Management	1,256	1,332	1,341	1,452	1,762	1,926	2,023	2,212	1,576	1,615	1,636
Inspector General	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	9	11	14	15	15
Total	7,248	7,552	7,764	10,775	9,001	10,898	12,296	13,869	14,333	14,330	14,551

SOURCE: Congressional Budget Office based on National Aeronautics and Space Administration, *Budget Estimates* (1984-1994).

NOTE: Numbers may not add to totals because of rounding. n.a. = not applicable.

Box 2.
Changes to the National Aeronautics and Space Administration's Appropriations Proposed in the 1995 Budget

The National Aeronautics and Space Administration's (NASA's) budget request for 1995 includes a proposal to redefine NASA's appropriations. Instead of the current division into five appropriations (Research and Development; Space Flight, Control, and Data Communications; Research and Program Management; Construction of Facilities; and the Inspector General), NASA would divide its budget into four categories: Human Space Flight; Science, Aeronautics, and Technology; Mission Support; and the Inspector General. (See the table below, which provides a "bridge" between the current and proposed categories.)

The appropriation structure proposed for 1995 highlights the division of NASA's program between piloted and unpiloted activities in a way that the current structure does not. For 1994, the Research and Development appropriation stood at $7.5 billion, including $1.95 billion for the piloted space station program. The Space Flight, Control, and Data Communications account was funded at $4.9 billion, of which $3.8 billion was allocated to the piloted space shuttle. Under the classifications proposed for 1995, NASA would combine spending for development of the space station with funds for the operation and continued development of the space shuttle. The combined spending would constitute the Human Space Flight appropriation, which in 1994 would have totaled slightly more than $6 billion (with the addition of $300 million for other piloted spaceflight activities). The proposed Science, Aeronautics, and Technology appropriation--which would have been $5.8 billion in 1994, had the new categories been in effect--is essentially the sum of funding for current robotic space science, aeronautics, and technology programs, or the current Research and Development appropriation minus the funding to develop the space station.

The proposed Mission Support appropriation would include all of the current Research and Program Management appropriation (more than $1.6 billion in 1994 for NASA's federal employees). The category would also include funds currently appropriated under the Construction of Facilities accounts and funding for NASA's ground and space tracking system, which is now divided between the Research and Development appropriation and the Space Flight, Control, and Data Communications appropriation.

The budgetary presentations and analysis in this study use the current appropriation categories but translate well into the proposed new structure. This is particularly true of the discussion in Chapter 4 of alternatives to the current NASA program that either dramatically increase or decrease the share of NASA's budget devoted to piloted spaceflight.

Current and Proposed Appropriation Structure for the 1994 Funding for the National Aeronautics and Space Administration (In millions of dollars)

	Proposed Categories			
Current Categories	Human Space Flight	Science, Aeronautics, and Technology	Mission Support	Total
Research and Development	2,435	4,725	369	7,529
Space Flight, Control, and Data Communications	3,601	860	392	4,853
Research and Program Management	n.a.	n.a.	1,636	1,636
Construction of Facilities	33	262	222	518
Total	6,070	5,847	2,619	14,536

SOURCE: Congressional Budget Office based on *Budget of the United States Government, Fiscal Year 1995*, Appendix, p. 821.
NOTES: The Inspector General category is not shown because it remains the same under both structures.
Numbers may not add to totals because of rounding.
n.a. = not applicable.

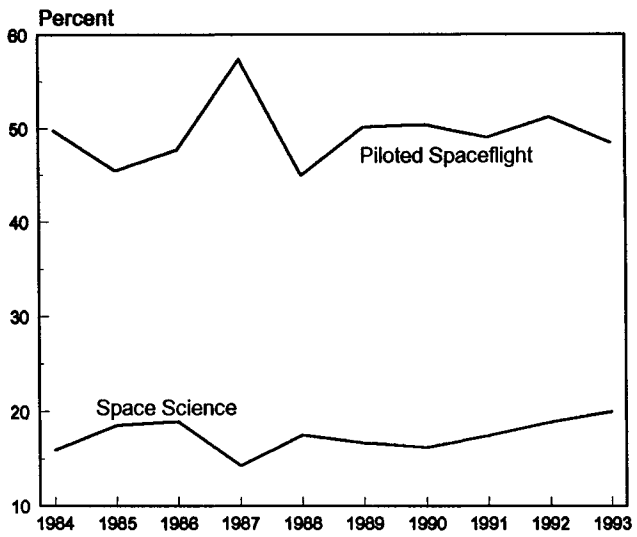
EOS were the two largest civilian R&D projects in the federal budget.[14]

Funding for the space shuttle, traditional unpiloted rockets, and the orbital communications and tracking network is included in the Space Flight, Control, and Data Communications category of accounts. This aggregate has grown more slowly than spending for research and development, as shown by its decline from about 50 percent of the agency's spending in 1984 to around 35 percent in 1994. The spike in funding for spaceflight in 1987 represented the purchase of a replacement orbiter for the Challenger lost in 1986. The other consequences of the Challenger accident for NASA's program do not show up as clearly in budget data. In 1984, the agency received about $3.1 billion to support between 12 and 14 shuttle flights annually. Ten years later, in 1994, the shuttle system was funded at a modestly higher level of $3.8 billion but planned to support only eight flights a year.

The last two major categories of NASA funding are Construction of Facilities and Research and Program Management. The former has more than tripled in size over the past 10 years, but it still accounted for only 4 percent of NASA's spending in 1994. The latter increased from $1.3 billion in 1984 to more than $2.2 billion in 1991 but then fell to $1.6 billion in 1993. (The drop was a consequence of NASA's redefining its accounts to shift about $400 million in funding for maintaining NASA centers and installations from the Research and Program Management accounts to the Research and Development and Space Flight, Control, and Data Communications accounts.)

Several other trends can be identified. The proportion of NASA's budget devoted to piloted spaceflight has remained constant at about 50 percent throughout the decade, as measured by spending for the space station and the space shuttle, development of space transportation capability, and associated space science projects (see Figure 1). The share of space science and applications, a subset of the Research and Development category that is dominated by the development and operation of robotic spacecraft, increased from 16 percent of NASA's budget in 1984 to 20 percent in 1994. If life sciences and microgravity research--activities associated with piloted spaceflight--were excluded, however, the gain in the share of space science would be more moderate. Finally, spending for aeronautics, as measured by program expenditures, has roughly tripled over the past 10 years, and the share of these activities has increased from 4 percent to 7 percent of NASA's budget.

Figure 1.
Budget Shares for Piloted Spaceflight and Space Science, National Aeronautics and Space Administration, 1984-1993 (In percent)



SOURCE: Congressional Budget Office based on data from the National Aeronautics and Space Administration.

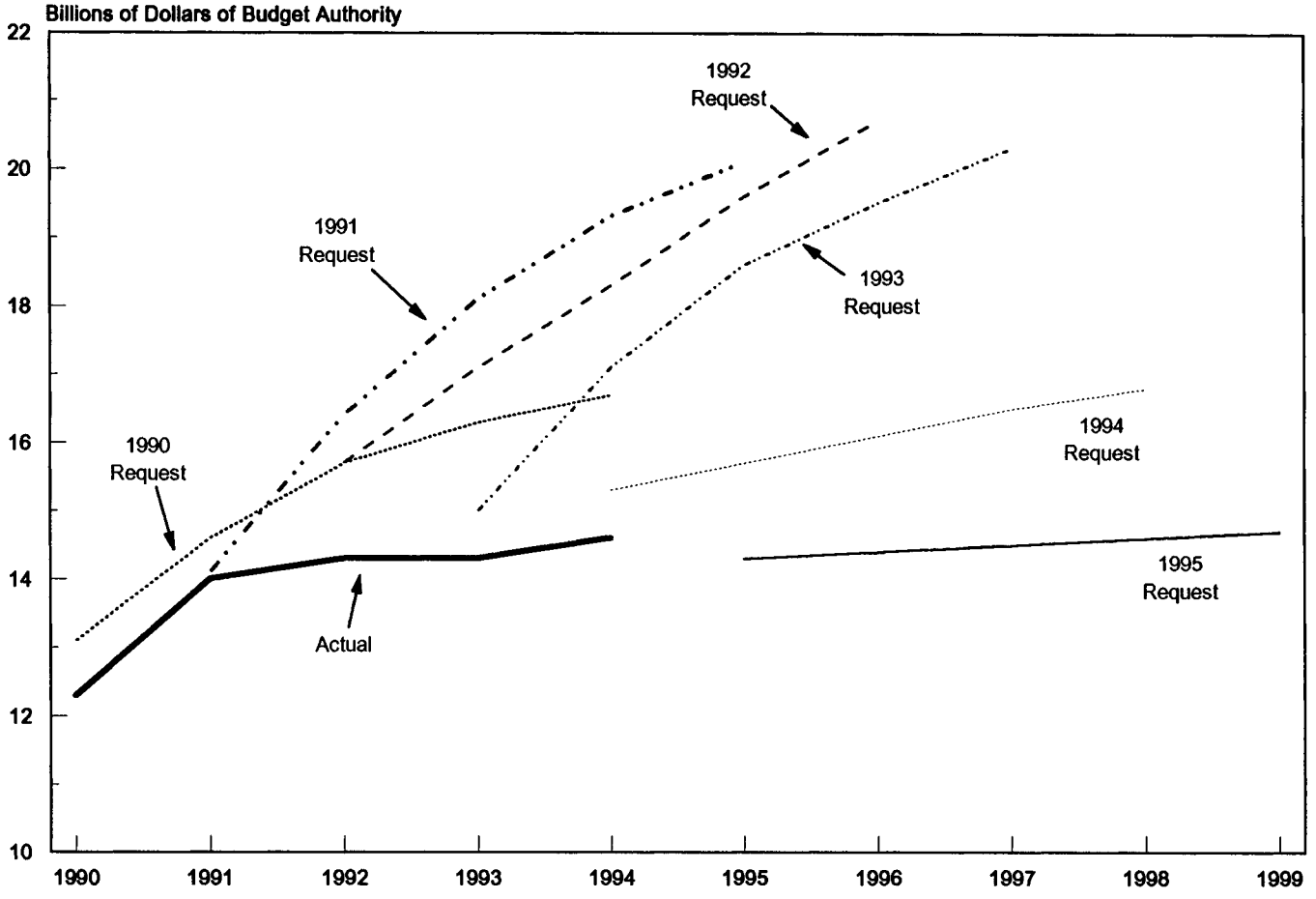
NOTE: Piloted spaceflight includes spending for the space transportation system and the space station only.

The Breaking Bow Wave

What is not apparent in reviewing NASA's funding over the past 10 years is the expectation of future growth that permeated the agency's planning. Since

14. Congressional Budget Office, "Large Nondefense R&D Projects in the Budget: An Update," CBO Staff Memorandum (March 1992), p. 2. For a general approach to measuring the budgetary effects of large projects, see Chapter 2 in Congressional Budget Office, "Large Nondefense R&D Projects in the Budget: 1980-1996," CBO Paper (July 1991).

Figure 2.
Five-Year Budget Requests of the National Aeronautics and Space Administration, 1990-1995
(In billions of dollars of budget authority)



SOURCE: Congressional Budget Office based on *Budget of the United States Government* (various years) and 1993 projections from the NASA Comptroller's Office.

the mid-1980s, NASA's program has required increases in its annual budget above the rate of inflation (see Figure 2).[15] The force driving NASA's future budget requirements upward in the late 1980s was the anticipated cost of first developing and then operating new spacecraft that were to be integrated in a low-Earth-orbit infrastructure. NASA envisioned the infrastructure as including the space shuttle, the space station, tracking and data relay satellites, and several large satellites carrying instruments that looked outward to the stars or back at the Earth. Once in place, this investment was to produce near-term benefits measured in scientific advances, new technologies, and contributions to economic growth. Over the long term, the low-Earth-orbit infrastructure was seen as a stepping-stone for pursuing NASA's long-held goals of a Moon base and a piloted mission to Mars.[16]

The plans for NASA's program outlined in its budget requests for 1990 through 1993 continued to show increasing funding requirements, despite the completion of major parts of the infrastructure. In 1992, GAO testified that NASA's program plan for

15. Congressional Budget Office, *The NASA Program in the 1990s and Beyond* (May 1988), pp. xi-xiv.

16. See Chapter 2 in Howard McCurdy, *The Space Station Decision* (Baltimore, Md.: Johns Hopkins University Press, 1990).

Table 3.
Budget Requests and Appropriations for the National Aeronautics and Space Administration, 1989-1994 (In billions of dollars of budget authority)

	Request	Appro-priation	Differ-ence
1989	11.5	10.9	0.6
1990	13.3	12.3	1.0
1991	15.1	13.9	1.2
1992	15.8	14.3	1.5
1993	15.0	14.3	0.7
1994	15.3	14.6	0.7

SOURCE: Congressional Budget Office based on National Aeronautics and Space Administration, *Budget Estimates* (1989-1994).

