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Congress has appropriated about $4.4 billion to the National Aeronautics and Space Administration (NASA) and $106 million to the Department of Defense through fiscal year 1977 for development of the Space Transportation System (STS), about one-third of estimated development and production cost. Congress must decide whether to approve a full-scale operational STS by authorizing the start of production of additional orbiters and construction of a second-line launch and landing facility. Findings/Conclusions: Production would be justified if no technical problems are encountered, space activity increases as predicted, and the cost of operation is significantly reduced over expendable vehicles. However, there were indications that these conditions may not be met. Other alternatives presented were delaying production or proceeding with one of the three orbiters. Recommendations: Until more information is available, Congress should assess the advantages and disadvantages of starting production of a third orbiter in FY 1978 and of delaying funding of the remaining two proposed orbiters. The NASA Administrator should delay implementing a user charge policy until costs and policies for all elements of the STS have been formulated. (Author/HTW)

REPORT TO THE CONGRESS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

Space Transportation System: Past, Present, Future

National Aeronautics and Space Administration
Department of Defense

This report examines the status of NASA's space shuttle development program, its proposed policy on charges to those who use these facilities, and several options available to the Congress on the question of production of orbiters in fiscal year 1978.

The Congress should assess the advantages and disadvantages of starting the production of a third orbiter in fiscal year 1978 and of delaying funding of the remaining two proposed orbiters.

MAY 27, 1977

PSAD-77-113

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-183134

To the President of the Senate and the
Speaker of the House of Representatives

This report describes the technical problems the National Aeronautics and Space Administration has encountered in developing the Space Transportation System. It recommends that the Congress assess the advantages and disadvantages of initiating procurement of the third orbiter and delaying funding of orbiters four and five.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

Copies of this report are being sent to the Director, Office of Management and Budget; the Secretary of Defense; and the Administrator, National Aeronautics and Space Administration.

Elmer B. Staats

Comptroller General
of the United States

COMPTROLLER GENERAL'S
REPORT TO THE CONGRESS

SPACE TRANSPORTATION SYSTEM:
PAST, PRESENT, FUTURE
National Aeronautics and
Space Administration
Department of Defense

D I G E S T

The current cost estimate for Space Transportation System development and production is $13.2 billion. This estimate does not include about $2.3 billion for Government salaries, travel, and related costs for shuttle development to be funded separately by the National Aeronautics and Space Administration (NASA).

Through fiscal year 1977 the Congress has appropriated about $4.4 billion to NASA and $106 million to the Department of Defense for Space Transportation System development. The Congress must decide whether to approve a full-scale operational Space Transportation System by authorizing the start of production of additional orbiters and construction of a second-line launch and landing facility at Kennedy Space Center.

Funds required to carry out the NASA and Department of Defense plan would total about $3.4 billion, of which $2.1 billion is for production of three additional orbiters (for a total of five), $1.2 billion is for Vandenberg Air Force Base facilities and $0.1 billion is for second-line Kennedy Space Center facilities. Additional Government funds would be needed for shuttle operations and for the design and development of payloads.

The decision to proceed with or delay production of the three orbiters is complex with little assurance that either option selected will ultimately prove to be the best decision. NASA officials believe the best approach is to proceed with production at this time. Defense officials believe the program should proceed as now planned by NASA.

The five orbiters, according to NASA, would provide an assured launch capability for all users, and most expendable launch vehicles could be eliminated. Recent NASA studies indicate that a five orbiter fleet is more economical than other mixes of fewer orbiters supplemented by expendable launch vehicles, assuming a minimum of 300 flights between 1980 and 1991. Additionally, NASA studies have shown that a delay of 3 years in the production of orbiters 3, 4, and 5 could result in a cost increase of $4 billion (1978 dollars) to $5.6 billion (1978 dollars). (See pp. 60 and 61.)

There is little doubt that production should proceed if (1) no technical problems are encountered, (2) space activity increases twofold as predicted, and (3) the cost of operation is significantly reduced over expendable vehicles. Under these conditions, a delay in production would increase costs but not to the extent projected by NASA. (See pp. 60 to 62.)

On the other hand, there are no assurances that technical problems will not be encountered (see pp. 8 to 43), that space activity will increase twofold (see pp. 56 and 57), or that the Space Transportation System will greatly reduce the cost of space operations. (See pp. 58 and 59.) Information presented in this report suggests that these three prerequisites for proceeding with production may not be met.

The most cost-effective approach is usually to delay production until there is adequate assurance that the system will accomplish its objectives. The issue for congressional decision is whether a delay in production, and thus a delay in achieving a more extensive manned program than two flights a month, would adversely affect national prestige. If so, the Congress may wish to proceed with the production of the remaining three orbiters. (See pp. 59 and 60.)

A third alternative might offer some advantages over either delaying or proceeding with full-scale production. Production of the third orbiter could be initiated and the remaining two could be delayed until there are more adequate assurances regarding technical problems, space flight activity, and the cost of operations. (See pp. 63 and 64.)

At the time of GAO's review, NASA had not determined what the total cost of operating the Space Transportation System would be or how much an individual user would have to pay for its services. Cost estimates for a portion of its operations had been prepared, and a preliminary shuttle user charge policy was under consideration. NASA's objective was to encourage users to change over to the space shuttle by offering a price competitive with expendable launch vehicles. (See pp. 44 and 45.)

This proposed policy does not provide for total recovery of shuttle operations cost on a per flight or yearly cost basis. Instead, NASA plans to charge users a fee based on the estimated average cost for each flight over the program's 12-year operating life. This will result in NASA's charging users less than actual operations cost in the early years to encourage users to change over to the shuttle with the expected recovery of these costs in later years. This average-cost concept, together with other policy provisions, raises the question of whether total operations cost will ever be recovered. (See pp. 45 to 48.)

RECOMMENDATIONS TO THE CONGRESS

Until there is sufficient confidence in the shuttle development program and more information is available on the Space Transportation System operations cost and plans for future space activity, the Congress should assess the advantages and disadvantages of

--initiating the production of a third orbiter and

--delaying funding of the remaining two orbiters.

RECOMMENDATION TO NASA ADMINISTRATOR

The NASA Administrator should delay implementing a user charge policy until costs and policies for all elements of the Space Transportation System have been formulated.

NASA and Defense officials believe a Space Transportation System pricing policy is required now. (See p. 55.)

<u>Contents</u>

ABBREVIATIONS

COMSAT	Communications Satellite Corporation
DOD	Department of Defense
FAA	Federal Aviation Administration
GAO	General Accounting Office
NASA	National Aeronautics and Space Administration
STS	Space Transportation System

GLOSSARY

Aerodynamics	The actions and forces resulting from the movement or flow of gaseous fluids against or around bodies, as the aerodynamics of a wing in supersonic flight.
Angle of attack	The angle between a reference line fixed with respect to an airframe and a line in the direction of movement of the body.
Attitude	The position or orientation of an aircraft, spacecraft, or other object, either in motion or at rest, as determined by the relationship between its axes and some reference line or plane or some fixed system of reference.
Center of gravity	The point at which the entire weight of a body may be considered as concentrated so that if supported at this point the body would remain in equilibrium in any position.
Circular orbit	An orbit with uniform height above the earth at all points.
Equatorial plane	The plane of the Earth's equator extended indefinitely into space.
Equatorial orbit	An orbit lying on the equatorial plane.
Geosynchronous orbit	An orbit with the same period as the Earth's rotation.
Geostationary orbit	An orbit on which a satellite is in a fixed relationship with a point on Earth.
Glide slope	The flight path of an aeronautical vehicle in a glide, as seen from the side; the angle between the horizontal and the path of the vehicle.
High-energy orbit	An orbit beyond the reach of the shuttle, primarily restricted by height. There are also inclinations that cannot be reached.
Low-energy orbit	An orbit that can be reached by the shuttle.

Nautical mile	A unit of distance used principally in navigation--equal to 1.151 statute mile or 6,080 feet.
1971 dollars	The purchasing power of the dollar with 1971 as the base year. Estimates are in base year dollars when future costs are adjusted to exclude inflation so that they reflect the level of purchasing power in the base year.
1977 dollars	Same as 1971 dollars but with 1977 as the base year.
Orbit	A closed path under the influence of a gravitational or other force.
Orbit plane	The plane of an orbit extended indefinitely in space, determined by inclination and celestial longitude.
Payload	A specific complement of instruments, space equipment, and support hardware carried aloft to accomplish a mission or discrete activity in space.
Plane	A surface such that the straight line joining any two of its points lies wholly in that surface.
Real year dollars	Also known as current dollars, are always associated with the purchasing power of the dollar in the year that the expenditure will occur. When future costs are stated, the figures given are actual amounts which will be paid, including inflation.
Remote manipulator arm	A mechanical arm in the orbiter's cargo bay. It is controlled from the orbiter aft flight deck to deploy, retrieve, or move payloads.
Rendezvous	The point in space at which two or more objects meet with zero relative velocity at a preconceived time and place.
Sun-synchronous orbit	An orbit in which a satellite passes overhead at the same time of day every day.
Umbilical connection	Any of the connecting electrical or fluid lines, such as the connecting lines between the external tank and the orbiter.

CHAPTER 1

INTRODUCTION

This is our sixth study of the Space Transportation System (STS) under development since 1971 by the National Aeronautics and Space Administration (NASA). This report discusses STS program status and issues facing the Congress and NASA.

STS, composed of the space shuttle, expendable upper stages, spacelab, and related launch and landing facilities, is to provide a new space transportation capability that will substantially reduce space operations costs and support a wide range of scientific, defense, and commercial uses beginning in the 1980s. The current cost estimate is $13.2 billion for system development and production. (See p. 4.)

The space shuttle consists of a reusable manned orbiter with three main engines, two reusable solid rocket boosters, and an expendable liquid propellant tank referred to as the external tank. It is being designed to place payloads weighing up to 65,000 pounds into a 150-nautical-mile due-east orbit from Kennedy Space Center, Florida, and up to 32,000 pounds into a specified 100-nautical-mile near-polar orbit from Vandenberg Air Force Base, California.

The upper stages are propulsive systems designed to place payloads at altitudes exceeding the capabilities of the orbiter. The space tug, a reusable upper stage, is not expected to be available until 1985 to 1987 at the earliest. 1/ Until then, two expendable spinning solid upper stages and an expendable interim upper stage will be used. The spinning solid upper stages were added to the program in 1976.

The spacelab is being developed under a cooperative program with the European Space Agency as a laboratory and observatory for in-orbit space research.

1/NASA officials advised us that they were strongly considering eliminating the tug. Therefore, we assumed, for purposes of this report, that expendable upper stages would be used during the 1980s instead of the more versatile, reusable tug.

MANAGEMENT RESPONSIBILITY

NASA is responsible for developing the space shuttle, the space tug, the two expendable spinning solid upper stages, and launch and landing facilities at Kennedy Space Center. NASA and industry have reached agreements whereby the spinning solid upper stages will be developed as commercial ventures at reduced cost to the Government. The Air Force, representing the Department of Defense (DOD), will develop the interim upper stage and, if approved by the Congress, fund facilities construction at Vandenberg Air Force Base.

The development of the space shuttle is divided among four prime contractors and numerous subcontractors. Rockwell International's Space Division is developing the orbiter vehicles and supporting Johnson Space Center, Texas, as the lead center for overall shuttle integration.

The remaining contractors and their responsibilities are (1) Rockwell International's Rocketdyne Division--main engine, (2) Martin Marietta Corporation, Denver Division--external tank, and (3) Thiokol Chemical Corporation--solid rocket motor portion of the booster.

SCOPE OF REVIEW

We made our review at NASA headquarters, Washington, D.C.; three NASA field centers--Kennedy Space Center, Florida; Marshall Space Flight Center, Alabama; and Johnson Space Center, Texas--Vandenberg Air Force Base, California; and the Air Force Space and Missile Systems Organization, El Segundo, California.

Our examination included a review of the STS program's cost, schedule, and performance status; the current need for additional orbiters and related facilities; and the preliminary estimates of shuttle operations cost and user charge policy.

We used the technical expertise of a consultant to assist us in reviewing the areas of orbital mechanics, satellite retrieval, center-of-gravity effects, landing profiles, and associated technical areas.

In conducting our review, we looked at documents, records, and reports and interviewed officials at Government agencies and commercial organizations who are potential users of STS. We also discussed program aspects with officials at NASA headquarters and NASA and DOD field centers and installations.

CHAPTER 2

COST AND SCHEDULE STATUS

Through fiscal year 1977 the Congress has appropriated about $4.4 billion to NASA and $106 million to DOD for STS development totaling about one-third of the estimated development and production cost. The primary development effort to date has been the space shuttle and related launch and landing facilities at Kennedy Space Center. Other STS elements, excluding the European Space Agency's spacelab, are in the preliminary design stages.

The table on page 4 presents NASA's initial estimates in 1971 dollars together with more recent estimates which include inflation through program completion (real year dollars) for the development and production phases of STS. The estimates do not include Government salaries, travel, and certain related costs to be funded through NASA's research and development appropriation--about $2.3 billion for the space shuttle development program alone. Additionally, the table does not include STS operations costs or payload costs for any of the users. NASA could not provide us with estimates of these costs but identified $11 billion (1978 dollars) for total operations and $19.5 billion (1978 dollars) for NASA payloads. Unless otherwise stated, cost estimates throughout this report are stated in real year dollars.

The remainder of this chapter addresses the status of the space shuttle development and production programs.

PROGRESS THROUGH 1975

Space shuttle development began in April 1972 with the award of the main engine contract. All development work was initially scheduled to peak in 1976 and be completed by March 1979. However, development schedules have been extended twice for a total program delay of 13 to 15 months. According to NASA and the Office of Management and Budget, the delays were necessary to keep costs within the Office of Management and Budget's annual budget constraints.

Estimated Space Transportation System

Development and Production Costs

Elements		Original estimate (1971 dollars)	Current estimate (Real year dollars) 1975 (note a)	1976 (note a)	Increase or decrease (-) (1975 to 1976)
		---(millions)---			
Space shuttle development costs		$5,150	$ 6,932	$ 6,940	$ 8
Orbiter inventory (note b)		1,000	2,234	2,739	505
Facilities (including two launch sites):					
NASA		300	453	458	5
DOD		500	996	c/1,170	174
Expendable upper stage development (note d)		290	241	268	27
Reusable space tug:					
Design, development, test, and evaluation	$638				
Production	171	809	1,303	e/1,303	-
Spacelab development and procurement		-	427	317	-110
Total		$8,049	$12,586	$13,195	$609

a/These estimates are internal NASA and DOD estimates and do not represent official agency positions.

b/Refurbishment of the two development orbiters and production of three orbiters.

c/In March 1977 DOD said the current program baseline for Vandenberg Air Force Base facilities does not include a second launch pad or deep-water harbor and is estimated at $849 million in real year dollars through fiscal year 1983.

d/Original and current estimates are for different configuration of the expendable upper stages.

e/NASA did not provide an update of its 1975 real year dollar estimate for this item so we used the 1975 estimate for 1976 also.

The schedule changes resulted in cost increases that reduced program reserves planned for technical and other unforseen problems. NASA began a series of program content and interim schedule modifications to prevent major cost growth. Despite these efforts, NASA announced a $50 million (1971 dollars) cost growth in 1974. Further adjustments were made in 1975 to reduce program content thereby compounding the risk of future schedule delays and cost growth because major test programs were delayed, deleted, and/or reduced in scope.

In 1975 NASA identified potential schedule slippages of an additional 3 to 6 months and projected major reserve shortages. Even without considering possible future technical problems and schedule delays, we estimated, in our April 21, 1976, report, "Status and Issues Relating to the Space Transportation System," (PSAD-76-73) that the development program would probably exceed original estimates by $1.145 billion. This estimate is comprised of

--$50 million (1971 dollars) for NASA's announced increase,

--$195.1 million for work tasks transferred to other budgets and the production and operations phases of the program,

--$524 million for increases in the rate of inflation, and

--$376 million for inflation increases due to the program stretchout.

NASA does not consider inflation as cost growth because its original cost commitment to the Congress was expressed in 1971 dollars. The Congress, however, must appropriate funds to cover all costs, including inflation.

CURRENT STATUS

NASA is continuing to work under severe cost and schedule constraints. In February 1976 it announced an additional $20 million (1971 dollars) cost growth, bringing the total announced growth in 1971 dollars to $70 million. As in previous years, NASA reduced or delayed program content to stay within its annual budget ceiling.

Project estimates increased by about $147 million 1/ during the year, which further reduced available contingency reserves. Additionally, the agency reduced or deleted from the development program work tasks totaling $110 million and transferred $37 million to later program years.

Project estimates may be further understated by at least $268 million since prime contractors' estimates for orbiters and main engines exceed NASA's estimates by this amount.

Potential for future cost growth in the development program

In our opinion, there is a high probability that NASA will encounter major cost growth during the remaining program years. It is possible that serious technical problems will be identified because some test programs, such as the thermal vacuum and vibroacoustics tests, have been deleted, reduced in scope, or delayed until the orbital flight test program scheduled to begin in March 1979 or until the shuttle is operational. Our past experience in reviewing major civil and defense acquisitions has shown that delaying and deleting testing can lead to costly retrofit or redesign at a later date or to deploying systems that cannot adequately fulfill their intended role.

If major technical problems are encountered, some cost increases may not be absorbed by the reserve funds since over 60 percent of the reserves have been used in overcoming funding constraints. In addition, a recent report by NASA's Aerospace Safety Advisory Panel shows "there is little schedule margin, funds, or extra test hardware in any of the major test programs."

Production program cost growth

NASA had expended $850,000 for production of long leadtime materials as of July 1976 and expected to obligate a total of $14.9 million for these items by the end of fiscal year 1977.

1/Consistent with our previous reports, we have used field center shuttle project offices' cost estimates used in NASA's internal budgetary process.

Cost estimates for refurbishing the two development orbiters and producing three additional orbiters have increased in 1971 dollars from $1 billion to $1.5 billion, an increase of $500 million (1971 dollars). About $200 million of this amount is due to a 1-year delay in beginning orbiter procurement. At least $181 million (1971 dollars) was caused by the transfer of tasks from the development and operational phase of the shuttle program. We could not identify a specific cause for the remaining amount of the increase.

In real year dollars the production program cost estimates have increased about $1.4 billion from $1.350 billion in 1971 to $2.739 billion in 1976.

