The Role, Rationale, and Economics of a Shuttle Derived Cargo Vehicle

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ABSTRACT

The Space Transportation System is now operational and a new evolution of space activities is emerging. Space is an international frontier and will be pursued by many nations, individually and collectively. Commercial exploitation of space systems is increasing with international breadth.

Launch services, formerly a government provided function, also are encountering an evolution. International competition is keen and plans proliferate for private industry involvement in this vital element of the space flight scenario.

The United States has made good its commitment to develop and bring into operational status a STS to meet its own need as well as to provide launch services to industry and other nations.

The STS has tremendous growth potential utilizing existing flight elements, production capacity, logistics systems and launch/flight operations facilities. This paper describes the growth potential, develops a rationale for a Shuttle Derived Cargo Vehicle and illustrates its role as well as the economic implications of its addition to the STS inventory of launch systems.

INTRODUCTION

The United States is entering a new era in launch vehicles with the very successful completion of the design, development, test and evaluation (DDT&E) phase of the Space Transportation System. It can be readily projected, based on the history of launch vehicles, that the shuttle configuration will evolve over time, that its basic concepts will find operational use for several decades and that a number of factors will interact to produce specific derivatives of the original configuration.

The evolution of space launch vehicles in the past has been motivated by increasing payload weights, volumes, and economics. This is reflected by Figure 1 in which specific launch cost trends, developed by Messerschmitt-Bolkow-Blohm (MBB) for an ESA study, are shown. Therefore, it is reasonable to assume that the same motivations will govern the development of launch vehicles in the Space Transportation System (STS) era. For example, there is an increasing recognition that later in this decade, additional investments will be required to support the growth in volume and weight of payloads to geosynchronous earth orbit (GEO). To satisfy these future requirements, the U.S. space launch program must remain economically attractive to be able to continue to support the growing U.S. commercial and international market.

The four reusable Space Transportation System (STS) Orbiter vehicles now planned were originally expected to be able to place DOD and NASA payloads into low earth orbit and have sufficient operational capability to launch other domestic, foreign and international payloads.

However, current forecast of requirements and capability indicate that even the total capability of a five orbiter STS program, the ESA Ariane, and the continuation of some of the current U.S. expendable launch vehicle fleet will be marginal in meeting the requirements in the late 1980's and the Free World's total launch capability will be inadequate to meet the demand of the 90's and beyond.
Accordingly, it is imperative that the possibilities for the evolution of the U.S. space launch capabilities in the STS era be reviewed from the standpoint of maintaining economical space operations.

**LAUNCH DEMAND PROJECTIONS**

The NASA uses a space transportation Traffic Model, formerly Mission Model, as support for planning and budgetary estimates which list the launch site and the flight rate by user. Since the inception of the STS, the model has been changed periodically to reflect the NASA's understanding of the user community's needs and the availability of the STS to meet those needs.

This STS model is sometimes misinterpreted to say that it portrays users' requirements. While it does incorporate the NASA's understanding of those requirements as they can be satisfied by the STS, it is not required to cover the full breadth of the users' needs - nor is that its purpose. The basic purpose is to assist the NASA budgeting/planning function for the STS.

Determination of the total requirements for space activity from the user's perspective remains a much more elusive task. In the near term, 3 to 5 years, existing launch vehicle manifests can be used to establish reasonably firm requirements. To this point, users have made sufficient commitments to be included on the schedule. Beyond 5 years, these requirements are usually not well enough defined to be discussed outside of the particular user's organization.

For the purposes of this assessment, user requirements were developed primarily from NASA and AIAA projections (References 1 and 2). A summary of the projections are shown in Figure 2. Two user requirements models are shown - low and high - to bound the anticipated demand.

Basically, the low model supports limited new NASA space program starts, assuming funding constraints. The commercial portion of the low model is dominated by the AIAA projection of a continued 15% annual growth in communications on orbit capability - possibly a very conservative estimate. The high model considers a more favorable economic climate for NASA and other civil government and international science programs, including support of a manned space station. In the commercial environment, the high model projects a 20% per year growth, starting in 1990, including orbit materials processing and manufacturing.

**LAUNCH VEHICLE AVAILABILITY**

The Western World's space launch capability currently consists of the STS, Titan, Delta, Atlas, Scout, ESA's Ariane, India's SLV-3, and Japan's N-1 and N-2 launch vehicles. The Scout and Scout class vehicles are not considered in this assessment because of the relatively low performance capability in comparison to the others. Japan and India are each developing larger, Delta class launch vehicles which should be ready for service in the early 1990's.