1992 through 1997 would require almost $13 billion above the Congressional Budget Office baseline for the agency.[17] This finding was consistent with the conclusion reached two years earlier by a federal advisory committee convened by President Bush. The Advisory Committee on the Future of the U.S. Space Program, better known as the Augustine Committee, found that NASA was over-committed in terms of the scope of its program and would require annual increases of 10 percent above the rate of inflation to realize all of its objectives.[18] As the Clinton presidency began, NASA's budget still required strong growth because the cost of operating current projects remained high and the cost of projects in development continued to increase.

NASA's program plan has attracted the attention of critics in part because of the recent focus on the nation's budget deficit. Concerns about the cost of the NASA program grew after 1990 and the tightening of all domestic discretionary spending required by the Budget Enforcement Act. When the caps in the act began to restrain spending, the Congress significantly lowered NASA's budget from the amounts requested by the President in 1992 and 1993 (see Table 3). For 1994, the Congress again appropriated less than the President requested, despite the Administration's proposal to slow the growth in NASA's five-year program plan by $16 billion compared with the plan included in President Bush's last budget (see Table 4).

Further reductions could be in the offing. The Omnibus Budget Reconciliation Act of 1993 contains a series of caps on appropriations for the next five years that will essentially freeze all discretionary spending at 1993 levels. The caps have led the Administration to scale back NASA's budget even further.

Future budget requirements are easier to scale down than the programs that underlie them. The expectations represented by NASA's plans in the 1980s may be equally difficult to deflate.

Table 4.
Five-Year Budgets in the 1993 and 1994 Plans of the National Aeronautics and Space Administration (In billions of dollars of budget authority)

Plan	1994	1995	1996	1997	1998
1993	17.0	18.6	19.5	20.3	21.0
1994	15.3	15.7	16.1	16.5	16.8
Difference	1.7	2.9	3.4	3.8	4.2

SOURCE: Congressional Budget Office based on data from the National Aeronautics and Space Administration.

17. Testimony of Neal P. Curtain, Director of Planning and Reporting, National Security and International Affairs Division, General Accounting Office, before the Subcommittee on Science, Technology, and Space, Senate Committee on Commerce, Science, and Transportation, March 17, 1992, pp. 1-3.

18. National Aeronautics and Space Administration, *Report of the Advisory Committee on the Future of the U.S. Space Program* (December 1990), pp. 1-9.

Chapter Two

The Risks of a Strategy of Marginal Adjustment

The National Aeronautics and Space Administration has chosen to make marginal adjustments to its basic program as one way of coping with the prospect of flat budgets in the foreseeable future. The agency has scaled back individual projects, stretched them out, and in some cases even canceled them, but it remains committed to a program structure that includes the development and operation of major piloted systems (the space station and the shuttle), the development and operation of major robotic space science missions (for example, the Earth Observation System and the Hubble Space Telescope), and support for new aeronautical and space technology.

Although NASA has adjusted its program in each of the past several years, when the Congress provided less funding than the Administration had requested, adjusting the agency's program to flat out-year budgets (those for the four years beyond the fiscal year of the budget request) is a more difficult and riskier exercise.

The strategy of marginal adjustment, and its complement of improving the way that the agency does business, may be successful in accomplishing NASA's planned missions and delivering their ultimate benefits. But success is not assured. The attempt to fit a program that was projected to cost more than $20 billion a year in the late 1990s into an annual budget of $14 billion risks delay, mission failure, and the loss of anticipated benefits. Essential characteristics of NASA's program increase the risk of failure associated with a strategy of marginal adjustments. Moreover, that type of strategy may exacerbate perceived problems with the current program. This chapter explores both of those factors in assessing the risks of NASA's plan for marginally adjusting its program.

Program Characteristics

Three characteristics of NASA's current program increase the risks associated with marginally adjusting it to fit the smaller future budgets that NASA expects. First, many of NASA's programs have high fixed costs. Second, the agency must allocate substantial funding for mission operations and data analysis late in a project's life cycle to realize a return on the sizable investment it has already made in the spacecraft. In addition, successful small-scale projects have led to the spread of larger-scale efforts with high fixed costs and long-term and substantial operating funding to many areas of the agency's program. Third, NASA has consistently underestimated the costs of its projects.

High Fixed Costs

Economists sometimes characterize high fixed costs as "lumpiness." A lumpy expenditure or cost is essentially an all-or-nothing proposition. The good or service desired cannot be purchased in smaller quantities, even if the buyer has no use for the full quantity. This characteristic applies to large parts of NASA's program and budget and limits the areas in which adjustments can be made to bring projects into line with a no-growth budget. The space shuttle and space station programs--the mainstays of NASA's activities in piloted spaceflight--and large

space science missions are all examples of projects with high fixed costs.

The shuttle system best illustrates the concept of lumpiness and the problems it presents to a strategy of marginal adjustments. A recent analysis by the General Accounting Office estimated that the total operating cost of flying eight shuttle missions in 1993 was about $3.3 billion, or 23 percent of NASA's 1993 funding.[1] Adjusting NASA's program by scaling back the rate of shuttle flights by two missions (25 percent of the planned annual rate) would save less than $100 million a year according to NASA, or less than 3 percent of the shuttle's total annual operating costs. Once the agency decided to engage in piloted spaceflight and to adopt the shuttle as its primary flight system, it accepted a "lump" or fixed cost of between $3 billion and $4 billion in its annual budget.[2] Marginally adjusting the rate of shuttle flights will not generate significant budgetary savings.[3]

A less strict example of high fixed costs involves the development phases of the space station program and large space science missions. According to NASA, the space station requires a minimum of $2 billion annually to make progress toward actually developing and launching the facility. The fixed cost of maintaining project teams--funding for personnel and overhead within NASA and among its contractors--is a substantial part of this annual expenditure. As a result, with the current program plan and hardware design, it would be unproductive to attempt a program funded at $1 billion annually because that level would be insufficient to support the fixed cost of the program, let alone make progress in actually building a space station.

The case is much the same for major space science missions in development--for example, the dual-spacecraft Comet Rendezvous Asteroid Flyby (CRAF) and Cassini missions approved for development in 1989. A 1993 GAO report examined the cancellation of the CRAF spacecraft. After spending $700 million of a projected $3.7 billion total cost for both spacecraft, NASA canceled the CRAF project in 1994. But it reduced its total project costs by only $700 million, $535 million of which was accounted for by reduced costs for the launch and operations.[4] The saving in development costs was only about $165 million because the fixed cost of developing the spacecraft to be used for both missions was relatively high.

Although not all of NASA's activities can be characterized as high-fixed-cost projects, many have aspects that would permit such a characterization, particularly projects in which the agency seeks to maximize productivity by completing them within schedules that allow development at close to minimum cost. The implication of high fixed costs in the context of NASA's current budgetary realities is that large parts of NASA's program are not candidates for marginal reductions. However, other parts--largely in the operation and actual use of the hardware and systems developed over the past decade--could be disproportionately cut under a strategy of marginal adjustment.

Mission and Operations Funding Late in a Project's Life Cycle

The life-cycle characteristics of a typical NASA project could also limit the effectiveness of the strategy of marginal adjustments. Specifically, they would inflict a high price in the form of lost bene-

1. General Accounting Office, *Space Transportation: The Content and Uses of Shuttle Cost Estimates* (January 1993), p. 4. Because the cost of a shuttle flight is incurred over three fiscal years, the cost of flights flown in 1993 does not equal the 1993 appropriations for shuttle operations. However, when the annual flight rate of the shuttle is roughly constant, as is currently the case, the annual appropriations for the shuttle and the annual cost of the shuttle system are roughly equivalent.

2. In addition to expenditures to operate the shuttle, NASA spends around $1 billion annually on improvements to the system. This spending is more amenable to budgetary reductions that result in comparable reductions in program activities. Most recent decreases in projected funding for the space shuttle are attributable to the canceling of planned improvements--for example, the Advanced Solid Rocket Motor, the extended durations orbiter kit (proposed), and spare parts for the shuttle orbiters.

3. National Aeronautics and Space Administration, *Budget Estimates, Fiscal Year 1993*, p. SF 2-3, projected the costs of future shuttle operations by reducing the fixed costs of operations by 3 percent over each of the following five years. The agency has been largely successful in achieving this goal, although further reductions are likely to be more difficult.

4. General Accounting Office, *Space Science: Causes and Impacts of Cutbacks to NASA's Outer Solar System Exploration Missions* (December 1993), p. 20.

fits as a result of reducing funding in the operations phase of a project. In some senses, this outcome is another manifestation of high fixed costs because the additional cost of operating a spacecraft is small compared with the cost of developing, producing, and launching it.

The typical NASA project incurs large annual costs early in its project life but delivers most of its benefits later during the operating and data analysis phase, a period of relatively smaller annual costs. Adjusting NASA's program to fit within smaller future budgets by reducing spending for mission operations and data analysis could significantly decrease the benefits of past investments. As a concrete example, it would be difficult to produce a return on the nation's past investment in the Hubble Space Telescope if its current operations were not funded.

In the space science and applications area, funding for mission operations and data analysis for the physics and astronomy, planetary exploration, and Earth science programs totaled $728 million in 1993, or 25 percent of the $2.9 billion allocated to the area.[5] The best examples of long-term operational costs are found in the physics and astronomy program. The Hubble Space Telescope cost $1.7 billion to develop. To reap the full benefit from this past expenditure, spending in excess of $200 million annually for servicing, operations, and data analysis was necessary in 1992 through 1994. Five other astrophysics missions now in the operational phase, the most prominent being the Compton Gamma Ray Observatory, required a total of $85 million over each of the past three years for operations and data analysis.[6]

If NASA continues on its present course, the space station and Earth Observation System will also require annual operating support to secure the benefits of the nation's current investment. NASA estimated in September 1993 that the space station would require a minimum of $1.5 billion annually. According to data that NASA furnished to the Office of Technology Assessment, also in 1993, the EOS could require as much as $500 million annually for operations, data analysis, and management.

Progress in achieving space-related goals has led to larger-scale projects in a widening array of scientific disciplines and subdisciplines. As with the problem of high fixed costs, the demand for ongoing operational expenditures across a number of program areas increases the risks of a strategy of marginal adjustment.

Cost Overruns

The problems that NASA has experienced in estimating the cost of its projects are not inherent to its mission. Unlike high fixed costs and postdevelopment operating expenditures, underestimated costs are not a necessary condition of the NASA enterprise, although they have been a pervasive characteristic. As the agency's decisionmakers strive to bring the cost of its program down to a level that can be productively supported by a flat budget, cost overruns represent a significant risk to their success.

NASA's problems in estimating costs, although neither unique nor limited to this period of the agency's history, are nevertheless quite serious. A 1992 study by the Institute for Defense Analysis (IDA) examined NASA's record and concluded that the agency had enjoyed considerable technical success but that its record in meeting schedules and goals related to costs was "considerably worse even than the DoD's experience."[7] A recent GAO study found that 25 of the 29 projects with initial cost estimates above $200 million that NASA started between 1977 and 1991 cost more than originally estimated.[8] The range of overruns stretched from 14 percent to over 400 percent, with a median of about 75 percent. Of the four projects that did not experience overruns, two were significantly reduced in scope from their original conceptualization.

5. National Aeronautics and Space Administration, *Budget Estimates, Fiscal Year 1994*, pp. RD 3-1, RD 4-1, and RD 6-1.

6. Ibid., p. RD 3-21.

7. Karen W. Tyson, J. Richard Nelson, and Daniel M. Utech, *A Perspective on Acquisition of NASA Space Systems* (Alexandria, Va.: Institute for Defense Analysis, December 1992), p. 79.

8. General Accounting Office, *NASA Program Costs: Space Missions Require Substantially More Funding than Initially Estimated* (December 1992), pp. 1-4.

The GAO study reported both general and specific reasons for the overruns. Insufficient studies to define the projects, instability in the programs and their funding, overoptimism on the part of program officials, and unrealistic estimates by contractors were noted as general causes. Specific factors included program redesigns, technical complexities, incomplete cost estimates, shuttle launch delays, and unanticipated inflation. The IDA study noted most of these factors as well and stressed the roles of underestimating the technical difficulty of projects and inadequate planning.

The budgetary appetite of the whole NASA program and the agency's failure to estimate the costs of its projects accurately have reinforced one another. In the past, the out-year projections of the agency's overall program that showed growing budgetary requirements in future years must certainly have understated the actual cost of completing the program as planned. (Those estimates, after all, were no more than the sum of costs for individual projects that the GAO and IDA studies showed were consistently underestimated by NASA.) At the same time, the requirement for growth in the agency's total budget placed pressure on program managers and contractors to be overly optimistic in making cost estimates, a factor identified by GAO as contributing to NASA's consistent underestimations.