CHAPTER 3

LIFT-OFF--2 YEARS AND COUNTING DOWN

This and the next two chapters describe a space shuttle mission of the 1980s as envisioned by NASA and discuss some challenges and technical problems which must be overcome.

The space shuttle flight system--orbiter and main engines, external tank, and solid rocket boosters--will be assembled and the payload(s) installed in the orbiter's payload bay. The payloads are located in the orbiter to insure that its center of gravity is maintained throughout the flight, from lift-off to landing. Maintaining the center of gravity is necessary for a stable and safe flight and to assure the safe landing of the orbiter, particularly in the event of an emergency abort.

> Safety abort systems--During the powered ascent flight from lift-off to orbital insertion, the space shuttle is required to have "intact abort" capability for selected failures which have the highest probability of occurring. Examples include total loss of thrust from one main engine and the loss of one orbital maneuvering system engine. Intact abort is defined as safely returning the orbiter, crew, and payload to the primary landing site.
>
> NASA has identified other failures which it believes have a lower probability of occurring and for which it has not provided intact abort capability. These failures, referred to as contingency abort cases, will most likely require the orbiter to ditch in the ocean. NASA studies have shown that the orbiter should be able to land on water but, together with the payloads, would probably be damaged beyond repair. Contingency aborts include loss of thrust from more than one main engine, premature orbiter separation from the external tank, and failure of the solid rocket boosters to separate from the external tank.
>
> NASA identified a third set of failures for which no provisions have been made for crew survival. NASA believes these failures, defined as "loss of critical functions," have the lowest probability of occurring because

the space shuttle design includes high factors of reliability. Loss of critical functions includes major structure failure, complete loss of guidance and/or control systems, failure of one solid rocket booster to ignite, failure of the orbiter to separate from the external tank, and premature solid rocket booster separation.

If one of the contingency abort cases occurs, both the orbiter and payload could be damaged beyond repair, and the crewmen could be seriously injured. Since no abort capability exists for loss of a critical function, if one occurs, the orbiter, payload, and crew will probably be lost. NASA has studies in progress to further define the potential for intact abort capability for the failures now included in the contingency abort category.

The space shuttle will be moved from the Vehicle Assembly Building (see fig. 1) to the launch pad where it will be readied for launch and stand exposed to the natural elements for about 2 days. The external tank will be fueled about 2 hours before launch.

<u>External tank</u>--The 154-foot-long, 28-foot-diameter external tank is actually two separate tanks--one for liquid oxygen and one for liquid hydrogen. (See fig. 2.) It is mated to the bottom of the orbiter and supplies propellant to the main engines through an umbilical connection. A spray-on foam insulation covers the external tank's outer surface to prevent ice formation on the external tank before lift-off, protect the tank from aerodynamic heating during ascent, provide propellant insulation, and protect the lower portion of the tank from engine plume heat.

The major development concern with the external tank is that it may eventually exceed design weight goals. If design goals are not met, the orbiter's payload-carrying capability could be reduced. As of November 16, 1976, there were several development problems which could increase the external tank's weight by as much as 3,240 pounds over design goals. Two of the problems were:

1. <u>Structural loads</u>--March 1976 estimates of external tank structural loads during ascent

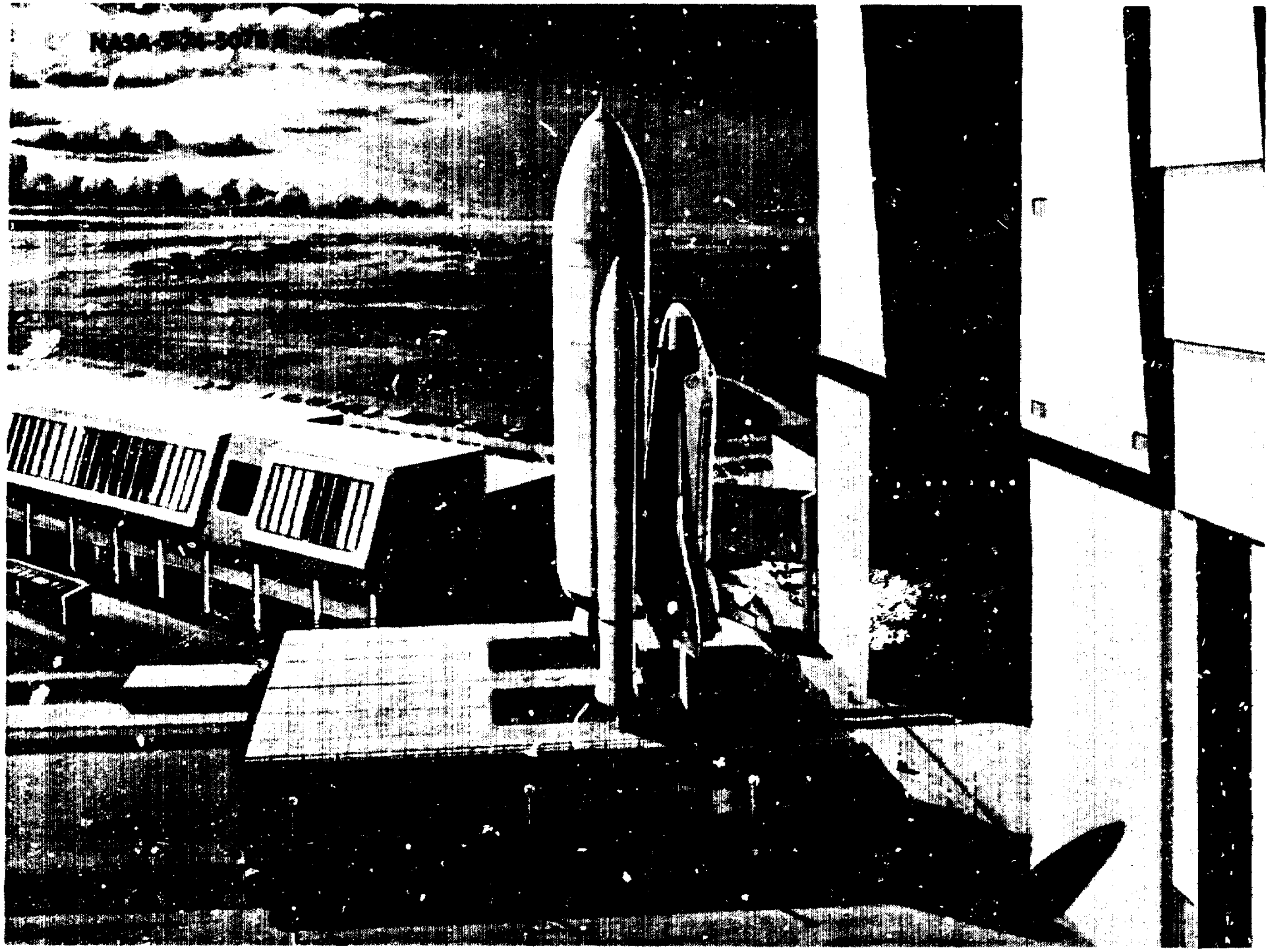
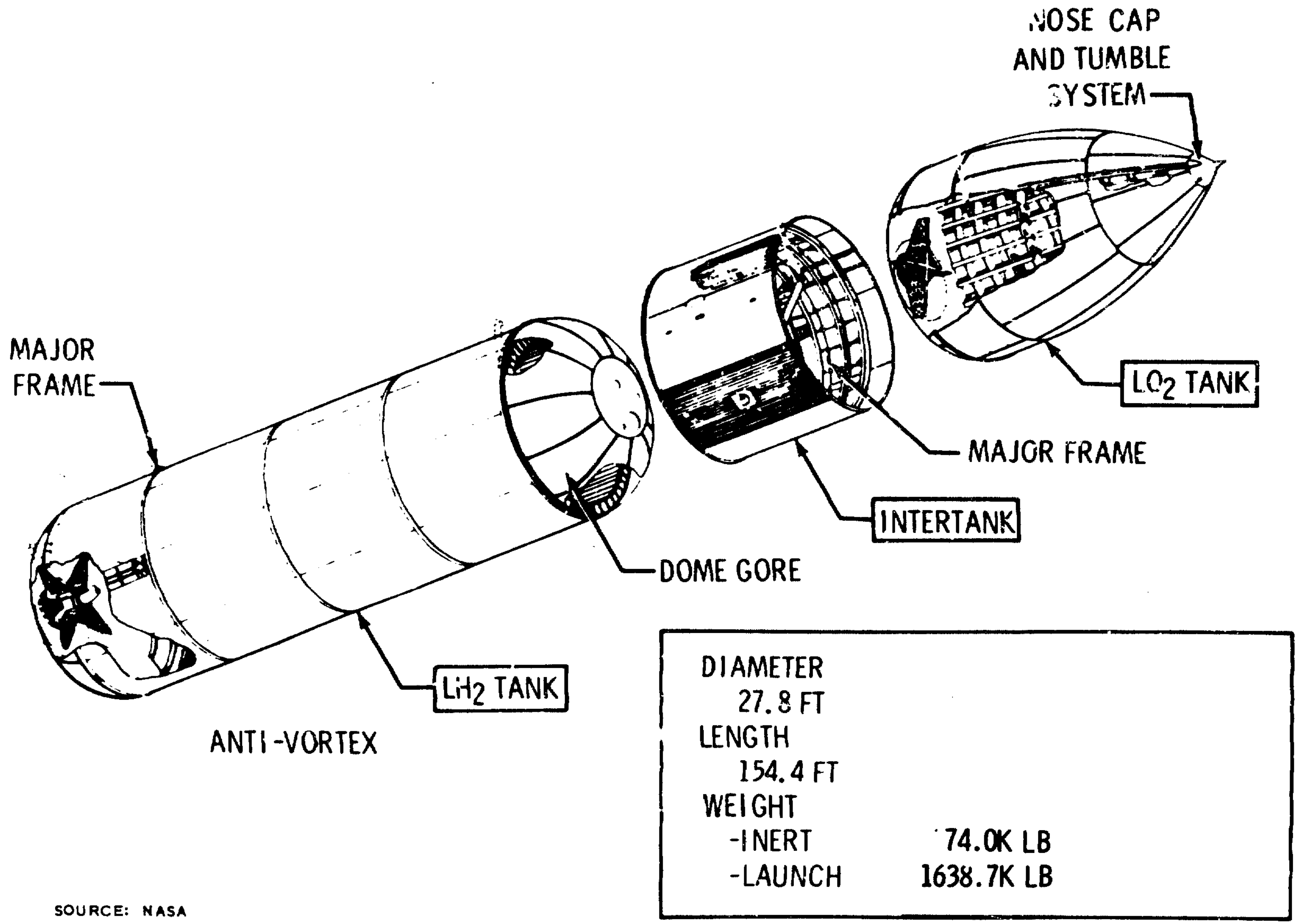


FIGURE1: ARTIST'S CONCEPT OF THE SPACE SHUTTLE FLIGHT SYSTEM LEAVING THE VEHICLE ASSEMBLY BUILDING

SOURCE. NASA



SOURCE: NASA

FIGURE 2. SPACE SHUTTLE EXTERNAL TANK

were higher than those used in the current tank design. Additional strengthening of the external tank may be required, with weight and cost penalties.

2. Thermal protection system--aerodynamic heating on the external tank may be higher than originally anticipated, requiring larger areas of spray-on foam insulation. More insulation is also required to reduce ice formation which could break off and damage the orbiter during lift-off.

Several problems can occur while the space shuttle is on the launch pad. Because external tank thermal protection materials are incompatible with liquid oxygen, an oxygen leak or spill during launch operations could result in a spontaneous fire or explosion. 1/ Also, an electrostatic charge could build up on the surface of the external tank and possibly interfere with the orbiter's electronic guidance and control systems and/or provide a potential ignition source for (1) hydrogen leaks or spills, (2) the propellant dispersion system, and (3) the thermal protection system itself if it is in an oxygen enriched environment.

While the liquid propellants are loaded in the external tank, the crewmen and passengers board the orbiter and perform the final prelaunch orbiter systems checkout. The orbiter will normally carry a crew of four, but provisions could be made for a crew of up to seven, for missions lasting up to 30 days.

Weather constraints--The space shuttle may not be launched during inclement weather because of the possibility of lightning strikes and rain or hail impingement on the orbiter's thermal protection system. Flying through rain or hail during ascent would severely damage the orbiter's thermal protection system and possibly preclude safe return to earth.

Weather-caused delays could also create scheduling problems because many payloads must be launched at a specific time of

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1/NASA informed us in March 1977 that this problem may have been resolved.

day. Otherwise the launch may have to be delayed for as long as 24 hours. Numerous delays could limit the total number of shuttle flights to less than NASA's goal of 60 a year.

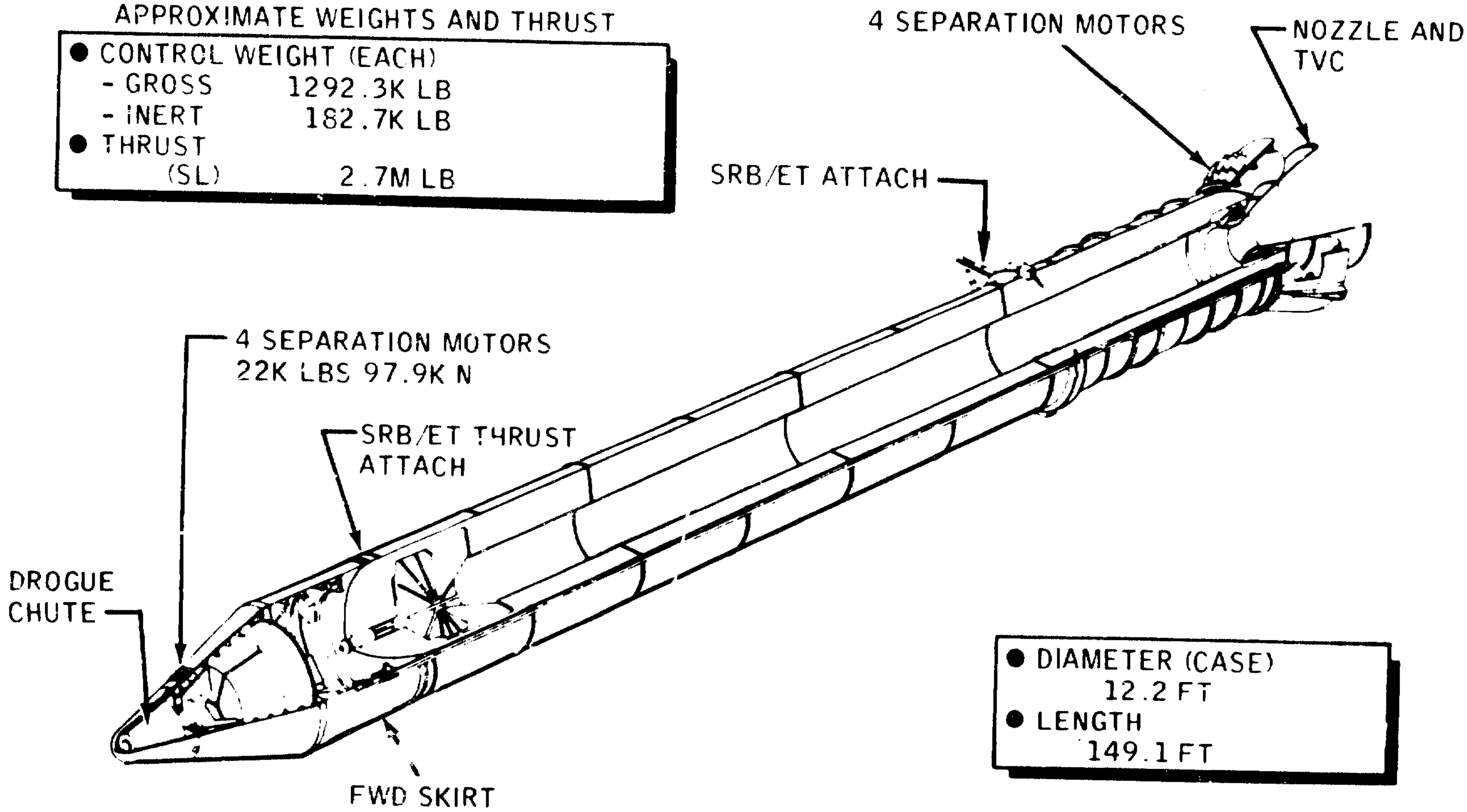
The final countdown begins: ten-nine-eight . . . When the countdown reaches four, the orbiter's main engines will be ignited.

Main engine--The space shuttle main engine is an advancement of technology, because it is intended to be more efficient than previous engines and is the first attempt to build a reusable rocket engine for an operational space vehicle. The design goal is 55 uses before major overhaul. Whether this reusability criterion can be met is not known; however, NASA believes reusability is not a major concern.

The most serious problem identified to date in the engine development program is high pressure fuel turbopump vibration. The vibration causes premature wearout of the bearings supporting the shaft, and the pump fails. This has prevented firing the engines at full thrust to simulate actual engine operation. Although this problem has been under investigation for over a year, NASA officials believe it can be resolved without delaying the first manned orbital flight. If the problem cannot be corrected, however, the pump may have to be completely redesigned.

The main engines should reach 90 percent thrust within 3.5 seconds. If they do not reach this power level within 4 seconds, the main engines will shut down and the launch will be aborted. The solid rocket boosters will be ignited when the main engines reach 90 percent thrust.

Solid rocket boosters--These boosters (see fig. 3) will be the largest ever used by the United States. Each booster, which is over 12 feet in diameter and about 149 feet long, contains over 1 million pounds of solid propellants, about twice that of previous solid boosters (Titan III-C).



SOURCE: NASA

FIGURE 3. SPACE SHUTTLE SOLID ROCKET BOOSTER

The major uncertainty with the solid rocket boosters is reusability. This is the first time solid rocket boosters will be recovered, refurbished, and reused to reduce operating costs. NASA officials have said, however, that solid rocket booster components may not achieve the designed number of reuses due to water impact damage, salt water corrosion, and marine growth.

Lift-off should occur about 0.3 seconds after solid rocket booster ignition. (See fig. 4.) During ignition and lift-off, water will be pumped into the flame ducts at a rate of 1 million gallons a minute to absorb noise and vibrations. The water suppression technique was recently added because projected payload-bay vibrations and acoustics levels exceeded those of expendable vehicles. DOD has been concerned with the payload-bay environment and is working with NASA to insure that problems in the areas of dynamic loads, random vibrations, acoustics, electromagnetic incompatibilities, and contamination are resolved. Payload costs could increase if these shuttle design specifications are not met.

