Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization (1986)

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Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization

Prepared by a Panel Convened by the

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Commission on Engineering and Technical Systems
National Research Council

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Members of the Panel

EDWARD E. DAVID, JR., President, EED, Inc., Bedminster, New Jersey, Chairman
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HERBERT FRIEDMAN, Retired Chief Scientist, E.O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D.C.
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EUGENE E. COVERT, Professor of Aeronautics, Massachusetts Institute of Technology, Cambridge, Massachusetts, Ex Officio Member

ROBERT H. KORKEGI, Study Director
JoANN C. CLAYTON, Assistant Study Director
ANNA L. FARRAR, Administrative Assistant

Preface

The Committee on NASA Scientific and Technological Program Reviews was created by the National Research Council in June 1981 as a result of a request by the Congress of the United States to the National Aeronautics and Space Administration that it establish an ongoing relationship with the National Academy of Sciences and the National Academy of Engineering for the purpose of providing an independent, objective review of the scientific and technological merits of NASA programs whenever the Congressional Committees on Appropriations so direct.[1]

To date five tasks have been undertaken.[2-6] The sixth task, which is the subject of this report, resulted from a request by the House Committee on Appropriations to the NASA Administrator in late April 1986 for an examination of space shuttle flight rates and utilization following the loss of the Orbiter Challenger (Appendix A).

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[1]Congressional Conference Report 96-1476, November 21, 1980.

[2]National Research Council, The International Solar Polar Mission--A Review and Assessment of Options, 1981, National Academy Press, Washington, D.C.

[3]National Research Council, Aeronautics Research and Technology--A Review of Proposed Reductions in the FY 1983 NASA Program, 1982, National Academy Press, Washington, D.C.

[4]National Research Council, Assessment of Constraints on Space Shuttle Launch Rates, 1983, National Academy Press, Washington, D.C.

[5]National Research Council, Review of NASA's Numerical Aerodynamic Simulation Program, 1984, National Academy Press, Washington, D.C.

[6]National Research Council, Assessment of Candidate Expendable Launch Vehicles for Large Payloads, 1984, National Academy Press, Washington, D.C.

At its meeting on May 16, 1986, the Committee nominated a panel to undertake the task. The areas of expertise sought included launch vehicle systems, airline operations, propulsion systems, aerospace logistics, and user requirements--space station, military, space science and applications, and commercial.

In appointing such a group of individuals to make scientific and technical assessments, it is essential that most have a high degree of knowledge in the subject of the study. Since such individuals may appear to have a potential for bias, every effort was made to achieve a balance in backgrounds and attitudes of the panelists in order to present as objective a report as possible.

The short period during which the review had to be undertaken put severe demands on the Chairman and members of the panel, who deserve much credit for their effective and timely response.

Norman Hackerman
Chairman, Committee on NASA
Scientific and Technological
Program Reviews

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Introduction

Background

The space shuttle had 24 successful flights beginning with the Orbiter Columbia in 1981 until the Challenger accident on January 28, 1986. The Challenger loss caused a general reassessment of the space shuttle program.

The Presidential Commission on the Space Shuttle Challenger Accident in its report made several recommendations that included a redesign of the Solid Rocket Motor, a review of critical items in shuttle components, and several aspects of safety. NASA formed a large number of in-house and contractor teams to review technical, operational, and management aspects of the space shuttle program.

After an anticipated resumption of space shuttle flights in July 1987, NASA later announced a postponement of the launch target date to the first quarter of 1988.

The Air Force announced that it would not be using its Vandenberg Launch Site for the space shuttle before 1992. Furthermore, it presently has a program for production and development of expendable launch vehicles with orders for 23 Titan IVs (formerly known as Titan 34D7s) and plans for medium launch vehicles (MLVs).

On August 15, 1986, President Reagan announced that a fourth Orbiter would be built to replace Challenger and that the space shuttle would no longer be used to launch commercial payloads.

The present study is in response to a Congressional request in the aftermath of the Challenger accident, for an assessment of possible space shuttle flight rates and their implications in respect to payloads and the need for expendable launch vehicles.

Approach of the Study Panel

The ad hoc panel met on July 21-22 and August 11-12, 1986, at the National Academy of Sciences in Washington, D.C. In addition, 2 panel members visited the Johnson Space Center (JSC) and 3 visited the Kennedy Space Center (KSC) in connection with information presented to the entire panel. Members also met with Admiral Richard H. Truly, Associate Administrator for Space Flight, at NASA Headquarters.

During the meetings, briefings were presented by NASA personnel from the Office of Space Flight and the Office of the Space Station, JSC, the Marshall Space Flight Center (MSFC), and KSC, as well as contractors from Martin Marietta External Tank Division, Rockwell International Corporation, Rocketdyne, the Lockheed Space Operations Company, Grumman, and Morton Thiokol. The panel held discussions with staff from the Office of Management and Budget and the Strategic Defense Initiative Office, as well as with representatives of the commercial communications satellite industry (Hughes Communications Company, RCA Astro-Electronics Company, and Ford Aerospace and Communications Corporation) and the launch vehicle industry (General Dynamics, Martin Marietta, and Arianespace). In addition, much written testimony was received as noted in Appendix G.

Since the study request, 2 events have occurred that affect assumptions: In July 1986, NASA announced there would be a delay of at least 24 months in resumption of shuttle flights, and on August 15, 1986, the President announced the intent to build a fourth Orbiter and to take NASA out of the business of launching private satellites, except under special circumstances. The panel took note of both of these announcements in preparing the following report.

This report states each of the requested assessments followed by the ad hoc panel response. In order to present its findings as clearly as possible, the panel opted to provide concise statements in the body of the report and more extensive background information and details in the appendixes. Subjects covered in greater depth in the appendixes include shuttle launch rates, launch utilization, logistics considerations, cost trade-offs, and the national commitment to a sustained manned spaceflight program.

The report builds upon the 1983 report of the Committee on NASA Scientific and Technological Program Reviews, the Assessment of Constraints on Space Shuttle Launch Rates, which analyzed the individual components determining flight rates.

This report assesses certain specific technical issues but neither endorses nor criticizes the general nature of NASA's programs.

Preamble

This report was requested following the Challenger loss and several months before the President's August 15, 1986, statement announcing intent to build a fourth space shuttle and to end NASA's launching of commercial satellites. The assessments requested in the letter of April 21, 1986, from Congressman Boland to the Administrator of NASA (Appendix A), in the opinion of the ad hoc panel, remain timely but with a few minor changes in assumptions. The 18-month standdown is replaced by a 24-month standdown. The assumption on shuttle launching of commercial satellite payloads is modified to reflect both the near-term shuttle program and manifest and the longer-term intent expressed in the President's statement.

Early in its deliberations, the ad hoc panel found that it had to make an assumption regarding whether the national intent was to have a sustained manned spaceflight program--one in which manned flight was a regular and continuing occurrence year in and year out--or to treat the shuttle fleet as a declining resource (like the Apollo), which in due course would, through use or accident, diminish to zero. It also had to decide whether the requested assessments should apply to the transition period between now and 1991 or to the period thereafter when both the shuttle and ELV fleets presumably would be available for launch.

The panel, considering the nature of the requested assessments, decided to assume a sustained manned flight program and to consider flight rates in both the post-1991 time frame and the build up before 1991. Discussions of these assumptions can be found in the appendixes.

It is the understanding of the panel that the purpose of the assessments is to estimate flight rates for a 3- or 4-Orbiter fleet. Both fleet sizes are therefore addressed without making any recommendation on which fleet size is preferable or needed. (It is clear, however, that the Space Station program has assumed the existence of a "robust shuttle fleet" of at least the 3- or 4-Orbiter size, from which its own flight rate demands would have to be satisfied.)

Congressman Boland's letter also asks for an examination of the assumptions behind the shuttle manifest for the foreseeable future. This matter raises the issue of expendable launch vehicle (ELV) availability--for ELVs are the alternative to shuttle launches. The

Air Force has recently procured a number of heavy-lift ELVs (Titan IVs) and is negotiating to begin production of a medium-lift ELV (MLV). The early production of these vehicles seems likely to be devoted to DoD payloads. Even were production lines for existing ELVs to be reactivated immediately, it would take several years for vehicles to become available. Thus, the availability of ELVs as a shuttle alternative for other than DoD payloads is likely to be severely limited until at least around 1990. NASA and commercial interests have yet to decide to procure ELVs. Thus, particularly in the coming interim period, NASA and commercial interests that have contracted for launch service will be depending on the shuttle as the most immediate launch capability, with corresponding pressure on its manifest.* For activities requiring the specialized use of people, the shuttle cannot be replaced by ELVs.

Before addressing the questions raised by the House Appropriations Committee, the panel will state certain fundamentals drawn from its members' association with research, development, operations, logistics, fleet maintenance, and space activities. These fundamentals must be recognized if shuttle flight rates and manifests are to be discussed without misunderstanding.

One fundamental is that in addressing flight rate, there is an essential distinction between capability and demand. Capability refers to the number of flights that can be mounted given the equipment, people, spare parts, and facilities available. Capability is thus the available supply of launch services. Demand, on the other hand, refers to the number and configuration of payloads to be launched. While this distinction is clear enough, there is often confusion since both capability and demand are discussed in terms of flight rates.

