United States General Accounting Office

GAO

Report to the Chair, Subcommittee on VA, HUD, and Independent Agencies, Committee on Appropriations, U.S. Senate

December 1991

SPACE SHUTTLE

NASA Faces Challenges in Its Attempt to Achieve Planned Flight Rates

GAO/NSIAD-92-32

GAO United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-246151

December 6, 1991

The Honorable Barbara A. Mikulski
Chair, Subcommittee on VA, HUD,
and Independent Agencies
Committee on Appropriations
United States Senate

Dear Madam Chair:

As requested, we reviewed the National Aeronautics and Space Administration's (NASA) plans for future shuttle flights. Specifically, we evaluated the (1) factors associated with achieving planned flight rates, (2) processes to ensure that safety is not compromised by increasing flight rates, (3) impact of variations in flight rate estimates on procurement of subsystems and spare parts, and (4) planned use of expendable launch vehicles for payloads not requiring the shuttle. The report recommends that the Administrator implement plans to reduce advanced solid rocket motor manufacturing equipment to be consistent with current shuttle flight rate estimates and determine how much could be saved by reducing the size of motor manufacturing facilities.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days after its issue date. At that time, we will send copies of the report to the Administrator, NASA, and appropriate congressional committees. Copies will also be made available to others on request.

Please contact me on (202) 275-5140 if you or your staff have any questions concerning this report. Major contributors to the report are listed in appendix II.

Sincerely yours,

Mark E. Gebicke

Mark E. Gebicke
Director, NASA Issues

Executive Summary

Purpose

The space shuttle is the nation's only manned launch vehicle and one of the National Aeronautics and Space Administration's (NASA) largest programs, consuming over one-fourth of the agency's total budget. The shuttle's viability and that of some other programs, such as the space station Freedom, depend in part on whether NASA can increase the shuttle flight rate to a reasonable and sustainable level without jeopardizing safety.

The Chair, Subcommittee on VA, HUD, and Independent Agencies, Senate Committee on Appropriations, asked GAO to assess (1) factors associated with achieving NASA's planned flight rate, (2) processes to ensure that safety is not compromised in order to increase flight rates, (3) impact of variations in flight rate estimates on procurement of subsystems and spare parts, and (4) planned use of expendable launch vehicles for payloads not requiring the shuttle.

Background

The shuttle was designed as the nation's primary launch vehicle for both civilian and military payloads. NASA originally planned to launch the shuttle up to 60 times a year. Before the January 1986 Challenger accident, NASA reduced its maximum launch rate estimate to 24 times a year. However, according to the Report of the Presidential Commission on the Space Shuttle Challenger Accident, this estimate was not based on an assessment of available resources and capabilities.

After the accident, NASA again revised its plans downward to a maximum of 16 shuttle flights a year. Outside groups, however, questioned NASA's ability to safely achieve even this rate. Also, the nation adopted a mixed-fleet policy under which only those payloads requiring human interaction or those involving other compelling circumstances such as national security or international agreements would be launched on the shuttle. Other payloads would be launched on unmanned rockets.

As the number of shuttle flights decreased, the average cost per flight increased dramatically. Estimated costs have increased seven fold from a June 1976 average of about $50 million a flight when NASA projected flying the shuttle up to 60 times a year to a September 1991 estimate of about $358 million each for the 8 flights conducted in fiscal year 1991.

Results in Brief

NASA has reduced its projection of the maximum annual shuttle flight rate to 10 flights a year and does not anticipate flying at this rate before late in the decade. Actual experience through June 1991 suggests that it may not be able to achieve 10 flights a year, especially if it (1) fails to reduce shuttle ground processing time or (2) loses or severely damages another orbiter. Unless NASA can reduce shuttle ground processing time, GAO calculates that it will not be able to consistently launch the shuttle more than 7 or 8 times a year.

GAO found no evidence to suggest that NASA might compromise safety to increase the flight rate. Thus far, NASA flight schedules have been subordinated to safety concerns in launch decisions, and the agency has controls to ensure that safety is considered in decisions about modifying or eliminating shuttle processing steps.

Also, GAO found no evidence that overly optimistic flight rate projections have resulted in excess procurement of spare parts, but adjustments in delivery schedules for shuttle subsystems made necessary when NASA did not achieve projected flight rates have created some inefficiencies. Moreover, NASA has contracted to build advanced solid rocket motor production facilities in excess of current requirements.

NASA is evolving from a policy of almost exclusive reliance on the shuttle to launch its payloads to one of using the shuttle only when necessary. Of the payloads on the shuttle's current manifest, 89 percent require either human interaction or some unique shuttle capability. The remaining payloads are on the shuttle manifest for national security reasons or because expendable launch vehicles are not available to meet launch schedules. Most new payloads are being designed to fly on expendable launch vehicles.

Principal Findings

Uncertainties in Achieving Flight Rate

Since resuming flights after the Challenger accident, NASA has reduced its estimate of the maximum shuttle flight rate from 16 to 10 a year. The reduction was based, in part, on refined estimates of launch capabilities and in part on funding constraints.

To date, NASA has not achieved its planned flight rate for any year. To achieve its current flight rate projections, NASA plans to reduce shuttle ground processing time from an actual post-Challenger average of about 160 days to 98 days for most flights. According to NASA, the reduction will be accomplished by eliminating or modifying some processing tasks and by enhancing shuttle processing efficiency. However, attempts to reduce processing requirements have had only limited success to date, and the impact of efficiency improvements will not be known for some time. Also, the amount of time needed for planned triennial orbiter structural inspections and modifications is uncertain.

Actual ground processing times exceeded planned times by an average of about 45 days for 13 post-Challenger flights, due largely to unexpected circumstances such as hydrogen leaks. If this rate continues, and it may as the shuttles get older, NASA will be able to launch shuttles only 7 or 8 times a year. Loss or severe structural damage to one or more of the orbiters would also preclude NASA from achieving projected flight rates because replacements are not currently available.

Safety Controls Have Been Improved

Since the Challenger accident, NASA has shown its willingness to delay shuttle launches when reasonable questions arose over safety. NASA has taken action to reemphasize flight safety in light of recent incidents. Also, Kennedy Space Center has implemented controls to help ensure that employees who are involved in shuttle processing are not fatigued by excessive overtime. According to Kennedy Space Center officials, NASA will have to reduce shuttle inspection and maintenance requirements to achieve 10 flights a year. Requirements changes are reviewed by boards at three levels, all of which include representatives of NASA's independent safety and mission quality organization.

Flight Rate Changes Caused Production Inefficiencies

GAO found no evidence that NASA was procuring excessive amounts of spare parts because of unrealistic flight rate projections. Spare parts requirements are not directly linked to flight rates. However, overly optimistic estimates of shuttle flight rates caused inefficiencies in the production of subsystems such as external tanks and solid rocket boosters. When projected flight rates did not materialize, external tank and solid rocket booster contract delivery schedules were stretched out to more closely parallel reduced flight schedules. Contract costs increased, in part, due to inefficiencies when personnel and facilities operated over a longer period of time to manufacture the same number of subsystems.

NASA Acquiring Excess Production Capacity

NASA has contracted for facilities and equipment to support a maximum annual production of 16 sets of advanced solid rocket motors even though only 11 sets—10 flight sets and 1 test set—are needed to support the current shuttle flight schedule. Marshall Space Flight Center has identified $10.5 million of equipment that can be eliminated by reducing production capability to 11 motor sets, and the Center plans to direct the contractor to make the reductions as soon as it receives firm guidance from headquarters. At the completion of GAO's field work, NASA officials told GAO that the agency did not plan to reduce the size of motor production facilities and had not estimated the savings that could result from facility sizes that would parallel reduced production requirements. Subsequently, officials advised that the agency had decided to eliminate one of two planned propellant mixing and casting buildings at the motor manufacturing facility in order to offset other facility cost increases and that the contractor is studying other possible reductions to conform the facility size to reductions in the shuttle flight rate.

NASA Implements Mixed-Fleet Policy

About 80 percent of the payloads listed on the shuttle's pre-Challenger manifest have been either canceled or shifted to expendable launch vehicles. Of the 61 payloads still scheduled to fly on the shuttle between April 28, 1991, and September 30, 1996, 28 require a human presence, 26 require the unique capabilities of the shuttle, and 7 are included for "other compelling reasons." Most new payloads are being designed for launch on expendable launch vehicles. Of the 34 payloads in concept development or preliminary design, which had requested launch services as of February 1991, 27 are projected to fly on expendable launch vehicles. The remaining seven are payloads that require human interaction or that must be returned to earth after being flown. NASA has established a flight assignment board to help assure that only payloads requiring the shuttle are on its manifest.

Recommendations

GAO recommends that the NASA Administrator

- implement plans to reduce advanced solid rocket motor manufacturing equipment consistent with the agency's current maximum shuttle flight rate,
- identify possible cost savings from reducing the size of advanced solid rocket motor production facilities, and
- review the decision not to reduce facility sizes if warranted by the potential cost savings.

Agency Comments

NASA concurred in GAO's findings but stated that it believes a buildup to 10 flights a year is a realistic target. The current shuttle manifest, however, projects only seven flights in fiscal year 1992 and, according to an official in the Office of Space Flight, NASA does not anticipate 10 shuttle flights a year before late in the decade. NASA also stated that advanced solid rocket motor production rates and facility capacities are being adjusted to the currently authorized flight rate and that the reductions are expected to result in significant cost savings. (See app. I for a copy of NASA's comments.)