During lift-off the orbiter's thermal protection system could be damaged by ice breaking off the external tank and structural buckling caused by thermal stresses. The thermal protection system consists of various insulating materials applied to the orbiter's outer surface to maintain the temperature of the aluminum airframe within acceptable limits. (See fig. 8.) Since the thermal protection system cannot be repaired in space, severe damage could prevent the orbiter from a safe return. NASA is attempting to solve these problems by adding additional insulation to the external tank and by redesigning portions of the orbiter's structure.

During lift-off when the main engines and solid rocket boosters are burning simultaneously, the space shuttle will develop about 6.4 million pounds of thrust. The solid rocket boosters, which account for about 80 to 90 percent of this power, present a threat to the environment in and around the launch site.

Ground cloud--A cloud of hot exhaust gas produced during lift-off drifts with the prevailing winds and diffuses into the atmosphere as it moves. The exhaust products in the ground cloud could potentially lead to (1) acidic rain, (2) toxic gas and dust effects, (3) weather modification,

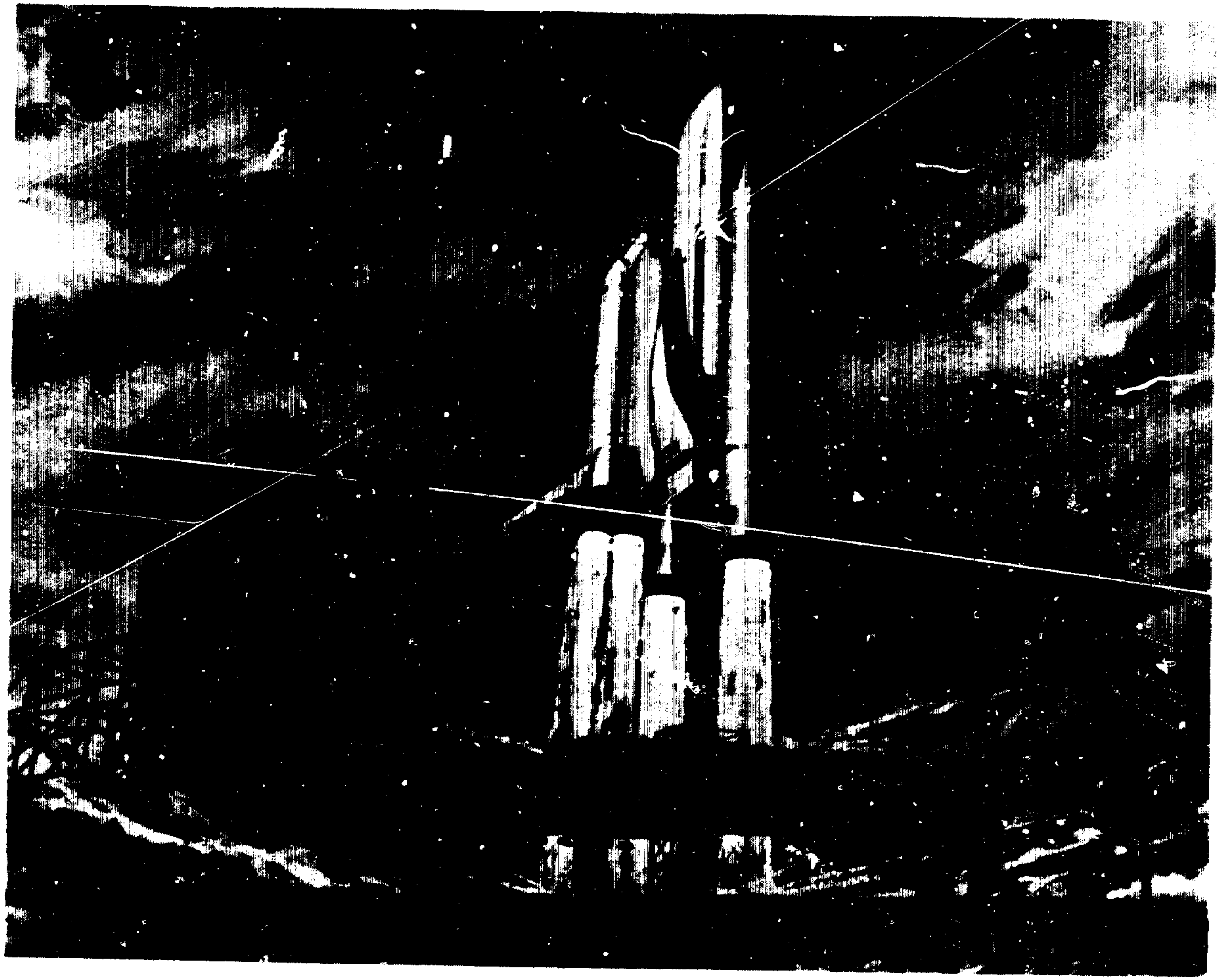


FIGURE 4: ARTIST'S CONCEPT OF A SPACE SHUTTLE LIFT–OFF

SOURCE: NASA

and (4) cumulative damage to the local ecology. 1/

1. Acidic rain--Rainfall through the cloud (wash-out) or induced by the cloud (rainout) could be acidic due to dissolved hydrogen chloride, resulting in damage to plants and soil if acidity is sufficiently high. Damage to vegetation, such as lime and avocado crops, has occurred previously from solid propellants. Postponing shuttle launches when meteorological conditions could produce potentially damaging acidic rain may solve this problem. NASA has not yet defined the specific meteorological conditions under which acidic rain may occur. It is continuing to work in this area.

2. Toxic gas and dust effects--The toxic gas and dust, primarily hydrogen chloride, may affect people, wildlife, and vegetation on the Earth's surface below the ground cloud. Theoretical predictions show that under certain weather conditions, hydrogen chloride concentrations could approach the allowable toxic limit for human exposure for a period of about 5 minutes (50 percent of the allowable time) within 6.2 miles of the launch site. These weather conditions occur about 5 percent of the time at Kennedy Space Center. NASA, however, believes these theoretical predictions are probably too high since experimental tests using actual Titan launches showed hydrogen chloride concentrations will be substantially less than the allowable toxic limits for human exposure. NASA's predictions will have to be verified against

1/Information herein is based on NASA studies of the environmental effects at Kennedy Space Center. The effects may be different at Vandenberg Air Force Base. DOD would not release its draft environmental impact statement for use in this report.

actual space shuttle launches because the Titan vehicle is much smaller and does not simultaneously fire solid rockets with liquid propellant engines.

Other individual toxic elements in the exhaust cloud--aluminum oxide, chlorine, and nitrogen oxide--are not expected to exceed established toxic limits for human exposure. However, limits have not been established for aluminum oxide with absorbed hydrogen chloride, which could be more toxic than aluminum oxide alone. In addition, the effects of exhaust products on vegetation and wildlife are not completely understood.

3. Weather modification--It is conceivable that the exhaust products could induce precipitation or alter the radiant heat balance in the atmosphere near the launch site, resulting in local weather modification. This effect has been studied, and NASA has concluded that no major weather modification by shuttle operations will occur.

4. Cumulative damage--A slow accumulation of exhaust products in the launch area could alter the environment sufficiently to change the ecological or environmental quality of the region. NASA is establishing an ecological baseline for Kennedy Space Center, so that adverse cumulative environmental effects can be detected during shuttle operations.

About 6 seconds after lift-off, the shuttle will roll to its launch azimuth and then pitch over on its back. This maneuver will eventually cause a focused sonic boom, with overpressures as high as 30 pounds per square foot, to occur about 30 nautical miles downrange. Overpressures of this magnitude could cause structural damage; therefore, mission trajectories have been chosen to cause the boom to occur over the ocean.

After pitchover, the vehicle continues to climb. The solid rocket boosters will burn for approximately the first 120 seconds of flight. After about 75 seconds, the space shuttle will enter the stratosphere. The burning solid propellant will emit exhaust products directly into the stratosphere.

Ozone depletion--Pollutants could deplete the stratospheric ozone layer which protects the Earth from ultraviolet radiation. This concern has prompted national efforts to understand the physical and chemical processes of the stratosphere.

Of the shuttle's exhaust products, NASA believes the only major stratospheric concern is the hydrogen chloride's depleting the ozone. NASA predicts the hydrogen chloride from the shuttle's solid rocket boosters would deplete ozone by 0.2 percent. In making this prediction, NASA used five different stratospheric models. The model results varied from 0.07 to 0.29 percent because of uncertainties in current stratospheric knowledge. Unable to eliminate any prediction as incorrect, NASA selected the median value. A recent study by the National Academy of Sciences concluded that the potential ozone reduction attributed to the space shuttle may range from 0.05 to 0.45 percent.

Although the ozone depletion caused by the space shuttle appears small, it will result in an increase in the ultraviolet radiation reaching the Earth. An increase in ultraviolet radiation could possibly produce biological damage. Potential effects include human skin cancer, including life-threatening melanoma; "cancer eye" in cattle; reduced agricultural productivity; and detrimental disturbances of terrestrial and aquatic ecological systems. Some scientists also postulate that changes in temperatures, cloud cover, precipitation, and other weather elements could occur. NASA and other scientific groups believe additional research is needed to define the biological and meteorological importance of ozone depletion.

The solid rocket propellant will be depleted at an altitude of about 150,000 feet. The boosters will then be separated from the orbiter/external tank (see fig. 5) and parachute into the ocean some 150 nautical miles downrange for recovery and reuse. Shortly before orbital insertion, at an altitude of 300,000 to 550,000 feet, the orbiter's

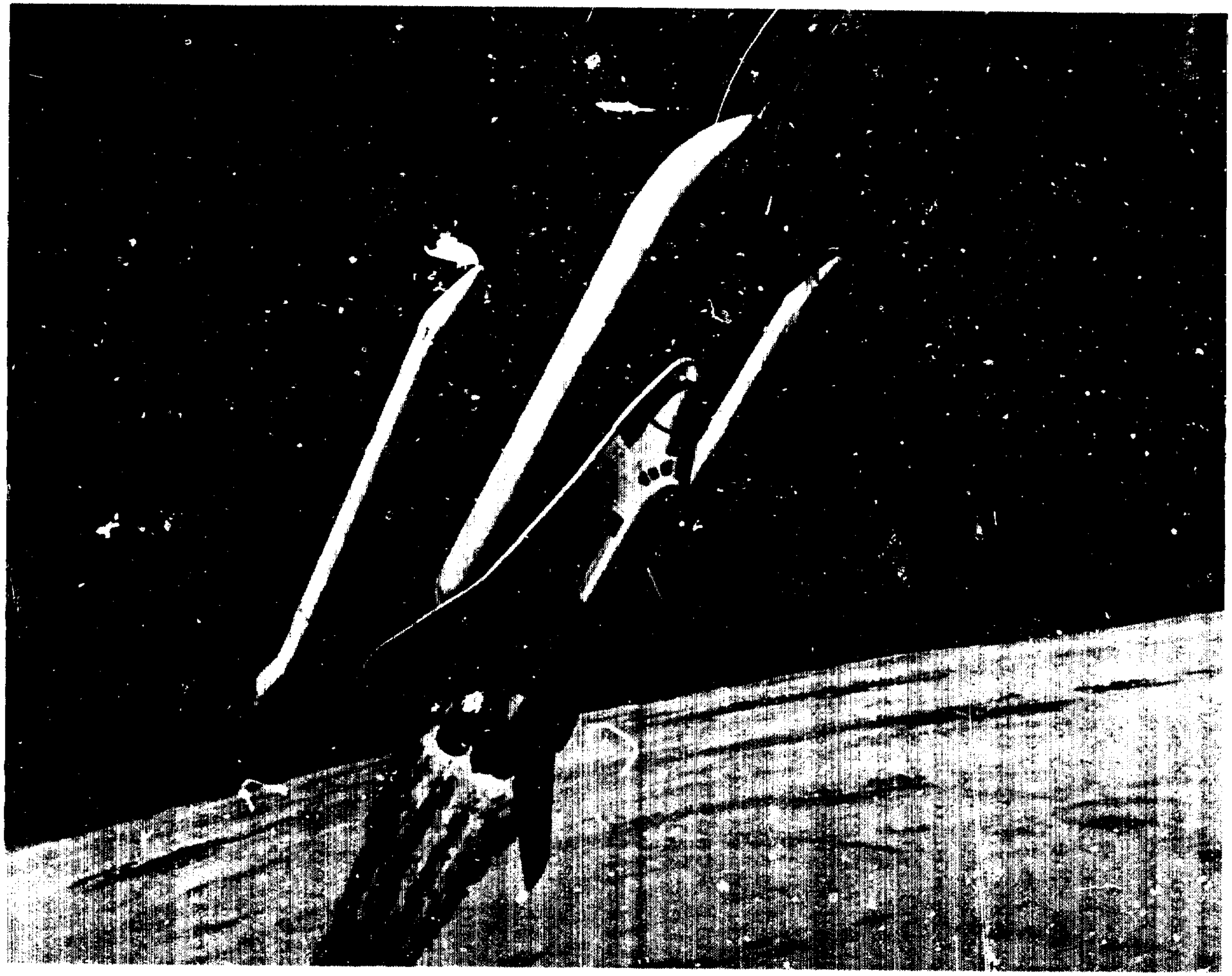


FIGURE 5: ARTIST'S CONCEPT OF SOLID ROCKET BOOSTER SEPARATION

SOURCE: NASA

main engines will be shut down and cannot be restarted during the remainder of the mission.

About 11 seconds after main engine cutoff, the external tank will be jettisoned. By releasing gas through openings in the nose, the external tank will begin tumbling back to Earth, impacting in a preselected remote ocean site. The tumbling motion is intended to insure that the external tank lands within the designated impact zone.

After external tank separation, two small orbital maneuvering system engines will propel the orbiter into space. The orbital maneuvering system will also be used, together with the reaction control system engines, to perform in-orbit maneuvers.

CHAPTER 4

OPERATIONS IN SPACE

T. :bital manuevering system engines will be shut down at the proper time to place the orbiter into the desired orbit. A circular orbit requires a specific height, inclination, and celestial longitude. Height is the distance above the Earth's surface; inclination is the angle at which the orbit crosses the Earth's equator; and celestial longitude gives the location of this crossing. Inclination is determined by the launch site and launch azimuth, whereas celestial longitude is determined by the time and date (launch window) that a satellite is launched. Inclination and celestial longitude are expressed in terms of degrees--30 degrees, 28.5 degrees.

Considering all combinations of these three factors, a satellite can be placed in an infinite number of distinct orbits, a small number of which can be reached by the shuttle. The initial orbit for all payloads will be limited to a narrow range of orbits which the shuttle can reach, referred to as "low-energy orbits." All expendable launch vehicles also first place payloads in a circular low-energy orbit. Destinations beyond the capability of the space shuttle, "high-energy orbits," will be attained--again like all expendable launch vehicles--using expendable upper stages.

Orbiter maneuverability--The low-energy orbit to be attained by the space shuttle will have to be carefully selected in advance, based on the particular payload requirements. Earth observation satellites, for example, must be placed in the proper orbit to pass over the land or water under study at the desired time of day. Preselection of the orbit would not be particularly critical if the orbiter had unlimited maneuverability in space. The large mass of the orbiter, coupled with its limited fuel-carrying capability, limits the shuttle, for all practical purposes, to the orbital plane--inclination and celestial longitude--it attains upon entry in space. Small changes in height are possible.

Once the orbiter is in its predetermined orbit, the crew prepares to perform the mission. The first steps will be to orient the orbiter using the reaction control system engines and to open the payload-bay doors.

SPACE SHUTTLE CAPABILITIES

NASA believes the space shuttle will provide significant operational advantages over existing expendable vehicles. Aside from economics which are addressed on pages 59 and 60, these advantages include (1) an increase in payload weight and volume capacity and (2) the ability to rendezvous with and/or return payloads. These capabilities are expected to permit greater flexibility in space operations. However, during the past 10 years only about 22 percent of the payloads NASA launched could have been placed in orbit by the space shuttle without upper stages.

The space shuttle will attain inclinations between 28.5 degrees and 104 degrees. The maximum circular orbit height attainable with a fully loaded orbiter (65,000 pounds) is 220 nautical miles. This height corresponds to one inclination--28.5 degrees.

> Weight penalties--The orbiter cannot carry maximum weight to all the inclinations between 28.5 degrees and 104 degrees. Additional height can be achieved by adding up to three extra fuel tanks for the orbital maneuvering system engines, but the weight of the fuel--up to 42,000 pounds--will count against payload weight. For example, only 21,000 pounds of cargo weight can be carried to a 56 degree inclination if a 500-nautical-mile circular orbit is desired. The capabilities of the space shuttle, with and without extra fuel tanks, from Kennedy Space Center and Vandenberg Air Force Base are shown in figure 6.