The panel will address the shuttle capability in terms of the sustainable flight rate. This is the rate of flights that can be sustained over a substantial period of time and after buildup from the cautious resumption of flight subsequent to the Challenger accident. This buildup will, of course, require some period of time, perhaps 2 years, before the sustainable rate can be reached.

For short periods of time, a launch rate in excess of that sustainable can be achieved with adequate planning, lead time, and a minimum of changes. The panel will refer to this as the surge rate, recognizing that it places severe stresses on people and facilities. It cannot be sustained for longer than a brief period, approximately 4 months.

The shuttle fleet concept is also fundamental. The fleet Orbiter inventory is the number of Orbiters on hand at any given time; today it is 3. The number of schedulable Orbiters is fewer than the inventory because of a number of fundamental factors, some common with

*The statement by the President, dated August 15, 1986, precludes continuing launch of commercial satellites by space shuttle. It appears at this time that certain contracted commitments will be honored.

fleets of other flight vehicles such as those operated by the Air Force and commercial airlines (e.g., age of hardware, availability of spares, damage, normal wear). The panel's experience suggests that the schedulable Orbiter fleet is smaller than the inventory by almost one Orbiter. Thus today, the schedulable fleet is only a bit in excess of 2. Therefore, the Orbiter fleet flight rate in the remainder of this report will be calculated on that basis. The reasons for this discounting of the Orbiter inventory arise from essential scheduled maintenance of the flight articles and the possibility of damage or needed modifications to an Orbiter that would keep it or the whole fleet out of service for a significant period.

Reliable, sustainable flight rates hinge upon other factors as well. Underfunded logistics has been a recognized problem for the shuttle program in the past. Today there is still not an adequate complement of spares on hand. This has necessitated cannibalization to keep the fleet flying and has lengthened the turnaround interval for individual Orbiters. In this report the panel attempted to estimate sustainable flight rates based on certain conditions, e.g., adequate spares, logistics, and all the facilities needed for turnaround and training. These conditions will not be necessarily satisfied under programs now in place at NASA. If they are not, a further decrease of sustainable flight rates would be in order.

Another fundamental concern is the industrial base for the manufacture of Orbiters. Because there is a sufficient probability of an Orbiter-involved accident over the operational lifetime of the Orbiter fleet, the capability to produce and repair Orbiters should be maintained. Without it, there will be no viable shuttle fleet. With a small number of flight articles, such as the inventory of Orbiters, no management can sustain a reliable flight schedule since contingencies and new requirements will surely arise from unanticipated events. In other words, the partial equivalent of a contingency Orbiter (one available within a time period that would not seriously disrupt schedules, perhaps 2 years at maximum) should be in the construction process. This is consistent with the President's declaration for a fourth Orbiter and with the panel's judgment that over a period of years (15-20) there must be replacements available because of possible Orbiter wearout (there are no reliable statistics at present on Orbiter life)* or irreparable damage in an accident.

There have been suggestions that a new-technology reusable launch vehicle is in prospect for the 1990-2000 time frame. Even then, any such vehicle is likely to be shuttlelike. Barring an unforeseen, new, space initiative, the panel believes that the shuttle fleet, with improvements, will be required until at least the year 2000 and probably well beyond if the United States is to have a sustained manned space program.

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*Regarding wearout, it is well to note that the Orbiter is stressed near its design limits each time it is launched and returns to Earth. An ordinary airliner is rarely, if ever, so stressed.

On the demand side of shuttle launches, the situation is quite fluid. An important point is that the payload backlog from today's extended launch standdown is not as large as it may appear to be. Many payloads now listed will not be launched at all since they will have missed a window of opportunity. Lack of reliable launch schedules and available insurance for payloads will depress not only future demand, but also the backlog. Just how large this effect will be is difficult to judge. The principal point is that supply and demand will always tend to come into balance.

As launches using shuttles resume, there will be a buildup phase before reaching a sustainable flight rate. This report comments on both phases, but does not attempt to evaluate in detail the buildup operations. However, it is evident that a period of caution will be prudent regardless of the apparent demand for launches and the unavailability of ELVs. Present NASA planning appears to reflect this philosophy.

Post-Challenger Assessment of Space Shuttle Flight Rates and Utilization

The following 4 assessments were requested by Congressman Edward P. Boland in a letter dated April 21, 1986, to NASA Acting Administrator William E. Graham. The request for information is stated, followed by the response of the ad hoc study panel.

ASSESSMENT ONE

> An assessment of the possible flight rate assuming a baseline of an 18-month delay in shuttle operations. The analysis should be based on the assumed flight rate and manifest most recently promulgated by NASA.

Note: Subsequent to the request for this report, NASA announced that the delay would be 24 months from the time of the Challenger accident, and the following responses are based upon that estimate.

Utilizing the current 3-Orbiter inventory, NASA can sustain a flight rate--following a transition phase of approximately 2 years after resumption of shuttle operations--of 8-10 flights per year (Appendix B) from the KSC* under the following conditions:

- o no Orbiter is lost or rendered inoperable,
- o sufficient logistic support is available to meet the scheduled manifest with reasonable confidence, and
- o structural or other system problems requiring substantial, recurring downtime do not occur.

With a 4-Orbiter fleet, the sustainable flight rate would be 11-13 per year; however, there are additional qualifications. The principal

*The U.S. Air Force announced that the Vandenberg Launch Site would not be used before 1992. Should it be used for DoD missions thereafter, the yearly flight rates for either 3- or 4-Orbiter fleets would be reduced by approximately one.

constraints to launch rates higher than 8-10 are limits on launch-processing facilities at KSC, limits on mission operations facilities and skilled personnel at JSC, additional time demanded by increased program review and oversight, yet-to-be-defined new safety rules, need for improvement in crew-training facilities, and necessary logistic support (Appendix C).

The importance of the logistics requirements needs emphasis: to sustain any shuttle flight rate with reasonable confidence requires an adequate inventory of spares, including line replaceable units (LRUs), shop replacement units (SRUs), and expendable parts.* Such items must be available on demand in the shuttle turnaround process. One other limitation should be mentioned: Columbia (OV 102) does not have the performance of the other Orbiters. Many of the Department of Defense (DoD) and NASA payloads require either Atlantis or Discovery, which is effectively a 2-Orbiter fleet for these payloads.

If structural or system problems do occur--contrary to our basic assumption--the sustained flight rate will diminish immediately. This lower rate cannot be calculated because it is dependent upon the particular mission scenario and the severity of the problem. If Orbiters were to require downtimes of several months every few years, outside of planned maintenance, the sustained flight rate for 3 Orbiters would be lower than the 8-10 range. For 4 Orbiters the rate would be lower than 11-13 per year.

Under special conditions, the 3-Orbiter flight rate might surge to approximately 12 per year for a limited period of time, if the major shuttle cargos have standard Payload Assist Module (PAM) or equivalent upper stages, are repeat missions with few flight plan changes, and are launched and landed at KSC. Any mix of other cargo or missions such as classified payloads, Vandenberg Air Force Base (VAFB) launches, Edwards Air Force Base landings, Spacelab flights, rendezvous, or first-of-a-kind missions will reduce the rate to less than 12. For a 4-Orbiter fleet the surge rate may reach 15 flights per year, with stringent operational limitations such as reasonably standard payloads and relatively short mission durations.

The most critical assumption in estimating flight rates is that no Orbiter will be lost or become inoperable for a significant time. The possibility of a loss or irreparable damage to an Orbiter cannot be discounted. In case of loss, the options are to replace the Orbiter or to reduce the flight rate proportionately and permanently. To preclude having a launch capability based on only 2 functional Orbiters for a period that would be at least 5 years, a replacement Orbiter will have to be on order by 1987 for delivery in the early 1990s. Procurement of a fourth Orbiter as announced by the President would fill this need until 1992. Beyond that, some continuing

*Line replaceable units are shuttle components that can be replaced on the line, e.g., on the launch pad. Shop replacement units are shuttle components that cannot be replaced on the line, but need to be sent back to the shop or the manufacturer.

production level to provide replacements will be required since an unutilized manufacturing base will vanish in a very short time.

While maintaining an efficient industrial base implies an order rate for new Orbiters higher than payload demand suggests (Appendix C), it is clear that an accommodation between production and requirements must be reached if replacement vehicles are to be had. The need for additional Orbiters may increase in the 1990s in response to Space Station and other demands, and thus may bring supply and demand into balance. Alternately, the industrial base may function at somewhat less than optimal conditions with spread out production rates. Further study of the maintenance of a viable industrial base is well warranted.

Some concern exists in 3 additional areas that the panel believes need further study: (1) the adequacy of simply upgrading existing training flight simulators when additional, more modern equipment may be required as well, (2) the repeated late addition of payloads to the manifest at the expense of maintaining schedules, and (3) the nature of the shuttle processing contract and the possible need for clearer contractor responsibilities vis-a-vis NASA in quality assurance, spares planning and acquisition, and design change demands on shuttle component designers and manufacturers for reliability and reduced turnaround costs. Until NASA establishes a complete operating organization or elects to contract the total function, these inconsistencies in responsibility will remain a problem.

ASSESSMENT TWO

> An assessment of the assumptions made in.... [partitioning] between payloads manifested on expendable launch vehicles and payloads manifested on the shuttle and whether such assumptions are reasonable.

The following assumptions regarding potential partitioning of payloads between ELVs and the shuttle were deduced by the panel, based upon NASA presentations. The panel did not receive any <u>explicit</u> baseline definitions regarding the partitioning.