The strategy of marginal adjustment will not change this relation. Indeed, margins for error may decrease and even disappear. Reducing NASA's total budget could intensify pressure to underestimate the costs of individual programs. In a general climate of cost cutting, project managers and their contractors might be tempted to accept overly optimistic cost estimates, realizing that projects that could claim cost reductions but preserve their potential output would fare better in a demanding fiscal environment. If help for a project experiencing an overrun is sought by restricting other projects operating on slimmer-than-usual margins, problems in one project or area can be transmitted to other projects or areas. For the program as a whole, the prospect of cost overruns distorts the choices made in marginally adjusting the content of NASA's program and increases the risk that the benefits of NASA's activities will be diminished, deferred, or lost entirely.

Marginal Adjustment and Problems with the Current Program

Even when NASA's out-year budgets arched upward, critics questioned the agency's priorities and speculated that its program was not delivering enough benefits to justify its cost. Marginally adjusting the content of the current program is likely to intensify concerns about the agency's priorities and the value of the benefits it provides.

Winning the race to the Moon in 1969 is viewed by some observers as the peak of the agency's accomplishments and usefulness. Since the Apollo era, the political system has been unwilling to fund fully the agency's overriding objective--piloted exploration of the solar system. The end of the Cold War eliminated any lingering reason to support NASA's emphasis on piloted spaceflight as a demonstration of the superiority of democratic capitalism over totalitarian communism.[9] Although the Administration's initiative to include Russia in the international space station has resurrected foreign policy as a primary reason for piloted spaceflight, other justifications for the agency's program have grown in importance. These include NASA's contributions to the advancement of science, to the understanding and monitoring of the global environment, and to the activities of aerospace industries.

Specific dissatisfactions with the content and potential benefits of NASA's program are many, but three are of particular importance because they are likely to be aggravated as NASA adjusts its program. First is the question of people in space. Enthusiasts of piloted spaceflight and human exploration are unhappy with the slow pace of NASA's

9. Vice President's Space Advisory Board, *A Post Cold War Assessment of U.S. Space Policy* (December 1992), pp. 1-11.

activities in this area. Other critics contend that the more than 50 percent of NASA's budget spent on piloted spaceflight is too large a share.[10]

Second is the criticism that NASA's space science program is too focused on large-scale, expensive projects with long operational and budgetary lives. For example, the Hubble Space Telescope cost billions of dollars to build and operate and is expected to enjoy a project life span of at least 20 years, from the beginning of development to the end of operations.[11] Critics argue that such projects extract too large a cost when they fail and are overly subject to bureaucratic inefficiencies.

Third, and finally, the content of NASA's program has been criticized as unresponsive to the economic challenges facing the nation. From this point of view, NASA should place more emphasis on activities to increase private productivity--for example, research and development supporting U.S. aircraft, rocket, and satellite manufacturers.

People in Space

Putting people in space is costly, a point on which most critics agree, whatever their position. Advocates of spending more on piloted spaceflight view its benefits as sufficient justification for those high costs.[12] Moreover, they argue that investing in new technology that reduces the cost of having people in space will drive the benefit-cost ratio even higher. Opponents of piloted activities counter that such programs do not produce sufficient benefits to justify their high costs and that in a constrained budget environment they impose an unacceptably high cost by crowding out more worthy science projects. From this point of view, reducing federal spending, investing in other space science projects, or supporting other scientific enterprises that do not involve space are likely to produce a higher level of benefits.

For many years, rising budgets and the expectation of future increases in funding muted the conflict between advocates and opponents of piloted spaceflight within the community of interests that generally supported spending for space. For example, the Augustine Committee assigned its highest priority to NASA's largely unpiloted scientific activities. But the assumption that NASA's budget would continue to grow by 10 percent a year after inflation allowed the committee to downplay the friction between NASA's budgetary tilt toward piloted spaceflight, the desire for even more spending to support the future exploration of Mars by humans, and the committee's own observation that the scientific benefits of piloted spaceflight were limited.[13]

The progressive constriction of NASA's five-year budget outlook and the strategy of marginal adjustment have now brought more of the tensions about piloted spaceflight to the surface. President Bush's proposal to commit the United States to a human outpost on the Moon and a piloted mission to Mars by early in the next century was rejected by the Congress, largely because of its expected cost. The Clinton Administration's initiative to lower the cost of the space station and at the same time reduce the growth in NASA's total budget has left both advocates and opponents of piloted spaceflight only partially satisfied. Further downward pressure

10. The Congressional Budget Office's (CBO's) estimate of the share of piloted spaceflight is based on National Aeronautics and Space Administration, *Budget Estimates, Fiscal Year 1994*, p. AS-8. CBO's estimate includes 1993 funding for the space station, space shuttle, and life sciences and microgravity projects, and a prorated share of research and program management.

11. Development of the Hubble Space Telescope began in 1978 with funding of $36 million; see General Accounting Office, *Status of the Hubble Space Telescope Program* (May 1988), p. 18. In December 1993, NASA serviced the telescope, which allowed its orbital life to be extended until at least 1996. An additional nine years of operation are possible, according to NASA's plans, if servicing missions are undertaken every three years. Thus, from birth to death, the Hubble could "live" 24 years.

12. General Accounting Office, *Space Projects: Astrophysics Facility Program Contains Costs and Technical Risks* (January 1994), sheds light on the benefits of piloted spaceflight in space science enterprises. The success of the repair mission on the Hubble Space Telescope demonstrated that the risk of failure for a space science mission could be decreased by developing systems that could be repaired by astronauts. However, the redesign of the Advanced X-Ray Astrophysics Facility (AXAF) described in the GAO report illustrates the costs of lowering risk by providing for repair by astronauts. GAO found that without a link to piloted spaceflight, the AXAF would cost less than half as much and deliver roughly the same scientific contribution as the alternative that provided for repair by astronauts.

13. National Aeronautics and Space Administration, *Report of the Advisory Committee on the Future of the U.S. Space Program* (December 1990), pp. 5-8.

on NASA's budget will increase the tension over the content of NASA's program as the Administration and the Congress confront choices between major piloted programs (for example, the space station) and unpiloted efforts (for example, the Earth Observation System).

Too Big, Too Expensive, and Too Long?

The thrust of NASA's program as it evolved during the 1980s was toward large, expensive space "platforms" that would serve many users. This approach extended beyond the piloted spaceflight program to the activities of the space science and applications program. Over the past 10 years, each of the three major areas of that program, which together accounted for roughly 90 percent of the $2.9 billion spent in 1993, sponsored one or more large-scale science projects. Cost overruns and failures in achieving the goals of the projects spurred criticism. The prospect of adjusting to flat out-year budgets has intensified those concerns.

Advocates of big projects in space science contend that investment in expensive, multiple-user spacecraft with long operational lives would allow more investigators to undertake more science, ultimately at a lower cost. Although the typical "too big, too expensive, too long-lived" project begun in the early 1980s cost more to develop than its predecessors, it was heralded as providing more science per dollar of investment. A part of that boost in productivity was to come from integrating the new project with other components of the low-Earth-orbit infrastructure: the space shuttle would lower transportation costs, the shuttle and the space station would permit on-orbit repair and maintenance, and the network of tracking and data relay satellites would provide superior communications.

Large-scale projects were also justified based on their ability to address questions that smaller projects could not. For example, NASA has sent probes to all of the planets in the solar system except Pluto. To learn more would require probes that carried a larger array of more capable--and expensive--instruments.

According to the "cheaper, better, quicker" proponents, the best way to accomplish NASA's science objectives is through smaller, less costly projects that focus on fewer or relatively limited scientific questions, have shorter budgetary lives, and allow both risk and opportunity to be more widely dispersed.[14] Failures may occur, but each would be less costly in both dollars spent and science forgone than a complete or partial failure of a major mission. For some critics, the problems with the Hubble Space Telescope's lens and the Galileo Jupiter probe's antenna stand out as examples of the high cost of such failures.

Advocates of more small projects also accuse large projects of suffering from a "Christmas tree" or "last-train" effect. In many large projects, the segment of the science community that is benefiting from a project piles instruments on a spacecraft for fear that its next flight opportunity will be years off. Project costs increase, as does the risk of slippage in the schedule. Increasing costs enlarge the size of the fixed-cost budgetary "lump" represented by each project and diminish overall budgetary flexibility. And investigators run an ever larger risk that their careers will be hurt by delays because observations follow proposals by years and decades rather than months.

Finally, critics of big projects contend that the long operational life of these efforts changes NASA's orientation from a research and engineering agency to an operational agency, a task for which it is ill suited.[15] The change in agency philosophy implied by the "cheaper, better, quicker" criticism is no less significant than questioning the worth of people in space.

A missing element of the current discussion about the appropriate cost, scale, and life of NASA projects is an evaluation of the big-science efforts of the past decade. The large-scale planetary and

14. See the address by NASA Administrator Daniel Goldin to the American Institute of Aeronautics and Astronautics, September 27, 1993, pp. 11-12.

15. Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore, Md.: Johns Hopkins University Press, 1993), pp. 141-146.

astronomy missions have not been entirely successful. Still in question is whether the long life and multiple-user attributes of the Hubble Space Telescope or the Compton Gamma Ray Observatory have allowed the science community to produce better science at lower costs than the alternative of several smaller but less capable spacecraft.

Criticisms of the scale, cost, and life span of NASA science projects have direct and obvious implications for the content and cost of the agency's overall program. Under a fixed budget, a number of smaller projects could be undertaken instead of a single large one. If NASA's science budget was reduced, the agency could retain the current scope of its science program by restricting each area to smaller projects. Less obvious is the connection of the "too big, too expensive, too long-lived" criticism to the way NASA conducts its overall program. Critics have suggested that big science provides too comfortable a hiding place for inefficiencies of one type or another.

The Economic Returns

The third major criticism of the content of NASA's program is that the agency fails to produce technologies and products that allow private productivity to increase. This criticism can be generalized to all mission-oriented federal R&D, as can the response that the benefits of mission-oriented R&D--for example, learning more about global climate change from the EOS--should be sufficient to justify the cost of these activities independent of any unintended effects. Yet the claims by NASA supporters of the agency's significant contribution to the economy and its prominent ranking among civilian agencies in amount of R&D expenditures open NASA to close examination.

Critics of the economic value of NASA's current program emphasize the potential contribution that its research and development activities could make to the aerospace industries. Among NASA's institutional predecessors was the National Advisory Committee on Aeronautics. Its purpose was to develop useful aviation technology, a task that by most accounts it accomplished well from its creation in 1915 until the late 1950s, when it was blended into NASA. This heritage and the more recent contributions to the U.S. aviation industry by NASA's aeronautical research and technology program have led some observers to suggest that more of NASA's resources than the $1 billion spent in 1993 should be devoted to aeronautics. Long-run decreases in the U.S. market share for general use, commuter, and long-haul airplanes have added to the pressure on NASA to increase its spending in support of the U.S. aircraft industry, even if such increases require that the agency reduce its activities in space. Critics of the content of NASA's current program also advocate the agency's funding of technology development for U.S. satellite and rocket manufacturers.

The criticism that NASA's current program is unresponsive to the needs of the private economy highlights the issue of how NASA might best contribute to the economy and by implication the content of its program. The heritage of the National Advisory Committee on Aeronautics stresses the deliberate, direct approach of developing technologies intended for private use, whereas the spin-off model calls for proceeding with the mission and hoping that positive consequences follow. As noted earlier, the large share of the national R&D effort accounted for by NASA punctuates the importance of resolving this issue.

Chapter Three

Changing the Way NASA Does Business

The second prong of the National Aeronautics and Space Administration's strategy to adapt to flat future budgets is to spend the funds that the agency receives more efficiently.[1] The proposals for increasing efficiency span a wide range. The agency has proposed relatively small but definite changes in management and procurement practices and policies. Many observers both inside and outside of NASA have suggested more fundamental changes in the agency's approach to the private sector, program management, internal organization, other government agencies, and international cooperation. Finally, other critics have called for revolutionary changes in the institutional charter of the agency, which they view as necessary to create an environment conducive to improved performance.

Many of the suggestions to change the way NASA does business have merit and deserve examination because they offer the prospect of improved performance over the long run. Yet conclusive evidence is lacking that changes in conduct would allow NASA to dramatically reduce the cost of its program. On the one hand, NASA's isolation from the competitive forces that drive efficiencies in the private sector suggests that there is ample room for improvement. On the other hand, experiences to date in reforming NASA and the Department of Defense offer little hope that the right mix of incentives can be created to bring about this improvement. And even if reform ultimately did reduce costs, it would probably take several years of concerted effort to achieve that goal. In the near term, smaller budgets are likely to require more reliance on adjusting the content of NASA's program, be it through reducing the scope of current projects, stretching out their schedules, or canceling them outright. Buying more for less will not allow NASA to escape hard choices if its budget is restricted to slow growth or even reduced.