Contents

Abbreviations

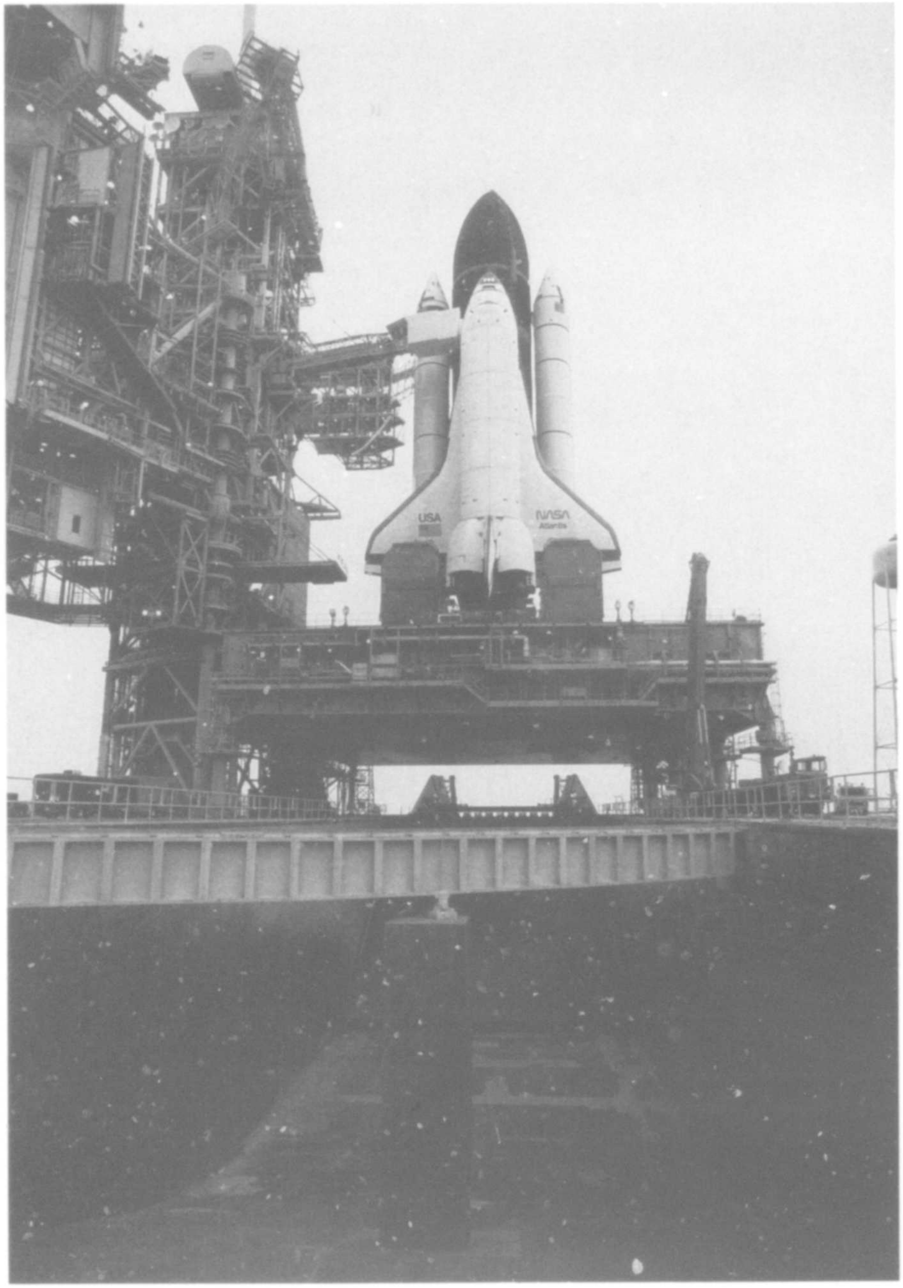
GAO	General Accounting Office
NASA	National Aeronautics and Space Administration
OMB	Office of Management and Budget

Introduction

The space shuttle, or National Space Transportation System as it was formally known, is one of the National Aeronautics and Space Administration's (NASA) largest programs, consuming over one-fourth of the agency's proposed fiscal year 1992 budget. Since the shuttle is the nation's only manned launch vehicle, its viability and that of some other major programs, such as space station Freedom, depend in part on whether NASA can increase the shuttle's flight rate to a reasonable and sustainable level.

The shuttle is the world's first reusable space system. When first developed, it was to be the nation's primary launch vehicle for both civil and defense payloads. Unmanned, expendable launch vehicles were to be phased out of U.S. inventories. Figure 1.1 shows a space shuttle on the launch pad.

Figure 1.1: Space Shuttle Atlantis



Source: NASA

The objective of the shuttle program was to make space access routine and economical. The greater the annual number of flights, the more economical they would be. Originally, NASA planned to fly the shuttle up to 60 times a year, launching it from both East and West Coast launch facilities.

Realism forced several downward revisions in annual flight rate predictions. In 1985, NASA published a projection calling for an annual rate of 24 flights by 1990 using both launch sites, still 2 flights a month.

The January 1986 accident of the space shuttle Challenger, however, changed the way people thought about the shuttle. According to the Presidential Commission that investigated the accident, the nation's reliance on the shuttle as its principal space launch capability created a relentless pressure on NASA to increase the flight rate.

NASA's attempt to increase shuttle flights to 24 a year created difficulties such as the compression of training schedules, the lack of spare parts, and the directing of resources to near-term problems. According to the Commission, NASA did not provide sufficient resources to support the flight schedule.

As a result, according to the Commission, the capabilities of the system were stretched to the limit to support the flight rate during the winter of 1985-86. Evidence suggested that NASA would not have been able to achieve the 15 flights it planned in 1986. The Commission concluded that reliance on a single launch capability should be avoided and recommended that NASA establish a flight rate that was consistent with its resources.

The shuttle also proved to be more costly to operate than originally anticipated. As the number of flights decreased, the average cost of operating the shuttle increased significantly. A June 1976 estimate placed the average cost of 572 flights at about $50.3 million (1992 dollars)[1] a flight. In September 1991, NASA estimated that the eight flights conducted in fiscal year 1991 cost an average of $358.1 million (1992 dollars) each, an increase of more than 700 percent over the 1976 estimate. According to NASA, the cost increase was due primarily to the reduction in the number of flights.

[1]The June 1976 estimate was $16.07 million in 1975 dollars. To make it comparable with current estimates, we added an allowance for the inflation that occurred between 1975 and 1992 using a factor NASA supplied.

Estimates of Post-Challenger Flight Rate

In response to the recommendation of the Presidential Commission on the Challenger accident, NASA established a Flight Rate Capability Working Group to conduct a "bottoms up" assessment of flight rate capability. The group concluded that NASA could achieve a maximum flight rate of 16 a year, beginning in fiscal year 1991, if a replacement for the Challenger were available in early 1991, giving the agency four orbiters.

An independent assessment, conducted by the National Research Council at the request of the Chairman, House Committee on Appropriations, Subcommittee on HUD-Independent Agencies, projected the shuttle's capability at 11 to 13 flights a year with a 4-orbiter fleet. According to the Council, a rate of about 12 flights a year was a reasonably sustainable level, although the system might have the capacity to "surge" above this for short periods. The Council projected a lower flight rate than NASA because, in its view, only three of the four orbiters would be available at a time due to maintenance and inspection requirements and unexpected problems.

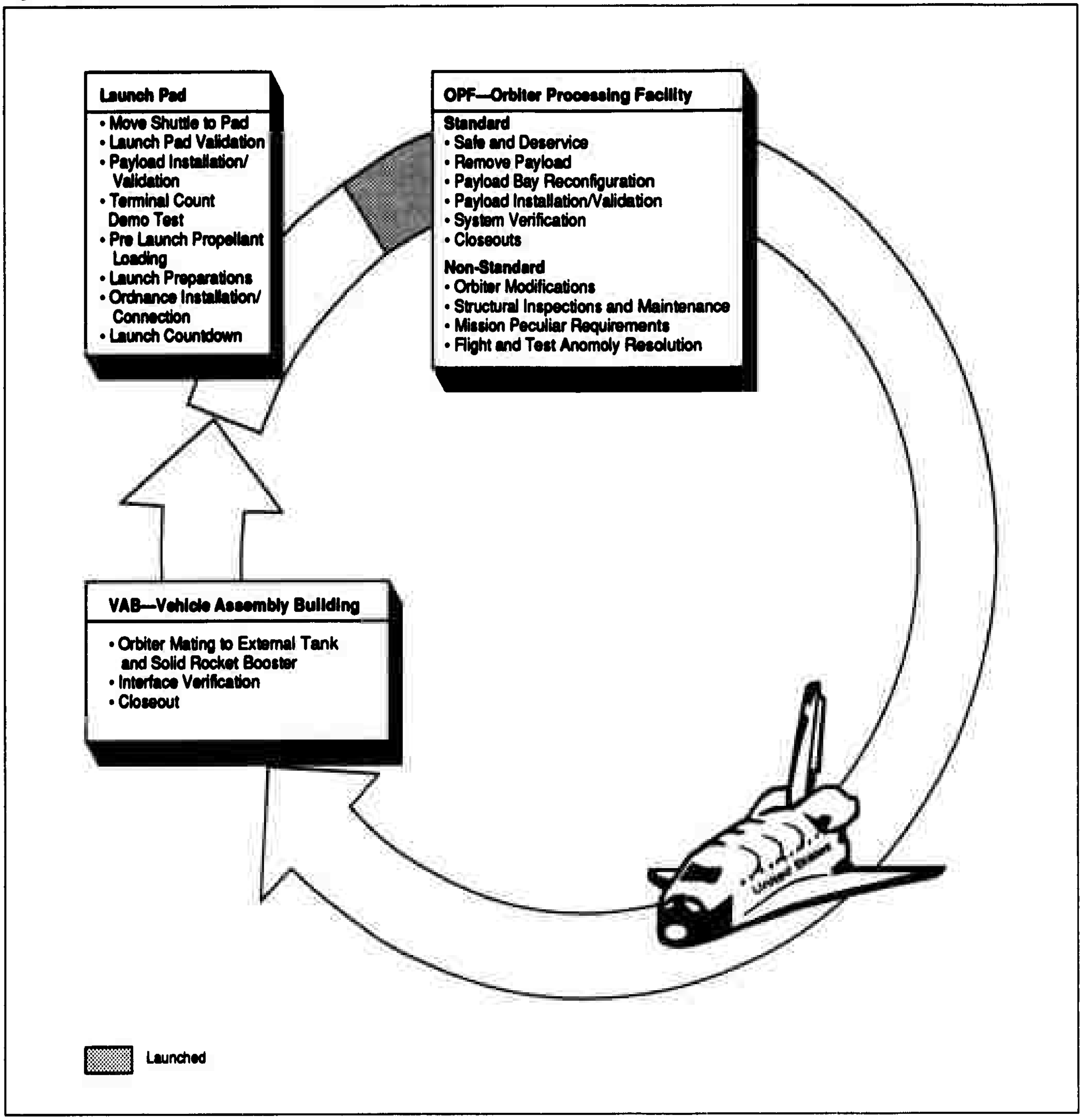
Outside groups such as the National Research Council and NASA's Aerospace Safety Advisory Panel[2] have cautioned that, if not careful, NASA could jeopardize shuttle safety because of pressures to meet launch schedules. For example, in its March 1989 annual report, the Aerospace Safety Advisory Panel cautioned that "there remains the clear and present danger of slipping back into the operating environment at Kennedy Space Center that contributed to the Challenger accident." In March 1990, the panel reported on NASA's efforts to reduce space shuttle ground turnaround time to meet a 13-mission per year schedule. The panel cautioned that "this effort must be conducted with great care."