It is understood that the manifest for the period from resumption of shuttle flights to approximately 3 years later will be determined on a case-by-case basis within classes of payloads (national security, NASA science and other, and commercial). A number of payloads originally scheduled for the shuttle could be launched by ELVs if these boosters were available; however, only the DoD is committed to build ELVs for this purpose. In the absence of firm shuttle or ELV manifests, the panel examined NASA assumptions regarding payload off-loading, commercial satellites, and availability of launch vehicles.

Payload Off-Loading

The DoD has made a major attempt to off-load free-flying payloads from the shuttle, for example, the Defense Meteorological Satellite Program (DMSP), Defense Support Program (DSP), MILSTAR, and certain classified payloads. Further, DoD may off-load certain additional satellites such as the Defense Satellite Communications System III (DSCS) and Global Positioning Satellites (GSP) replacements. Looking into the far future (mid-1990s), relatively few DoD free-flying payloads will require shuttle launch provided ELVs are available and operational. NASA estimates only 4 such shuttle-unique DoD payloads between resumption of flight and 1993. To this must be added SDI experiments (1 to 2 shuttle equivalents per year beginning in 1989) and potential SDI deployment later. The DoD seems well on its way to relieving its total dependence on the shuttle through ELV procurement.

NASA estimates that approximately 22 of its own payloads could be off-loaded between now and 1993 leaving approximately 110 for shuttle launch. The panel has no reason to doubt the validity of this partitioning. However, in the longer-term future, many payloads could be designed for ELV launch. Based upon the criticality of the Tracking, Data, and Relay Satellites (TDRS) in supporting other missions, NASA should seriously consider launching the TDRS by an appropriate ELV such as the Titan IV. Two TDRSs are presently contemplated for early shuttle launch.

In reference to the planned manifest, the panel notes that no action has been taken by NASA to procure ELVs for its payloads. Lack of funding is one cause for this inaction. Another is the apparent confusion of responsiblities between the space transportation charters of the Departments of Commerce and Transportation and NASA. Also NASA has not as yet stated a policy for partitioning its payloads between the shuttle and ELVs. It seems true that many people in the space science community* would prefer ELV launch because of past experience with shuttle uncertainties and costs. This preference is not yet being taken into account by NASA. It is important to note here that, as presently designed, the NASA Space Station alone could require 8-10 shuttle flights per year for deployment and support in the middle 1990s.

Commercial Satellites

The commercial satellite situation is confused by existing contractual commitments for launch by NASA. The assumption is that shuttle launches of commercial satellites with existing contracts will continue. It is hoped, but not yet planned, that significant numbers of ELVs will become available in the future for the commercial

*This is with the exception of scientists involved in some aspects of earth, life, and astronomical sciences and in space-processing research.

market. The competitors for the proposed DoD medium-lift launch vehicles (MLVs) have indicated these vehicles could be ready by early 1989; however it will be several years after that before new ELVs become available to users other than DoD. The primary requirement of commercial satellite users, in addition to a launch reliability of more than 93 percent (the approximate reliability of past ELVs), is availability of timely launch. Assuming availability, most commercial satellite suppliers and operators now express preference for ELVs. The panel believes that the assumption of availability is open to question. The economic viability of commercial launch suppliers may not be decided for many years because of the long transition period from total shuttle dependence to some combination of foreign and speculative domestic suppliers.

Also, the longer-term demand for commercial launches is nebulous at best. At the present, 44 commercial payloads are contracted for NASA launch; another 46 have made lesser commitments. Though many of these will fall by the wayside because of the delay and uncertainty, others will retain their reservation and lobby for shuttle launch if the contracted costs are maintainted. Still others will move to Ariane or other foreign launchers. However, demand will decline because of the difficulties: launch supply and demand will tend to come into balance. As contemplated today, approximately 15 commercial shuttle launches are anticipated between resumption of flight and 1993. To the panel, this rate of commercial utilization seems significantly too low if additional DoD and NASA off-loading to early ELVs becomes possible.

Availability of Launch Vehicles

It has been implicitly assumed that launch vehicle production (whether of shuttles or ELVs) could keep up with demand, regardless of the mix of shuttle and ELV launches. The matter of shuttle production and support was addressed earlier. ELV procurement is limited at present to DoD. Representatives from the launch vehicle industry indicate adequate numbers of ELVs for DoD, NASA, and commercial needs could become available, with present or slightly expanded production facilities within 3 to 4 years of orders. Thus ELV production capability does not seem to be a limit, at least in the long run, to future space activities. As for timing, ELVs for the military will be available within 3 years after the contracts are signed. However, because of DoD needs, and government budget limitations, it seems unlikely that ELVs could be available for commercial payloads before the early 1990s.* Arianespace representatives stated that Ariane is completely booked until after 1990 as well. Thus, there is a time gap of several years before a commercial launch capability could be

*It is noted that in September 1986 a commercial company contracted with Federal Express to launch a private payload in 1989.

available to meet the needs of commercial payloads, despite adequate production and launch facilities.

ASSESSMENT THREE

> An assessment of the impact on both flight rate and manifest of the existing 3-Orbiter fleet with no fourth Orbiter replacement. This assessment should include manifest requirements for both launch and operation of a Space Station. This assessment should also be based on the assumption that the shuttle will fly at least one-third of the average number of commercial satellites launched over the manifest period.

As stated in the the first assessment, the panel believes that a sustained flight rate of 8-10 per year for a 3-Orbiter inventory and 11-13 for 4 Orbiters can be maintained only under the conditions previously noted. Support of a Space Station requires a robust shuttle fleet, even were a new Space Station design to reduce launch requirements. The panel does not consider a 3-Orbiter fleet robust because of accident possibilities and other needs for downtime. Given the assumptions presented by the Space Station office, the entire 3-shuttle capability would be absorbed by this project, i.e. a need for 32 shuttle flights is projected for the initial 3-year construction phase. However, the construction and operation of the station is still under study and these estimates may be modified. Although some ELVs could be used for purely cargo flights, operating the Space Station adds another requirement, nearly the same weight must be returned from orbit as was originally launched to orbit in the operational phase, a requirement not met in ELV designs.

Estimates of the number of commercial satellites that will be shuttle-launched in the 1990s are difficult in today's uncertain launch and insurance environment. However, NASA has indicated that some 15 commercial launches will be available between resumption of flight and 1993. This is about one-third of the 44 contracted launches. Others beyond contracted payloads number 46. To launch one-third of all commercial payloads would require 30 launches. This number is not possible given the current situation. However, a resolute effort by the federal government to accelerate production, and procurement of ELVs would allow for more commercial launches in the period before potential privately supplied launches could become available. Clearly, there is a need to proceed with ELV procurement for NASA payloads and for fulfilling contractual obligations to commercial operators. Competitive pricing of ELV launches with shuttle and foreign suppliers should be a principal consideration.

ASSESSMENT FOUR

An estimate, based on available data, of the various cost trade-offs of the above assumptions.

Due to the many political, financial, and market variables in the immediate post-Challenger environment, it is not possible to make detailed cost trade-off analyses at this time. Nonetheless, one general statement can be made.

Total national space launch costs depend principally upon the size of the nation's space program. Perhaps surprisingly, the total launch costs are relatively independent of the particular mix between shuttles, Titan IVs, MLVs and Titan IIs (for example) for a given total weight to orbit in equivalent shuttle loads (Appendix E). In other words, policy decisions such as the long-term commitment to man's presence in space (Appendix F), the timing and cost of a Space Station, the nature of the SDI, and the robustness (spares on orbit and survivability) of national security space systems will have a greater effect on national launch costs than the shuttle/ELV mix.

Summary

POLICY ASSUMPTIONS

1. The United States will have a sustained manned space launch capability.
2. The present shuttle will have to assure that function at least until the turn of the century.
3. An ELV production commitment will be made to achieve a mixed fleet of launchers.

FLIGHT RATES

Three Orbiters can sustain a rate of 8 to 10 flights per year after an initial buildup period of approximately 2 years providing: (1) no Orbiter is lost or becomes inoperable, (2) adequate logistics support exists, and (3) no problems exist that require extensive downtime. A surge rate of 12 flights per year should be possible for short periods of time for simple payloads and flight plans.

With a 4-Orbiter fleet the sustainable flight rate would be 11-13 per year with a surge rate of 15 flights per year only if appropriate ground support facilities are acquired.

In order to sustain such rates and take account of possible contingencies, the shuttle scheduling should be based upon fewer vehicles than are actually in the inventory by almost one Orbiter.

FLEET CONCEPT

If the space shuttle is to serve manned launch requirements for an extended period of time, then it should be viewed in terms of a fleet in the same manner as other transportation systems and consideration must be given to vehicle attrition necessitating replacement Orbiters over time. This will necessitate a balance between production rates and replacement requirements.

LAUNCH DEMAND

With the temporary cessation of shuttle flights, it is expected that the backlog of manifested payloads will actually decrease as some previously scheduled satellites will not be flown and the DoD will off-load many payloads for launch on ELVs.

The heaviest launch demand arises for the Space Station--32 shuttle launches are anticipated during the 3-year construction phase--and, presuming schedules do not slip, this could not in itself be accommodated by 3 Orbiters. This situation is recognized by NASA study groups currently reexamining the configuration of the Station.