Increased capability

The space shuttle should provide greater payload volume and weight capacity than current expendable

SPACE SHUTTLE WEIGHT CARRYING CAPABILITIES BY INCLINATION

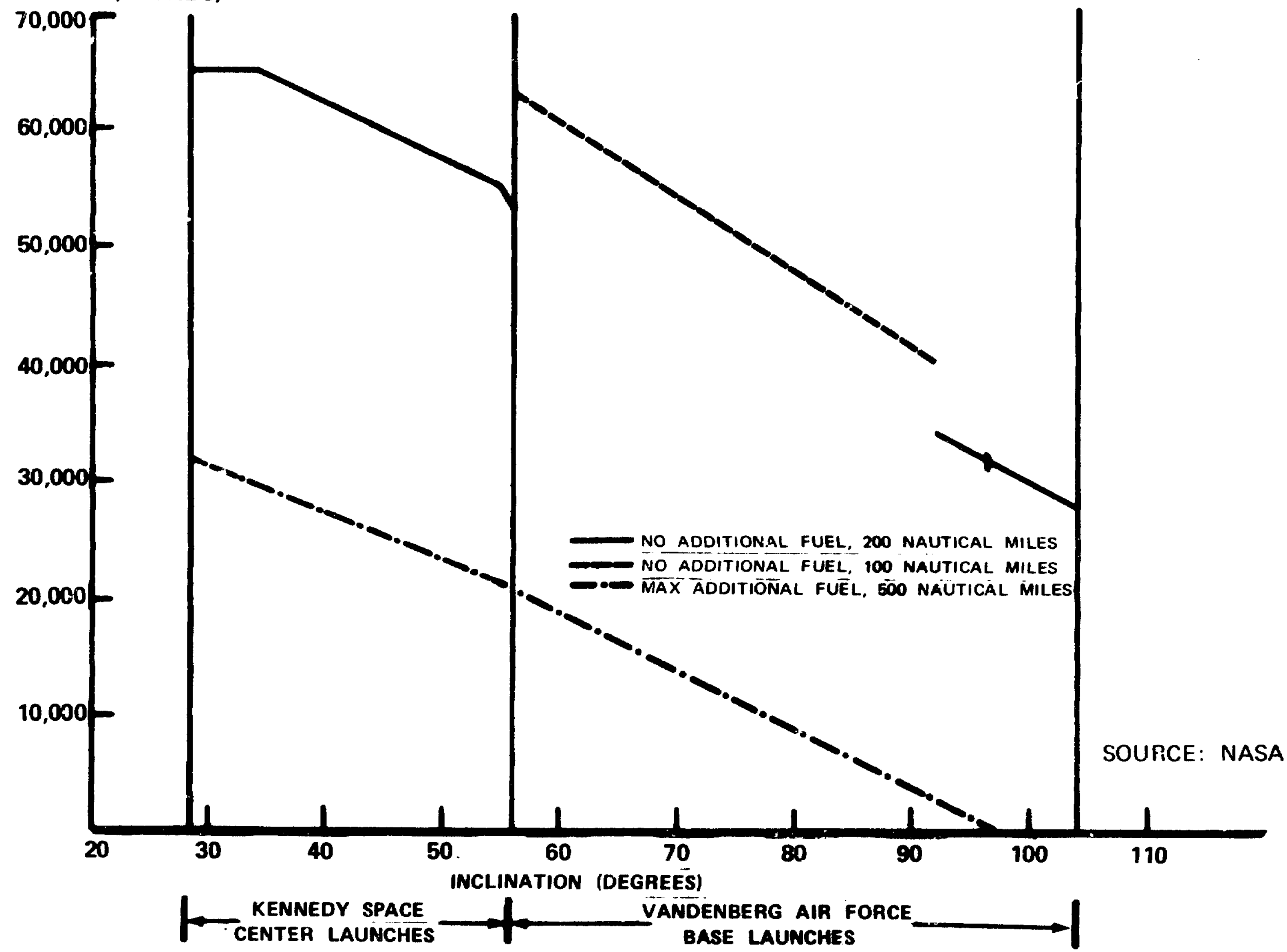


FIGURE 6

launch vehicles. According to a study 1/ Battelle Columbus Laboratories conducted for NASA, the only factors keeping designers from taking advantage of increased volume

> "* * * is the uncertainty as to when the shuttle will be available and fully operational and what the price of using it will be. Once confidence in the shuttle is established * * * (this may be several years after the shuttle IOC [Initial Operational Capability] date), the bay diameter should be a strong competitive plus for the shuttle in a number of mission areas."

Battelle found little indication that the shuttle's weight capacity was changing satellite design or planning. However, according to NASA, there is some indication that the payload community is increasing its awareness of the shuttle's capability.

Keeping the space shuttle's weight within design goals has been a continuing problem during the development program. If these weight goals are not met, or if maximum thrust goals for the main engine and/or solid rocket boosters are not achieved, the weight-carrying capability of the space shuttle could be less than expected. Even with the full weight-carrying capability, the extent to which it will be used is difficult to predict.

The shuttle's capacity could be used to carry heavy objects into low-energy orbits or to combine missions on a single flight to reduce an individual user's launch cost. However, Battelle's survey showed potential users do not consider the ability to combine flights as an advantage because it presents a number of schedule, interface, and risk problems. Finding payloads going to the same orbit plane is not always easy because many payloads need to be launched to specific orbit planes to be effective. Unless payloads on the same flight are going to virtually the same orbit plane, upper stages

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1/"External Competition for the Space Transportation System" dated Nov. 4, 1975. On Mar. 15, 1977, Battelle readdressed the study issues in a letter to NASA and concluded that some changes have occurred since the time of the original study. However, the letter generally confirmed the original findings.

or some other form of propulsion are needed. Using upper stages or other propulsion systems also increases a user's cost, partially reducing the savings of combining payloads. Use of an upper stage creates the following problems.

<u>Problems using upper stages</u>--First, weight and length of the upper stage and associated hardware--ranging from 7,500 to 61,000 pounds and from 6 to 33 feet long--reduce the shuttle's payload delivery capability. Second, the upper stage propellants, upon firing, could contaminate the remaining payloads. A Communications Satellite Corporation (COMSAT) official told us, for example, that because of potential contamination, COMSAT would insist its payload be deployed first when sharing a flight. NASA plans for the orbiter to achieve adequate separation from the upper stages before firing to prevent contaminations.

Rendezvous and return

NASA expects the orbiter's ability to visit and/or return payloads to permit (1) on-orbit checkout before final deployment, (2) the retrieval of satellites for on-orbit servicing or return, and (3) the use of the spacelab for conducting space research. However, potential users (other than NASA) generally do not believe these undemonstrated capabilities will be widely used during the 1980s, the period of time for which NASA's justification of STS is based.

On-orbit checkout

In the past, some satellites have completely failed shortly after insertion into orbit. NASA believes these failures can be reduced significantly by checking out a payload in space before deployment. If the payload is not functioning properly, it could be repaired or returned to Earth. The usefulness of on-orbit checkout is uncertain, however. Over the years increased reliability of electronic circuitry has reduced the incidence of early satellite failure. A Goddard Space Flight Center study of 57 satellites showed 5 had unsuccessful missions due to first-day failures. Satellite failures are now attributable more to wearout due to (1) the disruption of power supplies because of the limited number of recharges the batteries will hold or (2) the exhaustion of the fuel supplies that maintain a satellite's stability or position.

On-orbit checkout may also be impracticable during the 1980s, except for a few payloads.

> Checkout problems--Potential users believe there is little need to check out satellites which will be subjected to the stresses of upper stages before final deployment and activation. On-orbit checkout could also be time consuming. For example, satellites having high voltage circuits require up to 1 week for the atmosphere brought with them to dissipate. Premature testing could burn out the high voltage circuits. In addition, complete on-orbit checkout will require special equipment which must be provided by the user. This equipment is so massive and complex that at least one spacecraft manufacturer does not foresee any desire for such services before 1990.

Retrieval

Retrieval which enables payload refurbishment and reuse is the key to NASA's most recent economic justification for STS, accounting for 75 percent of the projected savings. It has also been a controversial issue. In 1973 the National Academy of Sciences concluded that payload recovery and in-orbit servicing would be economical for expensive systems, such as orbiting observatories, but for the less expensive payloads the economic advantages were unclear. According to the more recent Battelle survey, all users interviewed believed the demonstrated reliability of current satellites was quite satisfactory. As on-orbit lifetimes are now approaching 7 years and may reach 10 years, returning a satellite which incorporates antiquated technology would not be particularly useful. However, NASA does plan to recover a few of its payloads where practicable.

Economics aside, technical challenges may limit satellite retrieval--one of the most complicated applications of the orbiter in terms of required maneuvers, hardware, and operational sequences. Retrieval is impossible for objects beyond the orbiter's limited range because expendable upper stages do not have retrieval capability. More than 66 percent of all non-Communist payloads in orbit as of February 1976 were beyond the reach of the orbiter, even with maximum fuel and no payloads.

In addition, rendezvous missions will require the orbiter and satellite to be in precisely the same orbit. This may be difficult to achieve without a dedicated shuttle flight because of the multitude of potential orbits and the orbiter's limited maneuverability. To increase the probability of combined delivery and recovery missions, as well as the probability of multi-payload launches, NASA is proposing four standard inclinations--28.5 and 56 degrees from Kennedy Space Center and 90 and 104 degrees from Vandenberg Air Force Base. However, standard inclinations may not fit all users' needs; and until the other orbit determinants, such as celestial longitude, are specified, there are still an unlimited number of orbits from which a satellite may have to be recovered.

Retrieval is further complicated because a satellite's celestial longitude changes daily. A satellite placed in orbit on one day will not be in the same orbit on the next. In addition, the rate of this drift varies based on the height and inclination of the orbit. Therefore, two payloads placed in the same orbit plane but at different heights will tend to drift at different rates and will not be in the same orbit plane at a later date. NASA points out that some satellites may be cooperative in terms of maneuverability relative to changes in altitude and celestial longitudes. This maneuverability, however, is limited at best. In many cases payload launch-window constraints may preclude retrieval on a given mission.

<u>Unstabilized satellites</u>--Even if the orbiter can maneuver within range, an out-of-control satellite cannot be recovered. Either the satellite's stabilization system must be working and be capable of being deactivated or the orbiter must carry equipment capable of neutralizing the motion. Many satellites are oriented by means of gyroscopes--rotating wheels which resist

changes in orientation. If an active satellite were pulled into the orbiter using the manipulator arm, the resistances could set up severe stresses and damage the arm. The satellite will be safe to recover only if all internal and external movements are neutralized.

Use of spacelab

In addition to insertion and rendezvous missions, the shuttle is to provide routine manned access to space from both Kennedy Space Center and Vandenberg Air Force Base. The orbiter is to be equipped with versions of the spacelab to provide a platform for observations of the universe and the Earth and a low-cost research laboratory in a space environment.

Spacelab, unlike the earlier Skylab, will remain attached to the launch vehicle at all times during the flight. The missions will last from 7 to 30 days during which time the spacelab will draw its power from the orbiter. The standard configuration orbiter will provide enough power for most 7-day missions; however, longer durations will require extra power kits. According to NASA officials at Johnson Space Center, installing extra power kits for a 30-day mission will be prohibitively time consuming and expensive. Even a 30-day mission may not provide enough time for applications such as Earth mapping. NASA headquarters officials indicated that the subject was receiving increased attention to determine the most practical design for extra power kits.

NASA is projecting extensive spacelab use--170 of the 396 projected shuttle flights during the 1980s are for spacelab. Whether this utilization rate will be achieved is uncertain. NASA is the only U.S. user we know with firm plans to take advantage of spacelab capabilities. About 79 percent of the total spacelab flights are NASA flights. Therefore most spacelab flights will be at Government expense and we have been advised that this will be one of the more expensive types of shuttle flights. The Europeans, who are developing the spacelab, have agreed to a joint mission with NASA for the first spacelab flight.

NASA considers research for in-space manufacturing to be one of spacelab's most promising uses. General

Electric's Space Division conducted a survey on potential manufacturing in space. Many processes and products were identified; and tungsten x-ray targets, high specificity separation of isoenzymes, surface acoustic wave electronic components, and transparent oxides were studied in depth. The study concluded that none of the four research projects would be undertaken by private industry without extensive Government financing, and the spacelab's limited mission duration, combined with a power shortage, would not support a production operation. NASA's fiscal year 1978 budget plan includes $6.3 million for "materials processing in space" payload development.

UPPER STAGE CAPABILITIES

Most space shuttle flights, other than spacelab missions, will require upper stages to deploy payloads to their final destination. Expendable upper stages will consist of (1) a two-stage interim upper stage under development by the Air Force, (2) three- and four-stage versions of the interim upper stage if NASA funds development of this configuration, and (3) NASA's planned spinning solid upper stages. There will be two basic sizes of spinning solid upper stages; one will accommodate a Delta-sized satellite and the other will accommodate an Atlas/Centaur-sized satellite. The upper stage used depends on the satellite's weight and destination.

All satellites except those requiring a spinning solid upper stage will be deployed in about the same way. The crew will use the remote manipulator arm to grasp the satellite or satellite and interim upper stage combination, lift it out of the bay, and release it in space. (See fig. 7.) If an interim upper stage is being used, the orbiter will back away to a safe distance, then the upper stage will be ignited. If more than one satellite is to be deployed, the crew will repeat the above process.

For satellites using a spinning solid upper stage, the sequence of events will be slightly different. The satellite and upper stage will be pivoted upward by the launch platform. Then the launch platform will be spun up and a spring will eject the upper stage and the payload into space. As with the interim upper stage, the orbiter will retreat to a safe distance before igniting the spinning solid upper stage. When an upper stage is used for final deployment of a satellite, the orbiter essentially replaces the first and second stages of expendable launch vehicles.

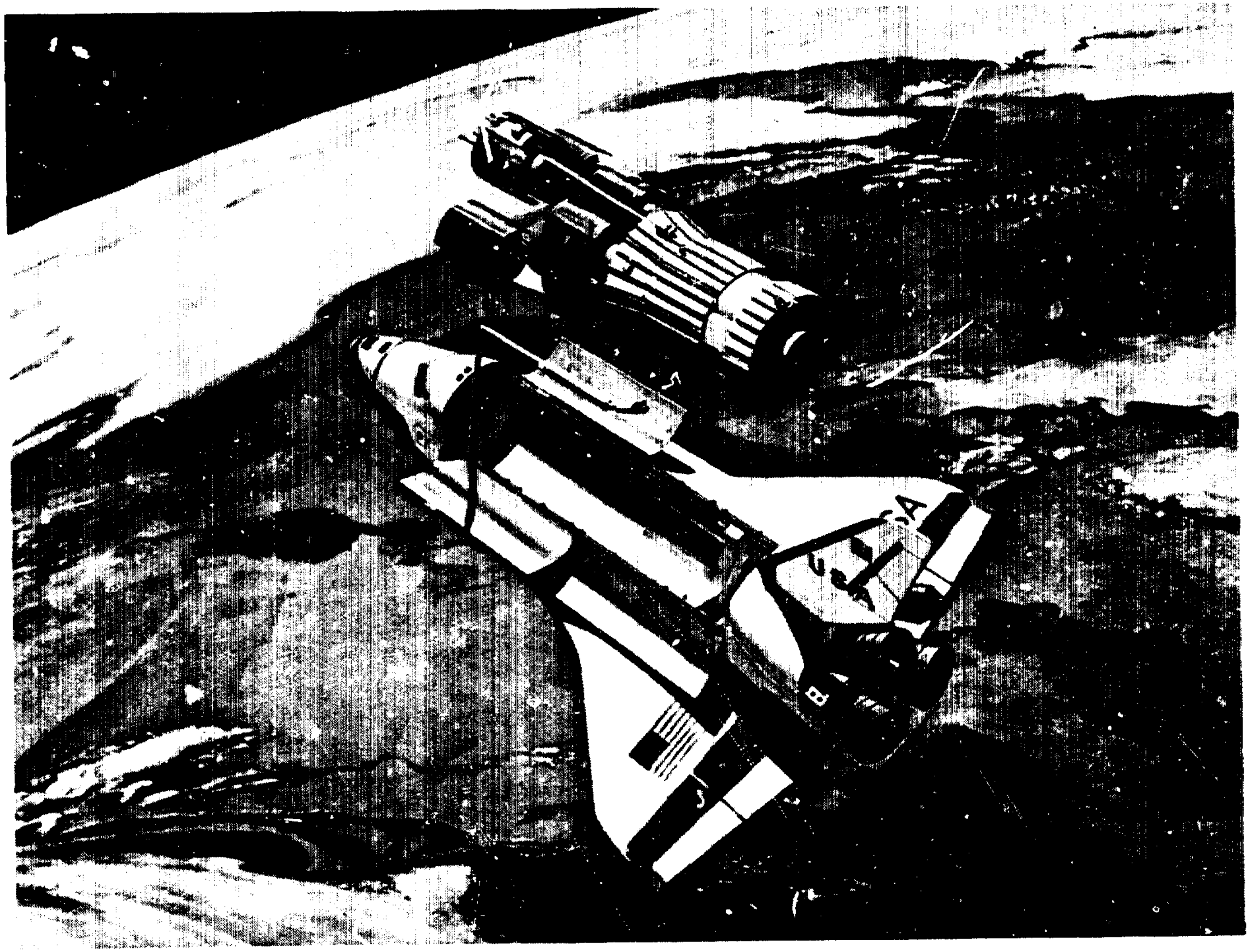

FIGURE 7: ARTIST'S CONCEPT OF THE ORBITER AFTER DEPLOYING A SATELLITE/UPPER STAGE

SOURCE: NASA

Examples of satellites which will require using upper stages include communications and weather satellites. Other potential uses of upper stages include (1) placing satellites in polar orbit from an orbiter launched from Kennedy Space Center and (2) final delivery when more than one mission is combined on a single shuttle flight.

Some satellites need to go to near-polar o bits--high inclination orbits which the orbiter cannot attain from Kennedy Space Center because of launch constraints. The basic interim upper stage, however, can deliver most of these satellites from an orbiter launched out of Kennedy Space Center. For example, from an orbiter launched from Kennedy Space Center, the basic interim upper stage can deliver over 4,000 pounds of payload to a 90 degree, 900-nautical-mile circular orbit.

Satellites could also be delivered to sun-synchronous orbits (a popular band of near-polar orbits including inclinations from 96 to 102 degrees), with height and weight penalties. However, this capability may be sufficient since satellites currently in sun-synchronous orbits typically weigh less than 2,000 pounds. In addition, NASA's three- and four-stage interim upper stage configuration, if developed, would increase the delivery capability to polar orbits from orbiters launched from Kennedy Space Center. Although the DOD agrees that some flights planned to near-polar orbit could be performed from Kennedy Space Center, it states that a small number of heavy, high-priority payloads planned for the future could not be launched in this manner.

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Once space operations have been completed, the payload-bay doors are closed and the crew can begin making preparations for return to Earth.

CHAPTER 5

AN AIRPLANE-LIKE LANDING

Following orbital operations, the crew will prepare for reentry into the Earth's atmosphere. A decision to change landing sites must be made before reentry if for some reason, such as unfavorable weather conditions, the orbiter cannot land as originally planned. The orbiter is committed to its landing site once it has entered the atmosphere.