This study describes specific proposals for change and discusses their potential effects by referring to past experiences of NASA or other public- and private-sector organizations. However, this evaluation of the ongoing effort to "reinvent" NASA is qualitative and incomplete.

Criticizing NASA's Conduct

Critics of the way NASA does business dismiss as superficial the diagnosis that NASA has more program than budget. In their view, the agency's real problem is ineffective management of its resources. Such critics contend that NASA could go forward with its current program without dropping items from its agenda by improving its management and procurement practices, streamlining its operations, and better coordinating its activities with the private sector, other U.S. government agencies, and foreign governments. In short, hard choices would not have to be made between the content of the current program and alternatives. Instead, NASA could aggressively pursue its piloted spaceflight and space science agendas and at the same time increase its spending on technology useful to industry.

1. National Performance Review, *National Aeronautics and Space Administration*, accompanying report to *From Red Tape to Results: Creating a Government That Works Better and Costs Less* (released February 1994), includes many of the suggestions that are included in this chapter. The Congressional Budget Office's evaluation of these issues was completed before the release of the National Performance Review report.

NASA was once perceived as a model government agency.[2] The successful Moon landings it carried out were heralded as a demonstration of managerial efficiency and innovation in the public sector. Thus, the current characterization of NASA in some quarters as a poorly managed agency that is immobilized by external and internal forces is all the more striking. For NASA's critics, the agency's difficulties, ranging from underestimating project costs to the Challenger accident to the recent problem with the Mars Observer, are directly related to the way the agency conducts its business. Specifically, critics place a large part of the blame for these failures on poor planning and contract management and careless acquisition and procurement practices.

The criticism of NASA's institutional character is sometimes so sweeping as to leave no apparent option but to dissolve the agency and start anew. In an extreme negative caricature, NASA is portrayed as an agency run by risk-averse managers who seek to maximize stability and budget growth at the expense of efficiently achieving program goals. Large programs that go on indefinitely and major NASA installations run as independent city-states are the result. This harsh view of the agency maintains that supporters of the program value it largely as a dispenser of local economic benefits--contracts and jobs--rather than as a key part of the nation's science and technology effort. Private contractors respond to NASA management practices by deliberately underbidding contracts, overrunning costs, and delivering unsatisfactory products. There is little incentive for any of the actors in the system to change their ways.

Of course, this extremely negative portrayal of NASA's conduct ignores the agency's strengths and successes by emphasizing only its failings and problems. Nevertheless, even the remotest resemblance of the agency to this unflattering picture raises general questions about the way NASA conducts its activities and specific questions about its management, procurement, and acquisition practices.

Management, Procurement, and Acquisition

Criticisms have been aimed at NASA from two different perspectives. One point of view sees the agency's problems as caused by too much regulation and bureaucracy. The other sees them as rooted in a failure to conform to procurement law and to operate as an efficient bureaucracy.

The position that sees NASA as having too much bureaucracy builds on an analysis of the agency's evolution as an organization and its interactions with a changing legal and institutional environment. In this view, procurement laws that are designed to ensure fairness and protect taxpayers from fraud decrease efficiency by increasing reporting requirements and preventing program managers from adopting cost-saving innovations that may appear. Reporting requirements in particular are seen as a problem because they increase as organizational aging leads to more bureaucratic layers and as a larger number of constituents in both the Congress and the executive branch demand accountability. Answering this critique points toward policy changes that free NASA from some aspects of procurement regulation. One such change--the Mid-Range Procurement Initiative--that the agency is seeking would diminish administrative burdens and expedite procurement. Another change would allow NASA to pursue some projects outside of normal procurement practices through independent program offices. This approach would invest program managers with substantial authority and discretion to accomplish their projects but at the same time hold them accountable for results. Tests undertaken as part of the Strategic Defense Initiative are sometimes suggested as models for this independent program office approach.

A large number of the audits of NASA projects and programs undertaken by the General Accounting Office criticize the agency's conduct of its program from a different point of view. A pamphlet prepared to support the transition to the Clinton

2. The testimony of John Pike, director of the Space Policy Project, Federation of American Scientists, before the Subcommittee on Legislation and National Security, House Committee on Government Operations, October 6, 1993, pp. 3-4, discusses this perception but concludes that NASA has always had major problems in the way it does business.

Administration summarized previous reports and emphasized NASA's failure to conform to procurement laws and its lack of bureaucratic rigor as causes of the agency's problems with performance.[3] Among the particulars offered by GAO were NASA's failure to oversee technical activities by contractors, its acceptance of unauthorized change orders, and the failure to impose uniform test standards across the agency's centers and programs. The solution implied by these criticisms is better bureaucracy supported by standardized, reliable information. Along those lines, GAO noted that during the 1980s, the dollar volume of NASA contracts as well as their absolute number grew by around 50 percent, although the number of procurement personnel increased by only 20 percent.

Institutional Character

NASA's organizational history is relevant to the criticism of its current conduct. A recent scholarly analysis traces the evolution of NASA as an organization from its beginnings as a combination of existing governmental research groups to the present day.[4] That approach reveals the origins of some current problems and suggests how difficult it will be to change the way NASA does business.

NASA's original organizational culture was dominated by engineers and scientists who valued research, testing, and verification and created an organization that had the in-house capability to implement those processes. The young NASA was a dynamic organization supported by growing budgets and freed from the normal constraints of government by a mandate to execute a crash program. In this environment, a detailed, centralized style of program management coexisted profitably with an organizational ethic of technical discretion and dissent.

Yet the factors that contributed to the success of the young NASA also began to undermine its culture. For example, the Apollo program brought large increases in the agency's budget but forced NASA to replace the ethic of "building it in-house" with contracting out work to private industry. The agency sought to retain tight control and its own technical capabilities, however, by "penetrating" the contractor--specifying what would be done and how it would be accomplished and closely monitoring production. According to some observers, this approach prevented NASA's contractors from accomplishing their work efficiently and ultimately proved to be so ineffective in maintaining the technical capacity of the agency that NASA is no longer considered an intelligent buyer.[5] In a similar way, the major NASA centers grew during the Apollo years but diminished the strength of centralized control by acquiring local political and economic significance that was to complicate later program decisions.

Management Reform

In early 1993, NASA announced a set of initiatives to improve management and procurement at the agency.[6] They represent the agency's latest response to the criticism of its practices. NASA's package of management reforms includes seven items:

- Improving planning by directing more funding and attention to the earliest phases of a project;
- Creating program commitment agreements between the NASA administrator and associate administrators to define program objectives, identify technical risks, commit resources, and specify technical and schedule milestones;
- Establishing a Program Management Council that regularly reviews program progress, medi-

3. General Accounting Office, *NASA Management* (January 1993).

4. This discussion draws heavily on Howard E. McCurdy, *Inside NASA: High Technology and Organizational Change in the U.S. Space Program* (Baltimore, Md.: Johns Hopkins University Press, 1993), pp. 159-174.

5. Testimony of Robert Frosch, Senior Research Fellow, John F. Kennedy School of Government, Harvard University, before the Subcommittee on Science, Technology, and Space, Senate Committee on Commerce, Science, and Transportation, November 16, 1993, p. 4.

6. National Aeronautics and Space Administration, *NASA Management and Procurement Reforms* (April 1993); and National Performance Review, *National Aeronautics and Space Administration*, pp. 19-24.

ates between the agency's overall budget constraints and its programs, and fixes or even cancels programs that are experiencing problems with costs, schedules, or technical performance;

- Setting up a mission review process that assesses the progress of spaceflight projects two years and again one year prior to launch;
- Creating an independent capacity for cost estimating in the Office of the Comptroller;
- Improving reporting by contractors to provide senior management with sufficient data to evaluate performance; and
- Developing measures of contractor performance to support oversight by NASA management and to include past contractor performance as an award criterion in selecting new projects.

If the agency's management practices are to improve, the commitment to improvement by senior managers and the political system is probably more important than the specific management approach. For example, improved project planning amounts to a more expensive early development phase for most projects. That kind of process would allow a better preliminary design and more accurate assessment of technical, cost, and schedule risks. The idea is a perennial favorite and is prominently noted, for example, in a 1980 NASA study of project management to support the transition from the Carter to the Reagan Administration.[7] The difficulty lies in carrying out the process and in protecting such funds from reductions in tight budgetary times. The point applies to the proposed program commitment agreement as well: tight budgets can cause commitments to be broken.

Both the proposed Program Management Council and the mission review process raise the question of adding layers of review and management to a system already viewed by critics as too bureaucratic. Unless other review levels are eliminated, such additions are inconsistent with the goal of streamlining NASA's process for procurement and acquisition. Center-level review processes are candidates for elimination because the general drift of the management package is toward more authority and accountability at the program level with oversight shifted to a centralized management authority at the headquarters level.

The management reform initiative to improve "independent cost estimating" implies more than simply reviewing methods and adding personnel. At the heart of the matter is the question of independence from whom or what. The 1990 Augustine report suggests the importance of independence from "overselling on the part of program advocates, both in government and industry."[8] The most radical proposals call for the largest NASA programs to be comanaged by an intra-agency group--for example, the National Space Council. The essence of these suggestions is that "overselling" occurs at the agency as well as at the program level and that truth in estimating costs will require a counterbalance to the authority of NASA's most senior management.

An example of this phenomenon can be found in one version of how the early estimate of $8 billion for the cost of the space station evolved. According to a scholarly analysis by Howard McCurdy, at the time that the idea for the station was being "sold," the formal process of cost estimating within the agency pointed toward a figure higher than $8 billion.[9] (The $8 billion estimate

7. Howard McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice* (Baltimore, Md.: Johns Hopkins University Press, 1990), p. 85.

8. National Aeronautics and Space Administration, *Report of the Advisory Committee on the Future of the U.S. Space Program* (December 1990), p. 37. For similar points, see National Academy of Public Administration, *Program Control in NASA: Needs and Opportunities* (Washington, D.C.: National Academy of Public Administration, 1989), pp. 14-15. This study, which is based on the results of an extensive survey of NASA and industry program managers, reports that "the contractor's negotiated bid generally becomes the baseline . . . this is true even though the contractor's estimate is usually considerably lower than the government's estimate. The rationale for the government's higher estimate is in most cases quickly forgotten. Credibility begins to be attached to the contractor's estimate which is not justified or borne out by history."

9. See McCurdy, *The Space Station Decision*, pp. 175 and 230-233. The author discusses the initial $8 billion estimate for the space station and concludes that the number was ultimately a political device to sell the program rather than a cost estimate of a well-defined project. NASA's professional cost estimators, according to McCurdy, were well aware that the estimate put forward by the agency's leadership was not realistic.

was the extreme low end of a range of estimates and excluded significant costs of the project.) According to McCurdy, the highest level of authority within the agency chose to put forward a more politically appealing lower estimate. Neither improving the quality of cost estimates at the program level nor seeking independent assessments is likely to result in the Congress's receiving better cost estimates, unless the agency's senior managers are committed to providing them.

If NASA can carry out its management reforms, it could reduce the cost of the space program in the future. But projects in the current budget have already been planned and are under contract. If the projects have been carefully designed and their costs accurately estimated, they will not fall victim to the cycle of shifting requirements, technical surprises, and contract changes that have characterized some programs in the past. If not, it is too late for NASA's current round of management reforms to help them.

Procurement Reforms

Among a larger set of offerings, NASA proposes three major changes in procurement:

- Modifying the agency's incentive contracting procedures to standardize them among the various NASA centers and make contractors more responsible for their performance by using types of contracts that allow the government to recover award fees when finished systems fail to perform;
- Streamlining "midrange" procurement (contracts between $25,000 and $500,000) to diminish administrative burdens and expedite the procurement process; and
- Assigning substantial weight to past contractor performance in awarding new contracts so as to place firms that have performed badly in the past at a disadvantage in bidding for new projects.

The direction of NASA's procurement reforms evident in these proposals and in complementary procurement and management initiatives is to create an efficient, standardized process within the agency. Such a process would better define the responsibilities of the government and the contractor and allow the agency to hold contractors accountable for their performance.

Incentive Contracting

The current dissatisfaction with NASA's performance--for example, the problems with the Hubble Space Telescope--has led to a mandated review of the agency's contracting practices.[10] Currently, over 75 percent of NASA's procurement dollars are spent under cost-plus-award-fee contracts (see Box 3). The appropriateness of this form of contract is being questioned, particularly for purchases that do not involve extraordinary technical risk and that might be made on more conventional commercial terms. Even in circumstances in which cost-plus contracting is appropriate, NASA's current incentive contracting practices have been criticized as relying too heavily on interim awards that cannot be adjusted even if the final product is unsatisfactory.[11] In addition, a perception exists that contracting and procurement rules are unevenly and loosely enforced and that award criteria vary across centers.