Flight Rate Depends Largely on Ground Processing Times

According to Kennedy Space Center officials, NASA's ability to achieve and sustain its flight rate goals is largely predicated on whether the agency can reduce shuttle ground processing times and sustain the reduction. Ground processing includes all activities performed to prepare a shuttle for its next flight. Figure 1.2 illustrates ground processing activities.

[2]The Aerospace Safety Advisory Panel was established in the aftermath of the Apollo fire of January 27, 1967, to advise the Administrator on the hazards of proposed operations and the adequacy of proposed or existing safety standards.

Figure 1.2: Space Shuttle Ground Processing

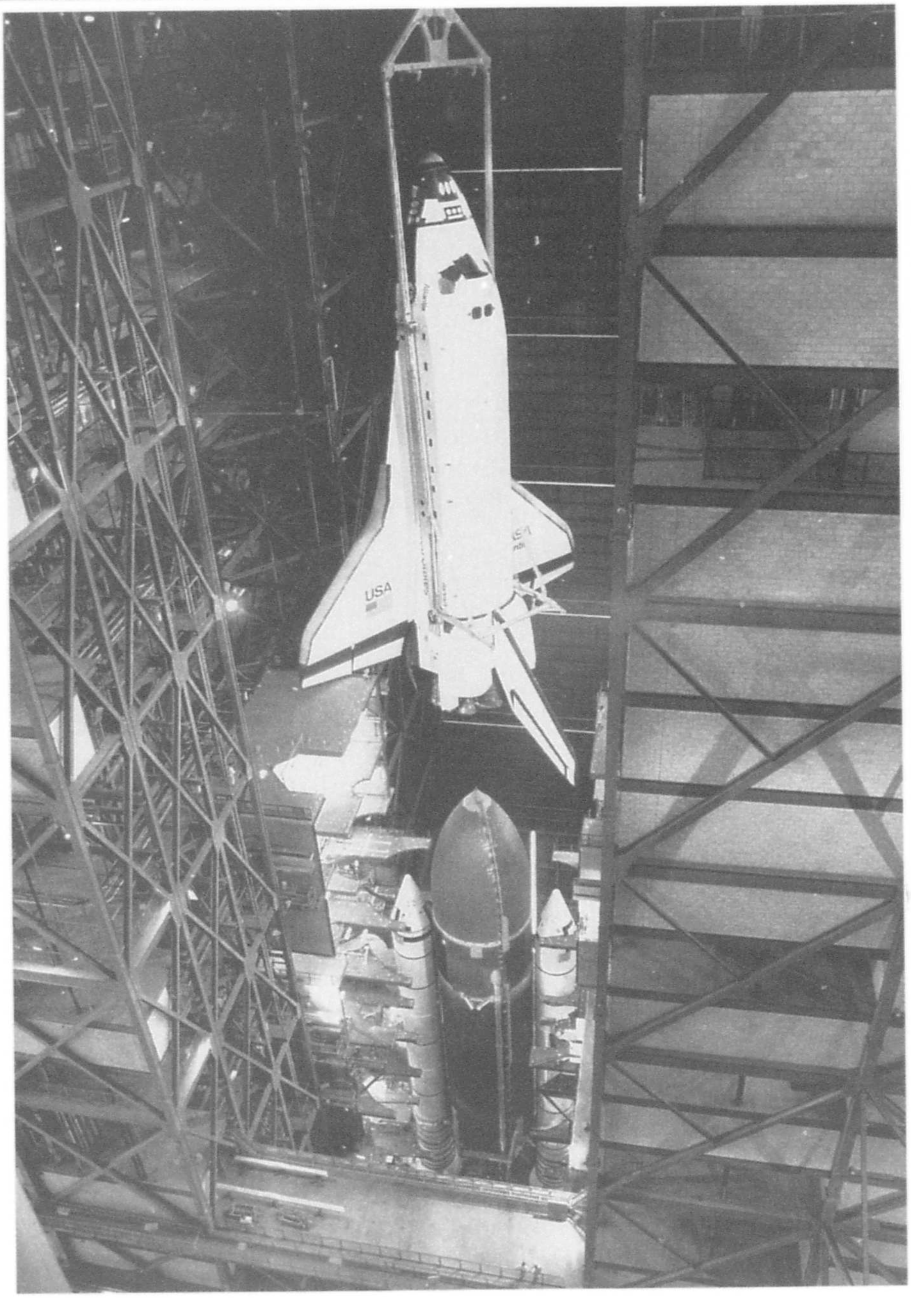


Ground processing occurs in three primary locations at the Kennedy Space Center. Most ground processing time occurs in the Orbiter Processing Facility,[3] where NASA's launch processing contractor checks, repairs, and refurbishes each major orbiter system after every flight. For example, the contractor currently inspects bearings and turbines in the main engines of the shuttle after each flight and replaces them after every third flight. Any of the about 24,000 ceramic tiles of the thermal protection system that are missing or damaged during a flight are also replaced and all tiles are waterproofed. Horizontal payloads, such as spacelab, are also installed in the Orbiter Processing Facility.

From the Orbiter Processing Facility, the orbiter is moved to the Vehicle Assembly Building, where it is joined with the external fuel tank and the solid rocket boosters. From the Vehicle Assembly Building, the shuttle is transported to the launch pad for final preparations, checkout, and launch. Some payloads are also installed at the launch pad. Figure 1.3 shows the orbiter being joined with the external fuel tank and the solid rocket boosters.

[3] NASA has three Orbiter Processing Facilities.

Figure 1.3: Shuttle Components Mated in Vehicle Assembly Building



Source: NASA

Nation Adopts Mixed-Fleet Policy

Following the Challenger accident, the President decided to limit NASA's launch services for commercial and foreign payloads to those that were shuttle-unique or had national security or foreign policy implications. NASA and the Department of Defense jointly established a mixed-fleet concept of expendable launch vehicles and the shuttle to meet national requirements for access to space. Many of the Department of Defense payloads previously scheduled for launch on the shuttle were to be transferred to expendables. An in-house NASA study concluded that about 21 percent of the NASA and National Oceanic and Atmospheric Administration payloads scheduled for the shuttle also could be launched on expendables.

The National Aeronautics and Space Administration Authorization Act, Fiscal Year 1991, enacted the mixed-fleet policy into law. The act specifies that:

"It shall be the policy of the United States to use the space shuttle for purposes that (i) require the presence of man, (ii) require the unique capabilities of the Space Shuttle or (iii) when other compelling circumstances exist. The term 'compelling circumstances' includes, but is not limited to, occasions when the Administrator determines, in consultation with the Secretary of Defense and the Secretary of State, that important national security or foreign policy interests would be served by a Shuttle launch."

The act requires NASA to submit to the Congress a plan for implementing the shuttle use policy. It also requires that the Administrator certify, at least annually, that payloads scheduled to be launched on the shuttle for the succeeding 4 years are consistent with the policy. For each payload to be launched from the shuttle that does not require a human presence, the report must also specify the circumstances that justify use of the shuttle.

Objectives, Scope, and Methodology

The Chair, Subcommittee on VA, HUD, and Independent Agencies, Senate Committee on Appropriations, asked us to assess NASA's planning for future shuttle flight rates. Specifically, we evaluated the (1) factors associated with NASA's achieving its planned flight rate, (2) processes to ensure that safety is not compromised, (3) impact of variations in flight rate estimates on procurement of subsystems and spare parts, and (4) planned use of expendable launch vehicles for payloads not requiring the shuttle.

To determine the factors associated with achieving a flight rate, we reviewed and analyzed NASA and contractor studies, reports, and briefings that addressed shuttle maintenance and inspection requirements, historical shuttle processing data and goals, and efficiency enhancements. We discussed shuttle flight rates, processing requirements, and proposed enhancements with program officials at NASA headquarters, Johnson Space Center, and Kennedy Space Center. We also interviewed cognizant officials with Rockwell International, Space Systems Division, the firm that designed and built the shuttle orbiters, and Lockheed Corporation, Space Operations Company, the firm that processes shuttles for launch at the Kennedy Space Center.

To determine whether NASA has processes to ensure that safety is not compromised, we reviewed the Report of the Presidential Commission on the Space Shuttle Challenger Accident, NASA's response to the Commission's report, internal NASA and contractor safety regulations, NASA policies, procedures, flow charts, and internal audit reports. We also discussed safety issues and roles and responsibilities for approving changes in shuttle processing requirements with NASA and contractor officials.

To determine the impact of varying flight rate estimates on procurement of space shuttle subsystems and spare parts, we reviewed and analyzed internal NASA procurement system documentation, maintenance trend analyses, contract modifications, and program, cost, and budget reports. At Kennedy Space Center and Marshall Space Flight Center, we discussed the impacts of varying flight rates on spare part and subassembly procurements with project, procurement, and logistics officials.

To determine NASA's planned use of expendable launch vehicles for payloads not requiring the shuttle, we reviewed and analyzed shuttle use criteria and policy, flight manifests, the 1991 NASA Authorization Act, and internal NASA documents relating to shuttle uses. We also discussed the mixed-fleet policy and its implementation with officials in the Transportation Services Division within NASA's Office of Space Flight.

Our review was performed from September 1990 through June 1991 in accordance with generally accepted government auditing standards.

On September 26, 1991, NASA provided written comments on a draft of this report. The agency agreed with the basic findings of the report and concurred in its recommendations. NASA's plans for implementing the recommendations are discussed in chapter 4. The complete text of the agency's comments is in appendix I.

NASA's Ability to Achieve Projected Shuttle Flight Rate Is Uncertain

NASA has reduced its projection of the maximum annual shuttle flight rate from an initial post-Challenger estimate of 16 flights to a current plan of 10 flights. According to an official in NASA's Office of Space Flight, the agency is currently reviewing shuttle flight rates and does not anticipate flying 10 times a year before late in the decade.