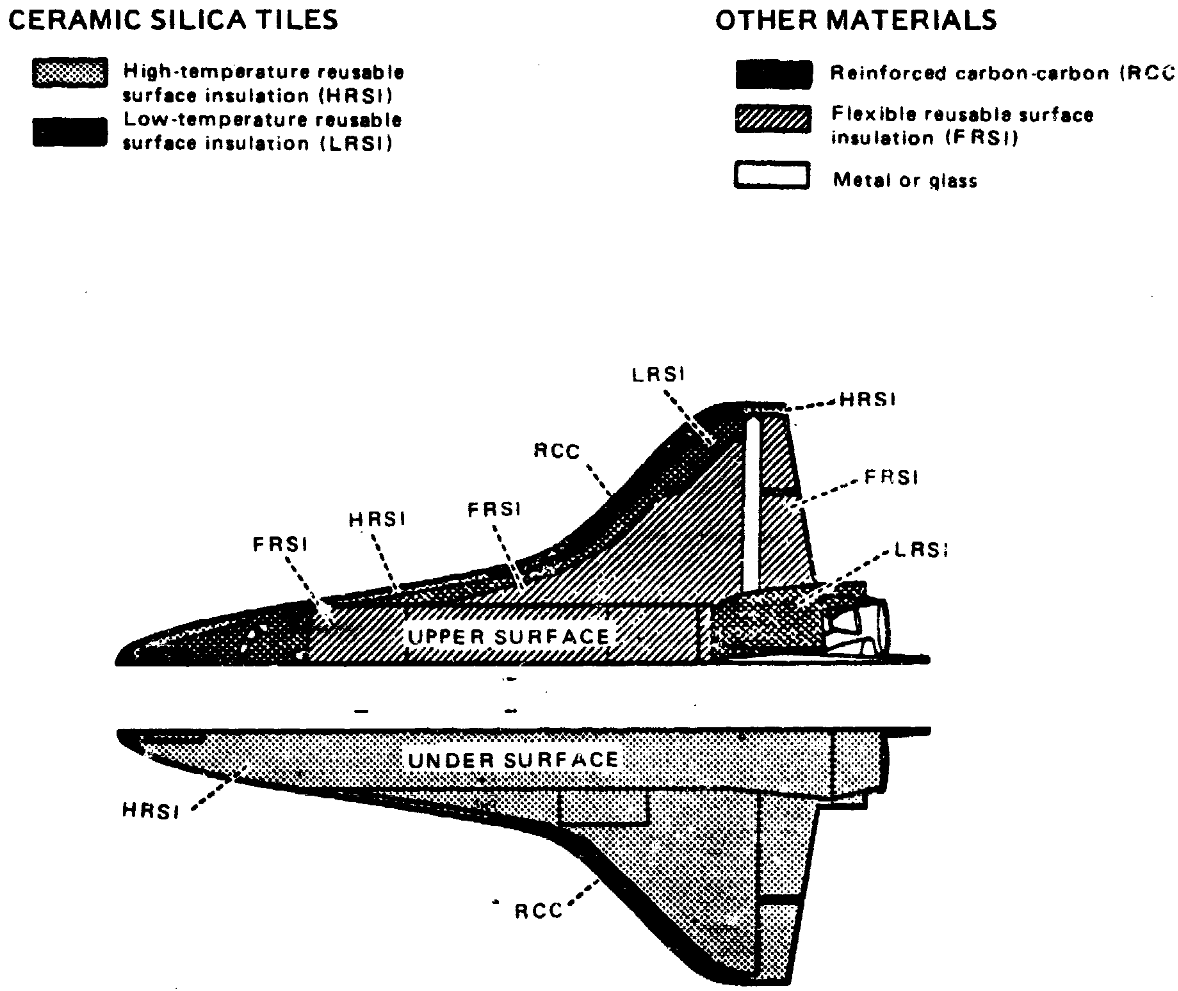
The orbital maneuvering system provides the deceleration thrust necessary for deorbiting. After the burn, the orbiter is reoriented nose-forward to the proper attitude, or position for reentry. At about 400,000-feet altitude the position of the vehicle is established and maintained by power from the reaction control system. Between 400,000- and 50,000-feet altitude, the orbiter can move laterally (crossrange) up to about 1,100 nautical miles to reach the designated landing site. NASA does not anticipate using maximum crossrange except under emergency conditions and therefore will not demonstrate this capability during the flight test program. An 800- to 900-mile crossrange capability will be demonstrated.

The orbiter reaches temperatures as high as 3,000 degrees Fahrenheit on the nose and leading edges of the wing during descent. The vehicle will normally be flown at a nose-up position (30- to 40-degree "angle of attack") to confine most of the heat to its lower surfaces where extensive thermal protection has been provided. The orbiter's thermal protection system, unlike previous space vehicles, is designed for reuse.

Thermal protection system--The orbiter's thermal protection system is a safe-life (no failures allowed) system designed to be reused for 100 reentries before replacement. It consists of five different types of materials, but about 65 percent of the orbiter's surface is covered with ceramic silica tiles. The various thermal materials are placed on the orbiter as shown in figure 8.

The ceramic silica tiles (about 32,400) are fragile and susceptible to ground handling damage. NASA has reduced the expected replacement rate after each mission from 3 percent to 1.4 percent. If the actual replacement rate is greater, increased operating costs and refurbishment times can be expected.

THE ORBITER'S THERMAL PROTECTION SYSTEM



SOURCE: NASA

FIGURE 8

Although the thermal protection system is an advancement in technology, NASA officials believe that most development problems have been overcome. Problems under investigation include:

--Adhesive used to bond the ceramic tiles to the orbiter cannot withstand temperatures below a minus 160 degrees Fahrenheit, limiting to 3 to 4 hours the orbiter's ability to hold certain attitudes in space. If an acceptable solution cannot be found, the space shuttle's on-orbit performance will be impaired. 1/

--Base heat shields for the main engines may not meet the 100-mission life requirement. If not, they may have to be redesigned, resulting in cost and weight penalties.

--Areas of the thermal protection system will experience temperatures higher than designed, resulting in these areas having less than 100-mission reusability. NASA explained that development costs have been lowered by relaxing reusability design constraints.

Between 300,000- and 160,000-feet altitude, the orbiter will experience a communication blackout lasting about 10 minutes. This phenomenon, caused by the ionization of atoms in the atmosphere, has been experienced by all previous manned space flights. After blackout, the navigation system immediately updates the orbiter's position to insure proper targeting to the landing site.

At an altitude of 250,000 feet, the atmospheric density is sufficient for some aerodynamic control surfaces (body flaps, elevons, rudder, and speed brake) to assist in flight control. However, the reaction control system engines are not deactivated until about 80,000 feet, where the orbiter begins its powerless approach and landing.

Unpowered landing--The orbiter's original configuration included air breathing engines to assist in landing the vehicle in an actual aircraft manner. To reduce costs and orbiter weight, the engines were deleted from the program. Thus the

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1/NASA officials informed us during March 1977 that this problem had recently been resolved.

orbiter will have only one chance to land safely and will not have the benefit of power to adjust speeds and make final adjustments for proper runway alinement and touchdown. Although the unpowered landing represents an inherent risk, NASA justifies the performance capability based on technology established using experimental vehicles.

At about 80,000-feet altitude, the orbiter will reduce its 30- to 40-degree angle of attack to about 10 degrees. This decrease exposes the tail of the vehicle to airflow, and all aerodynamic control surfaces will be used to adjust the orbiter's speed and altitude for final approach and landing. The profile flown during this phase of landing attempts to optimize flight performance while minimizing the sonic boom overpressures being created.

Sonic boom--No reasonable way exists to land the orbiter at either Vandenberg Air Force Base or Kennedy Space Center without creating sonic booms over populated areas, such as Orlando, Florida. Although the orbiter will become subsonic about 18 nautical miles from the runway, the sonic booms will carry beyond the 18 miles and approach the landing site. This can be seen in the sonic boom footprint projected for lower Florida. (See fig. 9.)

NASA originally predicted that the orbiter's sonic booms would be limited to 2 pounds per square foot within 100 nautical miles of the landing sites but is now projecting slightly higher maximum overpressures within 26 nautical miles of landing sites. Overpressures of these intensities could damage nonprimary structures, such as plaster, windows, and bric-a-brac, and be annoying to persons on the ground.

The United States Code (49 U.S.C. 1431), as implemented by the Code of Federal Regulations (14 CFR 91.55), prohibits civil aircraft, including Government aircraft carrying commercial cargo, from creating sonic booms over the United States. We believe the space shuttle may be subject to these regulations unless exempted by the Federal Aviation Administration (FAA). In March

SPACE SHUTTLE SONIC BOOM
OVERPRESSURES PREDICTED FOR KENNEDY SPACE CENTER APPROACHES

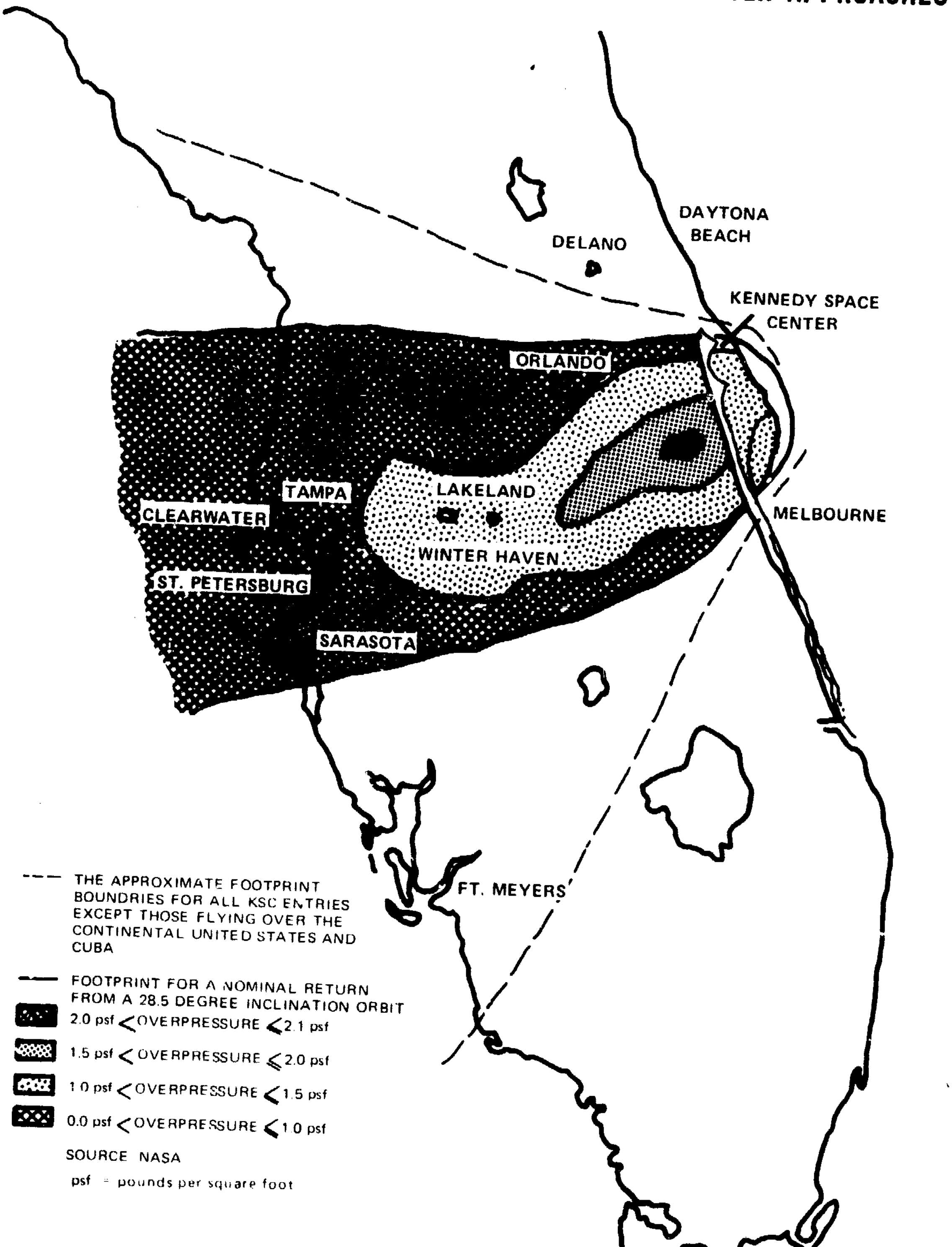


FIGURE 9

1977 the Chief Counsel of FAA, in a letter to NASA, concluded that the shuttle is not an aircraft within the meaning of the FAA Act of 1958 and would not be subject to all the operating requirements of the act. FAA is engaged in establishing the needed restricted-use air space and other operational conditions.

At about 10,000- to 12,000-feet altitude, or 5 to 6 miles from the runway, the orbiter will make its final approach gliding at a 24-degree angle to the Earth. This steep glide slope will be held until the orbiter is about 7,500 feet from the runway and 30 seconds from touchdown, when a 3-degree glide slope is initiated. Landing gear deployment will begin 20 to 50 seconds before touchdown. These power-assisted freefall mechanisms, one on the nose and two on the mid-fuselage, require up to 10 seconds for full deployment. No opportunity or capability exists to recycle one that does not extend properly. However, NASA believes the backup devices on the landing gear system are adequate for proper extension.

Touchdown speeds will range from 185 to 207 knots (213 to 238 miles per hour (mph)), depending on such factors as return payload weight and aerodynamic forces, which will make the orbiter one of the fastest landing aircraft today. Landing speeds of several military and commercial aircraft are as follows:

U.S. Air Force jet aircraft	135 to 155 knots (155 to 178 mph)
U.S. Air Force research aircraft	161 to 229 knots (185 to 264 mph)
Boeing 737 commercial aircraft	125 knots (144 mph)
McDonnell Douglas DC-9 commercial aircraft	112 knots (129 mph)

The orbiter will land about 2,700 feet down the runway and will begin a controlled rollout.

Landing gear tires--Certification of the landing gear tires for flight worthiness will not include a thermal vacuum test. Extensive tests were satisfactorily run on material similar to actual flight tires in 1973 and on the actual tire materials in 1976. However, the orbiter's tires/wheel assembly have never been exposed to the actual thermal vacuum environment for a typical 7- or 30-day mission. A Johnson Space Center safety report expresses the concern that the tires' rubber may become brittle from this exposure, causing failure at touchdown or during braking/rollout. Pressure loss may also occur, causing overheating or blowout during rollout. A failure of any or all tires may result in loss of vehicle and crew. Some NASA officials believe that existing certification requirements are adequate and that no additional thermal vacuum testing is required.

Once on the runway, the crew will apply the brakes and the orbiter will roll to a stop. The brakes are the only mechanical assistance used to stop the vehicle. NASA deleted drag chutes from the original design configuration to reduce unnecessary costs and weight. Simulations have shown that brakes and aerodynamic forces will allow the orbiter to safely stop on a 10,000- by 150-foot runway. The primary landing sites (Kennedy Space Center and Vandenberg Air Force Base) will provide extra margins of safety with their 15,000-foot runways. Alternate air fields must meet the minimum specifications.

Landing sites--Alternate airfields will provide landing opportunities for the orbiter if, during abort situations or unfavorable weather conditions, the primary landing sites cannot be used. Dryden Flight Research Center, Edwards Air Force Base, California, has been designated as the secondary landing site for the orbiter.

If the orbiter cannot safely return to the continental United States, about 15 worldwide airfields will be available as contingency landing sites. Principal contingency airfields designated by NASA are Hickam Air Force Base, Hawaii, and Anderson Air Force Base, Guam. Negotiations with the other U.S. owned and operated airfields and possibly three or four totally foreign facilities will be finalized during 1977 and 1978.

The contingency landing sites will provide for crew/passenger survival and orbiter towing only. No unique support equipment, such as the automatic landing system, will be available. Landing at these sites will be accomplished using manual control, aided by standard air navigation equipment. Kennedy Space Center is responsible for dispatching a ground crew with all necessary equipment to safe and deservice the orbiter and prepare it for ferrying to the launch site on the Boeing 747 shuttle carrier aircraft. (See fig. 10.)

Once the orbiter rolls to a stop, operations will be immediately initiated to prepare it for the next flight. Orbiter refurbishment and shuttle assembly for subsequent launches require quite an extensive process. (See fig. 11.)

Turnaround goal--NASA has established a turnaround goal of 160 hours--two 8-hour shifts a day for 2 work-weeks. This short period was established to reduce operating cost and to minimize the number of orbiters in inventory. A July 1976 analysis of turnaround times shows that the 160 hours cannot be achieved unless the orbiter's "design and maintainability" are improved. The analysis further shows that the probability of achieving the current turnaround estimate of 209.5 hours is also low.

The current turnaround estimate compared to the design goal is shown in the table on page 43. Both estimates are for a standard shuttle mission, excluding flight equipment not flown more than 50 percent of the time. For example, additional time will be required to install the spacelab and extra fuel kits for orbital maneuverability.

