

GAO

Report to the Chairman, Subcommittee  
on Investigations and Oversight,  
Committee on Science, Space, and  
Technology, House of Representatives

January 1993

# SPACE TRANSPORTATION

## The Content and Uses of Shuttle Cost Estimates

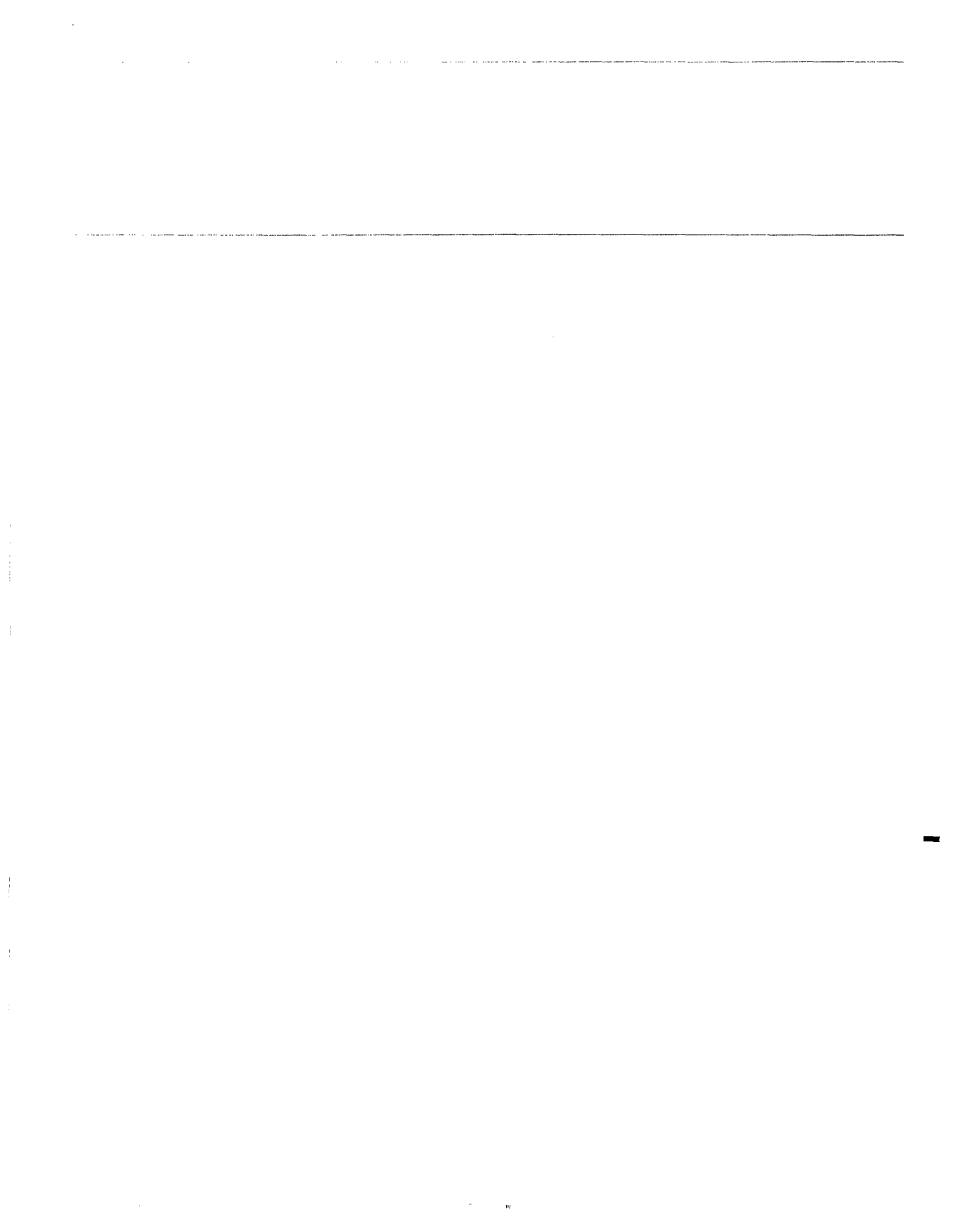


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**National Security and  
International Affairs Division**

B-251737

January 28, 1993

The Honorable James A. Hayes  
Chairman, Subcommittee on  
Investigations and Oversight  
Committee on Science, Space,  
and Technology  
House of Representatives

Dear Mr. Chairman:

This report responds to the former Chairman's request that we review the National Aeronautics and Space Administration's (NASA) estimates of the space shuttle's average cost per flight and marginal cost per flight. The Congress needs to understand the content of these estimates to avoid confusion over what it costs to fly the shuttle. Our specific objectives were to determine (1) what costs are included in or excluded from each estimate and (2) how these costs should be allocated to NASA payload missions that are transported to space in the shuttle.