While the current projection is more realistic, questions still exist about NASA's ability to achieve 10 flights a year. Flight rates are determined primarily by the time required to process each shuttle on the ground in preparation for its next flight.

As of June 30, 1991, NASA had never met its planned processing schedule for a flight since shuttle operations resumed in September 1988. Actual processing times have exceeded planned times by an average of about 45 days. If this trend continues, NASA will be unable to launch the shuttle more than about 7 or 8 times a year. NASA is attempting to reduce processing times by eliminating or reducing some processing tasks and enhancing the efficiency of ground processing, but the impact of these measures is not yet known. Loss or significant damage to another orbiter would reduce the maximum potential launch rate even further.

Operational Realities and Funding Constraints Caused NASA to Reduce Shuttle Flight Rate Projections

In October 1986, NASA projected that it would be able to resume shuttle flights by fiscal year 1988 and build to a maximum rate of 16 flights a year by fiscal year 1993. Since that time, actual experience in processing post-Challenger flights and funding constraints have forced NASA to reduce its estimate to 10 flights a year, beginning in fiscal year 1994.

NASA established a Flight Rate Capability Working Group to conduct an in-depth assessment of shuttle processing requirements. The working group identified enhancements to increase the flight rate. With the enhancements and a replacement for the Challenger orbiter, NASA projected a maximum capability of 14 flights a year by fiscal year 1994.

Actual experience with post-Challenger shuttle ground processing led NASA to reduce its maximum flight rate projection again—from 14 to 12—in January 1990. NASA had accomplished only 7 of the 11 flights previously projected through December 1989;[1] it had experienced unpredictable delays in processing all seven flights. For example, while preparing Discovery for a planned August 1989 launch, NASA detected a

[1] NASA's October 1987 shuttle manifest projected a total of 11 flights from the beginning of fiscal year 1988 through December 1989.

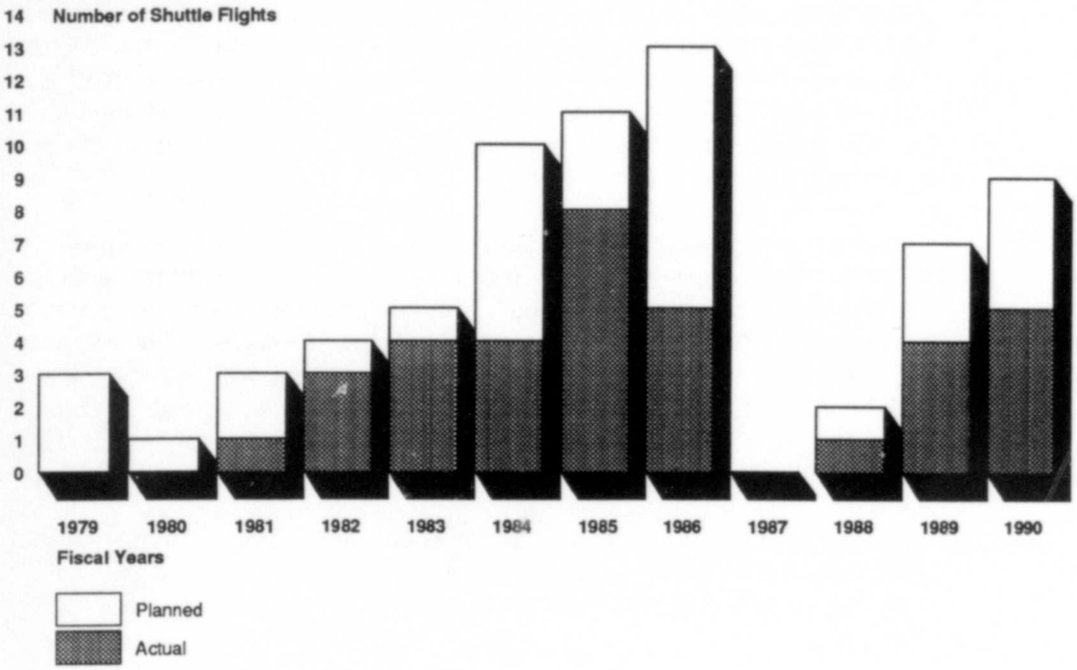
faulty high pressure oxygen turbopump. The pump had to be removed and replaced, and the launch was delayed until November 1989.

In February 1991, NASA again reduced the planned flight rate—from 12 flights a year to 10 flights a year. According to NASA officials, this reduction was due to funding constraints imposed by the Office of Management and Budget (OMB). According to the Director of Resources Management, Office of Space Flight, OMB reduced NASA's projected requirements for shuttle operations funding for fiscal years 1992 through 1996 in order to constrain NASA's overall budget. The reduction originally proposed by OMB would have supported a maximum rate of only about eight flights a year, according to the Director. NASA subsequently persuaded OMB to increase shuttle operations funding to a level that would support 10 flights a year, beginning in fiscal year 1994.

NASA Has Not Achieved Past Flight Rate Projections

NASA has not achieved its projected shuttle flight rate for any year. Figure 2.1 shows the planned and actual flight rates through fiscal year 1990.

Figure 2.1: Planned and Actual Flight Rates



In 1985, nine flights were launched, the highest number ever in any year. According to the Presidential Commission that investigated the Challenger accident, these flights strained the system. In fiscal year 1990, NASA planned nine flights but actually accomplished only five.

NASA Must Reduce Processing Time to Achieve Planned Flight Rate

To accomplish its current flight schedule, NASA plans to achieve an average ground processing time of 98 days for most flights. Excluding the first post-Challenger flight of each orbiter, the actual processing time has averaged about 160 days since the accident; the lowest processing time for a post-Challenger flight was 110 days.

The number of days required for processing varies by flight, depending on factors such as the nature of the next mission and the quantity and nature of inspections and modifications planned. NASA has established a minimum standard processing goal for fiscal year 1994 and later of 88 days for each flight—60 days in the Orbiter Processing Facility, 5 days in the Vehicle Assembly Building, and 23 days at the launch pad.

Other factors increase processing time. For example, extended duration missions require about 11 days longer in the Orbiter Processing Facility. Also, the number and types of inspections, tests, and refurbishment work conducted on an orbiter depend on the number of times the orbiter has flown. For example, orbital maneuvering system pods are refurbished after every fifth flight. An additional 28 days are scheduled for fifth interval flights and an additional 50 days are scheduled for 10th interval flights.

After every 3 years of service, NASA plans to take each orbiter out of service for an extended period of time to conduct structural inspections and to install major modifications. This period is referred to as orbiter maintenance down period. NASA estimates that 188 days will be required to inspect and modify the orbiter and to process the orbiter for its next flight. An additional 30 days of contingency time are planned for the first structural inspection and modification program for each of the first three orbiters.

Time at the launch pad also varies by flight, depending primarily on the payload. For example, payloads requiring an interim upper stage propulsion system require an additional 4 to 6 days processing at the launch pad.

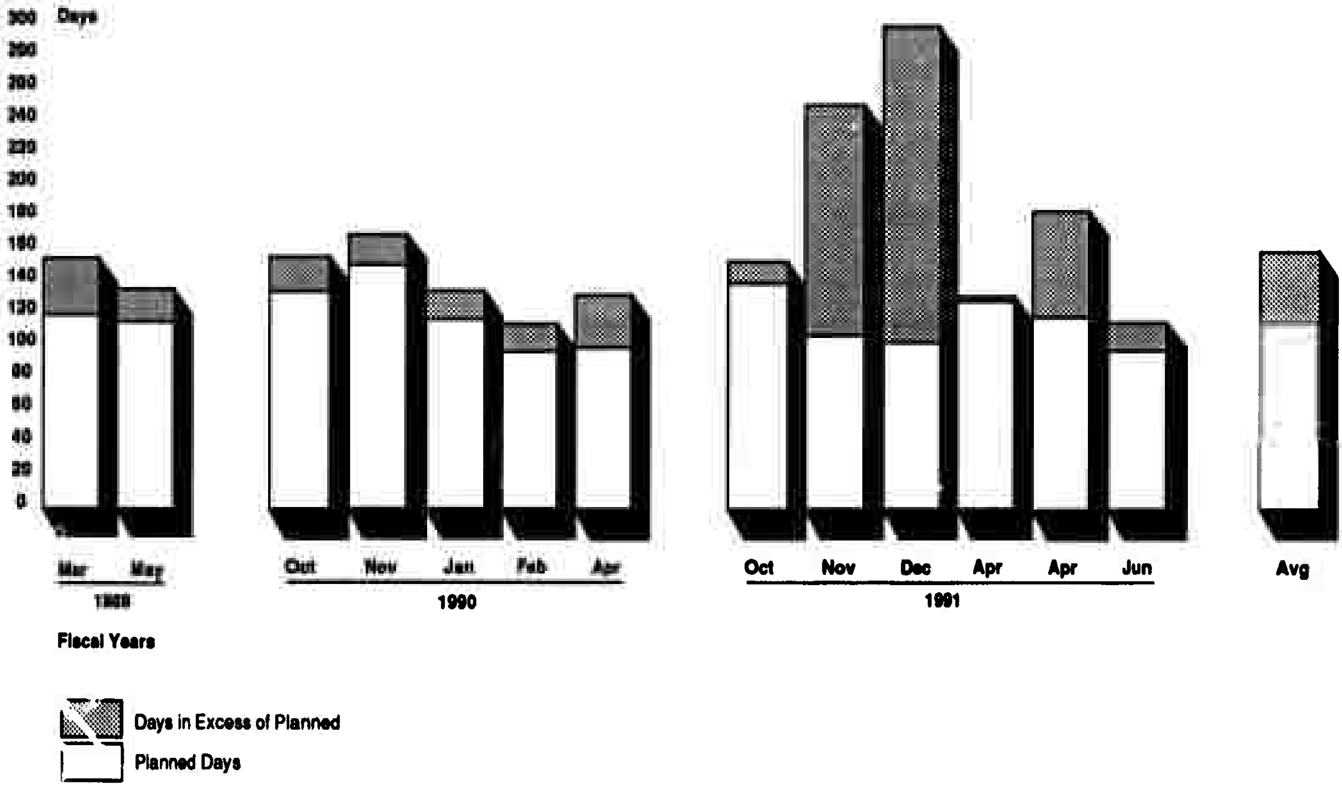
The June 4, 1991, manifest assessment for flights to be conducted in fiscal years 1992 through 1996 shows projected processing times that range from a low of 88 days to a high of 312 days. Excluding the first flight of the Endeavour and seven flights in which major structural inspection and modification programs are planned, the manifest assessment shows that NASA scheduled an average processing time of 98 days, or 10 days more than the standard processing goal.

