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CAPABILITIES AND LIMITATIONS OF THE SHUTTLE FOR FUTURE CARGO PROGRAMS

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ABSTRACT

This paper presents a view of future Shuttle cargo operations. Planned and potential performance improvements are addressed. On-orbit operations, performance and experience are discussed with a view of anticipated changes. Current and future cargo integration activities are also addressed. The future Shuttle user is provided a projection to assist in planning and payload development.

INTRODUCTION

Any definitive projection of the future Shuttle performance and cargo operations must be viewed with some skepticism. The Shuttle, like other programs, has a history of performance changes, and with the program in its infancy it is reasonable to expect additional planned and unplanned changes. Nevertheless, we will attempt to make a reasonable projection and provide some thoughts on improving cargo services for future Shuttle operations. The success of early Shuttle flights lends credibility that the major development issues have been solved and we can expect continued performance improvements.

LAUNCH PERFORMANCE

This discussion of launch performance will address the following topics:

- Programmed Performance Growth
- Baseline Variations List
- Flight Design Enhancement
- One-time Enhancements

Programmed Performance Growth: The Shuttle system launch performance specifications can be summarized as follows:

- 65,000-lb payload - 150-n. mi. circular orbit due east
- 32,000-lb payload - 50 X 100-n. mi. orbit at 104°
- 32,000-lb payload - 150-n. mi. circular orbit at 98°
- 32,000-lb payload - normal landing

The early Shuttle flights do not provide this capability and performance improvements have been planned for the next few years. Figure 1 illustrates the planned improvements as a function of discrete events and their projected schedule.

Beginning in late 1981, ascent trajectories are to be based on the ground rule that the main engines will operate at 107% rated thrust level for all abort modes for a payload lift gain of 5,000 lbs. A 1% increase of the SRB burn rate will yield an additional 1,000 lbs of payload gain in early 1982.

STS-5 has been identified as the first operational mission for the Shuttle. For STS-5, the main engines for OV-102 will be operated at 102% RPL (rated power level) for nominal ascent and 109% RPL for an abort trajectory. This change from 100%/107% to 102%/109% yields an additional payload capability of 2,500 lbs.

The next major step in payload lifting capability will come with the introduction of the lightweight external tank and the reduced case weight for the solid rocket boosters. The combined benefit from these two enhancements is approximately 8,000 lbs of payload lift capability. Orbiter OV-099 is currently programmed to be flown for the first time on STS-6 and will, by virtue of its lighter inert weight, provide an additional increase of 6,400 lbs of payload lift capability.

After two flights of OV-099 at 102%/109% SSME throttle settings, the ascent performance will be increased to 109% RPL for both nominal ascent and abort trajectories. This increase will provide an additional 5,900 lbs of payload lift. The introduction of a redesigned solid rocket motor and nozzle, referred to as the HPM (high performance motor) will result in a 2,000 lb performance increase. The HPM will be available for use in the third quarter of 1983.

The delivery weight of the third Orbiter is currently projected to be 3,700 lbs less than OV-099 which will increase the payload capability to 65,000 lbs for the mission identified in figure 1. The performance growth just covered refers to due east launches from the east coast. Launches from the west coast, suffering as they do from the lack of the aiding Earth rotational velocity, will show a payload lift capability of 32,000 lbs into a 150-n. mi. circular polar orbit. (See figure 2.)

These activities are expected to produce near specification performance for a portion of the Shuttle Orbiter fleet. In addition, there are a number of ways to realize additional payload capability.

Baseline Capabilities Variations (BCV) List. The STS program keeps track of a number of potential performance enhancements and is constantly assessing their cost vs. benefits. A sampling of the types of improvements that this list contains is shown below as copied from a NASA weight and performance document.

Modified ET Baffles +900

If the dumping criteria are reduced from 4% to 2% and a baffle configuration utilizing a sidewall support with lands is used to replace the current "bird cage" design, a 900-lb weight reduction can be realized. The modified weight was defined in a weight reduction review on 8-12-81. If the baffles are deleted and no structural beefup is required, a weight reduction of 1,400 lbs can be realized.

ET TPS Weight Update +500

The maximum thrust imbalance between the SRB's of 720,000 lbs could occur at tailoff and cause a side slip angle (b) of 11°. The associated increase in aerodynamic heating in the vicinity of protuberances requires the addition of SLA to the LH_2 tank, intertank, and protuberances and the addition of SLA and SOFI to the LO_2 tank. OFT data may indicate B max is less than 11°; therefore, the thermal environment will be appreciably less and the amount of SLA may be reduced.