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**Results in Brief**

The "average cost per flight," which NASA estimated at \$413.5 million in fiscal year 1993, includes most costs that NASA budgets as shuttle operations, as well as costs for operation of its space communications network and costs for civil service personnel working on the shuttle program. However, the average cost does not include any of the approximately \$30.2 billion spent through 1992 to develop the shuttle, acquire reusable hardware and equipment such as the orbiters, and construct and modify facilities. Nor does the average cost per flight include any of the more than \$1 billion that NASA estimates will be needed annually for future shuttle upgrades and for improvements such as the advanced solid rocket motor.

For fiscal year 1993, NASA estimated the marginal cost savings associated with deleting a single flight at \$44.4 million. Marginal cost includes consumable hardware and materials and personnel that can be added or removed with temporary adjustments in the flight rate. It does not include any of the fixed costs that are required if NASA is to maintain the capability to fly the shuttle eight or nine times per year. NASA says that these fixed costs account for about 90 percent of the total operations cost of a flight.

There is no single criterion that is generally accepted for determining what costs to include when attributing shuttle transportation costs to payloads. NASA uses the marginal cost per flight because the elimination of a single flight in a given year would allow the agency to avoid only incremental costs, such as the cost of propellants required for the flight. We agree that marginal cost per flight is appropriate for programs that are occasional users of the shuttle during a given fiscal year. However, we believe that the average cost per flight would better reflect the cost of transportation for payloads that are frequent shuttle users. Because the Space Station Freedom program will be the predominate user of shuttle services in fiscal years 1997 to 1999, it should be allocated a proportionate share of the shuttle's fixed operating costs when calculating transportation costs during those years.

## Background

The space shuttle, formerly known as the "space transportation system," was developed in the 1970s to transport scientific, defense, and commercial space payloads into earth orbit. The shuttle was originally expected to make space flight routine and inexpensive. It has never lived up to that expectation, however. Original plans to fly the shuttle up to 60 times a year have been pared down to about 8 flights a year. Policies that would eventually have resulted in the United States relying heavily on the shuttle for access to space have been changed. Current policy is to use the shuttle only for payloads that require a human presence and when the unique capabilities of the shuttle or some other compelling circumstance, such as national security considerations, dictate its use.

Congress and the executive branch officials need reliable information about the cost of space payload missions to make decisions about those missions and the programs they support. NASA provides information about the costs of its major payload missions in response to several legislative requirements.

- Since March 1990, NASA has prepared biannual project status reports for programs that meet the NASA Budget Administration Manual's definition of a "project" and are estimated to cost \$200 million or more for research and development. The format and content of the reports are agreed to by NASA and representatives of its four principal oversight committees. Costs contained in the reports include development and operations costs as well as supporting costs, such as space transportation costs.
- NASA does not prepare a status report for the Space Station Freedom program. However, the fiscal year 1988 Authorization Act requires NASA to

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develop a Capital Development Plan for the station and to submit the plan with the President's annual budget request. The plan outlines the design, cost, and schedule of the station. It identifies both direct and related costs such as shuttle transportation costs.

- Public Law 102-195, the National Aeronautics and Space Administration Authorization Act, Fiscal Year 1992, requires the Administrator to prepare estimates of the life-cycle costs associated with programs whose development costs are expected to exceed \$200 million. The life-cycle cost estimates are to be submitted at the time the President's annual budget is transmitted to the Congress. The act does not specify the cost elements to be included in the estimates.

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## Average Cost Per Flight Includes Most Recurring Operations Costs

NASA defines the "average cost per flight" as the total cost to operate the space shuttle on a recurring and sustained basis for a given year divided by the number of flights planned for that year. NASA's calculation of average cost per flight captures most, but not all, costs in the shuttle operations budget line, as well as prorations of civil service personnel and space communications network costs. However, it does not include any "capital-type" costs such as those required to develop the system, produce reusable hardware, construct and modify government-owned facilities, or develop system improvements and upgrades such as the advanced solid rocket motor. Table 1 shows the average cost per flight calculated by NASA in the development of its fiscal year 1993 budget.