Our analysis of processing times for 13 post-Challenger flights through June 1991 showed that the average processing time was about 160 days, approximately 61 percent more than the average time scheduled for flights for fiscal years 1992 through 1996. Our analysis excluded the first post-Challenger flight of each orbiter because, according to Kennedy Space Center officials, processing for these flights was not typical. The shortest of the 13 processing times was 110 days for the Atlantis launched in February 1990.

The June 1991 assessment shows the standard Orbiter Processing Facility time of 60 days for 15 of the 30 flights planned in fiscal years 1994 through 1996. However, the average Orbiter Processing Facility time for the 13 flights conducted through June 1991 was 98.2 days, about 64 percent greater than the standard processing time. NASA achieved an Orbiter Processing Facility time of 60 days on a recent Atlantis flight originally scheduled to be launched on July 24, 1991. According to the manager responsible for processing that mission, achieving the 60-day time required extraordinary performance that could not be sustained over a long period. Further, the manager stated that this flight experienced minimal unplanned work, less than anticipated tile replacement, and exceptional teamwork. The launch date was subsequently delayed to August 2, 1991, because of computer problems discovered at the launch pad.

NASA exceeded its planned processing times for each of the 13 post-Challenger flights. Actual processing times exceeded the plan by an average of about 45 days. In 1990, two flights experienced unusually long delays because of hydrogen leaks. If these two flights were excluded, actual processing times would exceed the plan by an average of 22 days. Figure 2.2 shows planned and actual processing times for the 13 flights.

Figure 2.2: Shuttle Processing Times



Most of the delays were due to unanticipated circumstances and unplanned work, according to Kennedy Space Center officials. For example, 1990 flights of the Columbia and the Atlantis were delayed 200 days and 144 days, respectively, primarily because NASA discovered hydrogen leaks in the propulsion systems.

These kinds of unexpected problems may increase with time, as the age of the orbiter fleet increases. According to a NASA team that investigated structural flaws in shuttle propulsion system temperature probes in 1991, more problems should be anticipated as the orbiters age. If flights planned for fiscal years 1992 through 1996 experience the same amount of delay as the previous 13 flights, NASA will not be able to achieve

10 flights a year. If NASA continues to experience processing delays averaging about 45 days, we calculated that the maximum flight rate would be seven or eight.[2]

We made our calculation by adding the average delay to projected processing times for each flight in the June 1991 manifest assessment. For example, the manifest assessment shows a November 22, 1993, planned launch of Discovery on a mission to repair the Hubble space telescope. The manifest assessment also shows a processing time of 93 days. A 45-day delay would increase processing time to 138 days and would slip the planned launch by over 1 month.

Full Impact of Plans to Reduce Processing Times Is Not Yet Known

In 1989, NASA and its contractors reviewed shuttle maintenance and inspection requirements and determined that by using more in-flight data from previous missions and rearranging and integrating testing, NASA could reduce or modify its maintenance and inspection requirements, which would reduce processing time. For example, if NASA were to decrease processing requirements for each flight by performing some inspections only at periodic intervals, Kennedy Space Center officials estimate that processing time would be reduced by 11 days. NASA initiated a second review of maintenance and inspection requirements in January 1991. This review, which was about 90 percent complete on August 15, 1991, reported a potential savings of 5 days in processing time. However, the launch processing manager for the August 2, 1991, Discovery mission told us that he believed the actual savings was less than 5 days.

According to Kennedy Space Center officials, after the current review is completed, little opportunity will exist to eliminate maintenance and inspection requirements. According to these officials, further requirements reductions would represent a major change in shuttle verification. As a result, they stated that NASA must find ways to enhance processing efficiency to further reduce processing time.

Kennedy Space Center has identified high priority efficiency enhancement efforts and established a management steering team to develop priorities, implement them, and monitor the efforts. One enhancement is a concept under which task leaders are given responsibility and

[2]Excluding the two flights delayed because of hydrogen leaks, NASA exceeded planned processing times by an average of about 22 days. If future flights continue to experience delays of this magnitude, the maximum flight rate would be eight to nine flights a year.

authority to make shuttle processing decisions and arrangements. According to Kennedy officials, this concept should alleviate many shuttle processing delays by permitting processing decisions to be made more quickly. Other enhancements include (1) reducing work authorization document signature requirements, (2) expanding systems training, (3) clarifying standard practice instructions, and (4) improving availability and readiness of ground support equipment. Kennedy officials told us that they believe the enhancements will reduce shuttle processing time. However, the amount of any reductions will not be known until the enhancements have been implemented on several flights, according to the officials.

Time Needed for Structural Inspections and Modifications Is Uncertain

NASA plans to perform major structural inspections and modifications to each orbiter every 3 years. Current schedules are based on the assumption that these inspection and modification periods and subsequent processing for the next flight can be accomplished in 188 days.

The triennial orbiter maintenance down periods include 90 days for major structural inspections. The remaining 98 days are for installing major modifications, performing other inspections, making repairs, and processing the orbiter for its next flight.

During the structural inspection, technicians will remove some detachable panels to inspect the structure for possible damage and will replace many major components. The first inspection began on the orbiter Columbia in August 1991, at the orbiter contractor's Palmdale, California, facility. NASA plans to conduct all remaining inspections at the Kennedy Space Center.

Since the inspection and modification program has only just begun, estimates of the time required are uncertain. According to an April 1990 Office of Technology Assessment report, some NASA officials have expressed concern that the 90 days for structural inspections may not be long enough to accomplish all of the necessary work. We also noted that during recent attempts to reduce processing times, NASA shifted a number of inspection requirements to the triennial orbiter maintenance down periods.

Orbiter Loss or Damage Would Limit Flight Rate

NASA's flight rate projections are predicated on the availability of four orbiters. Each time NASA launches the shuttle, it risks losing an orbiter from equipment failure or human error. Shuttle reliability is uncertain but, according to the Office of Technology Assessment, reliability estimates generally vary between 97 and 99 percent.[3] If reliability is and remains at 98 percent, there would be a 50-percent chance of losing an orbiter within 34 flights, according to the Office of Technology Assessment. Building a replacement orbiter could take up to 6 years, depending on the availability of spare structural components. Manufacture of the Endeavour, the replacement for the Challenger, was reduced to 4 years by using existing spare structural components.

In July 1991, the Vice President announced that the administration had decided not to purchase additional orbiters, except in the case of an accident or "other demonstrable need." According to the Vice President, "in all probability, we have purchased the last space shuttle."

A severe ground processing accident over the next several years could also reduce the orbiter fleet size. Any severe structural damage would likely ground an orbiter for a long period because structural spares are not available. NASA has contracted for replacement spares. The contract calls for delivery of the spares in 1994, but according to the Deputy Shuttle Program Manager, the contract is being rephased to extend deliveries until mid- to late-1995 because of funding constraints. According to the deputy manager, future budget constraints could cause deliveries to slip even further.

Conclusions

NASA has reduced its shuttle flight rate projections from an initial post-Challenger estimate of 16 a year to a current estimate of 10 a year. While the current estimate is more realistic, actual experience through June 1991 suggests that NASA may not be able to achieve this number of flights, especially if it (1) fails to reduce its shuttle ground processing time or (2) loses or severely damages another orbiter as some have concluded is likely. Unless NASA can reduce shuttle ground processing time, we calculate that it cannot launch the shuttles more than 7 or 8 times a year.

[3]U.S. Congress, Office of Technology Assessment, Access to Space: The Future of U.S. Space Transportation Systems, April 1990.

Agency Comments

NASA agreed that its early post-Challenger projections of shuttle flight rate did not fully take into account the increase in checkout and processing requirements introduced after the accident. Since then, however, understanding of the effects of this increase has matured, according to the agency. NASA said that it was encouraged by the accomplishment of eight flights in fiscal year 1991 and still believed that a build up to 10 flights as shown its August 1991 shuttle manifest was a realistic target.

We noted, however, that NASA's current shuttle manifest projects only seven flights in fiscal year 1992. Also, subsequent to NASA's commenting on a draft of this report, an official in the Office of Space Flight told us that the agency is reviewing its shuttle flight rate projections and currently does not anticipate 10 flights a year before late in the decade.

NASA Is Working to Ensure That Safety Is Not Compromised as Flight Rate Increases

Fears that NASA might compromise safety in order to increase the shuttle flight rate in the post-Challenger era appear, at least for now, to have been unfounded. NASA officials told us that the agency's philosophy is "safety first, schedule second." The agency has demonstrated its willingness to delay flights and, in one instance, even grounded the entire fleet because of safety concerns. While some recent incidents underscore the need for continued vigilance, NASA is taking action to prevent recurrences of the problems. Kennedy Space Center has also implemented controls to help ensure that employees who are involved in shuttle processing are not fatigued by excessive overtime. Although NASA has reduced or eliminated some of the inspection and maintenance requirements that were added after the Challenger accident, these changes were carefully reviewed by boards at three levels, all of which included representatives of the agency's independent safety and mission quality organizations.

Flight Schedules Subordinated to Safety Concerns

According to shuttle program officials, since the Challenger accident, NASA has reaffirmed safety as its first priority. NASA officials told us that the current shuttle processing environment is different from the pre-Challenger environment. Previously, when problems surfaced, processing continued while the problems were being resolved. Now, processing often stops until the problems are resolved, according to the officials.

All of the 16 post-Challenger flights conducted through June 1991 were delayed on the launch pad because of safety concerns. For example, NASA delayed a planned February 1991 launch of Discovery for about 2 months because of cracks in the orbiter's fuel door hinges.

NASA grounded the entire fleet for several months during 1990 while it searched for the source of hydrogen leaks. The Aerospace Safety Advisory Panel commended NASA for this action. The panel's 1991 annual report noted that the agency's commitment to find the hydrogen leaks was an excellent example of "safety first, schedule second." "NASA was under tremendous pressure during the summer of 1990 to 'get something off the ground,' but they remained steadfast in their commitments and did not succumb," according to the panel's report.