Reposition SSME Nozzels +900

The SSME's normally gimbal about the null position (-16°, -10°, -10°) in the pitch plane. If these engines can be reorientated to an initial position of 6° nozzle down (-10°, -4°, -4°) to reduce cosine losses, a performance improvement of 900 lbs at the 109% power level can be realized. Heating analysis is required to confirm this possibility.

Included in the BCV list is also a potential enhancement which includes the use of filament wound (composite) cases for the solid rocket motors. Current studies project an enhancement of between 6,000 and 8,000 lbs of additional payloads.

Flight Design Enhancements. Performance enhancement can be realized in several ways through the use of variations on standard flight design ground rules: ascent trajectory shaping may have a significant effect on launch performance capability; the use of direct insertion MECO target parameters may affect the altitude of mission orbits. Other flight-specific changes may be used to effect performance and include such factors as changes in the reserves used for dispersion allowance and changes in the maximum launch aerodynamic pressures allowed.

Most of these techniques are impossible to quantify without mission-specific details. However, direct insertion MECO targeting and target shaping deserve brief discussion.

Direct Insertion MECO Targets. For all ascent designs with allowable launch azimuths, the SRB's fall safely to Earth only a few hundred miles downrange. However, since the ET has essentially the same speed and direction at ET separation as the Orbiter itself, the design of the MECO target is greatly influenced by the ET disposal problem.

As long as the Orbiter's integral OMS propellant storage capacity is sufficient, the MECO target can be adjusted to solve the ET disposal problem without greatly affecting the Shuttle's maximum useful-weight-to-orbit capability. In these cases, standard MECO targets will be used. KSC has a standard MECO target which, for all allowable launch azimuths, provides virtually the same safe ET impact point in the Indian Ocean approximately 180° away from the launch site.

With standard MECO targeting, the Orbiter's OMS storage capacity is generally sufficient for mission altitudes up to approximately 225 n. mi., give or take 25 n. mi. depending on Orbiter configuration.

Direct insertion is a MECO targeting concept which puts more of the ascent burden on the SSME's by requiring an increased energy state at MECO in order to conserve OMS propellant, and yet provides a safe solution to the ET disposal problem for selected mission altitudes and inclinations. The requirement to dispose the ET safely in open ocean areas still limits the selection of the MECO target parameters which results in some loss in flexibility and ascent performance. However, for verified altitude/inclination combinations, direct insertion's increased energy state at MECO does permit the Orbiter to reach higher altitudes.

The ET disposal solution for direct insertion MECO targets has been verified at the feasibility level for transfer-orbit apogees ranging from 270 n. mi. to 320 n. mi. for due east launches from KSC. For these cases, the ET impact point falls in the Pacific Ocean approximately 200 n. mi. off the east coast of Hawaii. Other altitudes and launch azimuths may be possible at both launch sites, but have not yet been verified. The first use of direct insertion is currently planned for the shared flight of LDEF deploy combined with the on-orbit repair of the solar maximum spacecraft in early 1984 at altitudes in the range of approximately 275 to 300 n. mi., 28.5° inclination.

Ascent Trajectory Shaping. An optimal ascent trajectory which maximizes the Shuttle's weight-carrying capability to MECO for a given configuration is referred to as "shaped nominal." However, it is also a requirement to provide for an abort contingency in the event that a main engine fails after the last opportunity to return directly to the launch site (RTLS) but prior to MECO. This abort requirement can be satisfied if the Shuttle continuously has the capability between the last RTLS opportunity and MECO to fly at least one low-altitude revolution and land back at the launch site. This is referred to as an abort-once-around (AOA) capability. Depending on several factors, such as Shuttle configuration, OMS propellant load, and abort throttle setting, the "shaped nominal" ascent trajectory often results in a period of time after the last RTLS opportunity when the Shuttle would not have the minimum energy required to accomplish an AOA. This so-called abort gap can be handled in one of two ways. First, the ascent trajectory can usually be reshaped to close the gap. This reshaping may reduce the Shuttle's weight-carrying capability anywhere from zero to approximately 4,000 lbs. Another alternative which does not reduce the "shaped nominal" weight-carrying capability is to arrange for the Orbiter to land at an emergency downrange landing site (such as Rota Spain, for KSC launches) in the event of a single-engine failure during the abort gap. This concept, as applied to KSC launches, is referred to as the trans-Atlantic landing (TAL) option.