The purpose of this assessment is to identify the availability of launch vehicles which could satisfy user's scheduled requirements through the year 2000.

**STS Assessment**

The NASA Space Transportation Operations Traffic Model, 1 March 1982, has two options through 1994: a "24" option and a "40" option. The 24 option builds through 1988 to a maximum annual flight rate of 24 flights per year with a fleet of 4 orbiters. The 40 option builds through 1991 to a maximum flight rate of 40 flights per year; however, this requires the funding of the fifth orbiter in FY 1983, which has not been approved to date. Both of these options are shown on Figure 2. It is evident that neither option can satisfy the user launch requirements with STS alone. Thus, one must consider additional expendable launch vehicles to accommodate the projected user demand.

**ELV Status**

Each ELV total launch rate availability, as shown in Figure 3, was determined using present production program plans, the overall historical launch records, and launch rates consistent with the existing launch pads.

To provide a common base for comparison, total launch rate for each ELV is plotted in Orbiter-equivalent terms. This equivalency was established by the AIAA (Reference 2). The resulting equivalent orbiter flights for each ELV are also shown in Figure 3.

Titan. The Titan is capable of a maximum of 4 launches per year per launch pad. There is one launch pad for the Titan IIIC (34D) at ETR and two launch pads at the Western Test Range (WTR) - one for Titan IIIB (34B) and one for Titan IID (34D). Thus, a buildup to 12 flights per year is possible. The current planning date of Titan termination is at the end of 1987. It
should be acknowledged however, that commercial launchings of Titan are currently in progress.

Delta. The Delta is to be phased out early in the STS era, but may sustain new life due to STS launch rate uncertainties and the backed up launch demand for its services. A total of 12 flights per year is the maximum anticipated for the Delta, using two launch pads at ETR and one pad at WTR. Termination is planned for 1987.

Atlas/Centaur. Atlas/Centaur is currently scheduled to support Intelsat missions through 1985 with no further committed missions; however, FleetSatCom is a strong potential customer through 1987. A total of 10 flights per year is achievable for the Atlas/Centaur out of two launch pads at ETR.

Ariane. The Ariane launch availability was determined by the advertised intentions of the launch agency, Arianespace. They are building to a 2 launch pad capability at Kourou by 1985. The Ariane 3 is scheduled to come on line in 1984, and the Ariane 4 in 1986. The build up rate reflects this phase in, with a maximum of 12 launches per year being reached in 1988.

Japan and India. Both nations are working on a Delta-class capability, with an estimated availability early in the 1990's. At this time, it appears that this capability will be used to satisfy indigenous needs. Figure 4 reflects a 1 Orbiter equivalent (4 Deltas) flight rate through the 90's for these countries.

**LAUNCH CAPABILITIES VS USER DEMAND**

The maximum combined ELV and STS annual launch rate is shown in Figure 4. As indicated, the maximum launch rate is 50 orbiter equivalent flights per year. However, the data displayed assumes the most optimistic forecast for the launch vehicles - 100% scheduling and availability. If in fact, the schedule for the ELVs and STS follows launch system historical trends, as well as aircraft fleet operational experience, and assuming the Ariane follows that pattern, an overall reduction in launch rates by about 25% are anticipated. Therefore, a more realistic picture is portrayed in Figure 5 which reflects launch vehicle availability under expected realistic conditions.

Under these conditions, even if all launch vehicles are maintained at these expected rates, user requirements will exceed the launch vehicle availability by 1990 for the high model and by 1993 for the low model.

While maintaining the current U.S. ELV fleet to augment the STS appears to be a temporary solution, it is not a viable approach to meeting the user requirements in the 1990s. It is essential that an economical and responsive unmanned launch vehicle be developed to augment the STS. The most promising solution is a launch system based on existing STS elements, namely a Shuttle Derived Cargo Vehicle (SDCV).

**SDCV CONFIGURATIONS**

All SDCV configurations presented here share a common STS major element heritage: the external tank (ET), Space Shuttle main engines (SSMEs), solid rocket boosters (SRBs) and, to a major extent, orbiter avionics. Cost advantages accrue from shared STS/SDCV production, logistics and operations base and provide a near term heavy lift performance capability while avoiding major new DDT&E expenditures.