While many military payloads are slated for launch on the Titan IV and the MLV, there is not an ELV launch capability to accommodate the large number of space science or commercially contracted payloads. A resolute ELV procurement effort by NASA, or other civil government agency, is not yet in place but may be required to fulfill commercial contracts and NASA's space science program. Unless or until a commercial launch vehicle industry comes into existence, however, an extensive private launch industry is not likely to arise before the 1990s.

PAYLOAD PARTITIONING

Partitioning of payloads between the shuttle and ELVs has been materially affected because NASA is not funded at present to procure ELVs. Even in the short run, some additional off-loading of DoD-related payloads may be in order when alternatives are available.

Appendixes

Appendix A

Background

1. April 21, 1986, Letter from Congressman Edward P. Boland

2. List of Briefers and Participants

3. Committee on NASA Scientific and Technological Program Reviews Membership

Congress of the United States
House of Representatives
Committee on Appropriations
Washington, DC 20515

April 21, 1986

Honorable William E. Graham
Acting Administrator
National Aeronautics and Space
  Administration
Washington, DC   20546

Dear Dr. Graham:

I am writing to request that NASA call upon the National Research Council (NRC) Committee on NASA Program Reviews, to examine the future implications and possible scenerios resulting from the tragic loss of Challenger.

Specifically, it is requested that the following information be provided by the NRC:

1. An assessment of the possible flight rate assuming a base line of an 18-month delay in shuttle operations. The analysis should be based on the assumed flight rate and manifest most recently promulgated by NASA.

2. An assessment of the assumptions made in the above flight rate between payloads manifested on expendable launch vehicles and payloads manifested on the shuttle -- and whether such assumptions are reasonable.

3. An assessment of the impact on both flight rate and manifest of the existing three orbiter fleet with no fourth orbiter replacement. This assessment should include manifest requirements for both launch and

operation of a space station. The assessment should also be based on the assumption that the shuttle will fly at least one-third of the average number of commercial satellites launched over the manifest period.

4. An estimate, based on available data, of the various cost trade-offs of the above assumptions.

I would appreciate your cooperation in forwarding this request and in assisting with the study. A report covering these issues should be available to the House Appropriations Committee by October 15, 1986.

Sincerely,

Edward P. Boland
Chairman
House Subcommittee on HUD-
Independent Agencies

LIST OF BRIEFERS AND PARTICIPANTS

NASA REPRESENTATIVES

NASA Headquarters

Jerry J. Fitts, Deputy Director, Customer Services, Office of Space Flight
William Franklin, Technical Advisor, Launch and Landing Operations
John P. Hodge, Deputy Associate Administrator for Space Station
Ron Kinsley, Program Manager, Shuttle Payloads
Chester M. Lee, Director, Customer Services

Lyndon B. Johnson Space Center

A. A. Bishop, Deputy Manager, Mission Integration Office
Gregory Harbauch, Manager, Schedules and Flow Management Office
Elena M. Huffstetler, Manager, Flight Production Office
Leonard S. Nicholson, Manager, STS Integration and Operations Officer

John F. Kennedy Space Center

R. E. Heuser, Chief, Project Control and Contract Management Office Payload Projects Management and Operations Directorate
Dick Lyon, Deputy Director, Payload Operations
Russell Romanella, Technical Assistant, Payload Operations
Robert B. Sieck, Director of Shuttle Operations
Dick Thornburg, Manager, Shuttle Planning and Manifesting

George C. Marshall Space Flight Center

Jack M. Boze, Chief, Program Control Office, Office of Shuttle Projects
Jim Kennedy, Chief, SSME Project Control

U.S. AIR FORCE

Charles Cook, Deputy Assistant Secretary, USAF Space Transportation System

OFFICE OF MANAGEMENT AND BUDGET

Jeff Struthers, Chief, Science and Space Programs Branch

STRATEGIC DEFENSE INITIATIVE OFFICE

George Hess, Director, Survivability, Lethality, and Key Technologies
Gordon Smith, Deputy Director

INDUSTRY REPRESENTATIVES

Arianespace

Douglas Heydon, Executive Vice President and General Manager, U.S. Arianespace
Diane Josephson, Director of Marketing, U.S. Arianespace

Ford Aerospace

Robert E. Berry, Vice President, Space Systems Operations

General Dynamics

William F. Rector, Vice President, Program Development
Rudi Romero, Washington Office

Hughes Communications Company

John H. McElroy, Vice President for Technology

Lockheed Space Operations Company and Subcontractors

Carver G. Kennedy, Vice President, Space Programs, Morton Thiokol
David L. Owen, Executive Vice President
Herman E. Shipley, Director, Service Programs, Missiles, Space and Electronics Systems Group, Lockheed/Washington Office
John Walker, Lockheed
Wiley E. Williams, Vice President, Grumman Technical Services Division

Martin Marietta Denver Aerospace

Richard Blakley, Manager, Program Development, Space Launch Systems

Martin Marietta, External Tank Division

Richard Davis, President, External Tank Project
Thomas C. Wirth, Vice President, External Tank Project

RCA Astro Electronics

Jack Frohbieter, Division Vice President and General Manager

Rockwell/Rocketdyne

Robert Glaysher, Vice President for Shuttle Operations, Downey, California
Leroy D. Solid, Director of Launch Operations, Kennedy Space Center, Florida
Don L. Steelman, Director, Customer Representation, Washington, D.C.

COMMITTEE ON NASA SCIENTIFIC AND TECHNOLOGICAL PROGRAM REVIEWS

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ARDEN L. BEMENT, Vice President of Technical Resources, TRW, Inc., Cleveland, Ohio, Ex Officio Member

ROBERT H. KORKEGI, Director
JoANN C. CLAYTON, Senior Staff Officer
ANNA L. FARRAR, Administrative Assistant

Appendix B

SHUTTLE LAUNCH RATES

A detailed assessment of space shuttle launch rates was provided in an earlier report issued in April 1983 under the Committee on NASA Scientific and Technological Program Reviews, Assessment of Constraints on Space Shuttle Launch Rates. The present study takes into account lessons learned over the past 3 years, including circumstances following the loss of the Challenger on January 28, 1986.

During its short passage through the sensible atmosphere, the shuttle is stressed far nearer its design limits on every flight than is the case for transport aircraft, for which such an occurence is a rarity. Also, there are considerable differences between individual shuttle missions, unlike the repetitiveness of airline or more routine military operations. A shuttle flight manifest utilizing maximum possible turnaround rates must not compromise safety standards, since each flight is working so closely to the vehicle performance limits. The need for adequate safety reviews, logistics support (see Appendix C), spare parts, extensive inspection and maintenance, and extreme care in every facet of the turnaround operation cannot be overemphasized. In addition, sufficient crew-training facilities--including simulators and training aircraft--are needed to enable adequate training flowthrough to meet projected flight rates.

Present ground facilities at KSC with planned augmentation--e.g., the Orbiter Maintenance Facility--appear adequate to handle flight rates up to 12 per year. However, manpower at Johnson Space Center and spare parts production would have to be increased for such flight rates. The single Shuttle Processing Contractor (SPC) concept presently in place appears to be advantageous from an administrative point of view. While the SPC has improved in technical competence over the past 2 years, it still requires further improvement in the handling of individual systems--(Space Shuttle Main Engine, Solid Rocket Booster, External Tank, and Orbiter).

Crew training facilities and software development need improvement for flight rates up to 12 per year. Needed are an upgrading of existing facilities and an increase in the number of simulators as well as a fourth shuttle training aircraft.*

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*See Assessment of Constraints on Space Shuttle Launch Rates, National Research Council, 1983.

With Orbiter landings at Edwards Air Force Base for the foreseeable future, and a projected 18-month delay in procurement, an additional Shuttle Carrier Aircraft would be prudent.

Experience gained in the STS program, and from the accident, suggests that a sustained flight rate per Orbiter on a long-term basis should be more conservative than was thought necessary no more than 2 years ago.

The estimates given below are based on launch from KSC. The DoD shuttle launch complex at Vandenberg Air Force Base on the West Coast is being placed in "caretaker" status until 1992 according to Secretary of the Air Force Edward Aldridge.* Use of this complex for shuttle launches in the years beyond 1992 remains an open question.

Turnaround time

Shuttle turnaround time consists of 4 main elements: (1) processing time at the Kennedy Space Center, (2) mission duration, (3) transit time to ferry the Orbiter to KSC (if it lands elsewhere), and (4) planned periodic inspection and maintenance. These elements can be quantified on an average basis. A fifth element that cannot be quantified consists of contingencies--major damage to, or loss of, an Orbiter; diverted landing; weather delays; late manifest and/or flight plan changes; unforeseen payload delays; facility or support system downtime; lack of timely availability of spares/logistic support.

Shuttle processing at the KSC takes place successively in the Orbiter Processing Facility (OPF), the Vehicle Assembly Building (VAB), and on the launch pad (PAD). To be added in the near term is an Orbiter Maintenance Refurbishment Facility (OMRF) through which the Orbiters will flow on their way to the OPFs. The average shuttle processing time to date at the KSC has been 75 work days; the shortest was 46 work days. The latter is viewed as representing a surge condition and not a sustainable one. The former is viewed as an average conservative sustainable processing time. A more optimistic, but not unrealistic sustainable processing time would be 20 percent shorter, or 60 working days. Both are shown in breakdown in Figure B-1.

Average mission duration is estimated to be 7 days. Since Orbiter flights will be landing at Edwards Air Force Base for the foreseeable future, account is taken of ferrying time (including one day for weather uncertainties) of 6 days. Planned structural inspections and major maintenance are expected to require on average the equivalent of 2 weeks of downtime for every flight.