Safety Incidents Emphasize the Need for Continued Vigilance

In September 1990, NASA's Associate Administrator for Space Flight formed a team to review shuttle processing incidents that had occurred at the Kennedy Space Center between July 1989 and October 1990 that involved human errors. The team categorized and summarized the incidents to determine if there appeared to be a pattern to their occurrence. The team was also to recommend standards and criteria to be used in assessing whether the quantity of incidents was excessive and determining what could be done to lower the frequency of such incidents.

The team's May 1991 report stated that:

"when considering the number of functions, the technical complexity, and the number of individuals involved in shuttle processing, the NASA and contractor processing team had sustained an enviable track record. Nonetheless, the inherent safety risks in space flight require sustained efforts to do better."

The team did not identify any common thread or pattern to the incidents, but it did recommend further analyses to determine if factors such as training, planning and scheduling, design workability, adequacy of procedures, or worker fatigue might underlie the incidents. The team pointed out that "safety first, schedule second" must be continuously emphasized during shuttle processing activities. According to the report, the team perceived a strong sense of schedule as a very important element in job performance.

The team recommended that NASA reemphasize shuttle safety by (1) determining the underlying cause of incidents and mishaps, (2) increasing emphasis on reporting close calls, (3) developing a technique to measure overall quality improvement achievements and trends, and (4) improving management and worker awareness of the importance of quality and safety as job elements. According to Kennedy Space Center officials, an implementation plan to follow through on the team's recommendations was established in July 1991.

NASA delayed a planned May 22, 1991, flight of Columbia when it learned of structural defects in fuel system temperature probes. Investigation revealed that the probe's design was defective and that the probes were susceptible to cracking. The probes could have broken off and contaminated turbopumps in the shuttle's main engines. The probe, which was suspected of leaking hydrogen, was removed in September 1990 and sent to its manufacturer for further analysis. However, the probe was initially sent to the wrong vendor, and NASA did not learn of the structural problem until May 1991.

Subsequent investigation of the temperature probe incident concluded that, because of errors in technical judgment, NASA originally failed to recognize the significance of the problem. The investigation team recommended several changes in NASA's system for investigating potential flight problems, including expediting failure analyses, routinely using a "fault tree" technique to ensure that all failure possibilities are explored, and reemphasizing flight safety and communications. According to shuttle program officials, these recommendations are being implemented.

Overtime Rates Are Being Controlled

According to the Presidential Commission that investigated the Challenger accident, employees responsible for processing shuttle launches were working excessive amounts of overtime to decrease processing time and accommodate the accelerated launch schedule. Worker fatigue can affect flight safety, according to the Commission.

The Commission reported that the capabilities of the shuttle processing and facilities support work force became increasingly strained as the orbiter turnaround time decreased to accommodate the accelerated launch schedule. This factor resulted in overtime percentages of almost 28 percent in some directorates. Numerous contract employees had worked 72 hours a week or longer and frequent 12-hour shifts. The potential implications of such overtime for safety were made apparent during an attempted launch on January 6, 1986, when fatigue and shiftwork were cited as major contributing factors to a serious incident involving a liquid oxygen depletion that occurred less than 5 minutes before the scheduled lift off of one flight.

After the 1986 Challenger accident, NASA established a maximum work time policy to ensure that safety is not compromised by excessive overtime rates. This policy limits the numbers of hours an employee can work in a day, a week, a 28-day period, and in a year. According to the policy, critical employees cannot work more than 60 hours in a week without waivers. Only senior Kennedy and contractor officials are authorized to grant waivers.

During the 8 months prior to the Challenger accident, overtime rates for contractor personnel directly involved in shuttle processing averaged about 20 percent. From October 1988 through May 1991, the shuttle processing contractor averaged overtime rates about 16 percent annually for those employees directly involved in shuttle processing. Additionally, during the first 7 months of fiscal year 1991, the majority of the shuttle processing contractor's departments experienced overtime rates of less than 10 percent.

In early 1990, the NASA Inspector General conducted a survey to evaluate overtime planning, approval processes, and justification procedures for Kennedy Space Center civil service and shuttle processing contractor employees. The basic purpose of the survey was to determine if a detailed audit of overtime practices and procedures was warranted. The Inspector General concluded that further audit work was unnecessary. According to the Inspector General's June 1990 report, overtime was receiving considerable scrutiny by supervisors and managers, both civil service and contractor. According to the audit report, this was a direct result of the policy and associated visibility provided by the reporting requirements used to implement the policy.

Kennedy Space Center safety, reliability, and quality assurance staff also conduct periodic inspections to determine compliance with the overtime policy. For example, the staff surveyed overtime usage by the shuttle processing contractor in October and November 1990. According to Kennedy safety officials, no serious problems were identified.

The safety surveys have identified some instances of failure by in-house NASA staff to comply with the overtime policy. For example, the staff surveyed the Shuttle Operations Division's compliance with the overtime policy in January 1991 and found that the division had not identified employees critical to shuttle processing or obtained first-line director approval prior to employees working more than 16 hours in a single work day. The staff recommended that the division identify critical positions and track overtime worked by employees in those positions. According to Kennedy's Director of Shuttle Operations, these recommendations are being implemented.

Safety Organization Oversees Changes in Shuttle Processing Steps

Before resuming shuttle flights after the Challenger accident, NASA tripled the number of safety critical functions to be checked and verified during shuttle processing. This action included increasing not only the number of critical items from 1,350 to about 3,900 but also the number of items to receive failure analysis from about 5,000 items to about 15,000 items. These changes increased orbiter processing time by about 192 work shifts. Consequently, NASA is reviewing the maintenance and inspection requirements to determine if some can be combined, modified, or eliminated in order to reduce processing times.

The Shuttle Master Verification Plan establishes the basic philosophy of shuttle processing and provides guidelines for maintenance and inspection requirements. NASA and contractor officials convert the verification plan into Operational Maintenance Requirements and Specifications Documents. In turn, Kennedy Space Center officials transfer the requirements into specific operating maintenance instructions that technicians and engineers use to process the shuttle.

Following the Challenger accident, NASA and contractor officials revised the verification plan, with corresponding changes to the maintenance requirements documents. In the revision, NASA canceled all requirements waivers and added safety enhancing maintenance and inspection requirements. According to NASA officials, the new requirements approximately tripled the detailed instructions or elements used to verify or inspect shuttle systems. As a result, the time needed in the Orbiter Processing Facility nearly doubled.

Since the revision of the verification plan, NASA has initiated two major efforts to reduce shuttle processing time by modifying maintenance and inspection requirements. NASA and contractor officials conducted the first post-Challenger requirements review from May 1989 through December 1989. Generally, the goal of the review was to reduce required shuttle system verification to two levels of back-up systems where there were three levels of redundancy. NASA also sought to establish increased reliance on in-flight data when feasible. According to a Rockwell Space Systems Division official, the changes reduced shuttle processing time by 11 days.

The second requirements review, which began in January 1991, was about 90 percent completed on August 15, 1991. During this review, NASA and contractor officials identified potential processing time reductions by changing the frequency of maintenance and inspection requirements. For example, NASA deferred some inspection and maintenance requirements from after every flight to after every third or fifth flight, while others were deferred to planned triennial orbiter maintenance down periods.

According to NASA safety and quality control officials, the changes to shuttle maintenance and inspection requirements have not compromised safety. Independent safety officials attend and participate in all requirements review sessions, and requirements changes are reviewed by safety personnel before and, if necessary, after these sessions.

NASA's oversight process involves several formal review boards, which are composed of senior-level NASA engineers and project directors, as well as safety and mission quality officials. The Director of Safety at Johnson Space Center stated that safety and quality control officials attend all meetings when changes to operational maintenance requirements and specifications are discussed and that safety and quality control officials are involved throughout the entire requirements change proceedings. Safety officials must review and approve changes to operational maintenance requirements and specifications, according to the Director.

NASA has established separate configuration control boards for various shuttle projects such as the orbiter, external fuel tank, and space shuttle main engine projects. Any modifications to maintenance and inspection requirements for the various projects are initiated through change notices that are submitted to the cognizant control board. The control boards at each of the centers are composed of safety and mission quality officials who must review all change notices.

If approved by the control board, the change notice is then presented to a program requirements control board, chaired by the Space Shuttle Program Deputy Director at Johnson Space Center. Johnson's Director of Safety, Reliability, and Quality Assurance is a member of the requirements control board. If the change involves a project managed by another center, a representative of that center's safety organization is also a member of the board.

The Space Shuttle Program Director at NASA headquarters chairs a third control board that must approve all critical changes. This board is the controlling authority for approving all requirements changes that involve safety critical functions or hazardous materials. It is also responsible for resolving any safety issues raised by lower level boards. NASA's Associate Administrator for Safety and Mission Quality is a member of this board.

Conclusions

We found no evidence to suggest that NASA has compromised safety to increase the flight rate. Thus far, NASA flight schedules have been subordinated to safety concerns in launch decisions. NASA is taking action to prevent a recurrence of recent safety problems, and it has implemented controls to help ensure that employees who are involved in shuttle processing are not fatigued by excessive overtime. Although NASA is modifying or eliminating some of the inspection and maintenance requirements added after the Challenger accident, it has controls to ensure that safety is considered during this process.

Impact of Flight Rate on Procurement of Spare Parts and Shuttle Subsystems

Since the inception of the shuttle program, NASA has consistently overestimated the number of launches it could conduct in a year. The annual flight rate is one factor in determining the number of spare parts and subsystems such as solid rocket motors and external tanks that are needed each year. We found no evidence that unrealistic flight rates have resulted in an overprocurement of spare parts. Neither has NASA purchased more subsystem hardware such as external tanks and solid rocket boosters than it expects to eventually use, but cut-backs in delivery schedules caused by overly optimistic flight rate projections have created some inefficiency in the production of these subsystems. Also, the agency was contracted to build advanced solid rocket motor production facilities in excess of current requirements.