**SDCV Side Mount Configuration**

The SDCV Side Mount configuration, shown in Figure 6, retains the standard ET and 2 SRBs. A cargo carrier, consisting of a recoverable propulsion/avionics (P/A) module and an expendable payload (P/L) module, replaces the orbiter in the STS stack. The P/L module is capable of supporting payload up to 25 feet in diameter and 90 feet in length. The P/A module contains the main (3 SSMEs) and secondary propulsion systems, avionics, electrical power, auxiliary power and thermal control systems. Reentry and recovery systems include the aeroshell structure, thermal protection system, parachutes, retrorockets, and landing gear. The SDCV Side Mount performance to a reference 28.5° 160 NM circular orbit is approximately 150,000 lbs.

**SDCV Inline I Configuration**

The SDCV Inline I, shown in Figure 7, incorporates a shortened ET as the structural backbone. Two standard SRBs, a P/A module and a forward mounted payload shroud are all attached to the ET. The payload shroud can house a payload of up to 25 feet in diameter and 75 feet in length. The P/A module is functionally identical to the SDCV Side Mount configuration discussed previously; however, only 2 SSMEs are employed. The Inline I performance to the referenced 28.5° 160 NM circular orbit is approximately 150,000 lbs. A 3 SSME P/A module Inline I configuration would have a 195,000 lb. payload capability.
SDCV Inline II Configuration

The SDCV Inline II is a growth version of the Inline I. The Inline II, shown in Figure 8, incorporates a stretched ET, 2 standard SRBs and a total of 4 SSMEs housed in 2 P/A modules—identical to that of the Inline I. The payload shroud can house a payload of up to 33 feet in diameter and 100 feet in length. The Inline II performance to the referenced 28.5° 160 NM circular orbit is about 240,000 Ibs. Growth potential exists for Inline II by using 3 SSMEs in each P/A module and would result in a payload capability of over 300,000 lbs.

Performance Comparison

Figure 9 depicts the performance of the SDCV configurations up to equatorial geosynchronous orbits. The performance characteristics assume a single stage expendable integral SDCV LO₂/LH₂ upper stage properly sized to maximize the payload delivery capability. Performance characteristics of the STS and Saturn V are also shown for comparative assessment.

ECONOMIC BENEFITS

An analysis was performed to determine the life cycle cost (LCC) benefits of introducing SDCVs into the overall space transportation system to complement the orbiter fleet in satisfying the launch demand. Costs were estimated for all program phases—DDT&E, production, and operations. Additional orbiters were assumed to be acquired in a time phased manner to enable the "STS Only" to accommodate the user demand models and, in the case of the mixed STS/SDCV fleets, two additional orbiters were procured to accommodate the user demand until the SDCVs became available in the early 1990s.

The results of the analysis are shown in Figure 10 and graphically illustrates the significant savings potentially available through the incorporation of SDCVs to complement the STS.

Also, from the user point of view, the cost per pound, or volume, of payload delivered to orbit is substantially reduced as a result of the SDCV performance capability.

SDCV PROGRAM DEVELOPMENT SCHEDULE

A representative SDCV hardware development schedule was prepared to include the period of time from the authority to proceed (ATP) for a Phase C/D contract through certification of initial operational capability (IOC) of the overall SDCV program. This schedule, as shown in Figure 11, includes a typical Phase A/B time span as a reference point of departure.

For present planning purposes, one flight demonstration is baselined prior to certification of IOC and it is anticipated that the first flight unit will undergo a flight readiness firing (FRF) analogous to that conducted for STS-1.

The schedule indicates that, in order to have SDCVs on-line by 1991, a Phase C/D hardware development program must be initiated in 1985.

PAYLOAD GROWTH PROJECTION

The SDCVs provide an additional benefit to the user community through its capability to accommodate payloads beyond that provided by the orbiter — both in volume and weight. NASA Space Systems Technology Model, Reference 3, contains NASA system and program requirements, technology trends, and forecasts for space technology. The model provides a base of information for guiding technology development for future systems and programs. A review of this model reveals numerous payload requirements which exceed the performance capability of the present STS as summarized in Table 1.

With respect to DOD, again many programs are projected which would benefit from SDCV enhanced launch capabilities. For example, consider the development plan for MILSTAR under the current ground rules (Reference 4). The payload concept is currently constrained to the 5,000 lb. geosynchronous performance of shuttle/IUS. The final operating configuration will weigh approximately 10,000 lbs. and will require two launches per satellite. Thus, a constellation of 12 satellites will require 24 launches and cost approximately $2 billion in launch costs, not including IUS costs.