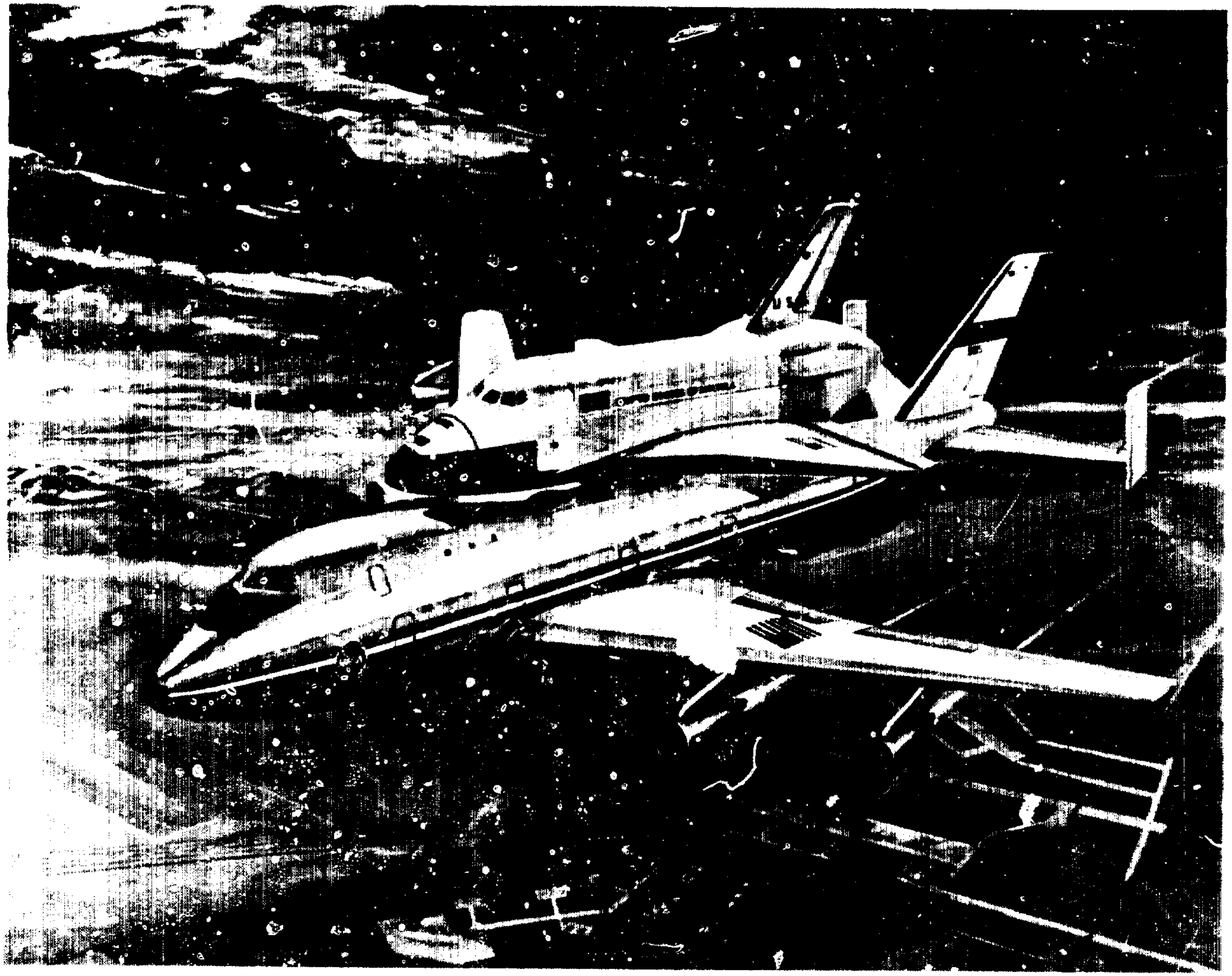
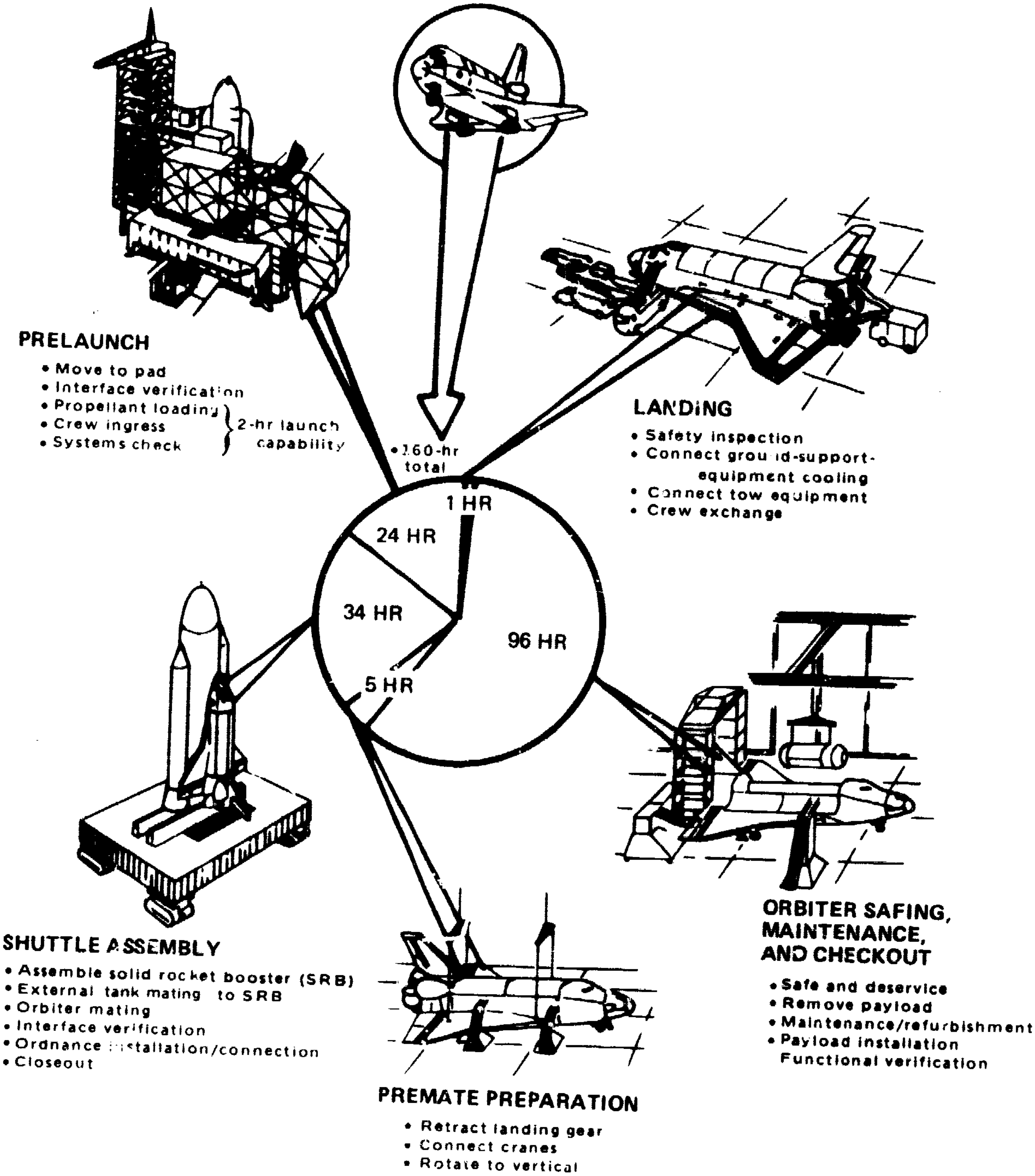


FIGURE 10: ARTIST'S CONCEPT OF AN ORBITER FERRY FLIGHT USING A 747 SHUTTLE CARRIER AIRCRAFT
SOURCE NASA

THE TURNAROUND CYCLE
(160 HOUR GOAL)



SOURCE: NASA

FIGURE 11

Turnaround Times

Facility	Goal	Current estimate	Difference
	----(Serial time hours (note a))-----		
Landing area	1.0	1.0	-
Orbiter processing facility	96.0	124.0	28.0
Vehicle assembly building	39.0	51.5	12.5
Launch pad	24.0	33.0	9.0
Total	160.0	209.5	49.5

a/Serial time is defined as that time required for a task which is part of a critical path of a flow chart. The task must be accomplished as a prerequisite to the next serial task of the critical path.

Some problems preventing NASA from achieving the 160-hour goal are

--the time required to refurbish the orbiter's thermal protection system,

--excessive time for changing the payload-bay liner and blankets, and

--the sagging of payload bay doors when opened while the orbiter is in a vertical position.

NASA headquarters personnel are confident that the 160 hour goal for turnaround time will be met during the operational phase of the space shuttle program.

After turnaround operations are completed, the space shuttle system--orbiter, main engines, external tank, and solid rocket boosters--will be ready to accommodate the next user's payload into space.

CHAPTER 6

WHAT WILL USERS PAY?

As of December 1976, NASA had not determined the total cost of operating STS or how much an individual user would pay for STS services. NASA had prepared cost estimates for a portion of STS operations and was considering a preliminary shuttle user charge policy. However, we could not fully evaluate the cost estimates or the policy because both are being revised. This chapter discusses some basic principles underlying the overall policy. We plan to conduct a detailed review and issue a separate report on operating cost and user charges after NASA's plans are more settled.

The basic criterion of NASA's user charge policy is to recover shuttle operations cost, not for each flight or for each year but, rather, over the 12-year projected operating life of the program. The projected costs for operations between 1980 and 1991 are divided by the total number of estimated flights, and this average is the basis for charging users of the program.

WHAT ARE THE ESTIMATED OPERATING COSTS?

In preparing the STS operating cost estimate, NASA has concentrated its efforts on a cost estimate for the space shuttle only. NASA officials estimated that the space shuttle operations for 572 flights would cost about $9.2 billion (1975 dollars), or an average of $16.1 million a flight. However, NASA established a price range of $16.1 million to $18 million (1975 dollars) to cover possible cost increases before reimbursement agreements are negotiated. NASA is revising the entire operations cost estimate and plans to continually update the estimate.

NASA officials said these estimates incorporate all recurring costs, including manpower, to provide the standard shuttle services. Nonrecurring costs--such as research and development, orbiter production, and investment in facilities and other capital equipment--are not included in the operations cost estimate. NASA is recovering a portion of the orbiter production costs and the investment in facilities and other capital equipment by charging a use charge levied on foreign and commercial users. NASA is not recovering any of the research and development funds incurred in conjunction with STS nor any interest on this investment.

Optional services will be available at an additional cost to tailor flights to the user's needs, and many users will require optional services. Some services available are (1) additional fuel and power kits to extend basic orbiter capability, (2) revisit and retrieval, (3) upper stages, (4) additional time on orbit, and (5) spacelab. NASA had not established cost estimates and user charge policies for optional services as of December 1976.

WILL THE POLICY RECOVER ALL COSTS?

The average-cost concept, together with other policy provisions--such as the shared-flight concept and exceptional selection process (see pp. 52 and 53)--raise serious questions as to whether total operations costs will ever be recovered. NASA's objective when preparing the policy was to encourage users to change over to the space shuttle by offering a price competitive with expendable launch vehicles.

Had NASA used actual costs rather than estimated average costs, the price to the users of a dedicated shuttle flight during the first years of operations would be much greater than the most frequently used expendable vehicle (Delta). For example, the average cost of a shuttle flight during the first 3 years of operations would be about $29 million (1975 dollars) compared to $13 million and $23 million (1975 dollars) for the Delta and Atlas/Centaur expendable launch vehicles, respectively.

NASA is lowering the per-flight price during the early program years by averaging the higher initial costs with the expected lower costs during the later years. Essentially, NASA, through appropriations from the Congress during the early years, will have to pay for costs incurred above the average cost per flight for its flights as well as for the flights for non-NASA users--both U.S. Government and commercial/foreign users. NASA expects to recoup the deficits experienced during the early years in later operating years when the average costs will be greater than actual costs. This concept can be seen in figure 12.

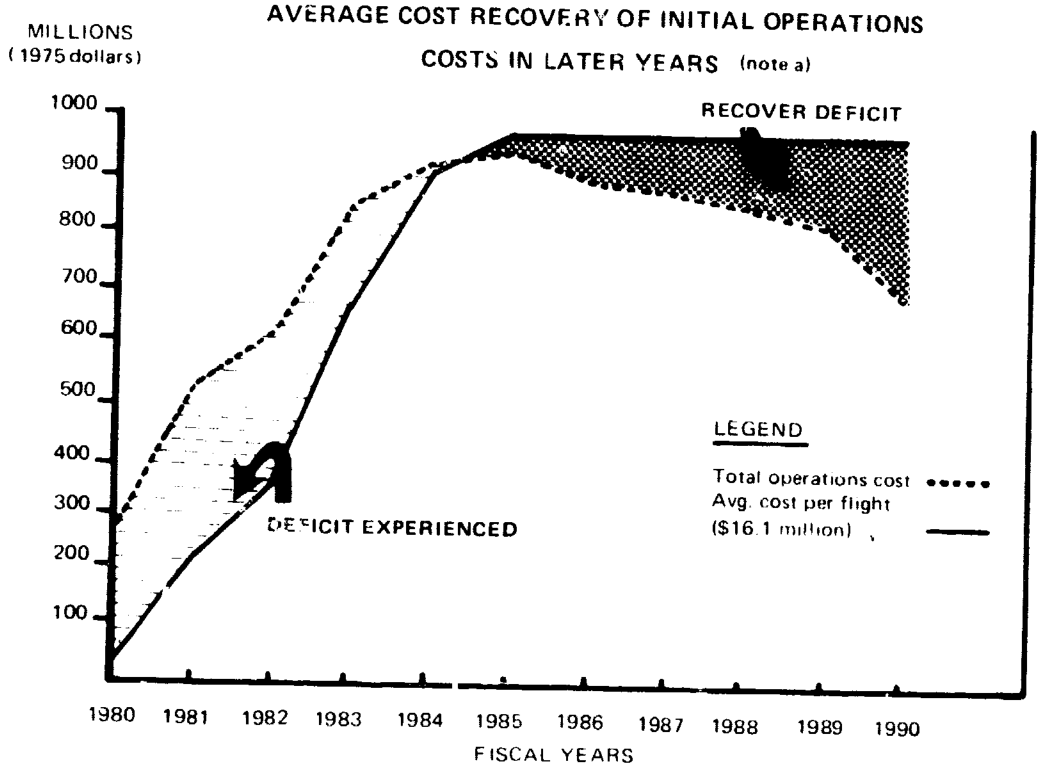


FIGURE 12

a/ THIS CHART NOT ONLY REFLECTS THE EFFECT OF AVERAGE PRICING FOR OTHER USERS OF STS BUT ALSO INCLUDES THE EFFECT FOR NASA'S FLIGHTS AS WELL. THEREFORE, THE DEFICIT SHOWN IS LARGER THAN THAT REQUIRED BY NASA TO FLY STS FOR OTHER USERS.

NASA officials stated that although deficits will be encountered during the early years, they are recovering their out-of-pocket costs, such as the costs for additional external tanks, solid rocket boosters, and other consumables. However, as cited earlier, NASA plans to charge an average dedicated flight price of $16.1 million (1975 dollars), compared to an actual cost of $29 million (1975 dollars) for each dedicated flight during the first 3 years of operations. NASA must fund the difference between the actual cost and the price it charges users.

If actual costs exceed the estimates, full costs may never be recovered.

> Potential for cost increases--NASA's cost estimates are based on a number of assumptions which may not materialize. For example, they are based on meeting all reusability assumptions, such as solid rocket booster reuses, 55 main engine starts, and 1.5 percent replacement for the thermal protection system per flight. Other assumptions which could increase operating costs are (1) a 200-hour turnaround time estimate, (2) no major overhaul of the orbiter, and (3) no orbiter attrition.
>
> Since the operational cost estimates are based on such assumptions, any deviation in actual cost from the estimates is most likely to be an increase rather than a decrease. Any changes in the operational cost estimates may be particularly important since NASA is establishing one fixed price for flights during the first 3 years of operations, with no actual operating experience on which to base the price.
>
> In March 1977 NASA informed us that it had conducted a pricing sensitivity analysis which showed that the price range of $16.1 million to $18 million (1975 dollars) was a reasonable and sufficient amount to cover probable cost variations prior to negotiating a reimbursement agreement. Once an agreement is signed, the flight price for the first 3 years of operations will be fixed.

NASA intends to compensate for potential cost increases by providing for annual price adjustments after the first 3 years of operations. (Cost decreases will also be compensated for.) The adjustments are expected to recover unanticipated losses experienced during the first 3 years (phase I) when the price is fixed and to include anticipated cost increases over the remaining years of the program (phase II). Phase II costs would again be based on the projected costs and number of flights. While the price adjustments would seem to result in full cost recovery, this may not be true because NASA is planning fixed-price-type contracts signed 3 years before flight date which, if the actual costs continue to increase, will continually push cost recovery to later years.

Therefore phase II prices might increase substantially. Such price increases may result in users' being unwilling to use the shuttle. According to House of Representatives Report No. 94-1220 which accompanied NASA's 1977 appropriations bill (H.R. 14233),

> "Unless the commercial sector accepts the shuttle as an economically viable alternative to conventional boosters, the space transportation system will not be viewed as a success."

Competition--The space shuttle may not handle all space traffic during the 1980s. Although NASA has had a virtual worldwide monopoly in providing launch services, the Battelle study conducted for NASA states that potentially serious space transportation competition is expected by the early 1980s. This competition, expected to influence primarily non-NASA/non-DOD users, will be from the Japanese 1/ and Europeans who plan to have and may actively market expendable launch vehicles roughly equivalent to the current NASA Delta and Atlas/Centaur vehicles. The foreign governments may be willing to subsidize launch costs in order to market their own communications or other satellites.

1/In March 1977 NASA officials informed us of an agreement signed in December 1976 with Japan, which prohibits the sale of N-1 launch vehicle services (equivalent to Delta) to third parties.

Commercial U.S. firms may also provide launch vehicle competition in the future if it becomes a viable economic proposition. If commercial companies get more involved in the expendable launch business, the cost of these vehicles may decline.

A reduction in the number of shuttle customers would further complicate the recovery of operations cost. If the projected number of flights during the 1980s does not occur, the average price for each flight will increase since there will be fewer flights among which to prorate the total operating costs. Figure 13 shows NASA's projected price increase for each flight if the 572 flights do not occur.