Flight Rate Has Not Caused Overprocurement of Spare Parts

NASA links shuttle spare parts requirements with spare parts failure rates and power-on time. Power-on time is the total time a part is used in ground processing, testing, and flight. According to Kennedy Space Center officials, ground processing time has a greater influence than flight rate in determining spare parts requirements. A decrease in the flight rate does not necessarily result in a corresponding decrease in spare parts usage because NASA may increase the use of the part in ground testing.

The Director of Kennedy Space Center Shuttle Operations told us that extensive ground testing causes systems to wear because ground power-on time can exceed flight power-on time by a 10 to 1 ratio. For example, in an earlier Columbia mission, that orbiter accumulated about 17,000 hours of power-on time during ground processing and only 1,700 hours of in-flight power-on time, according to the Director. The Shuttle Launch Director told us that many parts fail during the extensive ground testing that is conducted before each shuttle flight.

Even though flight rates are not a major factor in computing spare parts requirements, NASA headquarters reduces Kennedy Space Center shuttle logistics budgets when (1) the shuttle program fails to meet its planned annual flight rate or (2) the agency issues a flight assignment manifest that reduces previously planned flight rates. According to shuttle program logistics officials, NASA headquarters reduces the logistics budget by $3.7 million for each missed flight, $1.7 million for spares and $2.0 million for repairs. NASA budget documents show that the agency cut a total of $60.7 million from the Kennedy Space Center shuttle logistics budgets for fiscal years 1991 through 1996. NASA deleted $11.1 million of the $60.7 million because the shuttle program launched only five of eight planned flights in fiscal year 1990 and $49.6 million because of downward revisions in the shuttle's annual flight rates, as reflected in the February 1991 flight manifest.

Another reason NASA has not purchased too many spare parts is that the agency only recently completed its initial inventory of spares. At the time of the Challenger accident, the initial inventory of shuttle spare parts was only 65 percent complete because NASA had postponed spare parts procurement in favor of other budget items, according to Challenger accident investigators. NASA has since increased shuttle spare parts inventories, and in June 1991, it completed filling the initial inventory. According to Kennedy Space Center logistics officials, the shuttle program can be supported within spare parts funding levels, even though current levels are about the same as those in 1987.

Overly Optimistic Flight Rate Projections Caused Inefficiency in Subsystem Production

Overly optimistic flight rate projections have created inefficiencies in the production of shuttle subsystems such as external tanks and solid rocket boosters. For example, NASA purchased more manufacturing tools and equipment than was needed to support the actual flight rates. In addition, when the flight rates did not materialize as planned, NASA renegotiated tank and booster production contracts, stretching out the deliveries and creating some inefficiency.

NASA Reduced External Tank Deliveries

The government-owned, contractor-operated external tank manufacturing facility has the capacity, tooling, and equipment to produce up to 24 tanks a year. By 1986, the manufacturer had reached an annual production rate of 12 external tanks.

The Challenger accident, however, caused NASA to reduce the external tank production rate, and since 1987 the manufacturing facility has operated at the minimum sustainable production level of four tanks a year. Even at that rate, NASA had an inventory of 19 external tanks at the beginning of fiscal year 1991. According to the External Tank Project Manager, NASA only needs to maintain an inventory of three external tanks to support current shuttle processing operations. Based on NASA's current planned flight rates and its external tank production schedule, the agency will continue to have an excess inventory of external tanks until fiscal year 1995.

Changes in delivery schedules, made necessary by NASA's inability to achieve projected shuttle flight rates and subsequent reductions in flight rate predictions, have resulted in increased contract costs. In January 1990, NASA reduced its planned annual flight rate from 14 to 12 flights. As a result, the agency adjusted the external tank contract to reflect flight rate reductions and extend the delivery dates. This adjustment increased contract costs by about $240 million because personnel and facilities would operate over a longer period of time to manufacture the same number of tanks as before. According to NASA officials, the increase is primarily fixed costs, which would have been incurred in follow-on production contracts and, therefore, does not represent an increase in total program cost. The officials agreed, however, that efficiency does deteriorate as a result of this process and that costs increased as a result of the inefficiency. They could not, however, quantify the amount of the increase.

In March 1991, NASA once again modified the external tank contract to reflect the revised shuttle manifest, including the reduction in the maximum shuttle flight rate from 12 to 10 a year. Costs for the delivery schedule changes had not been negotiated at the completion of our review in June 1991.

NASA Slowed Deliveries of Solid Rocket Booster Components

In January 1985, NASA contracted with United Systems Booster, Incorporated, for 64 solid rocket booster flight sets to support a shuttle flight rate of 20 a year. The Challenger accident caused NASA, in December 1988, to renegotiate the contract for the remaining undelivered 59 flight sets and to extend some component deliveries until 1994. The renegotiated contract redefined solid rocket booster requirements, increased inspection requirements, and reflected a revised rate of 14 flights a year. The changes increased estimated contract costs by over $1 billion. Some of the increase was due to inefficiencies caused by the changing production schedule.

By the close of fiscal year 1990, NASA had accepted delivery of 81 percent of the contract's reusable hardware and 65 percent of its expendable hardware with final deliveries scheduled to begin in 1994. NASA, however, revised the contract again in September 1990 to reflect a reduction in the shuttle's annual flight rate from 14 to 12. Before the contractor submitted a cost proposal for the change, NASA further reduced the annual flight rate from 12 to 10. Agency officials said that the flight rate reduction from 14 to 10 will cause final component deliveries to slip from 1994 to 1996 and increase contract costs.

NASA Acquiring Excess Advanced Solid Rocket Motor Production Capacity

NASA plans to reduce advanced solid rocket motor production tooling and test equipment to be consistent with the latest reduction in the shuttle flight schedule. However, at the completion of our field work, the agency did not plan to reduce facility sizes to conform to current flight rate estimates. Subsequently, NASA officials advised us that they had decided to eliminate one building in order to offset construction cost increases and were studying the possibility of other facility size reductions because of reductions in the projections of future shuttle flight rates.

In April 1989, NASA selected Lockheed Missiles and Space Company, Incorporated, as the advanced solid rocket motor contractor and awarded two contracts. One was the motor development and production contract that provides for the design, development, test, and production of the first 50 sets of advanced motors. The other contract is to build facilities and acquire equipment to support a maximum annual production of 16 motor sets.[1] The facilities and equipment are to be government-owned and contractor-operated.

In October 1990, NASA changed the development and production contract delivery schedule to reflect a maximum annual production of 13 motor sets, based on the reduction in the maximum shuttle flight rate from 14 to 12 flights a year.[2] The Deputy Advanced Solid Rocket Motor Project Manager told us that the project office does not plan to modify the contract to the most current rate of 10 flights a year until it receives firm program guidance from NASA headquarters. According to the deputy project manager, the project office anticipates reducing production to a maximum of 11 motor sets a year once fiscal year 1993 budget guidance is received. Advanced solid rocket motor project officials told us that the delivery schedule changes will increase contract costs; however, the amount of the increase was not known at the completion of our review in June 1991.

NASA is studying savings to be obtained from reducing manufacturing equipment from that needed to produce 16 motor sets a year to that necessary to produce 11 sets a year. At the completion of our review, Marshall Space Flight Center had identified reductions that would save about $10.5 million. For example, two autoclaves[3] would be needed to

[1]The 16 sets include 14 flight sets and 2 sets for ground tests.

[2]The 13 motor sets include 12 sets of flight motors and 1 set of test motors.

[3]Autoclaves are used in the insulation of solid rocket motor cases.

support a production rate of 16 motor sets a year, but only one autoclave will be needed to produce 11 motor sets a year. Marshall Space Flight Center estimated that eliminating one of the autoclaves would save $2.4 million. As another example, reducing the maximum expected production rate to 11 motor sets a year will permit elimination of one propellant mixer at an estimated savings of $1.4 million. According to the deputy project manager, manufacturing equipment requirements are still being defined and NASA has not yet modified the contract to reflect the maximum expected production rate of 11 motor sets a year.

Although NASA has plans to reduce manufacturing equipment, Marshall Space Flight Center officials told us that, at the completion of our field work, the agency did not plan to reduce the size of the motor manufacturing facilities. For example, the facilities were to be built with space for two autoclaves, even though only one autoclave would be acquired and installed. According to NASA officials, NASA did not plan to scale back the facility size because it wanted to maintain the capacity to increase production if necessary. NASA was studying the possibility of using the advanced motors on other programs such as heavy-lift launch vehicles. According to the officials, NASA did not estimate the potential cost savings from reducing the size of the facilities.

In September 1991, the Space Shuttle Program Director instructed the Advanced Solid Rocket Motor Project Manager to delete one of two propellant mixing and casting facilities planned for the motor manufacturing site. According to the Deputy Director of Shuttle Systems Engineering and Analysis, however, the primary reason for the reduction was to offset other facility cost increases rather than the reduction in shuttle flight rates. Shuttle program officials also advised us that the contractor is studying other reductions in facility sizes as a result of the flight rate reductions.

Conclusions

We found no evidence that optimistic flight rate projections have resulted in overprocurement of spare parts; however, NASA had to modify delivery schedules and costs in contracts for subsystems such as external tanks and solid rocket boosters when shuttle flight rate projections did not materialize. Changing delivery schedules and reducing manufacturing rates for these shuttle subsystems and solid rocket motors created inefficiencies and increased contract costs. Also, NASA has contracted to build advanced solid rocket motor production facilities in excess of current requirements. At the completion of our field work, NASA had not reduced facility sizes or the quantity of production tooling and test equipment to be consistent with the latest reductions in shuttle flight rates. Marshall Space Flight Center planned to reduce tooling and test equipment when it received firm program guidance from NASA headquarters, but had no plans to reduce facility sizes. Subsequently, NASA advised us that it had deleted one propellant mixing and casting building in order to offset other facility cost increases and that the motor development contractor was studying the cost-effectiveness of other reductions in facility sizes to conform to currently authorized flight rates.

Recommendations

We recommend that the NASA Administrator

- implement plans to reduce advanced solid rocket motor manufacturing equipment to be consistent with the agency's current projection of the maximum shuttle flight rate,
- identify possible cost savings from reducing the size of advanced solid rocket motor production facilities to those needed to produce 11 motor sets a year, and
- review the decision not to reduce facility sizes, if warranted by the potential cost savings.