**Table 1: Average Cost Per Shuttle Flight in Millions of Current Dollars**

Cost element	Fiscal year				
	1993	1994	1995	1996	1997
Flight rate	8	8	8	8	9
Launch operations	\$78.7	\$82.9	\$82.2	\$81.9	\$77.2
Flight operations	88.9	91.3	90.8	90.8	90.6
Logistics operations	22.9	21.2	19.7	20.7	20.1
Propellants	2.1	2.2	2.3	2.4	2.6
Redesigned solid rocket motor	51.5	56.3	54.6	53.3	47.0
Solid rocket booster	20.4	21.3	19.0	20.0	22.4
External tank	52.0	53.4	54.6	54.2	52.0
Space shuttle main engines	19.1	17.7	16.9	16.9	18.1
Orbiter maintenance and support	22.5	23.5	23.1	22.7	21.6
Contract administration	2.9	3.0	2.9	2.9	3.2
<b>Subtotal: Shuttle operations</b>	<b>361.0</b>	<b>372.8</b>	<b>366.1</b>	<b>365.8</b>	<b>\$354.8</b>
Civil service personnel and travel	45.3	46.7	47.7	49.1	45.0
Space communications network support	7.2	7.5	7.9	8.2	8.6
<b>Average cost per flight</b>	<b>\$413.5</b>	<b>\$427.0</b>	<b>\$421.7</b>	<b>\$423.1</b>	<b>\$408.4</b>

Note: Current dollars reflect the estimated purchasing power in the year that the expenditures will occur.

Source: NASA.

Amounts shown in table 1 are as of September 1991, when NASA presented its fiscal year 1993 budget request to the Office of Management and Budget. According to NASA officials, the agency does not update average cost per flight calculations for adjustments made by the Office of Management and Budget.

Originally developed for use in determining the price to charge commercial shuttle customers, the average cost per flight is primarily used by NASA to monitor the efficiency of shuttle operations. The cost per flight estimates are based on the assumption that NASA can achieve goals the agency has set to reduce shuttle operations costs. The fiscal year 1993 budget request was based on reducing operations costs by 3 percent a year

over a 5-year period. According to shuttle program officials, NASA has identified program changes that would enable it to meet the goals through fiscal year 1993, but has not identified the means of achieving all of the target reductions in fiscal year 1994 and beyond. Failure to achieve the reductions would result in increases in the average cost per flight in those years. Shuttle program officials told us that since the fiscal year 1993 budget was prepared, the agency has increased its cost reduction goal. The new goal is to reduce shuttle operations costs by about 25 percent over 5 years, according to these officials.

NASA generally calculated the average operations cost per flight by dividing the estimated or budgeted cost for each element by the number of flights planned in a given year. For example, launch operations costs<sup>1</sup> were calculated by dividing total estimated costs of \$629.7 million for fiscal year 1993 by the eight flights planned for that year. There were two exceptions—the redesigned solid rocket motor and the external tank costs.

Average redesigned solid rocket motor costs were calculated by dividing the total annual estimated cost by the number of units being produced in a given year to reflect the work in progress on motors intended for use in future years. For example, NASA estimated that the contractor would produce the equivalent of 8.3 motor sets in fiscal year 1993.

External tank per flight costs were computed in a similar manner, after first reducing the total external tank cost estimate to reflect “stand down” costs. According to NASA officials, stand down costs reflect the inefficiency inherent in producing external tanks at below the current flight rate. Prior to the January 1986 Challenger accident, the contractor was manufacturing external tanks at a rate faster than NASA was flying the shuttle and had produced a surplus of tanks. Following the accident, NASA decided to keep the manufacturing facility operating at a minimum sustaining rate of four tanks a year until the shuttle flight rate increased and the surplus of external tanks was used up. Some aspects of the tank manufacturing operation, such as the contractor’s engineering and business management activities and the plant security and fire protection, are relatively fixed. They do not vary with the production rate and are capable of supporting a manufacturing rate of eight or more tanks a year. The stand down costs represent that portion of the fixed costs associated with manufacturing tanks below the current maximum planned rate of

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<sup>1</sup>“Launch operations costs” are primarily costs incurred to operate and maintain the Kennedy Space Center. These costs include preparing the shuttle for launch.

eight a year. NASA estimated that stand down costs would total \$157.2 million, or about \$37.4 million a flight, in fiscal year 1993 and \$66.1 million, or about \$11 million a flight, in fiscal year 1994. NASA did not calculate stand down costs for fiscal years 1996 and beyond, since tank production would be at the currently planned maximum rate in those years. According to shuttle program officials, including the stand down costs in the average cost per flight calculation would distort their year-to-year comparisons of average costs.

