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.

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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

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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.