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*"Air Force Secretary Describes Defense Department Space Recovery Plans," Press release dated July 31, 1986.

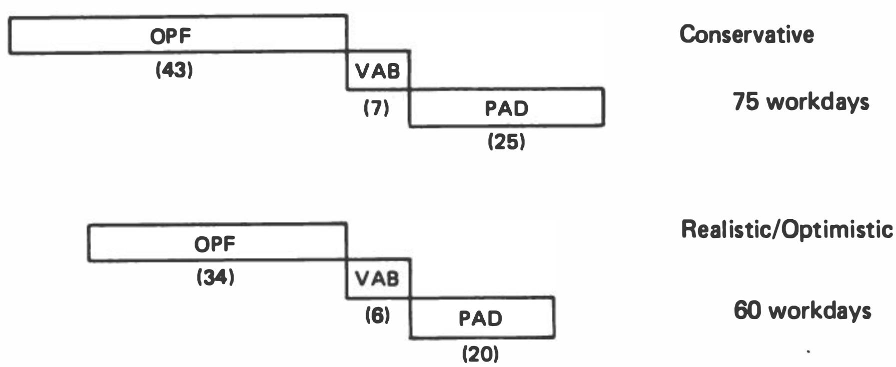

Figure B-1 Shuttle Processing Time.

With regard to the work week, bearing in mind the emphasis on safety and efficiency, it is postulated that ground crews work a 3-shift per day, 5-day week. The panel regarded a scheduled 7-day work week as undesirable over the long term because of the possible impact on flight safety.

Flight Rates

Based on the estimates above, the 75-work-day processing time results in an average number of flights per year per Orbiter of 2.7. With an improved processing time of 60 work days, the average rate per year per Orbiter becomes 3.3 (assuming a normal 3-shift, 5-day work week).

Thus, the average yearly sustainable flight rate for a 3-Orbiter fleet is 8 to 10. For a 4-Orbiter fleet the sustainable rate becomes 11 to 13 per year.

The above estimates apply to the KSC. Should the Vandenberg Launch Site be utilized for DoD missions after 1992, the U.S. Air Force expects to have one to 3 shuttle launches per year from the site. It is also expected that one Orbiter equivalent would be dedicated to Vandenberg. The effect would be to lower the flight rates noted above by approximately one flight/year--i.e., 7-9 for a 3-Orbiter fleet and 10-12 for a 4-Orbiter fleet.

It should be noted that these estimates do not account for contingencies noted earlier. While there is no way of predicting possible time lost due to some contingency or other, the experience of airlines and of U.S. Air Force aircraft operations shows that backup vehicles are needed to allow schedules to be maintained when an unforeseen event puts a vehicle out of commission.

Appendix C

LOGISTICS CONSIDERATIONS

The shuttle in 1986 has accomplished a long series of successful operational flights. Nonetheless, from a technical point of view, it is not yet out of the development phase. Design flaws, expected in a system of this complexity, are still being corrected. The spares complement is just being developed for main engines, solid rocket boosters, other line replacement units (LRUs), and so forth. In that respect, the past operational flights have been essential to determining the real, as opposed to the hypothetical, logistics needs for various sustainable flight rates. Consequently, a more efficient logistics program can now be set up than was possible some years ago. By the 1990s, most major development should be completed and the logistics picture should have stabilized. This appendix endeavors to estimate what that picture will be.

The panel accepts NASA's estimates of the immediate logistics needs. However, NASA has not systematically examined the consequences of the eventual loss, through use or accident, of Orbiters. Such losses must be expected, as NASA itself has stated in testimony on the Challenger loss. The complexity and uniqueness of the shuttle (critical elements, design margins, "rebuild" for every flight, etc.) reinforce that point. Well-recognized calculations relating system reliability, confidence level in accomplishing the mission, fleet size, and flight rate (equipment lifetime) have been used for years to determine the buy rate for aircraft, satellites, and other fleets. Figures C-1 and C-2 show the relationships among these factors for the range of parameters applicable to Orbiters. Figure C-1 shows the situation assuming no Orbiter losses: the upper curve gives an upper bound on flight rates per year so that there is a 50 percent chance of no Orbiter loss over the period. The lower curve represents an upper bound for a 90 percent chance of no loss. Figure C-2 shows the situation assuming one loss, i.e., the upper bounds on flight rates for no more than one Orbiter loss during the period. ("Loss" may be through wear out, severe overstress, or any accident that precludes further use.) An alternate way of showing the information in Figure C-1 is given in C-3. Based on all experience to date, one would have to have unachievable reliability to have a high confidence manifest without some planned backup, workaround and/or replacement Orbiter.

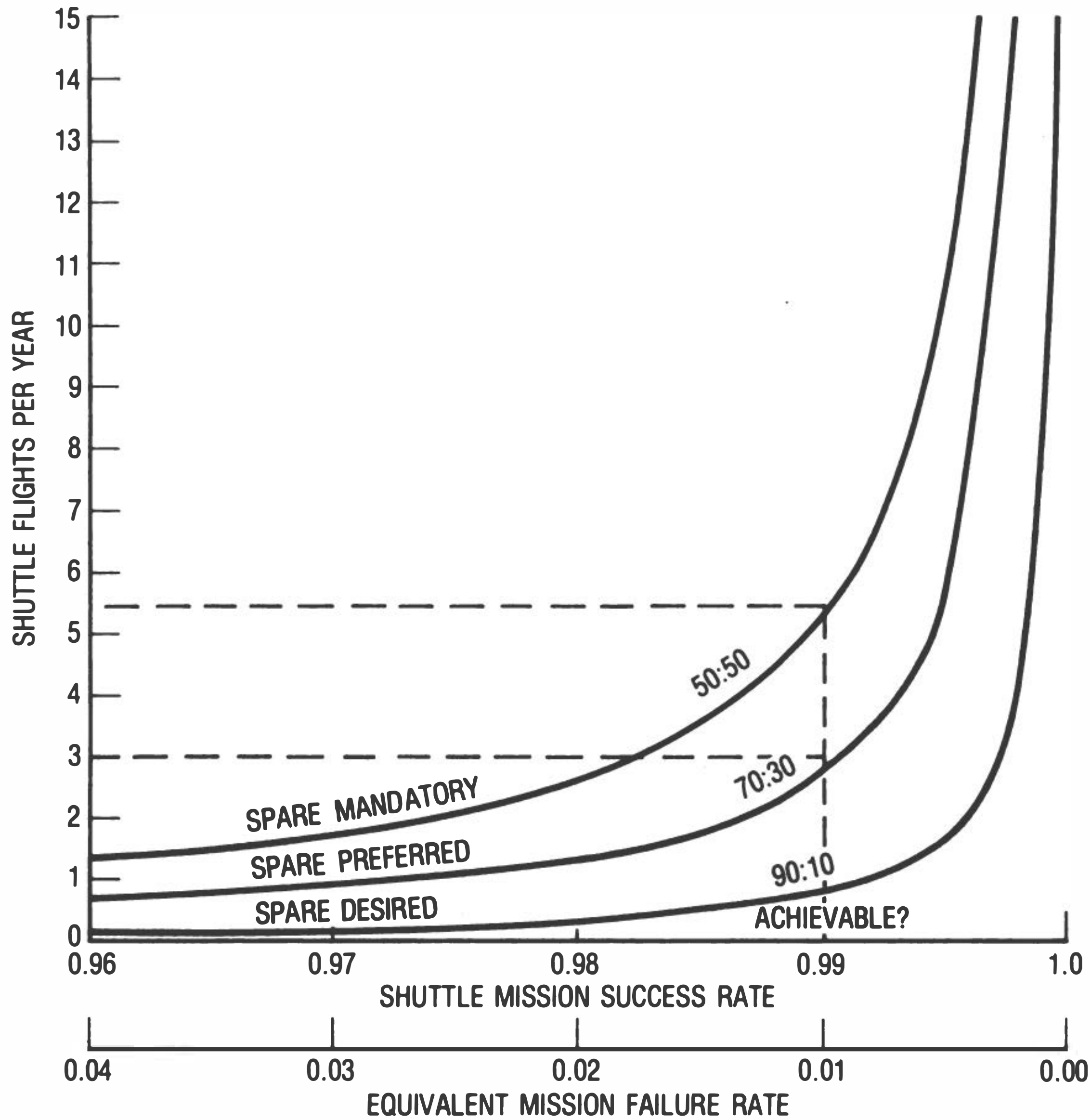

Figure C-1 The Chances of Losing Zero Orbiters 1988 through 2000 Time Period.