One-time Enhancements. Some projected missions of the Shuttle could be helped by special efforts that would not be considered as a multiple flight performance improvement. For missions that required performance over that inherently possible for the given STS configuration, certain items can be de-manifested. While each item de-manifested would not make a major change, the effect of de-manifesting several items from the Orbiter could well be the difference between an impossible mission and a viable mission. Following is a listing of a few of these de-manifestable items:

Radiator Panels 7 and 8	250 lbs
Remote Manipulator System	1,000 lbs
Cryo tanks	900 lbs
Crew and Crew Support Systems(from 4 to 2 crewmen)	500 lbs

Another possible one-shot performance enhancement has to do with deleting the SRB recovery-aiding systems (e.g., parachutes, locating beacons, etc.). This could net a performance enhancement of over 1,000 lbs. Obviously, this technique would best be considered at the end of the useful life of the SRB's.

While this is an optimistic view of the Shuttle launch performance, it must be considered in light of the nature of the Shuttle program goals of a high utilization rate for the Orbiter vehicle and standardization to reduce the launch costs. Not every user can be assigned to fly in the high performance Orbiters; main engine life considerations will dictate that we operate at the minimum throttle settings; standard ascent trajectories will be utilized to minimize costs; and the reconfiguration of the Orbiter vehicle must be minimized between flights to support the flight rate. For most users, this can result in a reduced performance to approximately 57,000 lbs to a 150-n. mi. orbit at an inclination of 28.5°. When performance above this level is required, it must be negotiated with the STS operator on a case-by-case basis.

ON-ORBIT PERFORMANCE

Early Shuttle flights have included limited payload services as the flights are designed to verify the Orbiter systems performance. As the program progresses, additional payload services in terms of hardware and software will be added to provide those services defined in JSC 07700, Volume XIV, Space Shuttle System Payload Accommodations. In particular, the payload data systems will be added for STS-5 providing payload command and data services through the Orbiter systems and the space flight tracking and data network. On STS-6, STS-8, and STS-12, tracking and data relay satellites will be launched to provide coverage of up to 80% for 28° inclination flights. On STS-7, the Ku-band communications system will be added to the Orbiter providing high-data-rate communications for the payloads in addition to radar tracking for Orbiter-to-payload rendezvous and station-keeping. The interfaces for these systems are well defined and many users are planning to take advantage of these services. The interfaces will be verified in the Shuttle certification process. Ground-based test can be utilized to verify particular payload-to-Orbiter interfaces during the integration process at the launch site, providing high confidence in the on-orbit performance of the interfaces. NASA is not currently planning major revisions to these services as we feel operational experience with this design is indicated before we consider any significant changes. The system is such that it is highly interactive with the Shuttle systems and software. This creates extensive integration activities between the user and the Space Transportation System. Our future thrust is likely to be directed to the elimination of this interaction with the Shuttle system to the extent practical, possibly at the expense of eliminating or curtailing some services if it can be determined that we are unlikely to adversely affect mission success probability for our users.

Many other aspects of the Shuttle characteristics and capabilities cannot be as well understood through ground test and analysis. It is probable that we can expect significant improvements in the understanding of the Shuttle on-orbit performance and permit users to take advantage of this knowledge. Examples of these areas and some possible applications are as follows:

Payload Pointing. The current commitment as regards pointing a payload is based on an analysis of the error sources to predict a root-sum-squared error prediction between the Orbiter navigation base and the payload attachment fitting. Major error sources are manufacturing tolerances, platform alignment, platform drift, and Orbiter deflection. Operational experience will provide refined data on the platform alignment and drift errors. Orbiter deflection and manufacturing tolerance data will be accumulated as various payloads fly pointing sensors which can be correlated to the navigation platform. A sensor providing limited correlation is planned to be flown on STS-3 and various pointing experiments will be included on Spacelab flights. It will be a number of years before we can provide the necessary correlation to update our specifications, but it is not unreasonable to expect improvement on the order of 30 to 50 percent. The current pointing error is specified at 2° at the payload-to-Orbiter attachment fittings. Any improvement in this error is a significant performance improvement for spinning upper stages, such as the PAM-D and SYNCOM, which depend on the Orbiter alignment to control their direction of thrusting to a different orbit. In addition, it may be possible to accomplish some experiments without requiring the use of complex pointing systems.