NASA proposes to tighten the contracting process overall, to evaluate contract performance more on the basis of end results than on interim goals, and to change fee policies to allow penalties for unsatisfactory performance.[12] The agency would create a hybrid contract type that used award fees as

10. The Schumer Amendment to the National Aeronautics and Space Administration Authorization Act for Fiscal Year 1993 directs the agency to review its contracting procedures, specifically those that allocate risk to the government and the contractor.

11. Data for 1992 and 1993 that NASA provided to the Congressional Budget Office in a letter dated August 18, 1993, show an average award score of 88.5 percent and an average award of 87.5 percent of possible fees.

12. National Performance Review, *National Aeronautics and Space Administration*, pp. 6-8.

Box 3.
A Brief History of the National Aeronautics and Space Administration's Contract Preferences

The National Aeronautics and Space Administration's (NASA's) mission emphasizes the development of systems that require technical innovation. The private sector cannot be expected to bear the risk of cost overruns when technologies of the type that NASA has historically purchased are first being brought into use. Accordingly, the agency has long preferred so-called cost-plus contracts that share the risk of unforeseen problems between the government and its contractors.[1]

Cost-plus contracts permit the government to cover the cost of unforeseen problems. Without such arrangements, private firms might be unwilling to take the risk of developing new spacecraft or other similar projects. In its earliest years, NASA combined the cost-plus feature with fixed fees that gave contractors only limited incentives to control costs and meet technical and schedule goals (see the table below).

In the 1960s, both NASA and the Department of Defense adopted the practice of awarding incentive fees at the completion of contracts to encourage better performance. Under this type of arrangement, the fee a contractor received on a particular contract was tied to meeting cost control goals--the incentive to control costs was the promise of higher fees. When cost goals were not met, the contractor's fee was reduced through a formula that divided the overrun between the government and the contractor.

The 1967 fire that occurred during a test of the Apollo capsule brought demands for tighter supervision of contractors. Cost-plus-award-fee (CPAF) contracts that required more frequent evaluations of a contractor's progress and tied fees to goals other than cost control became the dominant contract type until the mid-1980s, when cost-plus-incentive-fee arrangements and even fixed-price contracts came into wider use. The Challenger accident triggered a response similar to that after the Apollo fire: a return to the CPAF contract to insure direct agency involvement in quality and safety assurance.

1. Alexander R. Love, Chairman, Development Assistance Committee, *Development Cooperation* (Paris: Organization for Economic Cooperation and Development, 1992), pp. 112-115, A-8, A-23, and A-24.

Share of Net Value of Procurement Awards by the National Aeronautics and Space Administration, by Contract Type, Selected Fiscal Years (In percent)

Contract Type	1961	1965	1970	1975	1980	1985	1991
Firm Fixed Price	16	12	12	15	12	13	10
Cost Plus Fixed Fee	83	71	42	14	12	9	8
Incentive Fee	n.a.	16	46	69	72	16	3
Cost Plus Award Fee	n.a.	a	a	a	a	56	76
Other	1	1	0	2	4	6	3

SOURCE: Congressional Budget Office based on the National Aeronautics and Space Administration, *Annual Procurement Report* (various years).

NOTE: n.a. = not applicable.

a. Data on incentive fees include both incentive and award fee contracts.

incentives for interim progress but held back a final incentive payment against a last evaluation of a system's performance. The final evaluation process could result in a negative incentive fee and the contractor's returning part of the interim awards to the government. This penalty could be invoked in cases in which performance of the system is ultimately less than satisfactory and the contractor's performance can be identified as a cause.

Formal evaluations of the Department of Defense's (DoD's) use of incentive contracting--either the award fee or incentive fee type--suggest that incentives are positively associated with less growth in the costs for developing strategic missile systems and satellites.[13] The extent to which changing the mix of incentives between interim awards and final performance awards improves project outcomes has not been formally evaluated for either DoD or NASA. As with management reform, gains in efficiency and lower costs from improving NASA's incentive contracting are more likely for new projects than for those already in process.[14]

The Mid-Range Procurement Initiative

The second major procurement reform being proposed by NASA is called the Mid-Range Procurement Procedure. This proposal would streamline the process that NASA uses to buy goods and services valued at $25,000 to $500,000 by permitting it to use procedures similar to those it currently uses for smaller purchases. NASA has received approval from the Office of Federal Procurement Policy to undertake the effort as a pilot test. The objective of the project--less complicated procurement procedures--is conceptually similar to proposals that would allow the agency to buy much more expensive and technically challenging goods and services on commercial terms.

According to NASA's Office of Procurement, only 13 percent of NASA's 1992 procurement funding was spent under contracts covered by the Mid-Range Procurement Initiative. Thus, even an extremely successful reform effort that reduced costs by 5 percent would save only about $85 million annually. The initiative might yield additional savings by decreasing the number of NASA employees working in procurement. However, increasing productivity in procurement activities is more likely to allow the agency to make do with a smaller increase in such personnel than was recently recommended by examiners from both the executive branch and the Congress.[15]

Contractor Performance

A third significant change in procurement that NASA proposes is to take into account past performance by contractors in evaluating bids for new contracts. For example, a contractor that consistently underbid work in the past would lose evaluation points in the agency's assessment of any bid for new work. NASA is developing a set of measures of contractor performance to put this system into operation. The agency's evaluation of a major contractor's performance would be transmitted periodically to the contractor's most senior management.

A New Relationship with the Private Sector

A broad range of suggestions to change the way NASA does business would place more responsibility for final performance on contractors and rely less on NASA's monitoring of them to assure qual-

13. Karen Tyson and others, *Acquiring Major Systems: Cost and Schedule Trends and Acquisition Effectiveness* (Alexandria, Va.: Institute for Defense Analysis, March 1989), p. XI-3.

14. Charles W. Polk, "Contracting from Private Firms for Planetary Mission Subsystems" (discussion paper, California Institute of Technology, January 1994), illustrates a second point: the current set of proposals to reform NASA's contracting practices are neither the only nor the most innovative suggestions.

15. National Aeronautics and Space Administration, Office of Procurement, "Procurement Organization Metrics," letter to the Congressional Budget Office, October 16, 1992; and General Accounting Office, *NASA Contract Management* (December 1992), p. 29.

ity and safety.[16] The incentive contract reform discussed earlier is one move in that direction. A more aggressive action is to fully implement the buy-commercial provision of the Bush Administration's space policy.[17] That policy directed NASA, when feasible, to purchase data and services from the private sector rather than designing, developing, and operating its own hardware to provide similar products.

The various relationships between NASA and the private sector fall along a continuum. At one extreme is NASA's traditional mode of acquisition, which involves the government directly in the design, development, production, launch, and subsequent operation of a spacecraft that produces a data product or service. At the other extreme is the commercial purchase of those same data or services without government oversight of the nuts and bolts of spacecraft design, production, and operation. Between these extremes are contracts that permit the use of standard commercial components in NASA's spacecraft, that specify a system's final performance rather than design requirements, or that deliver a spacecraft in orbit to the agency.

The vision that underlies suggestions to buy more on commercial terms emphasizes two points. First, the aerospace industry can produce the technically sophisticated products that NASA needs more cheaply without government supervision than with that oversight. The traditional mode of procurement forces contractors to maintain separate systems for production and financial control and to use government-approved components. If NASA bought more on commercial terms, it could lower its costs because contractors could integrate their government business with their commercial production lines and accounting systems and could substitute less expensive commercial components for more expensive ones manufactured to government specifications.

There are many cases of higher prices being paid for the same good when purchased through the traditional mode of government procurement rather than commercially. For example, the cesium atomic clock, used in both government spacecraft and Earth-bound commercial navigation and communications systems, reportedly cost 12 times more when purchased through the traditional mode of procurement for government spacecraft than when purchased commercially for use on Earth.[18] The analysis attributed only a two-to-one difference in price to the rigors of use in space, leaving a six-to-one difference attributable to the government's way of doing business.

A 1993 study by the Defense Science Board used a small number of similar cases and expert opinion to develop rules of thumb for estimating savings. The board estimated that various changes in the conduct of government procurement--significant among them, purchasing on commercial terms--could reduce the cost of defense acquisitions by as much as 20 percent.[19] The study concluded, however, that this level of savings was likely only after five years of determined reform. The best judgment of the study board notwithstanding, questions can be raised about how much confidence could be placed in the study's conclusions, given that they were based on a small number of cases rather than on a large sample survey.

Among the candidates for purchases on commercial terms are NASA's communications satellites or the services they provide. Some of the data needed for global climate research, which are now provided by hardware that the government designed,

16. Congressional Budget Office, *Encouraging Private Investment in Space Activities* (February 1991), considers buy-commercial policies from the perspective of encouraging new private investment. The discussion above is principally concerned with buying from the private sector as a policy for lowering the cost and improving the performance of civilian space activities. The accompanying report to the National Performance Review dealing with NASA (pp. 5-7) includes the suggestion to buy data on commercial terms under the broader umbrella phrase of "performance-based contracting strategies."

17. National Space Council, *Final Report to the President on the U.S. Space Program* (January 1993), pp. III-19 through III-22.

18. Helmut Hellwig, "Cost Comparison Between the Space Flight and the Commercial Catalog Models of a Cesium Atomic Clock Module," in National Institute of Standards and Technology, *Reducing the Cost of Space Infrastructure and Operations*, part 2, *Topical Papers*, William C. Stone, ed. (August 1993), pp. 135-144.

19. Defense Science Board, *Report of the Defense Science Board Task Force on Defense Acquisition Reform* (Office of the Under Secretary of Defense for Acquisitions, July 1993), pp. C-1 through C-10. Savings for NASA could be considerably less than the 20 percent savings for DoD because NASA projects often require purchasing only one item, whereas defense procurement includes many multiunit purchases.

developed, and operates, are another frequently suggested candidate. An innovative program to give scientists vouchers for purchasing launch services for small scientific payloads on the commercial market rather than waiting for a government-provided launch is consistent with commercial purchasing.

Purchasing on commercial terms, however, is not a panacea for NASA's procurement problems. For example, when the government is the sole customer for a spacecraft or for the data it produces, the potential savings from commercial purchasing may be offset by the higher price that the government must pay for private financing and the cost of private insurance.[20] In a recent extreme case, the cost to NASA of services procured on commercial terms included the cost of insurance for the providers against the possibility that the government might fail to appropriate sufficient funds to allow NASA to meet its purchasing commitment.[21]

Risk is also an issue. Spacecraft that require advanced technology may ultimately perform better and cost the government less when procured in the traditional mode, which recognizes the uncertainties of cost estimates and applies the expertise of both NASA and its contractors in solving technical problems. One of the few general lessons from years of government acquisition of systems requiring new technology is that fixed-price contracting--an essential element of commercial purchases--is not appropriate for such systems.

Systems used for piloted spaceflight raise the issue of accountability. The public holds NASA directly accountable for the risk of loss of human life in spaceflight, implying a significant degree of oversight by NASA personnel in the design and development of hardware used in programs involving such activities. Each time lives have been lost in the U.S. space program, NASA's relations with its contractors have moved away from commercial terms and toward direct supervision. For example, in the wake of the Challenger accident, the Rogers Commission recommended that both NASA and its contractors maintain a high level of technical engineering skills because the shuttle program was likely to be always in a developmental phase.[22] The prevalence of piloted activity in the current program and its large share of the budget may impose a limit on the agency's commercial purchases and the potential of this type of reform to reduce costs.

A final drawback to wider adoption of commercial purchasing is its potential effect on NASA's ability to be an intelligent customer. The National Academy of Public Administration's 1991 study addressed this issue and concluded that the breadth of the current program and the personnel hours necessary to support award fee contracting were compromising the agency's ability to be a "smart buyer" because NASA personnel were increasingly cast in a hands-off role.[23] Transferring more responsibility to the private sector could further decrease NASA's in-house technical capacity.

Streamlining

The picture critics paint of NASA as an organization choking on its own procedural complexities underlies calls to streamline the agency's acquisition and management system. Advocates of streamlining see two necessary tasks: freeing NASA from excessive regulations for procurement and acquisitions and diminishing the role of NASA's field centers in program management.

20. For a discussion of these issues and several others concerning the budgetary treatment of commercial purchases and their relationship to lease-purchase agreements, see Congressional Budget Office, "Preliminary Analysis of NASA Commercialization Initiatives," CBO Staff Memorandum (February 1989), p. 7. The accompanying report to the National Performance Review dealing with NASA (p. 8) raises a second and related issue concerning the government's liability for termination costs should it choose to withdraw from a commercial purchase agreement.

21. National Aeronautics and Space Administration, "Analysis of NASA Lease and Purchase Alternatives for the Commercial Middeck Augmentation Module" (prepared by Price Waterhouse, the Center for Space and Advanced Technology, and Marsh & McLennon, June 6, 1991), Appendix C.

22. National Aeronautics and Space Administration, *Report of the Presidential Commission on the Space Shuttle Challenger Accident* (1986), pp. 194-195.

23. National Academy of Public Administration, *Maintaining the Program Balance* (Washington, D.C.: National Academy of Public Administration, 1991).