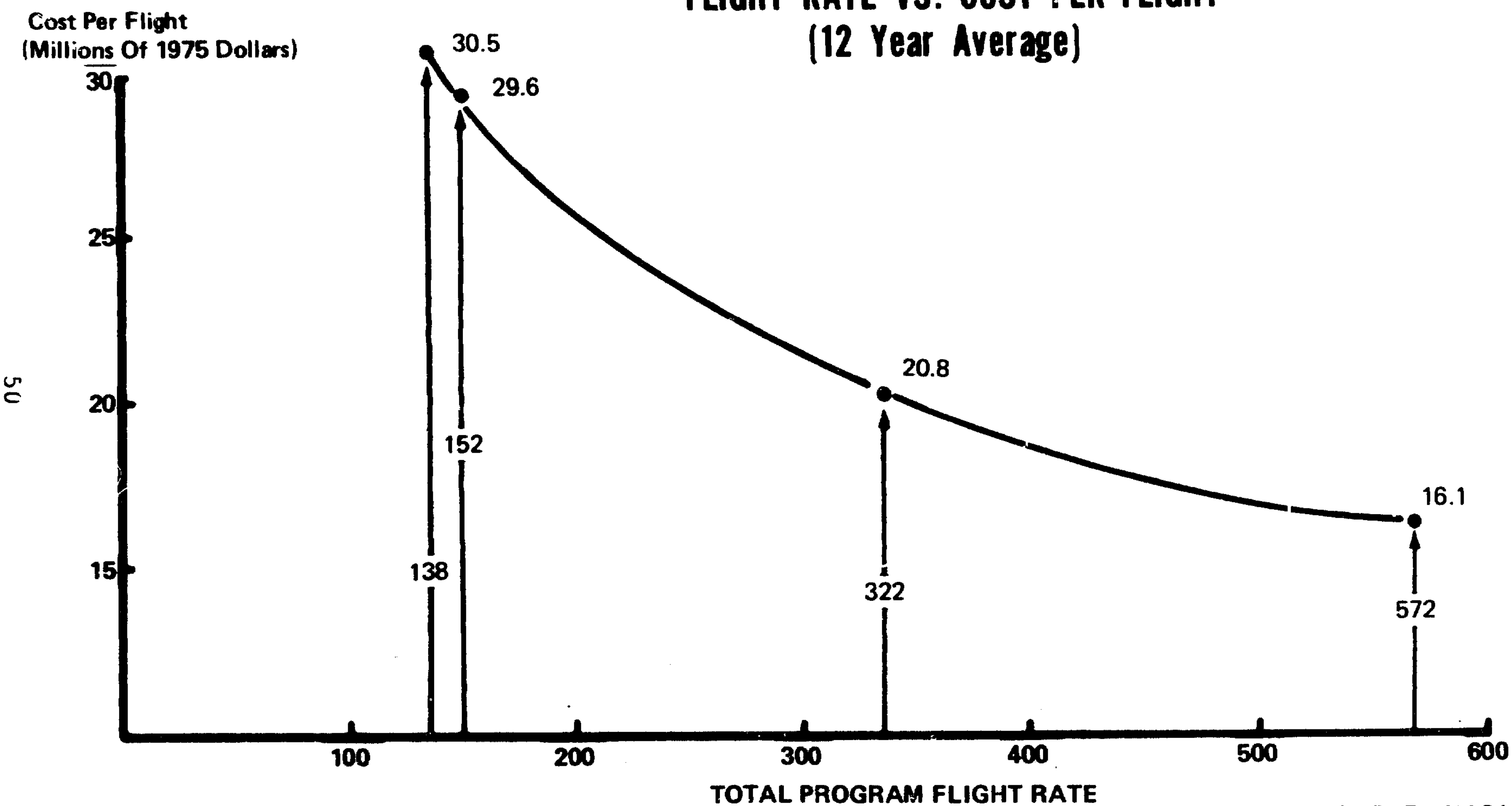
Projected flight rate--NASA's projection of the number of flights after the shuttle reaches full operation shows an increase in the average yearly flight rate of 15 flights (43 percent) over the rate experienced during the past 10 years as follows.

Experienced Flight Rate Versus Projected Flight Rate (note a)

Category of user	Average yearly flight rate: Expendables last 10 years	Average yearly flight rate: Full shuttle operations	Yearly increase or decrease (-)
NASA	10	25	15
Other Government agencies	2	3	1
Commercial	2	6	4
Foreign	4	6	2
DOD	17	10	-7
Total yearly flight rate	35	50	15

a/In calculating the projected average yearly flight rate, we used NASA's most recent projection excluding reflights necessitated for aborts.

USER CHARGE SENSITIVITIES
FLIGHT RATE VS. COST PER FLIGHT
(12 Year Average)



SOURCE: NASA

FIGURE 13

The increase in NASA's flight rate results primarily from projected spacelab usage (see ch. 7) and also considers expected growth in communication, meteorology, Earth resources, and oceanographic satellite programs. However, such increases cannot be taken for granted. NASA's increase would require an increase in funding levels for space technology/payload-oriented programs. In addition, any new major development programs, such as a follow-on reusable shuttle or a space station, could not be done without increased appropriations. This view is also held by NASA as reported to the Office of Management and Budget in October 1976 and the Congressional Budget Office in January 1977. Other Government agencies may also need increased funding to achieve the payload programs NASA projected.

NASA considers the increase in other Government agency flights reasonable because it extends NASA-developed technology and operational feasibility demonstrations in the areas of meteorology, Earth resources, and oceanography. However, we interviewed personnel in seven Government agencies and found that only one agency planned to use the space shuttle on a cost-reimbursement basis, and it does not plan to increase the number of satellites launched each year.

The increase in commercial flights is expected from traffic growth in the area of commercial communications satellites. NASA did not provide information to enable us to fully determine the basis for this projection. COMSAT officials, for example, told us that their current launch programs will be completed by 1982 and an average of one satellite a year is expected thereafter.

The projected increase in foreign government flights is doubtful. NASA did not obtain formal input from foreign governments. Since other governments are developing their own launch vehicles, will they continue to use U.S. vehicles regardless of the economic advantages? One exception might be spacelab.

DOD, the major user of space during the past 10 years, has evaluated its requirements and is projecting a decrease of seven flights a year.

At least two other provisions of NASA's proposed policy--shared flights and the exceptional selection process may make it more difficult to recover operating costs.

Shared flights

NASA's basic space shuttle flight cost exceeds the cost of the most frequently used expendable launch vehicle--the Delta. In addition to the basic $16.1 million to $18 million (1975 dollars) per-flight cost, commercial and foreign users must pay a use charge of at least $2.9 million (1975 dollars) per flight for depreciation of facilities, support equipment, orbiter inventory and reflight insurance. This brings the total charge to $19 million to $20.9 million (1975 dollars) a flight, compared to $13 million and $23 million (1975 dollars) for the Delta and Atlas/Centaur expendable launch vehicles, respectively. Adding extra services, such as an expendable upper stage or longer flight duration, will further increase shuttle per-flight costs over expendable vehicle costs since these extra services are included in the basic price of expendables.

Therefore NASA's user charge policy provides for flight sharing so that the total flight cost can be divided among two or more users. The policy guarantees a user a shared-flight price even though his payload may be the only one on the flight. In other words, NASA has assumed the risk of finding another user(s) to share the flight. Scheduling and other difficulties in sharing flights magnify this risk. If another user cannot be found, the payload will be launched by itself and NASA will absorb the loss. Normally, when two or more users share a flight, the total price recovered will exceed the average flight cost because under flight sharing, NASA will receive the full price of a flight when 75 percent of the capacity is used. NASA officials believe that these excesses will, over the long run, compensate for the losses.

NASA's shared-flight cost computation could discourage users from taking advantage of the shuttle's increased weight and volume capability. Since the computation is based on the greater of payload length or weight, compared to the shuttle's capability, the more compact and lighter a payload is, the less a user will pay. Then, a potential user could continue to build light, compact satellites consistent with the state of the art rather than the heavier, bulkier types that NASA projected in its economic justification for STS would result in large savings in payload costs. (See pp. 58 and 59.)

Exceptional selection process

Another user charge policy provision gives certain users "with a program of great value to the U.S. public" a reduced flight price. This provision could result in NASA's absorbing part of the flight costs. NASA has complete control over deciding what constitutes a program of great value to the U.S. public but, as of December 1976, had not established selection criteria.

REIMBURSEMENT ACCOUNTING

NASA has not established accounting procedures for shuttle operations costs and reimbursements. However, material NASA provided to the Office of Management and Budget, to congressional committees, and to us indicates NASA plans to use part of the receipts from reimbursements to reduce its pro-rata share of the shuttle's operations cost. (See fig. 14.) This practice, which is inconsistent with the procedure established by the Office of Management and Budget that collections go into the general fund of the Treasury as miscellaneous receipts (Circular No. A-25), may result in the loss of congressional control over a portion of NASA's budget.

NASA officials told us that they had placed their priority on establishing the preliminary user charge policy and had not yet established the necessary implementing accounting policies and procedures. Accounting procedures should, in our opinion, be considered during the development of the user charge policy to assure control over the resources needed for shuttle operations.

TOTAL OPERATIONS COST RECOVERY

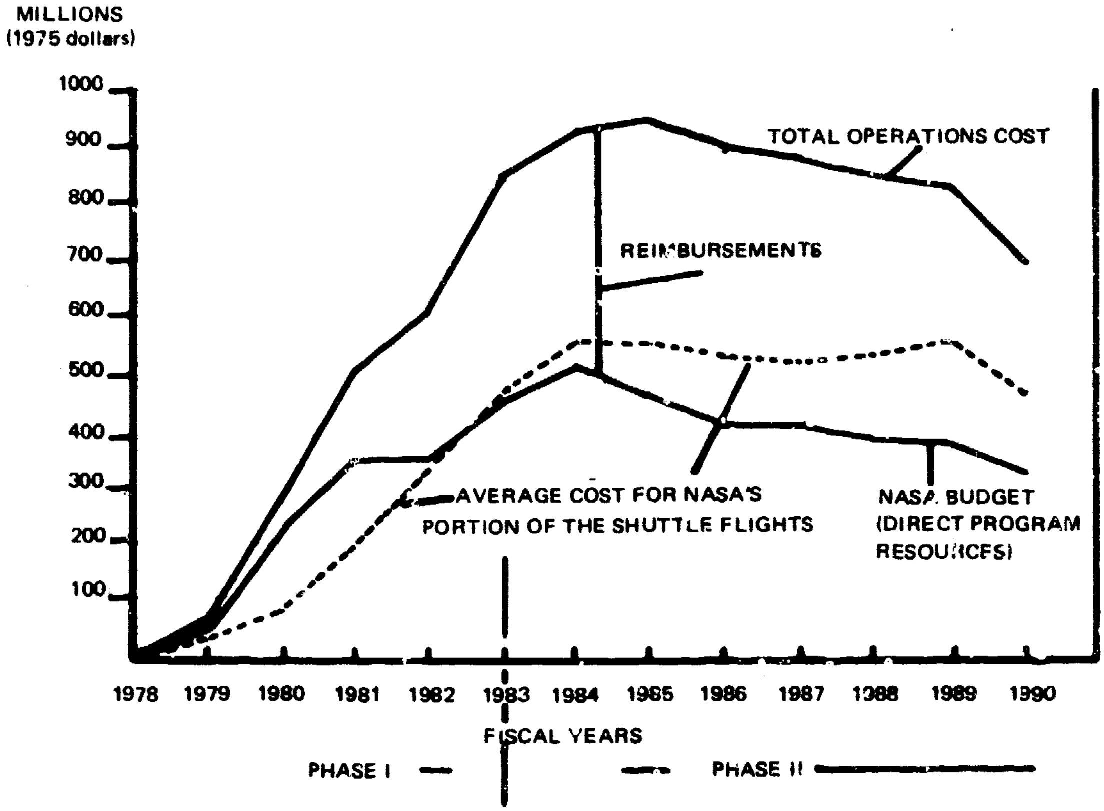


FIGURE 14

CONCLUSIONS

Sufficient information is not available to establish or evaluate user charge policies for STS. The policy should be evaluated on the basis of its merit in equitably distributing all costs to users. As of December 1976, NASA's operating costs and the proposed user charge policy were preliminary and were applicable only to a portion of STS. Neither cost estimates nor policies had been proposed for optional space shuttle services or other STS elements, such as upper stages and the spacelab.

The principles underlying NASA's policies raise serious questions as to whether total operations cost will ever be recovered. Additionally, NASA has not established accounting procedures for shuttle operations cost and reimbursements.

RECOMMENDATION TO THE NASA ADMINISTRATOR

We recommend that the NASA Administrator delay implementing a user charge policy until costs and policies for all elements of STS have been formulated.

AGENCY COMMENTS

NASA believes an STS pricing policy is required now to facilitate contracting with planned users. DOD believes a policy is needed now to allow timely budgeting for the cost of shuttle launches. In our opinion, however, NASA should not lock itself into a fixed price for the first 3 years of shuttle operation. NASA is using estimated average costs rather than actual costs to establish a dedicated flight price. Since NASA expects to recover the early-year deficits during later operating years, users might be unwilling to use the shuttle because of price increases later on.

CHAPTER 7

SHOULD PRODUCTION BE INITIATED?

NASA's fiscal year 1978 budget proposal contains $141.7 million to initiate refurbishment of the development orbiters and production of three additional orbiters in preparation for a full-scale operational STS. This chapter examines the major issues which the Congress should consider in deciding whether to initiate the production program at this time. No attempt is made to draw a conclusion on the more basic issue of how many orbiters are needed to support the space transportation requirements of the Nation through the 1980s, although the reasonableness of NASA's proposed five orbiter fleet is considered since it relates to the decision to initiate production during fiscal year 1978.

In our opinion, the primary issues which should be considered in deciding whether to initiate or delay production of three orbiters are:

--Space transportation requirements for the 1980s.

--Economic implications.

--National security and international prestige implications.

SPACE TRANSPORTATION REQUIREMENTS

The decision to initiate orbiter production is largely dependent on the expected level of future space flight activity. Based on the shuttle's performance goals and NASA's mission duration assumptions, the two orbiters obtained from the development program will provide more than enough capacity to handle the number of payloads flown during the past 10 years. 1/ The need for additional orbiters therefore depends on whether space activity increases beyond the capability of these two orbiters during 1980 to 1992. The Office of Management and Budget Circular A-109 states that before initiating production of a major system, an agency should make sure that the system fulfills a mission need.

NASA's five-orbiter fleet is based on the assumption that the number of payloads will more than double during

---

1/NASA points out that with two launch sites, the development orbiters could only come close to handling the specific payloads flown over the last 10 years.

the 1980s (from approximately 40 payloads a year to over 90 a year). NASA officials believe the five orbiters, which are expected to meet this requirement even with 31 aborted missions and the loss of one orbiter, will provide an assured launch capability for all users and will allow most expendable launch vehicles to be phased out. DOD officials, based on NASA projections of STS traffic in the future, support the view that a five-orbiter fleet is required and believe the STS program should proceed as now planned by NASA.

The extent to which space flight activity will increase is largely dependent on the willingness of the Congress to fund new space projects and applications because approximately 80 percent of the projected payloads will be Government financed. In our opinion, the congressional decision on the desirability of increased space flight activity should be based on (1) the merit or justification of proposed space programs and (2) the likelihood of STS reducing space operations cost.

NASA personnel believe and have prepared a study which shows that a five-orbiter fleet is the most economical approach, assuming that a minimum of 300 flights are flown during 1980 to 1991. We have not had an opportunity to evaluate this study in detail; however, we believe it is not economical to buy unneeded capacity. In our view the decision to proceed with or delay production should consider future space transportation requirements.

Projected space applications

At the present time, no explicit formulation of national objectives in space has been made. NASA's payload projections represent possible activities and most of the specific payloads and programs to be flown have not been identified. Although NASA personnel acknowledge that their projections of payload requirements are uncertain, they believe they have made a reasonable assessment of shuttle traffic requirements. They stated that this traffic level was substantiated by compiling inputs on generic payloads from within NASA's own payload development organizations; other civil users, including U.S. Government, commercial, and foreign users; and the DOD. (See pp. 49, 51, and 52.)

We recognize the difficulty in accurately projecting specific requirements as much as 10 years in advance and acknowledge that NASA's projections could eventually materialize. However, in our opinion, spending large sums of money to purchase a space transportation capability greater than known needs should be based on more evidence than is presently available. A projection should be available showing not only the number of flights anticipated but also the individual payloads together with the specific justifications.

Reduced costs of space operations

A primary objective of STS is to reduce the cost of space operations. To the extent that it does, the number of payloads may increase because commercial, foreign, and U.S. Government users may be encouraged to use the savings to increase space research and exploration. The Congress may also be more inclined to fund the increased number of payloads if an increase in the overall level of spending on space science is not required. On the other hand, increased cost of operations may be met with less enthusiasm by the Congress, Government agencies, and non-Government users.

Reductions in operating costs are expected from transportation and payload savings. However, there is concern that STS may not reduce the cost of space operations, at least not to the extent projected in NASA's economic justification. For example, several studies indicate that DOD's cost of acquisition and operations of an STS capability would be greater than continued use of expendable vehicles for the 1980 to 1991 period. As previously stated, NASA projects it will require a moderately increasing budget in order to fund its payloads projected for the 1980 to 1991 period.

NASA's position that the recurring transportation cost of STS will be less than expendable vehicles is difficult to substantiate because of numerous assumptions--such as the shuttle's reusability, high usage, and flight sharing capability--used to calculate the savings. As shown on pages 45 to 48, the recurring cost of STS will be higher than some expendable launch v hicles and there is reason to believe STS costs would increase. The recurring costs of STS cannot be determined with any degree of certainty without some operating experience.

Payload savings, which account for the bulk of savings in NASA's economic analyses of 1971 and 1973, are expected because the shuttle's capability to return heavier, bulkier payloads would allow cost saving techniques, such as modular design, less sophisticated components, and more rugged hardware. Payload refurbishment and reuse accounted for 75 percent of the savings, but evidence indicates that extensive use of these techniques is unlikely during the 1980s.

Although NASA and DOD, the major users, plan some recovery and reuse, Battelle surveyed potential non-Government users and found they do not believe these techniques will be widely used during this period. These users believed the demonstrated reliability of current satellites is quite satisfactory and the return of a 7- or 10-year-old satellite having antiquated technology would not be particularly useful. In addition, many satellites, such as those in geostationary orbits, cannot be reached by the orbiter, and its limited ability to maneuver in space may not allow satellites to be routinely and economically recovered.

The ability to transport heavier, bulkier payloads may not reduce operations costs. In 1973 the Federation of American Scientists stated that, while savings are possible, low-cost design is inconsistent with the trend in the American aerospace industry which emphasized high reliability, microminiaturization, and ruggedness. The Battelle survey found little indication that the shuttle's payload capacity is having any "serious impact on satellite design or planning." Furthermore, NASA's proposed user charge policy for flight sharing may encourage the continued design of compact, lightweight satellites because NASA bases charges on weight or length, whichever is greater.

ECONOMIC IMPLICATIONS

Another important consideration in the decision to initiate or delay production concerns the cost of each alternative. Unfortunately there is no way to predict with absolute assurance which approach will be the cheaper. Our reviews of major acquisitions have shown that it is generally less expensive to delay production until there is adequate assurance that a system will fulfill its intended role and perform effectively in its intended environment. As a result, the General Accounting Office, the Commission on Government Procurement, and the Office of Management and Budget have taken the position that the production of a major acquisition should be delayed until system performance has been satisfactorily tested and evaluated under expected operational conditions. The Office of Management and Budget position is set forth in Circular A-109, dated April 5, 1976.

NASA has not yet completed testing of all the space shuttle elements in their expected operational environment because (1) major hardware is just becoming available for testing and (2) cost and schedule constraints have resulted in the deletion, reduction in scope, or postponement of many development tests until the flight-test program or later. The flight-test program, scheduled to begin in March 1979, will be the first opportunity to test STS in an actual operational environment. Thus a decision to proceed with production prior to the flight-test program would be made without assurance that STS will perform effectively.