In addition to shuttle operations costs, the average cost per flight calculation includes portions of NASA's civil service personnel costs and the costs to operate the space communications network. Civil service personnel costs included salaries, travel expenses, and the cost of activities to support the civil service work force and the physical plant at the field centers involved in shuttle operations. Personnel costs were computed based on the number of civil service personnel working on shuttle operations. NASA estimated that in fiscal year 1993, 4,079 full-time equivalent work years—about 16 percent of its total civil service work force—would be used for shuttle operations activities. NASA also added a prorated share of overhead and support costs based on the ratio of people working directly on shuttle operations to the total work force at the field centers.

NASA allocated space communications network costs by first prorating shuttle-unique network costs such as the costs to equip, operate, and maintain the spaceflight tracking and data network stations, which are required during shuttle launches, to each of the 49 flights planned for fiscal years 1992 through 1997. NASA then added a per-flight charge for use of the tracking and data satellite system. The per-flight charge was based on actual historical usage of the satellite system by the shuttle and is consistent with NASA's pricing of the satellite system for other government users.

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### Cost Per Flight Does Not Include Capital-Type Costs or Contingency Reserve Funds

The major shuttle-related costs not included in NASA's estimated cost per flight are the costs to develop the system, to purchase reusable equipment, construct and modify facilities, and upgrade and improve shuttle components. Through fiscal year 1992, NASA spent about \$30.2 billion for shuttle development, production, and construction. Table 2 shows a breakdown of these costs.



**Table 2: Shuttle Program Funds Not Included in Cost Per Flight in Millions of Current Dollars (1971-92)**

<b>Cost element</b>	<b>Amount</b>
Design, development, test, and evaluation	\$10,086.9
Production	17,189.2
Replacement orbiter	1,800.0
Construction of facilities	1,118.5
<b>Total</b>	<b>\$30,194.6</b>

Source: NASA.

NASA did not include these capital-type costs in the cost per flight calculation because they are not a part of the recurring costs to operate the shuttle system.

Also excluded are costs projected for future system upgrades and improvements such as the advanced solid rocket motor and continued production of reusable equipment such as the space shuttle's liquid-fueled main engines. In preparing its fiscal year 1993 budget request, NASA estimated that over \$1 billion a year would be needed for the improvements and production through fiscal year 1997, not including the advanced solid rocket motor program.<sup>2</sup>

NASA also did not include contingency reserves in its calculation of average cost per flight. Contingency reserve funds, referred to as the "allowance for program adjustment," are intended to cover unforeseen changes in the program. NASA's fiscal year 1993 budget request for shuttle operations included a contingency reserve of \$36.1 million, or about \$4.5 million a flight. According to shuttle program officials, the contingency funds were not included in the cost per flight calculation because NASA did not know if the reserve would be used, or how much, or how the reserve would be used. However, we found that NASA has used the contingency reserve in each of the past 3 fiscal years.

## Marginal Cost Per Flight Includes Only Incremental Costs

As a part of its annual review of shuttle flight costs, NASA also calculates a "marginal cost per flight." The marginal cost per flight is the cost savings associated with deleting a single flight in any given year, independent of any other change to the manifest. It includes costs of personnel and any consumable hardware and materials such as propellants that can be added

<sup>2</sup>The President's fiscal year 1993 budget proposed termination of the advanced motor program. Congress rejected the proposal and appropriated \$360 million to continue developing the advanced motor and constructing facilities in fiscal year 1993.

or removed with only a temporary adjustment in the flight rate. NASA uses the marginal cost calculation to make budget adjustments when flights are deleted from the manifest. Table 3 compares the average cost per flight with the marginal cost associated with deleting a flight in fiscal year 1993.

**Table 3: Comparison of Average and Marginal Cost Per Flight in Millions of Current Dollars**

<b>Flight operations</b>	<b>Average cost per flight</b>	<b>Marginal cost per flight</b>
Launch operations	\$78.7	\$ 4.2
Flight operations	88.9	4.6
Logistics operations	22.9	3.7
Propellants	2.1	<sup>a</sup>
Redesigned solid rocket motor	51.5	10.2
Solid rocket booster	20.4	9.5
External tank	52.0	10.0
Space shuttle main engines	19.1	1.4
Orbiter maintenance and support	22.5	0.8
Contract administration	2.9	0.0
Civil service personnel and travel	45.3	0.0
Space communications network support	7.2	0.0
<b>Total</b>	<b>\$413.5</b>	<b>\$ 44.4</b>

<sup>a</sup>Propellant costs are included in the launch operations line.