Micro Gravity. A vast majority of the space processing experiments are based on the zero-gravity environment achieved by orbital flight. The Orbiter achieves an essentially zerogravity orbit but there are periodic disturbances caused by reaction control jets, crew motion, system venting, and experiment operation. As we gain operational experience with the Orbiter, we can expect to refine our understanding of the effect various Orbiter functions have on the micro gravity environment. The obvious areas for exploration are the use of gravity gradient stabilized attitudes to eliminate the use of the reaction control system and the management of Orbiter operations, such as water dumps, which create disturbances. There are a number of materials processing and biological experiments on early flights which desire minimum disturbances. Examples are the continuous flow electrophoresis system and materials experiment assembly. We will be developing techniques and understanding the system performance through Orbiter and payload measurements of induced environments. The techniques developed to minimize on-orbit accelerations will be a benefit in the development of future space processing experiments as well as increase the usefulness of current experiments.

Electrical Energy, Heat Rejection, and Mission Duration. The current Orbiter design provides adequate electrical power and energy, payload heat rejection, and mission duration for the early payload deployment missions. A moderate capability to support space processing on those flights is also available. It is, however, restricted to approximatley seven-day missions and cannot provide all of the requested electrical energy to support the Spacelab-type missions for processing, astronomy, and life sciences experiments. Early improvements in this area will be realized as a function of development of more efficient operating techniques for both the Orbiter and Spacelab systems. It is probable that only modest improvements will be realized in this manner and that additional improvements will eventually be required. Various techniques to add additional capability have been studied. Techniques which add cyrogenic storage tanks to the Orbiter and utilize the entrapped oxygen from the main propulsion system offer up to 50 percent improvement in the mission duration and available electrical energy. An alternate approach is to add a deployable solar array which is stowed in the cargo bay and deployed by the remote manipulator system. This approach would provide significant improvements in both the electrical energy available and mission duration (up to 21 days). In NASA's present budget posture, neither of these approaches has been funded and we cannot expect their implementation in the near term.

Payload Retrieval, Repair, and On-Orbit Assembly. Perhaps the most exciting aspect of the Shuttle capabilities is that of the promise of payload retrieval and/or repair and the ability to easily assemble large space structures and systems on-orbit. The NASA is vigorously pursuing a set of activities to develop the ability to effect on-orbit repair and retrieval and return of payloads from orbit. A building-block approach where the RMS is utilized to unberth and reberth experiments is used on STS-3 prior to full payload deployment, retrieval and reberthing on STS-7. An early satellite repair for solar maximum mission spacecraft is tentatively planned for STS-11. These early experiments support operational programs, such as the space telescope and long duration exposure facility programs, which are being developed dependent on this new spaceflight capability. Missions requiring on-orbit assembly have not been scheduled in near-term STS flight assignments. It is, however, the next logical step in the evolution of spaceflight. The Shuttle with its inherent capabilities to support on-orbit assembly provides the opportunity to accomplish future space objectives without the cost of developing a new launch vehicle. In the late eighties and nineties, we can reasonably expect to see on-orbit repair and assembly as well as payload retrieval and return as a major utilization of the Shuttle system.

CARGO INTEGRATION

The Shuttle era introduced a new level of complexity to the cargo services and integration as compared to that previously encountered for expendable launch vehicles. This complexity was introduced both by the choice of missions to be serviced and by the necessary Shuttle vehicle and mission design.

Expendable launch vehicles have traditionally provided transportation to a given orbit, separation, and a few discrete commands or functions. The payload shroud was RF transparent or a parasitic antenna was used to enable the payload to use its own data system during combined operations. Vibration, accoustic, and dynamic loading environments from the launch vehicle constituted the major design and analysis activities for the payload as regards integration with the launch vehicle. Thermal interaction between the payload and launch vehicle was minimized by the relatively short period of the combined flight.