Simplifying Procurement and Acquisitions Regulations

Some proposals for streamlining focus on the process by which the agency designs, develops, and operates even its most technically challenging systems. They emphasize increasing the authority and responsibility of program managers, who would report directly to a central oversight authority instead of being bound by each link in a long chain of command. Costs supposedly would be lower because decisions would be made more quickly and fewer resources would be consumed in oversight and assessment. These proposals overlap with the call for NASA to buy more on commercial terms, but even in traditional procurement, streamlining would place the agency in a more hands-off relationship with its contractors.

A particularly prominent proposal for streamlining was offered under the title of the National Space Enterprise Initiative. (The initiative was never implemented, but many of its ideas persist in other offerings.) Auditors like the General Accounting Office have often recommended that NASA improve the workings of its current management system by redoubling its efforts to carry out federal acquisitions regulations and agency management controls. But the National Space Enterprise Initiative moved in the opposite direction, proposing that NASA remove specific programs from the current system to the extent permitted by law.

In its broadest outlines, the proposal would have granted a special status to some percentage of NASA's new projects. That status would place a project outside of the normal NASA management structure by granting extensive discretion and power to the private contractor and the program manager, who would report to the National Space Council (which operates within the White House Office of Science and Technology Policy) rather than to various levels of NASA center and headquarters management. Administrative expenditures would be limited to 10 percent of costs. Documentation of program requirements and specifications would be subject to arbitrary page limits. Program managers would be shielded from outside interference by a four-year appointment; they would be granted considerable flexibility in resolving problems related to costs or schedules including the option of reducing the project's scope.

The evidence presented to support the effectiveness of these measures is not compelling. It is sometimes claimed that classified military projects or programs of the intelligence community organized along the lines suggested by advocates of streamlining perform better than NASA programs. But no comprehensive study has been undertaken that would allow comparison of the universe of classified and unclassified programs.

The Strategic Defense Initiative Organization (SDIO) is another program offered as an example of successful streamlining. In particular, some advocates of streamlining suggest that three SDIO experiments conducted during the 1980s at a cost of $700 million are comparable to a NASA project costing $2 billion. The previous NASA administrator and an independent space analyst reject this parallel, however, pointing out that the SDIO experiment used hardware that was already developed and launch vehicles already under contract to NASA. They also note that the complexity and duration of a moderate-size NASA mission far exceed those of the SDIO flights.[24] More generally, the independent analyst points out that the cost of subsequent SDIO experiments that required the development of new hardware was similar to comparable NASA efforts.

If streamlining is defined as a loosening of the federal acquisitions regulations, it could increase costs. According to the General Accounting Office's "High-Risk Series" review of NASA's contract management, NASA's failure to implement regulations fully and in a standardized way has led to higher, not lower, costs. Not complying fully with procurement requirements has led NASA field centers to approve changes in contracts without adequate technical evaluation and to allow unpriced

24. Letter from Richard H. Truly, NASA Administrator, to Mark J. Albrecht, Executive Secretary of the National Space Council, February 14, 1992; and testimony of John Pike, Director, Space Policy Project, Federation of American Scientists, before the Legislative and National Security Subcommittee, House Committee on Government Operations, October 6, 1993, pp. 10-11.

changes to persist. Those factors have contributed to cost overruns and unsatisfactory performance.[25]

Even if streamlining improves performance, there remain the social objectives of government procurement beyond buying a good or service at the lowest price. Those objectives include regional economic development and preferential contracting with small businesses and minority-owned firms. No compelling reason exists for space, above any other concern of the government, to be exempt from those objectives.

Changing the Role of NASA's Centers

The Augustine Committee's report and the more recent report on redesign of the space station have raised concerns about the role of NASA's field centers in project management.[26] The redesign report concluded that managers at the centers should act as providers of resources and facilitators, not program overseers. Analogies are often drawn between the role of the field centers in the space program and a negative caricature of the armed services, suggested by some defense analysts, as parochial and likely to pursue their own rather than national objectives. The direction of change in DoD has been toward more authority at the program level with centralized and standardized review at the level of the Office of the Secretary of Defense. Streamliners suggest that NASA take similar action.

Streamlining is unlikely to contribute immediately to resolving the fit of NASA's program into lower annual budgets. In NASA's most prominent attempt to generate savings by streamlining--the space station program--savings are to come from less contractor oversight and a reorganization of the responsibilities of the centers. According to the analysis of the space station redesign, those savings are necessary just to bring the cost of the current program down to the levels that were included in NASA's 1993 budget plan. Reductions below those amounts to the $2.1 billion limit proposed by the Administration could require stretching out the program relative to the January 1993 baseline.

Intragovernmental Coordination and International Cooperation

Another major avenue of reform for NASA that some analysts have suggested would lead to a dramatic increase in its intragovernmental cooperation with the Department of Defense and its cooperation with the space agencies of other nations. Common threads run through both forms of cooperation. New approaches are possible, say these analysts, because the Cold War is over, and those approaches should differ from past arrangements: NASA should enter into ventures in which its dependence on its partners' performance and participation is essential to the success of the venture. Only by fully embracing such joint ventures can the agency expect to make gains in a tight budgetary environment.

Intragovernmental Cooperation

Before leaving office, the Bush Administration issued a study that argued for NASA's involvement in more cooperative ventures with the Department of Defense and foreign nations.[27] The central idea in the report was that the U.S. space program had evolved to meet a unique set of circumstances driven by the conflict between the Soviet Union and the United States. Military efforts were closed and secretive to meet national security needs. In contrast, the civilian effort was open and expansive to meet scientific and foreign policy objectives. Accordingly, each sector developed separate research capabilities, launch vehicles, infrastructure, and op-

25. General Accounting Office, *NASA Contract Management*, pp. 15-21.

26. National Aeronautics and Space Administration, *Report of the Advisory Committee on the Future of the U.S. Space Program*, p. 40; and National Aeronautics and Space Administration, *Final Report to the President, Advisory Committee on the Redesign of the Space Station* (June 1993), pp. 16-19.

27. Vice President's Space Policy Task Force, *A Post Cold War Assessment of U.S. Space Policy* (December 1992).

erational mechanisms. Now that the Cold War has ended, the argument goes, the opportunity exists to eliminate duplication between the civilian and military space programs and reduce the cost of both.

The potential for more intragovernmental cooperation between NASA and other government agencies is largely an issue of NASA and DoD cooperation. One suggestion, to share weather and land-remote sensing satellite systems and data, is not new but may be more feasible now that security concerns have lessened. Another idea is to combine funds from NASA and DoD for new investments in space transportation. NASA and the national security community are the principal government users of space launch services. The nation should invest in only one new core capability to meet its future needs; thus, a basis for cooperation is evident.

As with many other changes in the way NASA does business, the cost of NASA's program may ultimately be reduced by cooperation with other government agencies, but results in the short term are unlikely. In the Earth science area, the long lead times built into military and civilian programs alike push potential savings into 1999 and beyond, even if prompt action is taken. Concerning the capability for space launches, neither NASA nor DoD has large new investments now in its budget plans. Although a coordinated effort might lower the cost to NASA of developing new space transportation systems, any major spending for new systems would require an increase in NASA's budget.

International Cooperation

NASA has long been involved in international space ventures. But the opportunity that now exists for cooperating with Russia would require a fundamental change in NASA's approach to international cooperation and could have significant implications for the long-run cost of achieving the agency's goals in piloted spaceflight.

The space station is the focus of current discussions about changing NASA's approach to international cooperation and many of the other suggestions to change the way NASA does business.[28] After six months of work, NASA has settled on a redesigned station called Alpha, which adds major Russian participation to the long-standing international partnership of the United States, Japan, Canada, and the member nations of the European Space Agency. Russia will contribute launch services and hardware--either selling or leasing equipment to the United States; it will also have an ongoing operational role, carried out by the Russian Space Agency.

The essential difference between this venture into international cooperation and previous NASA efforts is the agency's heightened dependence on foreign partners to fulfill goals of the mission successfully. NASA has limited its past ventures with foreigners to "value-added" activities that increased the output of a specific venture but that were not absolutely necessary to achieve the basic objectives of the mission. (An example is Europe's development of the spacelab module that increased the scientific capabilities of the space shuttle.) The broad outlines of the international partnership NASA describes would create a strong interdependence between the U.S. and Russian space programs, which introduces a substantial and obvious political risk into the U.S. space program. Counterbalancing this risk are the benefits of the facility's being fully operational earlier than it would otherwise and a claim of cost savings.

28. In March 1993, the President directed NASA to undertake a 90-day study to redesign the space station. Subsequently, an internal NASA redesign team and an external group of experts, the Advisory Committee on the Redesign of the Space Station (the Vest Committee, after its chairman Charles M. Vest, president of the Massachusetts Institute of Technology), were convened. The Vest Committee in particular foresaw gains in efficiency and savings; indeed, it asserted that the internal NASA team's estimate of annual program savings of $300 million constituted "minimum gains." The committee saw NASA realizing savings of $700 million to $1 billion annually once the improvements from the space station program worked their way through the entire system. By September 1993, the redesign culminated with the decision to include Russia in the international partnership. See National Aeronautics and Space Administration, "Space Station Redesign Team: Final Report to the Advisory Committee on the Redesign of the Space Station" (June 1993); and National Aeronautics and Space Administration, *Final Report to the President.*

That claim is controversial, however. Experience indicates that cooperative ventures usually cost more than national efforts.[29] Moreover, the estimated cost of the Alpha station is not fully developed as yet. A major review of the current design is scheduled for March 1994, and contracts to go forward with the design will not be finalized until later in the summer. NASA's preliminary estimates showed that Russian participation would lower the cost of Alpha by almost $4 billion.[30] Those savings proved tenuous, however, and the most recent estimates indicate only $2 billion in savings. A six-month slip in the schedule for the first launch of U.S. hardware could portend a further decrease in that figure.[31]

Even if one takes NASA's claims of savings at face value, there is still cause for concern because the savings are not achieved until after 1998. NASA projects that spending for the space station will be at least $2.1 billion annually through that year regardless of which option is pursued. Long-time observers of NASA are understandably skeptical; these claims sound similar to ones made for high flight rates and low operating costs for the shuttle system--claims that have proved to be false.

Skepticism seems warranted as well about whether the agency can support its estimates of the cost and content of the space station design. The agency is under extraordinary pressure to reduce costs. In the past, such pressure has led to underestimations of project costs. Although significant elements of the Alpha design are based on the very mature Freedom design (which preceded Alpha), new engineering and cost estimating issues arise with each new paper design and with the introduction of Russia as a partner. NASA readily admits that problems have arisen from such uncertainties in the past; they could well threaten the cost, content, and schedule of the redesigned space station in the future.

Opportunities also exist for international cooperation in areas other than the space station. (For example, the level of cooperation in Earth observation could be increased.) Like the savings generated by international partnerships for the space station, however, savings in other areas of NASA's budget are unlikely to be realized until the beginning of the next century.[32]

Total Quality Management

Beyond NASA's specific problems is a pervasive sense of institutional crisis. NASA's administrator has alluded to this on many occasions and has embarked on an effort to redefine NASA as an institution. The "quicker, cheaper, better" approach to spaceflight projects, the space station redesign, the planned reduction in NASA's federal work force, and the agency's proposed management and procurement reforms are all parts of this effort. Adopting and carrying out the managerial philosophy of total quality management (TQM) is both a symbol of the agency's commitment to reform and a unifying thread among the changes its senior management seeks. That thread also connects NASA with the broader movement to reinvent government.

TQM is a managerial philosophy whose objective is achieving customer satisfaction through continuous improvement of production processes.[33]

29. As Norman Augustine, chairman of the Advisory Committee on the Future of the U.S. Space Program, recently testified, "International programs are *far* more complicated to manage, governments and their priorities change . . . and anticipated cost savings are seldom realized." See his testimony before the Subcommittee on Science, Technology, and Space, Senate Committee on Commerce, Science, and Transportation, November 16, 1993, pp. 7-8.

30. National Aeronautics and Space Administration, "Space Station FY 1995 Budget to OMB" (October 12, 1993), p. 43.

31. Testimony of Daniel Goldin, NASA Administrator, before the Subcommittee on Space, House Committee on Science, Space, and Technology, February 23, 1994.

32. Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Systems and Applications* (July 1993), pp. 89-91.

33. The TQM literature is vast. A large part of it is definitional and historical or oriented toward applications. Relatively little research has attempted to apply formal analysis to determine how TQM works. The Winter 1991/1992 edition of *GAO Journal* has two articles and an interview with TQM pioneer Joseph M. Juran that define terms, evaluate TQM in the private sector, and discuss the application of the philosophy within GAO specifically and within the federal government generally. See John E. Watson and Thomas W. Hopp, "The Private Sector's Experience with Total Quality Management," pp. 34-38; Mary R. Hamilton, Allan Mendelowitz, and Richard L. Fogel, "TQM at GAO," pp. 39-47; and "Some Thoughts at the Outset," an interview with Joseph Juran, pp. 48-54, all in *GAO Journal* (Winter 1991/1992).