NASA has taken the position that Circular A-109, which advocates a "fly-before-buy" concept, does not apply to STS because the shuttle program is a single integrated entity, not a typical production program preceded by a research and development phase. Additionally, NASA points out that production has been initiated on all previous manned space vehicles before the first flight and the approach has been successful and cost effective. However, the space shuttle is being developed under a different management philosophy. In order of priority, cost has become one of the most important management concerns and as a result, test programs have been curtailed. Previous NASA programs contained more extensive and timely testing, and other management factors, including mission accomplishment, had priority over cost.

Although the Office of Management and Budget has included some money for production in the President's fiscal year 1978 budget, its circular is specifically applicable to "one-of-a-kind" space programs, with exceptions allowed when the fly-before-buy concept is physically or financially impractical. Regardless of whether Circular A-109 is applicable, the space shuttle does have two procurement phases--development and production. Any major technical problems encountered after production will increase the cost of the program because all five orbiters may require modification.

To aid in the congressional decision process, NASA personnel have estimated the potential cost of a 3-year delay, assuming that (1) no major technical problems are eventually identified, (2) STS recurring transportation costs will be less than expendable launch vehicles, and (3) the payload cost saving techniques--such as recovery and reuse--will be extensively used during the early 1980s. NASA's estimates show that under these circumstances the additional cost would be $4 billion to $5.6 billion (1978 dollars) primarily composed of

--$0.2 billion for development,

--$0.2 billion for production of the three production orbiters,

--$2.6 billion to $3.6 billion for space transportation operations, and

--$0.8 billion to $1.3 billion for payloads.

Although we agree that some increased cost would be encountered if all of NASA's assumptions are valid, we believe it would not be as high as $4 billion to $5.6 billion (1978 dollars). For example, the $5.6 billion (1978 dollars) is based on the currently planned production cycle of 60 months. We believe it is reasonable to assume the more economical 48-month production program would be followed if production is delayed. This would reduce the potential cost increase to $4 billion (1978 dollars).

The $2.6 billion (1978 dollars) operations cost penalty, which results from the use of more expendable vehicles than with five orbiters, includes over $1 billion (1978 dollars) that will be borne by commercial and foreign users. This amount would not be a direct cost to the American taxpayer. Furthermore, the cost increase assumes the two development orbiters would be underused. Three examples of inefficiency in NASA's flight profile are as follows:

--Two space shuttle flights, rather than three, would be flown during the first 6 months of shuttle operations. The third flight would be replaced by three expendable launch vehicles. However, one space shuttle would be capable of being launched at least once every month.

--Two expendable vehicles and the space shuttle would be used to fly three payloads which were previously planned for one space shuttle flight.

--No DOD payloads would be flown although there is sufficient capacity to fly some of them.

Significantly more flights could be flown on the two orbiters than NASA projects, particularly if about $100 million were invested in additional launch facilities and external tank production facilities.

The $0.8 billion (1978 dollars) increase in payload cost is projected by NASA because the numerous cost savings techniques--such as on-orbit servicing, retrieval, and refurbishment--will not materialize as soon as currently estimated. The question as to whether these techniques will be used and to what extent is discussed on pages 23 to 29. If extensive use of these techniques does not materialize, a production delay will have little if any effect on payload costs.

Aside from the question of increased cost of a delay, NASA officials believe that it is not reasonable to risk the Nation's investment, which will amount to about $7.9 billion (1978 dollars) through completion of the development orbiters, when only an additional $1.8 billion (1978 dollars) is needed for the remaining three orbiters and facilities. They believe a delay would risk the investment because users would not change over to the space shuttle without the assurance that five orbiters would be available to provide reliable transportation. They consider the $1.8 billion a prudent investment under these circumstances.

We believe this rationale should not influence the decision to delay or initiate production. A delay should not affect the investment one way or the other. NASA will be the major user of the space shuttle and is planning to shift its payloads to the space shuttle. Further, NASA and DOD planned to maintain expendable launch vehicles during the transition years, and all users are being encouraged to design payloads to be interchangeable between the shuttle and expendables. Additionally, the investment required for production orbiters and facilities is greater than the $1.8 billion (1978 dollars). The $1.8 billion (1978 dollars) equates to $2.2 billion in real year dollars and increases to $3.4 billion when Vandenberg Air Force Base facilities are considered. Furthermore, most of the estimated $42 billion (1978 dollars) for payloads and $18 billion (1978 dollars) for operations must be funded by the Congress.

NATIONAL SECURITY AND INTERNATIONAL PRESTIGE

NASA officials believe five orbiters are required to (1) assure a launch capability for national defense purposes and (2) establish a future space capability for an extended period so this Nation can maintain its leadership in space technology. NASA officials state that with STS the Nation can gain significant scientific and national defense benefits, as well as important international prestige, by greatly expanding its exploitation of space. We believe that these considerations do not significantly affect the decision to initiate or delay orbiter procurement during fiscal year 1978.

Although DOD plans to use the space shuttle as its primary launch vehicle during the 1980s, NASA officials believe that DOD will not commit itself to the shuttle until sufficient capacity exists to assure a launch capability. DOD must be assured that the shuttle is a workable system before national security programs will depend on the shuttle for space transportation. However, for certain programs, DOD plans to maintain expendable launch vehicles as a backup system even after its payloads are shifted to the space shuttle. Therefore a production delay would not risk national security since some form of space transportation would be available.

According to NASA, the manned reusable shuttle and its associated technology will permit the Nation to gain significant and important international prestige by greatly expanding the exploitation of space. At present, however, NASA's emphasis is on developing and acquiring shuttle hardware. Research and development resources will be shifted to science and applications research after the shuttle becomes operational. If orbiter production is delayed, resources could be applied to science and applications earlier, so the United States may gain international prestige by productively utilizing the space shuttle as soon as possible and not fall behind in space technology.

CONCLUSIONS

The decision to proceed with or delay production of the three orbiters is complex with little assurance that either option selected will ultimately prove to be the best decision. NASA officials believe the best approach is to proceed with production at this time. There is little doubt that production should proceed if no technical problems are encountered, space activity increases twofold as predicted, and operations costs are significantly reduced over expendable vehicles. Under these conditions, a delay in production would increase costs, although not to the extent projected by NASA.

On the other hand, there are no assurances that technical problems will not be encountered, that space activity will increase twofold, or that STS will significantly reduce the cost of space operations. Information presented in preceding sections of this report suggests that these three prerequisites for proceeding with production may not be met. Additionally, the most cost-effective approach is usually to delay production until there is adequate assurance that the system will accomplish its objectives.

The issue for congressional decision is whether a delay in production and thus a delay in achieving a more extensive manned program than two flights a month would adversely affect national prestige. If so, the Congress may wish to proceed with the production of the remaining three orbiters. However, there is another alternative which might offer some advantages over either delaying or proceeding with full-scale production. Production of the third orbiter could be initiated and the remaining two delayed until there are more adequate assurances regarding technical problems, space flight activity, and the cost of operations. This approach might:

--Minimize the amount of cost growth in the event of technical problems because only one additional orbiter would have to be modified.

--Minimize the amount of increased cost by delaying production if there are no technical problems because only two orbiters would remain to be produced.

--Allow at least three manned space flights each month which would enable the Nation to expand its exploitation of space and take advantage of operations cost savings if they materialize. At the same time, sufficient orbiters would be available to provide for the contingency of attrition.

--Provide for considerable international prestige since a fairly extensive manned system would be operational.

RECOMMENDATIONS TO THE CONGRESS

Until there is sufficient confidence in the shuttle development program and more information is available on STS operations cost and plans for future space activity, the Congress should assess the advantages and disadvantages of

--initiating the production of a third orbiter and

--delaying funding of the remaining two orbiters.

APPENDIX I

NASA

National Aeronautics and
Space Administration

Washington D C
20546

Office of the Administrator

APR 6 1977

Honorable Elmer B. Staats
Comptroller General of the
United States
General Accounting Office
Washington, DC 20548

Dear Mr. Staats:

I appreciate the opportunity to comment on the GAO's report on the National Space Transportation System (Space Shuttle). We have worked closely with your staff over the past months, and while most of our comments and positions have been incorporated in the report, I find myself in disagreement on matters of basic judgment. If the report is to be published in its present form, I request that this letter be included immediately after the Digest.

This report focuses on a recommendation that the Congress consider "the advantages and disadvantages" of deferring procurement of two or three of the five orbiters required for the National Space Transportation System. The report cites three prerequisites for proceeding: technical status, increase in space activity, and cost effectiveness. It either explicitly or implicitly states that none of the three are met, in effect, suggesting a decision to delay. In my judgment, all three prerequisites are in hand. and delay should not be considered.

The Shuttle has encountered the normal technical problems of a complex program. It has not encountered any unduly difficult problems, and I seriously question a judgment that "there are no assurances that technical problems will not be encountered" as a basis for delay. In my judgment, there will be technical problems--and they will be resolved, as they have been in all our prior programs. NASA's experience in four previous successful manned spacecraft programs has clearly demonstrated sound technical judgments in proceeding with follow-on procurements substantially in advance of the point that a system could be considered "proven."

The report's second prerequisite for proceeding is that space activity increase "two-fold." The Shuttle system itself is designed to facilitate an increase, which will be a natural evolution of increased use to meet DOD needs, for science, and for commercial applications. Our studies clearly show that a five orbiter fleet is the most cost effective means of carrying out space programs at activity levels ranging from an average of 25 to 60 Shuttle missions per year. Twenty-five Shuttle flights are the approximate equivalent of last year's national expendable launch rate of 39 payloads. "Waiting" for the Shuttle could become an impediment rather than a spur to progress.

The third prerequisite cited is that STS significantly reduce operations costs. Cost effectiveness was a central feature in the initial approval for the Shuttle, and remains so. On a payload cost basis, the Shuttle is the most economical Space Transportation System. Delay would only increase costs and tend to make the report a self-fulfilling prophecy. The surest way to make the Shuttle truly cost effective is to proceed without delay to realize the advantages it offers.

As further support for argument to delay, the report cites GAO experience with major acquisitions that "usually the most cost effective approach would be to delay production until there is adequate assurance that STS will accomplish its objective." Such delay is, perhaps, cost effective where a program involves a few research vehicles followed by long production runs. In the case of the Shuttle, the two initial vehicles represent 80% of the cost of the program and 40% of the total number of vehicles. There are only three additional vehicles whose costs are only 20% of the NASA program. If they are procured while tooling and assembly lines are in place, they unquestionably can be procured at far less cost than would be incurred by delay. Our estimates of total additional costs to the taxpayer, including those attributable to factors such as failure to realize savings by discarding costly expendable launch vehicles, are on the order of 3 to 4.5 billion dollars for a three-year delay. An additional cost penalty in excess of one billion dollars will be borne by non-government users.

As I have discussed, I find that I am in fundamental disagreement with the judgments in the report. The prerequisites for proceeding, as identified in the report, are well in hand and I recommend proceeding without delay. It is my considered judgment that the national interest will be best served by committing now to the procurement of a five-orbiter fleet, and that the eventual size of the national space program and the individual budgets of the several user agencies will in no way be predetermined by this decision. A five-orbiter fleet provides a cost effective launch posture even at the levels of space activity of last year; it also provides the additional capability to support future national aspirations in space.

Sincerely,

James C. Fletcher
Administrator

DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
WASHINGTON, D C 20301

30 MAR 1977

Mr. R. W. Gutmann, Director
Procurement and Systems Acquisition Division
United States General Accounting Office
Washington, D. C. 20548

Dear Mr. Gutmann:

This is in response to your letter to the Secretary of Defense dated February 17, 1977 requesting comments on your report "Space Transportation System: Past, Present, Future," Code 952139. (OSD Case #4553)

The Department of Defense does not agree with the main thrust of this General Accounting Office report

[See GAO note 1, p. 73.]

and that the need for additional orbiters has not been determined. The DOD believes that the STS program should proceed into the operational phase at a reasonable pace as now planned by NASA. The DOD also supports the view that a five orbiter fleet is required to meet national needs based on NASA projections of STS traffic in the future.

[See GAO note 1, p. 73.]

The DOD program to use the STS to launch all of our military payloads is carefully keyed to the STS development program milestones and progress. Our planning to make early effective use of the STS is consistent with technical, schedule, and cost constraints and is predicated on the availability of an adequate orbiter fleet.

[See GAO note 1, p. 73.]

[See GAO note 1, p. 73.]

On page vi, the report recommends that a user charge policy not be formalized at this time

[See GAO note 1, p. 73.]

The DoD believes that definition of a user charge policy is necessary at this time to allow programs to budget for their space launches in a timely manner. Further, the user charge must establish a firm reasonable price during the early years of Shuttle operation in order to encourage user programs to move from launch on current boosters to the Shuttle. Attempting to recover all costs during each of the first few years of Shuttle operation would certainly increase early-year user costs and discourage Shuttle use.

Detailed comments pertaining to various chapters in the report are attached.

Sincerely,

R. N. Parker
Acting Director

Attachment

Detailed Comments on GAO Report, "Space Transportation System: Past, Present, Future," Code 952139

Page ii, Line 4 - The increased VAFB facilities funding is based on potential program changes not yet baselined or programmed. This should be removed or revised to match the present program baseline.

VAFB "FACILITIES"

Page 6, Line 17 - The current DOD real-year dollar estimate for VAFB "facilities" is $849M through FY 1983. This is the program baseline today, which does not include a second launch pad or deep-water harbor at the Vandenberg coastline. USAF assumes that the term "facilities" used by GAO includes military construction, equipment, and activation costs.

Page 6, Line 18 - IUS Development - The GAO figures appear to include certain development tasks, such as development of auxiliary support equipment relating to IUS, more appropriately included in total program funding.

Page 28, Line 17 - All orbits required for DOD missions can be reached by the STS program.

Page 32, Line 9 - However, DOD has a number of new studies now in work regarding exploitation of the STS capabilities. New payload programs are planning now to take advantage of the increased weight and payload made possible by the Shuttle.

The need to add increased survivability capabilities to satellites alone will require significant weight increases. The increased survivability of space systems has been identified as an important new requirement.

[See GAO note 1, p. 73.]

Page 40, Line 17 - All DOD satellites launched on the Shuttle from KSC will require an upper stage to achieve final orbital altitude. While it is true that the IUS launched on the Shuttle from KSC can deliver 4000 lbs. of payload to a 900 nautical mile polar orbit without unacceptable overflight of populated areas, this may be an inefficient way to use the Shuttle. Shuttle launch and landing facilities are required at Vandenberg Air Force Base to launch heavy, high priority DOD payloads and NASA Spacelabs. These heavy payloads cannot be launched from KSC into polar orbits without unacceptable land overflight. Even with the IUS the Shuttle simply does no have the capability. Once Van enberg is in operation it will be more efficient to conduct all polar launches from Vandenberg. For polar payloads from Vandenberg requiring higher altitudes than the Shuttle provides, a small perigee kick stage or spinning solid stage can be used and the payloads flown on a space available basis as secondary payloads.

[See GAO note 1, p. 73.]

Page 65, Line 33 - The latest DOD projections for military space missions take into account the continuously im oving mean mission duration available as DOD satellite reliability improves. The existing DOD Space Miss a Model was largely based on expendable launch vehicle performance only, but draft revisions are now beginning to reflect new programs compatible with STS launches. The transition of some older programs to STS is already firmly funded (i.e., DSCS III) for certain payload programs, and new payload programs will be added.

Page 70, Line 2 - DOD considers sufficient evidence is available to establish user charge agreements for the STS program.

[See GAO note 1, p. 73.]

Page 79, Line 18 - Some flights planned from Vandenberg AFB could be performed from Kennedy Space Center, but not all. Certainly, the large, heavy payloads flown to low altitudes from VAFB cannot be accomplished by the Shuttle/IUS combination from Kennedy (KSC).

[See GAO note 1, p. 73.]

Page 82, Line 20 - DOD does not agree with the GAO recommendations. A joint-agency study completed late in 1976 reconfirmed the STS program baseline. This study, performed at the request of the Office of Management and Budget (OMB) completely concurred with the following results:

a. Five orbiters are needed to meet national fleet requirements.

b. Production funds for orbiters three, four and five should be included in the NASA FY 1978 President's Budget Submittal.

c. The NASA-developed Space Shuttle and DOD-developed Interim Upper Stage offer significant performance increases over existing space boosters.

DOD projections of the OMB study data show it is no more expensive for DOD to transition to the STS and close down expendable launch vehicle operations than it would be to remain on expendable launch vehicles and be forced to accept the limited space capabilities they provide.

GAO notes:

1. The deleted comments relate to matters which were discussed in the draft report but omitted from this final report.

2. Page number references in this appendix may not correspond to pages of this report.

PREVIOUS GAO

SPACE TRANSPORTATION SYSTEM REPORTS

June 2, 1972	Cost Benefit Analysis Used in Support of the Space Shuttle Program B-173677
June 1, 1973	Analysis of Cost Estimates for the Shuttle and Two Alternate Programs B-173677
June 1974	Space Transportation System Staff Study
February 1975	Space Transportation System Staff Study
April 21, 1976	Status and Issues Relating to the Space Transportation System PSAD-76-73

PRINCIPAL OFFICIALS RESPONSIBLE FOR ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of office From	To
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION		
ADMINISTRATOR:		
Alan M. Lovelace (acting)	May 1977	Present
James C. Fletcher	Apr. 1971	May 1977
George M. Low (acting)	Sept. 1970	Apr. 1971
Thomas O. Paine	Apr. 1969	Sept. 1970
DEPARTMENT OF DEFENSE		
SECRETARY OF DEFENSE:		
Harold Brown	Jan. 1977	Present
Donald H. Rumsfeld	Nov. 1975	Jan. 1977
James R. Schlesinger	June 1973	Nov. 1975
William P. Clements (acting)	May 1973	June 1973
Elliot L. Richardson	Jan. 1973	Apr. 1973
Melvin R. Laird	Jan. 1969	Jan. 1973
DEPARTMENT OF THE AIR FORCE		
SECRETARY OF THE AIR FORCE:		
John C. Stetson	Apr. 1977	Present
Thomas C. Reed	Jan. 1976	Apr. 1977
James W. Plummer (acting)	Nov. 1975	Dec. 1975
John L. McLucas	July 1973	Nov. 1975
John L. McLucas (acting)	May 1973	July 1973
Dr. Robert C. Seamans, Jr.	Feb. 1969	May 1973