With an SDCV only eight launches are required. The cost would be under $0.7 billion, thereby, reducing the DOD budget for the MILSTAR program by over $1.3 billion. This situation is representative of user cost considerations for GEO missions.

The Space Based Laser (SBL) program represents another good example. As indicated in References 5 and 6, the SBL requires diameters of 8 meters, or greater, depending on the power requirements and would weigh around 150-250K lbs. A typical fleet size might consist of 18 spacecraft;
thus, the STS launch requirements become excessive. Use of the SDCV with its greater weight and size capability would not only reduce the number of flights, but also the complexity of payload design.

OBSERVATIONS

To date the baseline STS program consists of a four orbiter fleet to provide launch services through the 1990s. Based on the projected user demand, the four orbiter fleet will only accommodate NASA and DOD requirements for the low model. Thus, the commercial market is largely left to be accommodated, to a major extent, by ELVs either government supported or funded by the private launch vehicle sector.

This is reflected by the increased interest within the private sector. For example, Dr. Klaus Heiss president of Space Tran, Inc. recently said "the lack of government funding for orbiter five should in no way prejudice the need for a commercial orbiter. Clearly, the country needs a fifth orbiter if the U.S. wants to capture its share of the commercial world space transportation market. It should not be left to foreign competition unchallenged." Foreign competitors now include ArianeSpace, and will include Japan, India, and Russia. Japan and India will have the potential for providing launch services to other countries. Russia has proposed to fly the Inmarsat maritime communications satellite for the European Space Agency (ESA) and is interested in establishing a marketing agent outside the Soviet Union.

The challenge to the foreign competition is surfacing through various private sector proposals to extend the useful lifetime of the present U.S. ELV fleet under private management - Transpace Carriers, Inc. for the Delta; General Dynamics Corporation and Space Services, Inc. for the Atlas Centaur; and Martin Marietta Corporation for the Titan. However, these programs will continue to use today's state of the art.

It is interesting to note that the ESA has approved funding for new space transportation systems' long term preparatory program which will study options beyond Ariane "in sufficient detail to lay down a long term policy and thus decide on new space transportation programs before the end of 1985." The priority of the European community is to maintain independent launch capability that meets foreseeable requirements of European and other users and is competitive with existing or planned systems. Therefore, the U.S. must also continue to maintain its role as a leader in space through the study and development of launch systems using our present high technology base incorporated within the present STS. This goal is best achieved by SDCVs.

Figure 12 illustrates two potential paths for the SDCV. Granted, if one considers the potentials beyond the mid 1990's other options are feasible such as a liquid rocket booster replacement for the SRB. However, it avoids the pivotal issue of a system to be operational in the early 1990's to meet the highly probable and very competitive market that will exist for space transportation.

The key issue that needs resolution in the immediate future is which course to follow; the SDCV Side Mount concept which would have minimum impact on the STS program, require the least investment and could be operational at the earliest date - recognizing that it has limited growth potential - vs the SDCV Inline approach which could result in a family of SDCV's to accommodate forecasted market and provide the growth potential to cover major new needs that have as yet not surfaced. The Inline approach will have somewhat more of an impact on the STS system, facilities and operations, but at the same time will draw heavily on the technology, production, logistics and operations currently in place.

In summary, the SDCV compliments the STS, provides the U.S. the most attractive method to meet forecasted space transportation needs in the most economical way. It takes advantage of the STS investment and has the potential of keeping the U.S. in the best competitive posture for the 1990's.

The SDCV is a low risk, low cost development and is economically attractive. The time to act is now if we are to retain the U.S. prominence in the 1990's.

REFERENCES

Figure 1. Launch Cost Trends - 1980 $

Figure 2. Launch Demand/STS Launch Projections
Figure 3. Maximum ELV Launch Availability
Figure 4. Maximum Combined Launch Rate

Figure 5. Launch Capabilities vs User Demand
Figure 7. SDCV Inline I Configuration
Figure 8. SDCV Inline II Configuration
Figure 9. Launch Vehicle/Upper Stage Performance Capabilities

Figure 10. Cumulative Costs Through Year 2000
### Potential NASA Programs in the 1990s

#### PAYLOAD WEIGHT

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**Figure 11. SDCV Program Schedule**
Figure 12. SDCV Development Options