Source: NASA.

The marginal cost per flight is small compared with the average cost per flight because the marginal cost does not include any of the fixed costs that NASA says are required to maintain the capability to launch the shuttle eight or nine times a year. According to NASA officials, eliminating a single flight in a given year has no effect on these costs, which it says account for about 90 percent of the average cost per flight.

For example, eliminating a single flight in fiscal year 1993 may allow NASA to avoid the cost of labor directly involved in the manufacture, inspection, and test of an external tank; the hardware and materials used in manufacturing the tank; and the expense of shipping the tank from the manufacturing site near New Orleans to the launch site at the Kennedy Space Center. However, for NASA to maintain the capability to manufacture up to nine tanks a year, it cannot avoid other labor costs such as those associated with production and industrial engineering, plant maintenance and operations, contract management, finance, planning, or personnel

management. It also cannot avoid the cost of nonflight materials required for production such as materials needed to maintain manufacturing tools, laboratory supplies, solvents, cleansers, and facilities maintenance materials. Similarly, NASA would not reassign any of the civil service personnel from the shuttle program as a result of deleting just one flight in a year. These personnel would continue to manage the program as well as administer and oversee contracts and maintain the basic shuttle flight rate capability.

## Allocating Shuttle Transportation Costs Depends on the Benefiting Payload

There is no single criterion that is generally accepted for allocating shuttle costs to payload missions. NASA appropriately uses marginal cost to portray the effect on its budget of small changes in the flight schedule. However, the Space Station Freedom program has unique characteristics that make average operating cost per flight a more appropriate estimate during some years. The space station is NASA's highest priority payload and the shuttle's predominant user during fiscal years 1997 to 1999. Also, while some payloads may have different space transportation options, there is currently no alternative means of transportation for the station.

Until March 1990, NASA did not include supporting costs such as space shuttle transportation costs in its estimates of payload mission project cost. NASA now uses marginal cost per flight estimates to allocate shuttle transportation costs in payload project status reports and the life-cycle cost estimates prepared in response to Public Law 102-195. According to NASA, marginal cost reflects the budgeted impact of changing the shuttle flight rate by one flight and, therefore, is appropriate for measuring the transportation services provided by the shuttle. For example, deleting one flight would save certain costs such as for propellants. The use of marginal cost per flight is consistent with agreements reached between NASA and its principal oversight committees on costs to be included in the project status reports.<sup>3</sup>

NASA, however, also used marginal costs per flight to calculate shuttle transportation costs included in its \$30 billion estimate contained in the Space Station Freedom Capital Development Plan. In May 1991, we testified before the Subcommittee on Government Activities and Transportation, House Committee on Government Operations, that NASA's \$30 billion estimate was understated by at least \$10 billion. About

<sup>3</sup>NASA Project Status Reports: Congressional Requirements Can Be Met, but Reliability Must Be Ensured (NSIAD 90-40, January 23, 1990).

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\$7.5 billion of the understatement resulted because NASA included only marginal shuttle flight costs in the estimate.<sup>4</sup>

For the years 1997 to 1999, the space station will be the predominant user or "customer" of the shuttle. The space station is one of NASA's highest priority programs, and there is currently no alternative to the shuttle for transporting the station to its planned orbit. During fiscal years 1997 to 1999, about 70 percent of the shuttle's capability will be required for the launch, assembly, and use of the station. According to the former Associate Administrator for Space Flight, without that demand, the space shuttle program would "wither and atrophy." Thus, in those years, NASA will incur the shuttle's fixed operating costs primarily to support the space station program. Without the need created by the station program, NASA would have the option of making a long-term reduction in the shuttle flight rate and avoiding at least a portion of the costs currently considered to be fixed. NASA officials agreed that at least a portion of the operating costs currently considered to be fixed could be avoided by a significant and long-term reduction in the shuttle's flight rate, but they do not have an estimate of the amount of cost that could be avoided.