Agency Comments

NASA concurred in our recommendations and stated that the advanced solid rocket motor production rates and the facility capacities are being adjusted to the currently authorized flight rate, retaining what the agency feels is a prudent reserve capacity. The advanced solid rocket motor development contractor is currently studying the cost-effectiveness of potential reductions in motor production facilities. Although NASA believes that savings from the reductions will be significant, an accurate projection of the savings will not be possible until contractor studies are completed later this year.

NASA Implements Mixed-Fleet Policy

According to the Presidential Commission on the Challenger accident, the accident demonstrated the fallacy of relying on the shuttle to launch most payloads. After the accident, the United States adopted a mixed-fleet policy to conserve the shuttle, reduce the likelihood of further loss of human life, and provide a more robust space transportation capability. Under the mixed-fleet policy, most payloads that do not require a human presence or the unique capabilities of the shuttle are to be launched on unmanned, expendable launch vehicles.

About 80 percent of the payloads listed on the shuttle's pre-Challenger manifest have been offloaded, either canceled or shifted to expendable launch vehicles. Some payloads that might have been shifted to expendables were allowed to remain on the shuttle because NASA judged that shifting them would involve unacceptable costs or risks or expendables were not available to meet the launch schedules. Most payloads on the shuttle's current manifest were designed before the Challenger accident to be flown on the shuttle; almost all NASA payloads still in an early design phase are being designed for launch on expendable launch vehicles.

NASA has established a Flight Assignment Board to determine how each payload will be launched and to help ensure that only those payloads requiring the shuttle are manifested on it. The board recommended that all but 3 of the 21 new payloads it has considered be flown on expendable launch vehicles.

Payloads Offloaded From Shuttle

Table 5.1 shows the status, as of August 1991, of those payloads on the last shuttle manifest prior to the Challenger accident. The manifest was published in November 1985 and updated through January 1986. The table reflects those payloads scheduled to be launched during January 1986 through September 1995.

Table 5.1: Status of Payloads on the November 1985 Shuttle Manifest

Payload source	November 1985 manifest	Flown or still on shuttle manifest	Offloaded
NASA	107[a]	41	66
Defense	95[b]	8	87
Commercial	99[c]	12	87
Total	**301**	**61**	**240**

[a]Includes eight payloads developed by NASA for the National Oceanic and Atmospheric Administration.

[b]The November 1985 manifest listed 47 Department of Defense payloads for the period 1986 through 1989. The November 1985 NASA/Department of Defense Phase III Pricing Agreement called for Defense to use a minimum of eight equivalent flights a year for the period 1989 through 1991. Assuming that this rate would continue through 1995, the total Defense payloads would be as shown.

[c]Some of these payloads were also holding reservations on expendables with a final launch decision still pending; some requests were NASA's own projections.

Some payloads offloaded from the shuttle were canceled; others were or are to be launched on expendable launch vehicles. For example, the Cosmic Background Explorer satellite was scheduled to be launched on the shuttle in July 1988. The satellite was redesigned and launched on a Delta rocket in November 1989. Through February 1991, three NASA payloads had been launched on expendable vehicles and another 25 were projected for launch on expendables through June 1996. In addition, NASA has supported the move of over 70 Department of Defense payloads from the shuttle to expendables. Commercial payload owners now negotiate directly with launch service providers. Of the 61 payloads scheduled to fly on the shuttle between April 28, 1991, and September 30, 1996, 28 require a human presence, 26 require the unique capabilities of the shuttle, and 7 are manifested on the shuttle for "other compelling reasons."

Payloads require a human presence to (1) make scientific observations, (2) operate payload instruments, (3) perform life sciences and medical experiments, and (4) service or repair orbiting payloads. Examples of payloads requiring humans are the Spacelab Life Sciences Laboratory launched on June 5, 1991, to investigate the effects of weightlessness on people and animals and the planned May 1992 mission to retrieve, repair, and redeploy a failed communications satellite. The Hubble space telescope repair mission planned for fiscal year 1994 and missions to construct space station Freedom, beginning in the last quarter of fiscal year 1995 also require humans, according to NASA.

Satellites requiring unique shuttle capabilities are those that (1) are to be returned to earth to recover a product or specimen, or so that payload hardware can be reused on future missions and (2) are of such a size and/or weight that they cannot be accommodated on expendables. The Atmospheric Laboratory for Applications and Science, a series of five missions planned through September 1996 to measure long-term variability in the energy radiated by the sun, variability in the solar spectrum, and global distribution of key molecular species in the atmosphere is an example of a payload requiring unique shuttle capabilities. Mission hardware remains attached in the shuttle's payload bay, where it is returned to earth to be refurbished for successive missions. The United States Microgravity Laboratory, two flights of a microgravity materials processing laboratory that remains attached to the shuttle, is another example.

Seven payloads remain on the shuttle manifest through September 1996 because of "other compelling circumstances." NASA defines other compelling circumstances to include those in which (1) national security or foreign policy considerations dictate the shuttle's use, (2) use of an expendable launch vehicle would result in an unacceptable risk of loss of a unique scientific opportunity, (3) expendable launch vehicle services are not available when needed, and (4) cost-effective expendable launch services to meet specific mission requirements are not available. Of these seven payloads, four cited national security concerns, two cited unavailable expendable launch vehicles, and one cited a combination of foreign policy considerations and the lack of an alternative expendable launch vehicle.

Most payloads on the current shuttle manifest were already in development at the time of the January 1986 Challenger accident. New payloads, for the most part, are being designed for launch on expendables. Of the 34 payloads in concept development or preliminary design phases, which had requested launch services as of February 1991, 27 are projected to fly on expendables. The remaining seven payloads will remain attached to the shuttle throughout the mission.

According to an official in NASA's Transportation Services Division, the only payload recently entering the detailed design and development phase that is being designed for launch on the shuttle is the Advanced X-ray Astrophysics Facility. NASA believes the X-ray facility should be launched on the shuttle so that astronauts can assist in deploying it if necessary or the shuttle can return it to earth if a malfunction occurs that cannot be corrected on orbit. The facility is estimated to cost about $1.8 billion in development.

Flight Assignment Board Helps Enforce Shuttle Use Policy

NASA established a Flight Assignment Board in September 1989 to formalize the process of determining which payloads should be launched on the shuttle and which should be launched on expendables. The board is composed of senior NASA officials and chaired by NASA's Associate Administrator for Space Flight.

At its first meeting, the board adopted a payload assignment policy under which all payloads are assigned to expendables unless (1) they require a human presence or some unique shuttle capability or (2) there are other compelling reasons for using the shuttle. The board also reviewed all primary payloads on the then-current mixed-fleet manifest for fiscal years 1990 through 1995. It concluded that all but two of the payloads included in the shuttle manifest met the assignment criteria. The board decided to review the two payloads—both communications satellites—again at its next meeting.

In two subsequent meetings, the board not only reconsidered the two payloads but also considered assignment of new payloads. Of the 21 primary payloads considered, only 3 were assigned to the shuttle. Seventeen payloads were assigned to expendables, and the board decided to withhold judgment on one payload until near the time NASA makes a firm decision on its development.

The three payloads assigned to the shuttle included the two communications satellites and the Advanced X-ray Astrophysics Facility. Subsequent to the board's last meeting, NASA decided to shift one of the communications satellites from the shuttle to an expendable, if funds are available to purchase the expendable launch vehicle and to cancel the other communications satellite.

Conclusions

NASA is moving from a policy of almost exclusive use of the shuttle to launch its payloads to one of using the shuttle only when necessary. The vast majority of payloads on the shuttle's pre-*Challenger* manifest have been canceled or shifted to expendable launch vehicles. Most payloads on the shuttle's current manifest were in development before the *Challenger* accident and 89 percent require either a human presence or the shuttle's unique capability. Also, most new satellites are being designed for launch on expendables. NASA's newly created Flight Assignment Board is helping to ensure that payloads are manifested on the shuttle only when necessary.

Comments From the National Aeronautics and Space Administration

NASA

National Aeronautics and
Space Administration

Washington, D.C.
20546

Office of the Administrator

SEP 26 1991

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and
International Affairs Division
General Accounting Office
Washington, DC 20548

Dear Mr. Conahan:

We have reviewed the General Accounting Office (GAO) draft report entitled "Space Shuttle: NASA Faces Challenges In Its Attempt to Achieve Planned Flight Rates" (code 397013).

We find the report, for the most part, to be thorough, accurate, and objective, with conclusions that closely parallel our own. In fact, actions already under way within NASA anticipate some of its specific recommendations. Where we have differences, it is more a matter of point of view, not of disagreement on the facts or on the objectives we are trying to reach.

With regard to flight rates, it is clear that the early post-Challenger projections did not fully take into account the increase in checkout and processing requirements introduced after the accident. Since then, understanding the effect of this increase has matured. Encouraged by the accomplishment of eight flights in fiscal year 1991, we feel that the buildup to ten flights a year, as shown in our August 1991 manifest, is a realistic target.

The Advanced Solid Rocket Motor production rates and facility capacities are being adjusted to the currently authorized flight rate, retaining what we feel is a prudent reserve capacity. While this is expected to result in significant savings, we cannot be specific about this until we have the results of contractor studies of cost-effectiveness, which are now under way.

As noted in the report, the mixed-fleet policy has been well integrated into our flight assignment process and into our program approval and budgeting procedures. This ensures that the Space Shuttle will be used only for payloads that require human presence, the unique capabilities of the Shuttle, or when other compelling reasons apply, and that unmanned expendable launch vehicles will be procured for payloads that do not require the Shuttle.

In summary, we are in accord with the basic findings in the report and believe that our actions, most of them already in effect, will meet the intent of the recommendations.

Sincerely,

John E. O'Brien

John E. O'Brien
Assistant Deputy Administrator

Major Contributors to This Report

National Security and International Affairs Division, Washington, D.C.

Charles F. Rey, Assistant Director
Larry Kiser, Senior Evaluator

Atlanta Regional Office

Lee A. Edwards, Regional Management Representative
Leo B. Sullivan, Evaluator-in-Charge
Karen B. Lindsey, Evaluator
Daniel E. Ranta, Evaluator

Ordering Information

The first copy of each GAO report is free. Additional copies are $2 each. Orders should be sent to the following address, accompanied by a check or money order made out to the Superintendent of Documents, when necessary. Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

U.S. General Accounting Office
P.O. Box 6015
Gaithersburg, MD 20877

Orders may also be placed by calling (202) 275-6241.