The Shuttle design and operation for mixed payloads requires consideration not only of the launch environment but also of the thermal environment of significant time period of combined operations on-orbit. In addition, the payload has to be prepared to withstand the landing environment in the event of a mission abort. Since the Orbiter midbody and payload bay doors are non-RF transparent, payload command and data services must be provided through the Orbiter systems. The extended operations period usually indicates the use of Orbiter-supplied electrical energy until payload separation from the Orbiter,and the manned operation of the Orbiter indicates payload design requirements and command and data interfaces between the Orbiter and payload to assure safety of the Orbiter and flight crew. For the attached or sortie payload, the integration becomes even more complex in that the Orbiter is required to provide payload cooling and additional command and data services, as well as extensive flight crew involvement. Each of the payload-to-Shuttle interfaces and services creates its own requirements for meetings, definitions, plans for verification, etc. In order to manage this activity for the Space Transportation System and to assist the user in the cargo integration process, the NASA has created offices at the Johnson Space Center and the Kennedy Space Center. The basic operations for payload integration are defined in JSC 14363, Shuttle/Payload Integration Activities Plan. Further, the NASA has developed standard payloads accommodations definitions in JSC 07700, Volume XIV, and has developed a standard Payload Integration Plan for deployable-type payloads in JSC 14029. Although appearing somewhat arbitrary from the user point of view, it provides a level of economic protection for the user and the NASA. We believe this provides a reasonable compromise of integration cost versus mission assurance from a launch services point of view for the Shuttle vehicle as we understand it today.

In previous launch vehicle programs, the performance and services have generally improved with the maturity of the program. Undoubtedly, this will be the case for the Shuttle also. There are definitive plans to improve the Shuttle boost performance. Our development tests and operational experience will improve our knowledge of the Shuttle's capability to provide payload services. The development of payload retrieval and on-orbit assembly techniques will introduce an era of space operations and provide a firm foundation for future space programs. On the other hand, we must be realistic about the economics of the use of the Space Shuttle and strive to control integration cost for both the Government and commercial users. For the commercial user, this will be reflected in a lower launch cost. For the Government user, it is reflected in the ability to accomplish more objectives with the allocated funds. This will likely take the form of a more rigorous pursuit of the standard integration process, simplified or reduced analytical services, and a reduction in the interface services performed by the Orbiter. It also means that those users who drive the system beyond its existing performance capabilities may well find their programs in jeopardy for economic reasons.

Today's technology offers us the opportunity to develop Shuttle and/or payload systems which can be operated without the heavy dependence on Orbiter avionics services. The NASA has performed preliminary studies of alternative onboard microprocessor-based command and data functions which are independent of the Orbiter computers and data systems. This approach does not provide a payload real-time data service to the ground for launch and entry and provides on-orbit service only when the Ku-band can be used to communicate with the TDRS satellite. While this is a reduction in services, it offers simplified interfaces and the opportunity for a payload to develop and verify its command and data services largely independent of the Shuttle. Think of the cost advantage to both the user and the NASA.

SUMMARY

We have attempted to provide a view of future Shuttle payload capabilities and constraints. The discussion, by necessity, has been limited, and we could have selected other topics of interest. In summary, there are a number of planned activities to increase Shuttle performance to fully realize the Shuttle potential. One of its greatest potentials, however, is economic operations through reuse of the Orbiters and SRB's standardization of operations. This inevitably means less than optimum performance for many missions in the interest of balancing the performance/cost equation. Here we need the support of the Shuttle user. Our joint challenge for the future is to develop realistic performance requirements, simplified interfaces, and integration techniques to control the cost of Shuttle operations and payload integration for our mutual benefit.

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SPACE SHUTTLE CAPABILITY EVOLUTION REFERENCE MISSION

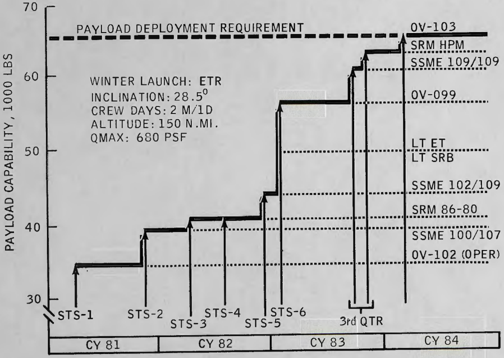

Figure 1

ORBIT INCLINATIONS

	28.5°	40°	57°	70°	98°	104°
ETR	65,000	60,000	50,000			
WTR				52,000	32,000	28,000

RANGE OF ORBIT INCLINATIONS FROM ETR

RANGE OF INCLINATIONS FROM WTR

PAYLOAD POTENTIAL TO 150 NM CIRCULAR ORBIT FOR A RANGE OF INCLINATIONS

Figure 2