Assigning fixed costs to some flights and not others is consistent with an economic approach used by many organizations, such as electric utilities and the postal service. Under this approach, fixed costs are allocated among buyers based on which one uses and values the good or service the most.<sup>5</sup> Accordingly, the shuttle's fixed operating costs would be allocated to the most valued or highest priority user of the shuttle. Thus, the role of the space station as predominant user and as a high-valued NASA project supports assigning it a portion of the shuttle's fixed operating costs, particularly for the heavy usage fiscal years of 1997 to 1999.

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<sup>4</sup>Questions Remain on the Costs, Uses, and Risks of the Redesigned Space Station (T-NSIAD-91-26, May 1, 1991).

<sup>5</sup>The logic for this allocation is based on Ramsey pricing, which argues for setting prices that deviate from marginal cost inversely with the degree of the buyer's sensitivity to price, or elasticity of demand. For a discussion of Ramsey pricing, see F. M. Scherer and David Ross, Industrial Market Structure and Economic Performance, 3rd ed. (Boston: Houghton Mifflin Co., 1990), p. 498.

## Pricing Shuttle Transportation for Commercial Payloads Is Different

This report does not address the question of what costs to use in pricing transportation for commercial customers.<sup>6</sup> Other reports, such as a 1985 Congressional Budget Office study<sup>7</sup> and a September 1992 NASA Advisory Council report on satellite rescue and repair,<sup>8</sup> address the question of commercial pricing. The Congressional Budget Office study developed a set of commercial pricing options and explored the implications of these options for space policy objectives. Some of the options included a capital charge to account for the investment required to develop and produce the shuttle capability. The report of the Advisory Council on satellite rescue and repair recommended that when NASA undertakes rescue missions for commercial and international customers, the customers pay marginal shuttle costs and other direct mission costs up front. The Council further recommended that if the mission were successful, the customer pay a negotiated portion of revenues until the full cost of the rescue is paid. However, the report concluded that the price should not include shuttle replacement, NASA facilities, or facility amortization costs.

## Recommendation

Although NASA should continue to use marginal cost per flight estimates to allocate shuttle transportation costs to payload missions that are only occasional users of the shuttle, we recommend that the Administrator of NASA use the average cost per flight when calculating shuttle transportation costs for the Space Station Freedom program during those years when the station is the predominant user of shuttle capabilities.

## Scope and Methodology

To determine what costs were included in or excluded from estimates of average and marginal costs per flight, we reviewed NASA reports, briefings, and budget submissions. We also discussed the estimates with officials at NASA Headquarters, the Johnson Space Center, Marshall Space Flight Center, and the Kennedy Space Center. We held detailed discussions with project officials about cost estimates for the external tank, the redesigned solid rocket motor, launch operations, the orbiter, and mission operations. Together, these elements comprise over 50 percent of the average cost per flight for fiscal year 1993.

<sup>6</sup>Current launch policy restricts the use of the shuttle for commercial and foreign payloads to those that require the shuttle's unique capabilities or have national security or foreign policy implications.

<sup>7</sup>Congressional Budget Office, Pricing Options for the Space Shuttle, March 1985. See also, Michael A. Toman and Molly K. Macauley, "No Free Launch: Efficient Space Transportation Pricing," Land Economics, Vol. 65 No. 2, May 1989, pp. 91-99.

<sup>8</sup>NASA Advisory Council, Report of the Group Task Force on Satellite Rescue and Repair, September 29, 1992.

To determine the uses of each of the estimates, we reviewed prior testimony and reports on this subject and other information relating to the allocation of fixed costs to benefiting programs. We also discussed the use of the estimates with NASA officials.

We performed our work from August 1991 to December 1992 in accordance with generally accepted government auditing standards. As requested, we did not obtain agency comments. However, we discussed the information in this report with NASA shuttle program officials and officials in the NASA Comptroller's Office. These officials believe that only marginal shuttle costs should be included in all payload mission cost estimates because the shuttle program is not solely dedicated to any specific flight project but supports a wide range of agency programs and interests. According to the officials, using marginal cost per flight in payload mission program estimates better reflects the budgetary impact of transportation services on these programs. However, as shown in this report, using marginal cost significantly understates the transportation costs for the predominant user of the shuttle.

Unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from its date. At that time, we will send copies of this report to other appropriate congressional committees, the Administrator of NASA, and the Director of the Office of Management and Budget. We will also provide copies to others upon request. Please contact me on (202) 275-5140 if you or your staff have any questions concerning this report. Other major contributors are listed in appendix I.

Sincerely yours,



Mark E. Gebicke  
Director, NASA Issues



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