Customer satisfaction and the positive performance indicators that go with it--profitable firms and well-paid workers--are achieved by committed managers and empowered employees seeking to continuously improve their products by applying empirical data and analysis to production processes.

First adopted by private manufacturing firms in Japan, TQM spread to private manufacturers in the United States in the late 1970s, achieved wide acceptance in the 1980s, and by late in the decade was being adopted by large parts of the federal government. In addition to those specific applications, the federal government adopted TQM as a general policy to improve private productivity and created the Baldridge Awards in 1987.[34] Modeled on the Deming Prize, which since 1951 has been awarded to firms in Japan that achieve success in quality management, the Baldridge Prize gave TQM a high profile in the United States.[35] Although the TQM philosophy originated in manufacturing, it has spread to the service sector, where it has gradually won adherents. That consideration is pertinent to NASA's internal attempt to implement TQM, because in some respects the agency functions more like a private-sector service firm than like a manufacturer.

TQM is perhaps best understood when contrasted with a caricature of "traditional" quality control in manufacturing: workers mindlessly executing the plans of middle management that incorporate quality into the production process only through end-of-the-line inspection and correction of defects. In contrast, TQM emphasizes the active participation of workers in determining how output will be produced and offers a set of tools to analyze processes, identify problems, and develop improvements.

Private-sector acceptance of TQM exceeds the available objective evidence of its effectiveness. Nevertheless, the claims of success that practitioners offer are impressive. In an open letter published in the *Harvard Business Review*, the chief executive officers of American Express, IBM, Proctor and Gamble, Ford, Motorola, and Xerox proclaim that TQM works: "Results from TQM at our companies range from halving product-development cycle time to a 75 percent improvement in 'things gone wrong' in shipping products to a $1.5 billion saving in scrap and rework over a five-year period."[36] Evidence of a positive relation between TQM and performance indicators in employee-related areas, operations, customer satisfaction, and financial results was also presented by GAO in applying for the Baldridge Award in 1988 and 1989.[37]

Several large sample surveys of firms that have adopted TQM show that not all of them have been successful in attempting to implement the approach. One survey of more than 500 companies in the United States, Canada, Germany, and Japan casts doubt on the universal success of TQM and, according to *The Wall Street Journal*, suggests that "many businesses may waste millions of dollars a year on quality improvement strategies that don't improve their performance and may even hamper it."[38] Another survey of 500 U.S. manufacturing and service firms found that only 36 percent of all firms (43 percent of manufacturing concerns and 28 percent of service firms) thought that TQM had had a significant impact on their competitive position. Two-thirds of the firms surveyed, however, anticipated future gains in their competitive strength.[39] This anticipation of future benefits emphasizes the long time frame over which advocates of TQM seek improvement. Japanese firms using the approach have decades of experience; the most successful U.S. practitioners (for example, Motorola) have used TQM for a little more than 10 years.[40]

34. David A. Garvin, "How the Baldridge Award Really Works," *Harvard Business Review* (November/December 1991), pp. 80-93.

35. Mary Walton, *The Deming Management Method* (New York: Putnam, 1986), p. 15, describes the Deming Prize and W. Edward Deming's role in the quality management movement.

36. "An Open Letter: TQM on the Campus," *Harvard Business Review* (November/December 1991), pp. 94-95.

37. General Accounting Office, *Management Practices: U.S. Companies Improve Performance Through Quality Efforts* (May 1990).

38. Gilbert Fuchberg, "Total Quality Is Termed Only Partial Success," *The Wall Street Journal*, October 10, 1992, p. B1.

39. Arthur D. Little, *Executive Caravan Survey Summary* (undated), transmitted to the Congressional Budget Office on August 30, 1993.

40. "The Cracks in Quality," *The Economist*, April 18, 1992, pp. 67-68.

NASA was among the first federal agencies to adopt TQM during the late 1980s. According to a 1992 GAO survey, eight NASA installations employing roughly 20,000 people have adopted the approach.[41] Four of the installations placed themselves in the GAO category of "just getting started," three in the category of "implementation," and one in the more advanced category of "achieving results." The GAO survey defined two categories of results from the benefits of TQM: external organizational performance (the implementing agency's perception of how it was doing with its customers) and internal operating conditions. For NASA installations as for a larger survey population of over 2,200 federal facilities, self-reported improvement in both categories was correlated with progress along GAO's five-phase scale. (The three categories noted above are bounded by a first phase, "deciding whether to implement TQM," and a final phase, "institutionalization.")[42] Among the improvements noted was a reduction in costs, although GAO does not report how much or in what categories of effort.

Even if TQM is ultimately successful, its adoption is unlikely to lower the cost of NASA's program or have a significant budgetary impact--at least in the next several years. Experience with TQM in the private sector indicates that it is most effective when consistently practiced over a long period. Experience with TQM in the federal government, including that of NASA, is relatively limited. Like the private sector, the federal units that have adopted and continued using TQM report success--but only after several years of effort. Those findings should create skepticism about claims that immediate cost savings will follow the decision to put TQM in place.

Such caveats, however, should not be taken to mean that TQM does not work or that it will not work for NASA. Surprisingly little empirical analysis exists about the effectiveness of TQM; most evaluations are flawed because they are based on self-reported data by the organizations practicing TQM and are not subject to external verification. Nevertheless, the wide adoption of TQM in the private sector attests to its general, although not universal, success.

Can Reforms Make a Difference?

Calls for improving acquisition and procurement procedures are not unique to NASA's activities. The Department of Defense has also been subject to waves of criticism and reform. The acquisition and procurement environments in which NASA and DoD operate have marked similarities. Both agencies are the sole customer for many of the systems that they acquire. Each requires the development and incorporation of advanced technology into the goods it buys. And the same industrial base supplies both agencies. A significant difference between the two is that most acquisition for DoD includes both a development and a production phase; in contrast, many of NASA's acquisitions end with the development of a single system. Yet even this difference has diminished in recent years. NASA's shuttle program requires relatively large production runs of some items--for example, the solid rocket boosters--and more and more of NASA's projects have long operational lives.

Overview studies of improvements in military acquisition are not a basis for optimism about the ability of reform to improve the costs, schedules, and technical performance of NASA's projects. A RAND study of DoD that was released in 1986 compared DoD's acquisition performance in the 1970s with its performance in the 1960s. The study cited improvements in several measures of performance: cost growth, schedule slippage, and functionality. Moreover, RAND analysts were optimistic that a trend had been established based on early data from the 1980s.[43] A later study by the Institute for Defense Analysis confirmed the RAND finding of improvement in the 1970s compared with the previous decade but expressed concern about the

41. General Accounting Office, *TQM Implementation at NASA* (April 1993), p. 2.

42. General Accounting Office, *Quality Management: Survey of Federal Organizations* (October 1992).

43. Michael Rich and Edmund Dews with C.L. Batten, *Improving the Military Acquisitions Process: Lessons from Rand Research* (Santa Monica, Calif.: RAND Corporation, 1986), p. vii.

1980s. The IDA concluded that there was "little indication that acquisition program outcomes are getting either substantially better or worse. Development schedule growth and cost growth in development, production, and the total program remain persistent problems, even though considerable improvements have been made in the information available to the program managers."[44]

The Congressional Budget Office's review of NASA's ongoing effort to change the way it conducts its business indicates that this effort probably will result in few budgetary savings. Experience shows that the costs of some projects are likely to exceed current estimates and that better management may be necessary just to bring costs to the level of the estimates, let alone reduce them. Furthermore, any reforms that are carried out will have their greatest budgetary effect on new projects rather than on those that are now part of NASA's program. The agency's present focus on piloted spaceflight is likely to limit the effect of cost reduction proposals that aggressively transfer the implementation of NASA's program to the private sector. The public's demand for accountability by the agency may not permit NASA to take the more "hands-off" stance that such a transfer would imply.

44. Tyson and others, *Acquiring Major Systems*, p. IV-12.

Chapter Four

A Focused Strategy and Alternative Programs for NASA

An alternative to the National Aeronautics and Space Administration's strategy of adjusting to lower future budgets is to radically restructure the agency's program to fit a more limited budget outlook. This chapter outlines three illustrative alternatives to NASA's current program. Each adopts a more focused strategy than the current program by emphasizing one of the major objectives that the agency has historically pursued.

The cost of each alternative is limited to $14.3 billion annually over five years. The Congressional Budget Office (CBO) has developed two of the three alternatives to require lower levels of funding in recognition of the national emphasis on deficit reduction and the prospect of fewer benefits from spending on programs that pursue more limited and narrower objectives than the current program. An implicit cost of each alternative is the potential benefits that each would forgo compared with successfully carrying out the agency's current strategy, which attempts to maintain the broad array of NASA's traditional activities and the benefits that those activities provide.

Program Alternatives

One way to address many of the criticisms of the cost and content of NASA's program is to narrow dramatically the focus of the agency's activities. If one of the agency's problems is trying to do too much with too few dollars, then a solution is to do less. Although the strategy of adjustment that NASA is now pursuing has required that projects be scaled back, delayed, or even canceled, the basic structure of the program has remained intact. The three alternatives that follow share the characteristic of breaking that recent pattern:

- Placing even greater emphasis on piloted spaceflight and exploration, within an annual budget of $14.3 billion;
- Emphasizing space science, including piloted spaceflight for scientific purposes, within an annual budget of $11 billion; and
- Emphasizing technology and missions with commercial potential and science with applications value, and eliminating the piloted spaceflight program, within an annual budget of $7 billion.

The selection of these alternatives is arbitrary, but each emphasizes one of the broad objectives from NASA's current program that the agency has pursued over its 37-year life span. Each alternative would narrow the focus of NASA's activity but would support the emphasized activity more aggressively than the current program, even when the total budget for the agency is smaller. For example, the technology and space science alternative emphasizes aeronautics, funding these activities at $1.5 billion--a 75 percent increase above the 1993 level--although the total NASA budget under this alternative would be only half of its current level. (See Table 5 for a budgetary outline of each alternative and of NASA's 1993 budget, the baseline from which they were developed.)

The alternatives are outlines of different program structures that NASA could adopt, not well-defined program plans. The descriptions of each alternative that follow include only illustrative activ-

Table 5.
National Aeronautics and Space Administration's 1993 Operating Plan and Alternatives
(In millions of dollars of budget authority)

	1993 Operating Plan	Alternatives		
		Piloted Spaceflight	Space Science	Technology and Space Science
Research and Development				
Space station	2,123	3,000	0	0
Space transportation capability	649	650	555	0
Space science and applications				
Physics and astronomy	1,104	400	1,200	450
Planetary exploration	474	800	700	300
Life sciences	140	190	200	0
Microgravity	173	200	200	0
Earth science	864	300	1,200	1,200
Other	111	0	200	200
Subtotal	2,866	1,890	3,700	2,150
Space research and technology	273	900	200	500
Commercial programs	164	0	0	100
Aeronautical research and technology	866	500	500	1,500
Safety, reliability, and quality assurance	33	33	33	33
Academic programs	93	93	93	93
Tracking and data advancement systems	23	23	23	23
Total	7,089	7,089	5,104	4,399
Space Flight, Control, and Data Communications				
Shuttle production and operations capability	1,053	1,053	600	0
Shuttle operations	3,016	3,016	2,800	0
Space and ground tracking systems	836	836	636	500
Launch services	181	181	280	1,000
Total	5,086	5,086	4,316	1,500
Construction of Facilities	525	525	300	285
Research and Program Management	1,615	1,615	1,265	800
Inspector General	15	15	15	15
Total, Operating Plan and Alternatives	14,330	14,330	11,000	7,000

SOURCE: Congressional Budget Office based on data from National Aeronautics and Space Administration, "Operating Plan for 1993" (1993).

NOTE: Numbers may not add to totals because of rounding.

ities taken from the voluminous literature cataloging and recommending activities for the agency. Although the costs of the second and third alternatives are provided as point estimates, their actual costs could vary by perhaps as much as a billion dollars above or below the illustrative estimate.

An actual program plan would include far more detail about the activities NASA would undertake in pursuing an alternative to its current program. An actual plan would also include a transition strategy and budget for personnel, facilities, and projects. As the ongoing adjustment to lower defense spending shows, significant costs are incurred when an agency reduces its work force, closes facilities, or dramatically alters its priorities, as NASA would if it were to carry out any one of the alternatives. The outlines that follow do not include such plans. The outlines also do not include the reformulation of international agreements that would have to take place if NASA's program and budget were substantially reduced.

Piloted Spaceflight and Exploration

This alternative would direct NASA's resources toward piloted spaceflight, concentrating on the space station program and new technology to support future piloted exploration of the solar system. It responds to those critics of the content of NASA's current program who contend that the agency does not give a high enough priority to human exploration of the solar system. Spending for space science and technology activities in areas that do not directly support human exploration would be reduced dramatically under this alternative.