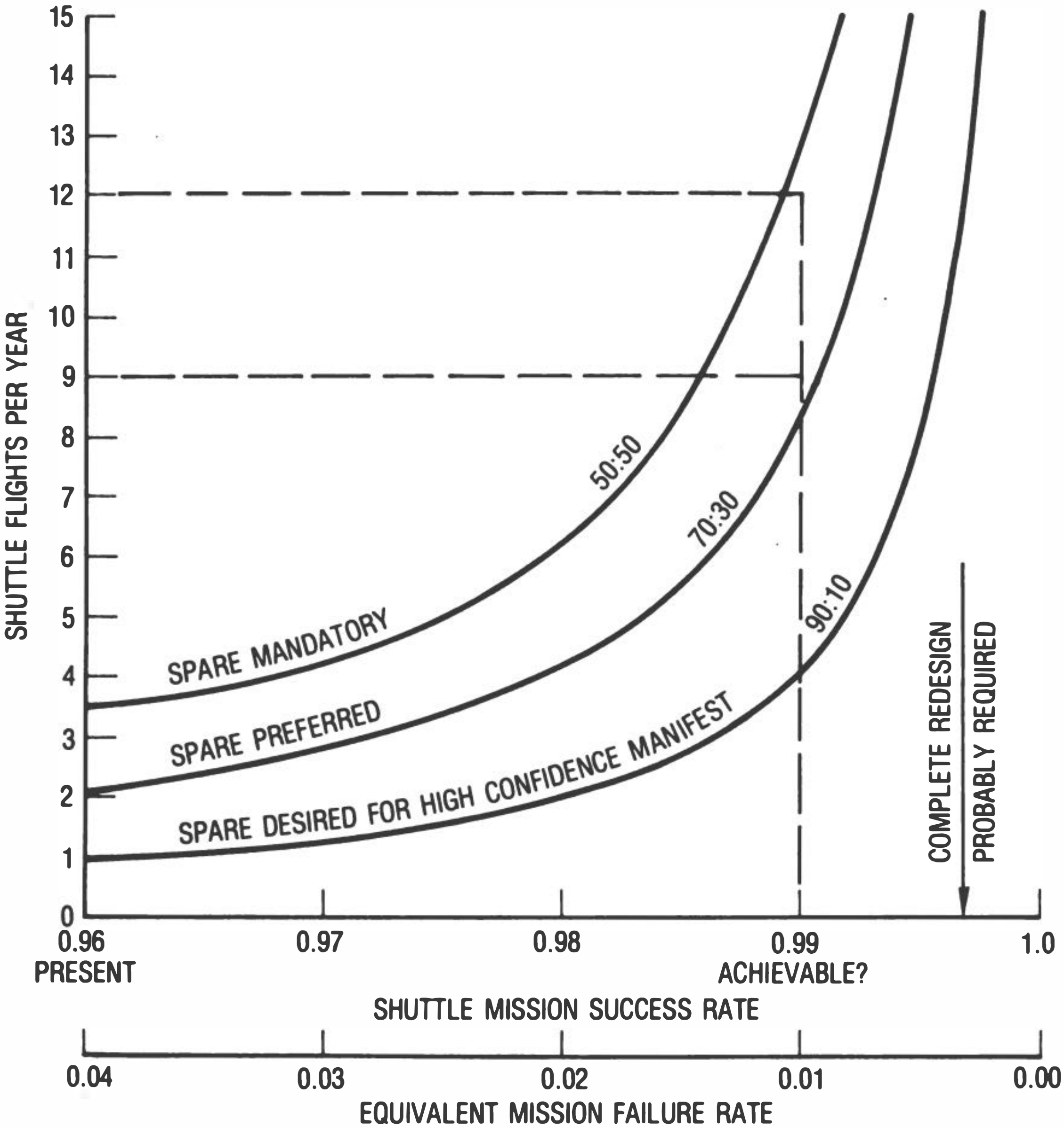

Figure C-2 The Chances of Losing No More than One Orbiter 1988 through 2000 Time Period.

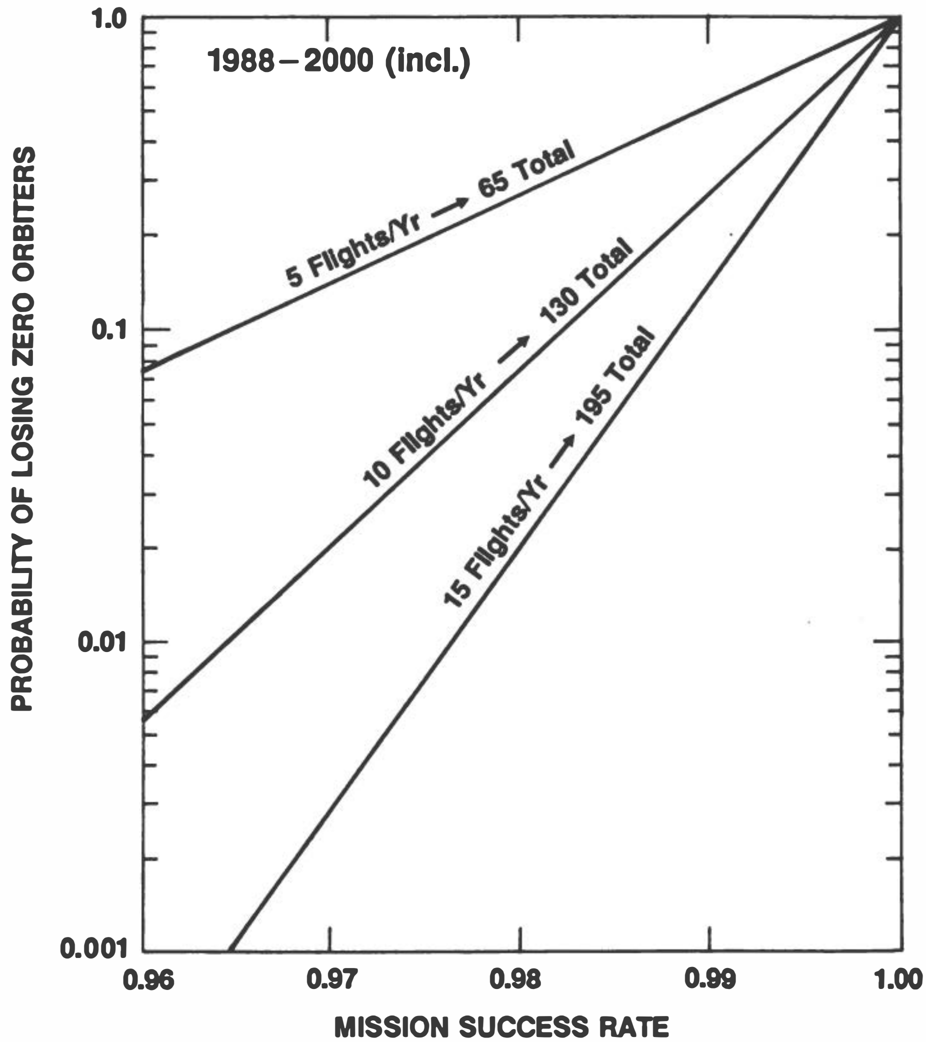

Figure C-3 (An Alternative View of the Information in Figure C-1.)

The shuttle system reliability to date is 0.96 (a failure rate of 4 percent). Given NASA's vigorous efforts at improved safety, this failure rate might be cut by a factor of 4; reducing it by a factor of 10 to a reliability of 0.996 is most unlikely in a short time or for costs less than the development cost to date (based on aircraft development experience).

It is important here to distinguish between having sufficient LRU spares and replacing a lost Orbiter.* The former is planned by NASA with appropriate budget requests; it is crucial for maintaining an acceptable Orbiter turnaround time. But, it assumes infinite life for the airframe, major structural components, and fittings. A noncatastrophic failure of an LRU--even if the cause were a design problem that grounds the Orbiter fleet for a while--is unlikely to affect the flight schedule for much more than a year. (The Challenger solid rocket problem will take somewhat longer but past ELV experience suggests that this is an exception.) Such schedule disruption can be accommodated through increased satellite design life of more than 5 years, as well as spares on orbit; planetary and space station programs clearly have more difficulty accommodating delays.

The loss of an Orbiter, however, as demonstrated by the Challenger accident, has long-lasting effects on all missions. Missions are placed in jeopardy. Mission and industrial teams are in danger of breaking up, especially university scientific teams and subcontractor teams. Time-critical satellites may be mothballed or discarded. The collateral costs are already a major fraction of the cost of another Orbiter. Yet this kind of disruption is inherent with small fleets of reusable, fully-booked vehicles with long replacement times.

There are several possibilities for minimizing the severity of impacts. First, a full-up spare Orbiter, with another ordered later, would help alleviate the buildup of backlogs if the anomaly is not a systems design-related one. Satellite constellations, for example, frequently have spares on orbit, but such an alternative for the shuttle may be too expensive. Another, albeit riskier, possibility is a flight rate sufficiently below the maximum rate where a multiyear "surge" could alleviate schedule conflicts until a replacement Orbiter is brought on line. Shifting of "standard" dual-compatible satellites to ELVs along with a sufficient inventory of "ready-to-go" vehicles, might help.

In any case, without an agreed strategy to accommodate Orbiter loss, long-term confidence in any shuttle manifest is certainly limited. This could be crucial for the space station, planetary launches, and some national security flights.

The Report of the Presidential Commission on the Space Shuttle Challenger Accident and the statements of individuals who met with the panel identified a number of relatively short-term problems that the panel believes NASA is likely to solve by the early 1990's:

- The cannibalization of LRUs from one Orbiter for parts or repair of other Orbiters (on the order of 50 percent on past flights).
- Limitations on nondestructive testing.

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*The NASA spares program does not supply a full "ship set" of spares, some of which have very long lead times. Consequently, a replacement Orbiter cannot be built just out of spares.