The pace of human exploration activities is likely to be slow, however, as most estimates of the cost of a base on the Moon or a mission to Mars make such activities unaffordable within the budget constraints on this alternative. Even under the best of circumstances, the space station would only become operational late in this decade, and the spending for new technologies to enable future missions might not bear fruit until even later. Nevertheless, reallocating funds to emphasize the objective of piloted spaceflight should build a better foundation for a return to the Moon or a piloted mission to Mars than either of the other alternatives or NASA's current program. Moreover, this alternative would allow the Administration to pursue the foreign policy objective of joint U.S.-Russian development of a space station with more confidence that adequate funding will be available.

Under this alternative, the space station program would receive $3 billion annually, $900 million above the 1993 level. This amount is sufficient to cover the annual cost of any of the three options identified in the space station redesign effort of 1993.[1] Over a five-year period, funding may even be sufficient to include a large centrifuge.[2] Funding for space research and technology would also increase under this alternative from the 1993 level of $270 million to $900 million to permit early development of the launch vehicles and spacecraft necessary for a base on the Moon or a mission to Mars. The ill-fated Space Exploration Initiative proposed by the Bush Administration provides a blueprint for a similarly expanded research agenda.[3] This alternative would decrease funding for aeronautical research and technology from $865 million to $500 million and redirect it to support the development of technology necessary for a transatmospheric vehicle that potentially could play a role in meeting the Earth-to-orbit transportation needs of future piloted exploration. The budget category for the space shuttle and space tracking net-

1. National Aeronautics and Space Administration, "Space Station Redesign Team: Final Report to the Advisory Committee on the Redesign of the Space Station" (June 1993), Table CS-4, provides estimates of the annual funding necessary to build each of the three options evaluated in the report. Peak annual funding is $2.9 billion in two of the options for 1996 but below that level in each option for all other years.

2. The centrifuge is needed to study the effects of varying levels of gravity on mammals and by some accounts is a necessary precursor to a piloted mission to Mars. A cost estimate (about $800 million over seven years) for a centrifuge and experiments is included in General Accounting Office, *Space Station: Program Instability and Cost Growth Continue Pending Redesign* (May 1993), p. 5.

3. See National Aeronautics and Space Administration, *Budget Estimates, Fiscal Year 1989*, pp. RD 15-1 through RD 15-7. NASA's budget request outlines a program of increased spending for space research and technology in justifying its request to increase funding for this activity from $239 million in 1988 to $391 million in 1989.

works--Space Flight, Control, and Data Communications--would be maintained at the 1993 level, anticipating eight shuttle flights per year.

The space science and applications budget that funds activities in astrophysics, planetary exploration, and Earth observation would be reduced from its 1993 level of $2.9 billion to $1.9 billion, its lowest level under any of the three alternatives. This smaller total would be redirected toward robotic missions to support future piloted exploration of the solar system and toward microgravity and life sciences research that would benefit most from having a permanent piloted facility in Earth orbit. Under the planetary exploration program, NASA would probably undertake robotic precursor missions to Mars and a lunar survey mission to facilitate future piloted activities.[4]

This alternative would dramatically change the Earth science and physics and astronomy programs, restricting them to a combined budget only 35 percent as large as the budget for 1993. In particular, the Earth Observation System program would be hard hit. This alternative would restrict even the operation of missions that are currently in orbit--for example, the Compton Gamma Ray Observatory and the Hubble Space Telescope.[5] In sum, planners of space science activities would be forced to pursue the "cheaper, better, quicker" philosophy because tight budgets would preclude the large-scale missions that have recently dominated NASA's activities in this area.

Space Science

The space science alternative would increase funding for this category of projects but at the same time decrease NASA's total funding from $14.3 billion to $11 billion. The total annual cost of this alternative could vary between $10 billion and $12 billion.

This plan emphasizes the creation of new scientific knowledge, including knowledge gained in piloted spaceflight. The mix of programs under this alternative addresses the criticism that NASA's current program places too much emphasis on piloted spaceflight when the agency's major contribution has been--and should be--creating new scientific knowledge.

The level of spending for space science in NASA's 1993 budget was $2.9 billion, but this alternative would increase that figure to $3.7 billion, a jump of 28 percent. Recent budget plans indicate that these funds could be productively spent. The program plan for NASA that underlay the last budget submitted by President Bush would have required $3.8 billion by 1994 to carry out its agenda for space science. And even after decreasing the capability of the Earth Observation System and the Advanced X-Ray Astrophysics Facility (AXAF), the Administration's request for NASA for 1994 projected a budget for currently active programs of almost $3.5 billion by 1996. This alternative would support new large-scale missions under its $11 billion ceiling as the development of current projects--AXAF and the Cassini mission to Saturn--was completed and funds were shifted from scientific efforts necessary to extend human activities in space to more fundamental scientific enterprises.

This alternative does not directly address the "cheaper, better, quicker" criticism of shuttle-era space science. It would, however, permit the small space-science satellite programs already on the NASA agenda to go forward. Additional funding for the planetary exploration program would be sufficient to allow, for example, the development of the small Discovery missions now under discussion. Because the alternative would eliminate research directed toward major new propulsion systems and piloted spaceflight, the lower level of funds for space research and technology is adequate to continue research on small satellite systems.

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4. An example of a precursor mission is the U.S. Mars Environment Survey, which would land several small rovers on Mars by the turn of the century at an estimated cost of $1 billion. See Craig Covault, "Mars Strategy Begs for Direction," *Aviation Week and Space Technology*, October 5, 1992, pp. 25-26.

5. Cutting funds for operating technically healthy spacecraft is an issue that is now under discussion. See Leonard David, "Science Spacecraft May Be Threatened with Tight Budgets," *Space News*, June 28-July 11, 1993, p. 17.

CBO has assigned an arbitrary figure of $11 billion to fund the programs that would be supported under this alternative, but that total could vary between $10 billion and $12 billion, depending on how much piloted spaceflight was justified on strictly scientific grounds. This alternative would exclude the space station (with a budget of $2.1 billion in NASA's 1993 program) on the grounds that the project cannot be justified on its scientific contribution alone, a point that many space station supporters accept.[6] This alternative would limit piloted spaceflight to four shuttle flights annually.[7] Most of those flights would be devoted to spacelab missions in support of scientific activities in astrophysics, materials research, and Earth observation.[8] The justifications for supporting piloted spaceflight that apply in the first alternative--improving relations with Russia, influencing Russian policies on arms and technology sales, and preparing for future piloted exploration of the Moon or Mars--would not be applicable under this alternative.

The space science alternative includes some funding for piloted spaceflight, however--$4.0 billion, or 80 percent of the total funding provided for the space shuttle program in 1993. The budget to operate the shuttle would be reduced by slightly more than $200 million (anticipating four rather than eight flights per year).[9] The budget for shuttle production and operational capability funding would be reduced from $1 billion to $600 million by terminating most efforts to improve the shuttle system. A final $200 million reduction would come from the data and communications account as a consequence of eliminating piloted spaceflight. A space science agenda that includes piloted spaceflight for life science and experiments with microgravity materials does not permit additional reductions.

Technology and Space Science

The technology and space science alternative would concentrate resources in those areas in which tangible payoffs are most likely: developing technologies directed toward specific industries and space science activities with significant applications value. (Satellite programs that gather data for understanding global climate change are a primary example of the latter.) Adopting this alternative program would effectively end the current era of piloted spaceflight for the United States but would not preclude future piloted activities that relied on less expensive but as yet undeveloped launch and spacecraft technologies. NASA's budget would be cut to $7 billion, less than half the 1993 level.

This alternative attempts to make NASA's program more responsive to economic concerns and addresses the criticism that NASA's activities do not make a significant contribution to productivity in U.S. industry. Accordingly, the aeronautics budget would be set at $1.5 billion, an almost 75 percent increase over the 1993 level of $865 million. With this level of program funding, NASA could work actively with industry to develop the technologies necessary for future generations of both long- and short-haul aircraft. Reorienting NASA away from piloted spaceflight also would free up construction funds to reconstruct wind tunnels and improve other facilities that support aviation research. For example, funding for the National

6. D. Allan Bromley, Assistant to the President for Science and Technology, in his letter of March 11, 1991, to Vice President Dan Quayle includes an attachment entitled "Scientific Rationale for the Restructured Space Station." Bromley's statement is an example of the kind of argument for the space station that acknowledges that its scientific usefulness is confined to preparing for future piloted spaceflight. The letter portrays microgravity science and other potential applications of the space station as far too insignificant to justify the cost of the program.

7. Questions have been raised about whether the shuttle system can be safely operated at a flight rate of only four missions a year. If it was necessary to fly six missions annually, a number that most observers agree is within the margin of safety, the cost of the space science alternative would be greater than the $11 billion estimate by roughly $100 million.

8. The spacelab system includes pallets that carry experiments and instruments in the shuttle orbiter's payload bay and a modular laboratory that extends the habitable volume of the orbiter. The laboratory can be used for experiments in processing materials; the pallets carry instruments that are designed to look outward for physics and astronomy observations or back toward the Earth for Earth science observations.

9. This estimate of savings assumes that the marginal cost of a shuttle fight is $50 million. NASA puts this cost at $44 million. See General Accounting Office, *The Content and Uses of the Shuttle Cost Estimates* (January 1993), p. 8.

Aeronautics Facilities Upgrade, which decreased in NASA's 1995 budget request, could be maintained under this alternative.

Space research and technology, and commercial programs would be funded at $600 million, an increase over the combined 1993 funding of $435 million for these activities. Spending would be shifted within these programs toward technologies that had commercial potential and away from those that required piloted spaceflight.[10] This alternative would include a technology program to support the development of lower-cost, lightweight satellites for communications, remote sensing, and navigation. Funding would also be sufficient to aggressively pursue commercial-style purchases of data that would encourage innovative approaches to Earth observation. Programs to improve unmanned launch vehicles and facilities could also be funded under the technology and space science alternative.

The technology and space science alternative would encourage cost-sharing arrangements with industry to fund activities that directly benefited specific manufacturers or service providers. This part of NASA's program could also be used to cofund, with the Department of Defense, demonstrations of new approaches to fundamental problems of space activity--for example, supporting the single-stage-to-orbit rocket program. Support for the Landsat program might also be drawn from this account.

Funding in the space science area would be cut under this alternative to $2.1 billion, or about $700 million less than the 1993 level. Earth science activities would receive priority because they have the potential to generate data for environmental policy decisions as well as new scientific knowledge. The physics and astronomy and planetary explorations programs would be cut below 1993 levels. A part of that reduction and the general reduction in the space science area would come from cutting science activities that depended on piloted spaceflight, which in the 1993 program accounted for at least $400 million.

Ending piloted spaceflight would decrease spending for space transportation dramatically. The program outline for this alternative includes only $1.5 billion for the Space Flight, Control, and Data Communications activity that was funded at almost $5.1 billion in 1993. This funding would support the purchase of expendable launch vehicle services and tracking for space science missions.

Comparing Benefits

The choice of which program NASA should pursue in a constrained fiscal environment should depend on which program provides the greatest benefit relative to its cost and other uses of the same resources. Uncertainties, however, present major obstacles to that type of analysis. NASA's output is difficult to measure and value. The probability of the agency's actually achieving the objectives of a specific program is also difficult to evaluate.

This analysis does not solve the problem of valuing piloted spaceflight or scientific missions. But it illustrates that the often mentioned "balance" between piloted and unpiloted activity in the current NASA program is neither the only one possible nor necessarily the "best" approach.

As the second alternative to the current program shows, a set of activities that would provide a more rapid expansion of scientific knowledge can be pursued under a smaller total budget if piloted spaceflight is deemphasized. The difference in cost between the two options, however, indicates that to prefer the piloted spaceflight alternative to the space science option is to grant that the former would provide $3 billion more in annual benefits.

In a like manner, the third alternative outlines a NASA program with an even smaller annual budget

10. Microgravity materials processing--primarily growth of protein crystals--is the commercial prospect in the current program that would be lost under an alternative that did not include piloted spaceflight. The importance of this research to the private sector is minimal. Microgravity materials processing on its own is of insufficient value to justify piloted spaceflight but is an area worth exploring if piloted activities are being pursued. For a discussion of the industrial prospects for microgravity materials processing, see Congressional Budget Office, *Encouraging Private Investment in Space Activities* (February 1991), Chapter 4.

that focuses on developing technology useful to the aerospace industries and environmental monitoring to provide both worthwhile "pure" science and information necessary to support future environmental policymaking. The technology and space science alternative could achieve most of the scientific objectives included in the space science option because it does not bear the costly burden of piloted spaceflight. To prefer the piloted spaceflight option to the technology and space science alternative is to value the results of piloted spaceflight at $7 billion more each year compared with those associated with the technology and science alternative.

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