- Main engine and landing gear replacement and repair provisions.
- Flight simulator limitations (technological and capacity).
- Critical skills, spares, and maintenance requirements at KSC.
- Critical skills, simulators, data storage and software development at JSC.
- Establishment of a long-range logistics support plan, updated annually or as experience dictates. General concurrence in the plan and its financing by the Executive and Legislative Branches.
- Agreement by the NASA and DoD as to which payloads would be compatible with both Orbiter and ELVs. In this connection, it is not necessary that all payloads be dual compatible in order to assure access to space. But those that are will require advance planning of launch support if changeover is to be practical.

The panel also notes the continuing trend toward the formation of a Shuttle Operations Organization, which could be an important factor in achieving confidence in any shuttle manifest.

A serious limitation to a reliable manifest is the maintenance of an industrial base to support the spares and replacement needs of the shuttle fleet. The shuttle fleet is a small one, with a low replacement rate. But according to Rockwell International, to ensure that a replacement Orbiter is available within, say, an 18-24 month call-up would require a production capability of 2 Orbiters on order all the time (or 1 every 2 years). However, an efficient industrial base can be maintained with a production rate of one Orbiter about every 3 years along with continued production of spare parts. But with an Orbiter fleet operating at about 10 flights per year and a loss rate of 1 to 2 percent, the replacement order rate would be one every 5 to 10 years, too low to retain an efficient industrial base. Increasing the shuttle's reliability to the point of not needing any further replacements nor an industrial base is not practical (see Figure C-1).

A compromise would be a shuttle production rate of about one Orbiter every 4 years along with a national commitment to aggressive use of shuttle-unique capabilities.

Appendix D

SHUTTLE UTILIZATION

Before the loss of Challenger, the shuttle fleet was fully booked. There were even indications that shuttle was overbooked. Presentations to the panel from several sources indicated that the demonstrated flight rate of 10-12 flights per year was severely stressing shuttle operations capabilities at all the affected NASA centers. The future manifest through 1991 indicated a still higher flight rate.

Post Challenger, the achievable fleet manifest will be significantly less than the pre-Challenger manifest. The difference between the 2 is usually called the "backlog." If accepted at face value, this backlog would call for flight rates approaching 20 per year well into the 1990s in order to reduce it to zero. Some immediate relief was obtained by off-loading payloads to ELVs, a more vigorous action by the DoD than NASA but done nonetheless. The August 15, 1986 Statement by the President indicates that commercial satellites in the 1990s (once the post-Challenger transition is completed) also will be off-loaded. The panel anticipates further reduction of the backload by acknowledging that satellites not launched during the transition phase represent "services not delivered," i.e., the blocks of satellites that were to be launched will simply be pushed out in time and future buys reduced accordingly. Some satellites may simply not be launched at all--by the time they could be launched they would be obsolete for the purpose they were to serve.

The backlog is also likely to be reduced by what is called "discounting" of the future manifest. Experience shows that launch schedules a year or more in advance are likely to be too great by about 30 percent. The reasons have to do with delays in payload delivery, unscheduled downtime of the launch vehicles, cancellation or stretchout of programs for funding reasons, etc. Whatever the cause, the discounting phenomenon is well documented for both shuttle and ELV fleets.

Another clear factor in the size of the backlog, at least in the past, is the price charged for a shuttle launch. (There are more customers for a free launch than for a "recovered cost" launch.) Reduced flight rates and reduced performance will increase per-flight costs relative to ELVs for customers charged for shuttle service.

The question then remains of what flight rate reasonably matches both the capability of a shuttle fleet and a realistic utilization (demand). From a purely technical point of view (i.e., putting aside funding considerations), there will clearly be a demand for man-critical flights such as Spacelabs, life and earth science experiments, recovery and repair missions. There will be a demand for shuttle-unique missions (sorties, short-duration on-orbit R&D, and certain classified low-orbit missions). Collectively, these might amount to 3 or 4 flights per year.

The demand for physical sciences was initially very high, particularly since physical sciences missions weren't assessed launch costs as part of project costs. But a severe disenchantment has set in with unexpected costs, procedures, man-rating specifications and delays, particularly for physical science missions that could be done at least as well, if not better, technically on free flyers launched by ELVs. In the long run, the demand will be for a launch capability that preserves the momentum and opportunity for engaging outstanding scientific talent in meaningful research. Therefore, until the shuttle is seen to fulfill its original purpose, the demand for physical sciences flights is likely to drop. In the short run, the physical sciences utilization may well be determined by the price, if any, that such missions are assessed for launch costs. Priorities being what they are, the utilization rate of shuttle for physical sciences might be a 1-2 equivalent shuttle flights per year. (Note: The number of payloads considerably exceeds the number of equivalent shuttle flights.)

The greatest change in utilization, however, is likely for geosynchronous and other high-altitude missions. For these missions, the shuttle is "just a truck." If fully costed, it is an expensive truck. With the cancellation of Centaur as a shuttle-compatible upper stage, the shuttle is, at least temporarily, no longer a high-performance path to high orbit. The ELVs should be expected to take over much of that capability. Where lesser performance is acceptable, cost may be the determinate. As noted in Appendix E, the total national launch cost is relatively independent of the shuttle-ELV mix, implying that customers could choose what appeared most cost effective to them. Many, but perhaps not all, would opt for ELVs, depending on the price and availability of the various future launch options.

The demand for the shuttle for Space Station launches was, until recently, relatively high--8-10 flights per year. Testimony of John Hodge to the House Subcommittee on Space Science and Applications (July 21, 1986) indicated that "Depending upon the future composition of this Nation's space launch fleet, it would be possible that the current Space Station would need to use both the shuttle and expendable launch vehicles in support of Space Station needs." It is the panel's estimate that the demand in the 1990s to support the current Space Station design will be roughly equivalent to 2 more Orbiters with an appropriate provision for a replacement if and when needed. It wouldn't be surprising if 1-2 flights per year were required for experimental purposes prior to the increased flight rate during construction.

Estimating the demand for the Strategic Defense Initiative (SDI) is best done in 2 parts. Barring drastic changes in the SDI program, there will be a continuing need for research flights requiring manned intervention, sortie, recovery and repair missions--essentially "proof-of-concept" flights of technologically very advanced systems. The shuttle could be a good match to these systems, especially if it is important to bring them back for analysis and modification. The SDI Office, however, estimates its utilization at only 1-2 flights per year for less than 10 years and no shuttle use in the deployment phase. However, even if the decision were made early in the 1990s to go into full-scale development, the impact on the shuttle fleet wouldn't be felt for at least 5 years. A more likely occurrence would be the development of a new launch vehicle (heavy lift, unmanned?) specifically for SDI weight lifting.

One major consideration suggests a significantly reduced shuttle utilization as compared with the NASA manifests. Projected costs in the 1990s of the NASA civil mission model (payloads and transportation) used in the NASA/DoD Space Transportation Architecture Study show a "bow wave" in costs far above likely funding, dropping well below later, indicating a major shift of programs into the next decade.

All things considered, a rate of 8-10 flights per year in the early to mid-1990s, prior to the construction of the Space Station, does not appear to be much off the track for a well-operated shuttle fleet of 3 Orbiters. If the demand turns out to be greater, the primary long lead item will be another Orbiter.

Appendix E

COST TRADE-OFFS

Reliable cost figures are difficult to come by at this time. Shuttle redesign, replacement, and operations costs are in flux. Titan IV, MLV, and Titan II costs either are being renegotiated or are competition-sensitive. The best that can be done is to use existing NASA and Air Force cost data bases and should-cost models to determine the likely cost drivers. While by no means accurate enough for budget purposes, their use in the past has proven useful in determining first-order trade-offs, i.e., more refined subsequent calculations seldom overturn the general results. The calculations were performed by the Aerospace Corporation.

Figures E-1 and E-2 indicate the total launch costs of various mixes (see Table E-1) of shuttles (STS), Titan IVs, medium-launch vehicles (MLVs) and Titan IIs corresponding respectively to 24 and 16 equivalent shuttle flight loads per year depending upon the annual depreciation assumed for the shuttle fleet. Depreciation includes the cost of replacements Orbiters regardless of cause.

Comparing the 2 figures, the total costs clearly depend upon the total flight load; it costs more to launch 24 than to launch 16 shuttle-equivalent flight loads per year, though the increase is not proportional.

Taking either figure, it doesn't make much difference what mix is chosen, though at more than a one percent depreciation it costs less to have fewer rather than more shuttles in the mix. Such differences as occur may well be within the estimating accuracy. The calculations assume that each mix is stable, i.e., changes from one mix to another could generate added costs unless the changes were well planned in advance. In any case, a commonly held assumption that ELV costs are simply an add-on to the (fixed) costs of the shuttle program is not substantiated by the available data bases and cost models when all costs are considered.

What is more important to total cost, again taking either figure, is the depreciation rate for the shuttle fleet. Based on the logistics considerations discussed in Appendix C, the depreciation rate one might expect is in the range of 1-2 percent. The clear cost trade-off here is between higher (and earlier) reliability improvement costs and higher (and later) depreciation costs. Safety will drive to the former; near-term funding and schedule pressure could drive to the latter.

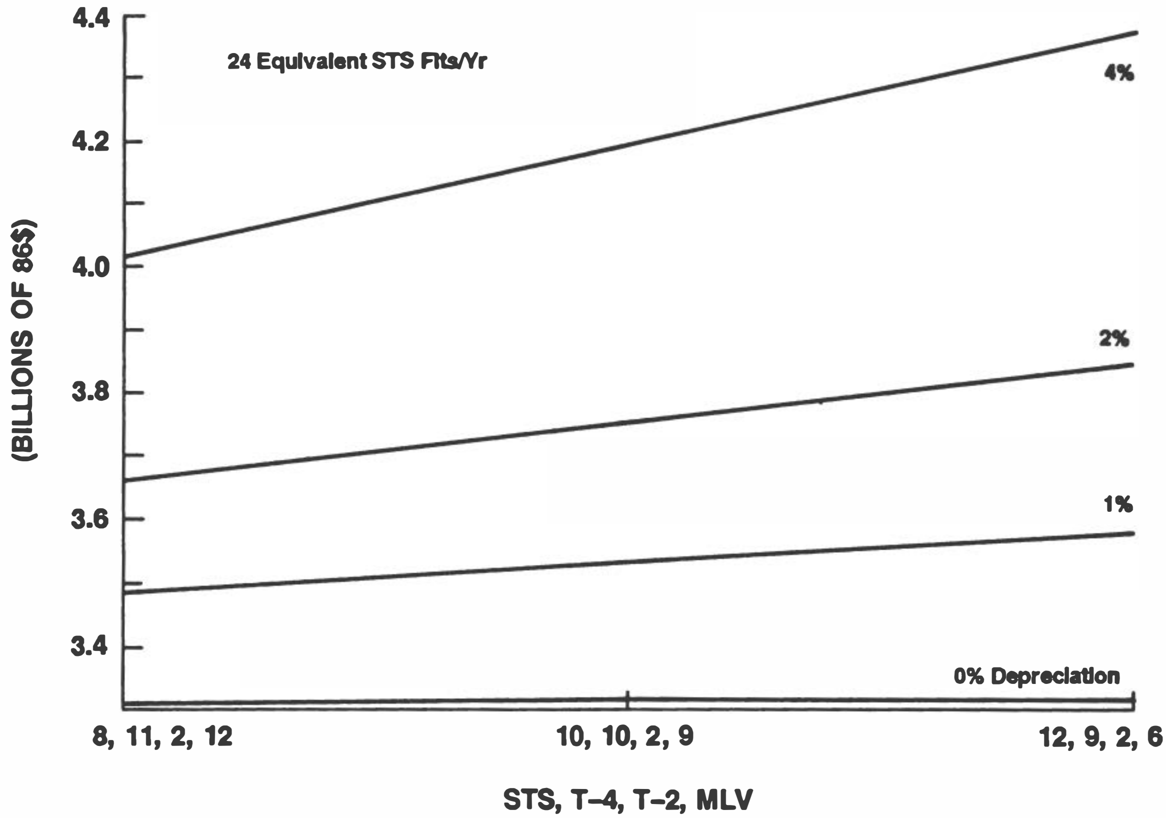

Figure E-1 Total Cost Trends--Mixed Fleet Options Studied (Case I)

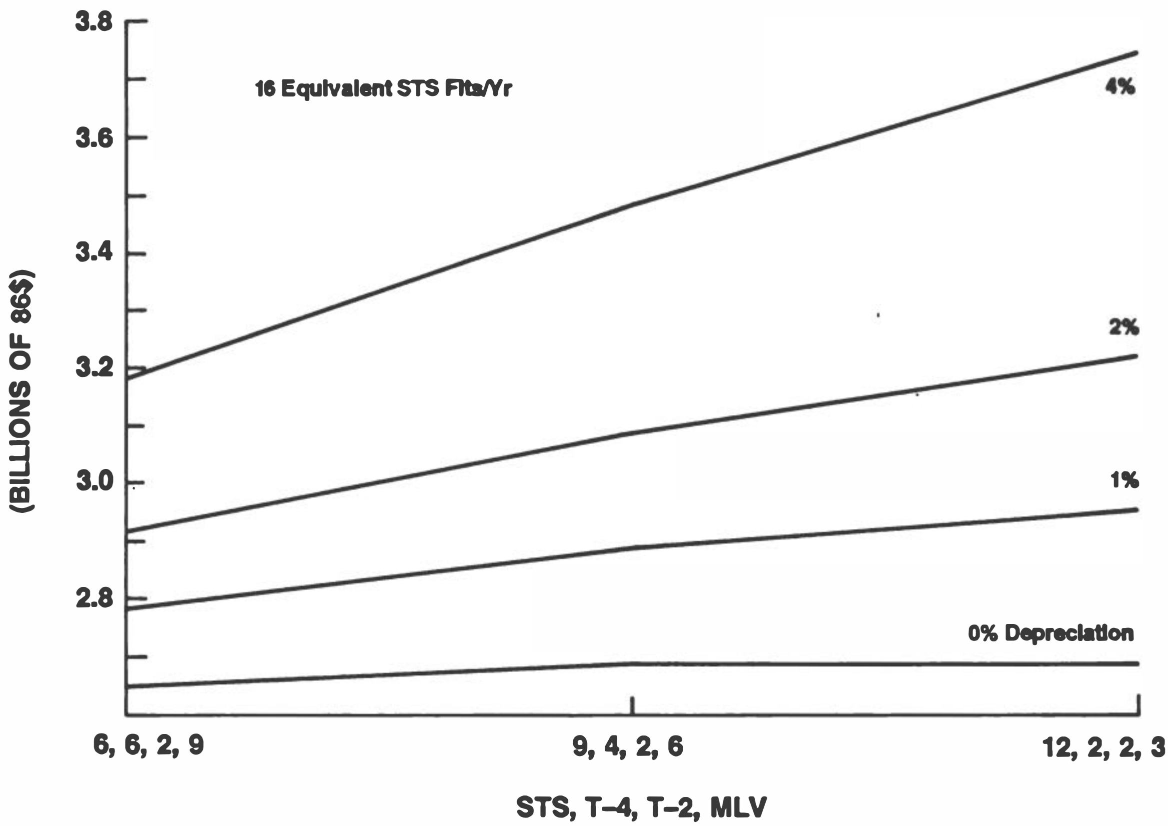

Figure E-2 Total Cost Trends--Mixed Fleet Options Studied (Case II)

TABLE I NATIONAL DEMAND MODEL POST FY-91

CASE I:	TOTAL DEMAND OF 24 EQUIVALENT STS FLIGHTS			
	STS	8	10	12
	TIV	11	10	9
	TII	2	2	2
	MLV	12	9	6
CASE II:	TOTAL DEMAND OF 16 EQUIVALENT STS FLIGHTS			
	STS	6	9	12
	TIV	6	4	2
	TII	9	6	2
	MLV	6	3	3

CASE I is a discounted version of the national demand presented by NASA Headquarters (J. Fitts).

CASE II is a much more conservative version of the national demand.

Appendix F

A SUSTAINED MANNED SPACEFLIGHT PROGRAM

Perhaps the single most important assumption made in this report is that the nation is committed to a sustained manned spaceflight program. If true, that commitment has direct consequences to shuttle operations. In particular, unless the shuttle fleet is maintained during the 1990s at approximately the realistic flight rates given in this report, the necessary foundations will not exist for manned Space Stations, SDI in-flight development, testing of tactical intelligence and battle management concepts, clinical research, countermeasure testing related to space adaptation, and development materials-processing systems that depend on the space environment.

The realistic or sustainable flight rates in this report are based on supply constraints and mission demands for presently committed missions, not those still in conceptual design. For example, Space Station needs cannot be supported without what the Space Station Director properly calls a "robust shuttle fleet."

The assumption of a national commitment to a sustained manned spaceflight program would be self-evident were not an alternative under discussion in the government. This alternative would not replace the present Orbiter fleet (either 3 or 4 Orbiters) when and as needed but would let the shuttle fleet decrease through attrition, relying on a future vehicle fleet of more advanced vehicles to pick up the manned flight effort and on ELVs to launch all payloads not requiring astronaut intervention. The advanced manned vehicle usually mentioned is the National Aerospace Plane (NASP), though a modified shuttle (high safety, minimal cargo) is also being discussed.

One difficulty with the alternative assumption (shuttle attrition) is timing. As the shuttle is demonstrating, it takes at least a decade to develop a space vehicle to the point of reliable operation even when the technology is believed to be in hand. Technology for the National Aerospace Plane is not yet in hand and the size of the vehicle contemplated for the turn of the century is too small to handle shuttle-equivalent payloads. Modifications to the shuttle are under study, but they are not yet past the conceptual design phase. The alternate assumption, therefore, would predictably result in a hiatus (5 to 10 years) in manned flight, precluding the Space Station planned for the 1990s.

A more serious difficulty, however, would be the imminent collapse of the shuttle manifest. As discussed in Appendix C, at 10 flights per year and a 1-2 percent loss rate, but with no replacements, the shuttle fleet would be down one Orbiter in about 5 years and down 2 in 10 with corresponding flight rates of 7 and 4, respectively, per year. Those rates would hardly handle the man-critical missions. In anticipation of an uncertain launch future and to protect their missions, mission directors would no longer design shuttle unique payloads and for planning purposes would schedule on ELVs. ELV production facilities would expand accordingly. Thus, even before any losses might occur, the uncertainty in the future of the shuttle fleet could result in a collapse of the 1990s manifest and an increased cost per flight, which would deal manned space flight a serious blow.

Appendix G

REFERENCE MATERIALS

NASA

"NSTS Flight Rate Projection (An Integrated Assessment)," Alfred Bishop, NASA-S-86-02368, 1986

"STS Flight Rate Briefing to the National Research Council," Alfred Bishop, July 21-22, 1986

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