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Paper Session III-A - STS Derivative Cargo Vehicles for the 1990's Decade and Beyond

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**STS Derivative Cargo Vehicles for the 1990’s Decade and Beyond**

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**Abstract**

Currently planned U.S. civil space activities for the late 1990’s into the early 2000 time period will require the development of a new earth-to-orbit unmanned cargo vehicle(s). This system will be designed to support an aggressive space activity, including Space Station Freedom and eventually lunar/planetary exploration programs. Primary mission needs include increased cargo weight and volume capability and lower operating costs.

A mid-90’s unmanned cargo vehicle (Shuttle C), which utilizes existing space-qualified STS booster elements, is currently being designed for delivery of 100K-150K lbs to low earth orbit. Variations of this design plus other concepts that offer very large lift capability of 200K-300K lbs, still utilizing STS booster elements, will be discussed. An evolutionary pathway, based on STS booster elements, is practical for providing heavy lift capabilities of 100K-300K lbs.

**Introduction**

President Bush, in his July 20, 1989 space policy speech, proposed a long-range, continuing commitment to space exploration and development – including going back to the Moon and establishing a permanent manned lunar base, and then manned missions to Mars.

NASA has recently completed a preliminary, 90-day study on human exploration of the Moon and Mars. This study divided the overall space transportation system into three logical phases: (1) transportation between Earth and low earth orbit, (2) transportation between low earth orbit and lunar or Mars orbits, and (3) transportation between lunar or Mars orbits and their surfaces.

This paper addresses the first phase, between Earth and low earth orbit (LEO), of space transportation for the lunar/Mars new initiative, and describes candidate unmanned heavy-lift launch vehicles to support the lunar/Mars mission requirements. The NSTS (space shuttle) is used for crew rotation and some limited cargo/logistics support. Current or planned expendable launch vehicles are used to support the precursor or robotic missions. However, a new heavy-lift vehicle, or family of vehicles, capable of lifting from 45t (100,000 lbs) to 140t (300,000 lbs) per flight to low Earth orbit is required to carry up the space transfer stages, propellant, and cargo/surface systems. Both shuttle-derived and advanced launch system (ALS)-derived vehicles were investigated in some depth in the 90-day study with a shuttle-derived set of vehicles selected as the “reference” Earth-to-orbit transportation system for purposes of comparing and evaluating various lunar/Mars program options. These shuttle-derived vehicle options and their evolution are described herein for both the lunar outpost and the Mars outpost missions.
Lunar Outpost

In support of the lunar outpost mission, the Earth-to-orbit (ETO) transportation system must ferry vehicles, cargo, crew, and propellant to Space Station Freedom (SSF), where it is then assembled for launch to the Moon by a lunar transfer vehicle (LTV). The mass requirement for payload delivery to SSF for each mission in support of the lunar outpost is shown in Figure 1, and broken out for lunar cargo flights and lunar piloted flights. Mass requirements shown for piloted flights include cargo in addition to the mass of the crew. Approximately 70-to-75 percent of the mass delivered to LEO is LTV propellant which can be carried to LEO in a shuttle-size (4.6m diameter) shroud. However, a larger diameter shroud is required to accommodate the LTV aerobrake and the lunar excursion vehicle (LEV). A 7.6m diameter shroud was chosen, compromising between design requirements on the ETO launch vehicle and the design complexity/in-orbit assembly of the aerobrake and LEV stage.

![Figure 1. Mass Delivered to LEO](image)

The Shuttle C, a shuttle-derived unmanned launch system currently being studied by NASA, has the capability to accommodate the lunar outpost mission requirements and was selected as the reference vehicle. Two versions of this vehicle are required - the standard Shuttle C with a 4.6m diameter shroud and a Block I Shuttle C which carries a 7.6m diameter shroud (Figure 2). These vehicles are described in more detail in the following text.

The Shuttle C is a largely expendable, unmanned launch system capable of carrying payloads up to 71t (156,000 lbs) to a 407-km (220 n. mi.) circular orbit at 28.5° inclination. Shuttle-C is not a new system, but rather an expansion of our current STS Program (Figure 3). It uses existing and modified STS qualified systems and the established STS infrastructure to achieve the earliest possible heavy-lift capability. The only new element is the Shuttle-C cargo element (SCE) that replaces the orbiter. Some design and definition work is required, but it is a relatively straight-forward concept that uses many existing components. A key aspect is that the payloads can be interchanged with the STS orbiter. The extended payload bay is 25m long and 4.6m in diameter and has orbiter-like doors. The SCE comprises a circular payload carrier attached to a new boattail, based around the STS main propulsion system (MPS) and engine thrust structure. The new boattail uses a less complex and cheaper design approach, including an integrated orbiter OMS/RCS system and use of all aluminum and steel construction. This approach, together with the simple cylindrical geometry, results in
production cost reductions and lower costs per pound of payload to orbit. In addition to the MPS, the boattail houses the internally mounted auxiliary propulsion system (rather than the external pods used on the orbiter) and a lower cost avionics system. Shuttle-C can be launched with either the redesigned SRB’s (RSRB’s) or the new, advanced SRB’s (ASRB’s) and is designed for either the two- or three-space shuttle main engines (SSME’s). The SSME’s will complete their life cycle on Shuttle-C after being used for many missions on the STS orbiters.

**Figure 2. Shuttle Derived Lunar Launch Vehicles**

**Figure 3. Shuttle-C**
While the Shuttle-C is being used to support the SSF buildup, development for a 2001 block change in support of a lunar outpost will be in work. The Shuttle-C/Block I, shown in Figure 4, will be a natural follow-on to Shuttle-C and will utilize the ASRB’s and a slightly modified ET (beefed-up interfaces). Two payload carrier configurations are required to meet the lunar ETO manifests. The 4.6m diameter version used on the basic vehicle maximizes propellant and high-density payload delivery to orbit. A 7.6m version is required to accommodate delivery of the low weight but large diameter LTV aerobrake and LEV stage elements. The basic Shuttle-C boattail configuration will be utilized for both the 4.6m- and the 7.6m-diameter payload carriers. The lift capability, to SSF orbit, of the 7.6m Shuttle-C is 61t (134,000 lbs). A recoverable propulsion/avionics (P/A) module to replace the expendable boattail is currently under consideration.

Figure 4. Shuttle-C Block I

Facility requirements and operations for the ETO launch vehicle will be driven by flight rates and the selected vehicle configurations. Figure 5 illustrates the launch site operations flow for the baseline lunar ETO launch vehicles. Current STS facilities support 14 flights per year. Several modified and new facilities are required to support the ETO vehicles which reach a combined STS and Shuttle C flight rate of 19 per year by 2004. These facilities include the Shuttle C cargo element processing facility (CEPF), an additional MLP, a cargo element (CE) transporter, reactivation of the Vertical Assembly Building (VAB) high bay 2, and a solid booster stacking facility (SBSF). Stacking of the SRB’s in the VAB is currently a bottleneck in the flow, and the new facility will be required once the combined STS/SDV launch rate exceeds 14 per year. Only minor modifications to the existing launch pads are needed to provide cryogenic handling and storage capability for the propellant delivery missions. A new mobile service structure (MSS) is needed, however, since the cargo element of the Shuttle-C/Block I vehicle precludes use of the existing rotating service structure (RSS) for on-pad access to the vehicle systems.
Mars Outpost

The ETO transportation requirements for the Mars outpost require a launch vehicle with an expanded payload volume and a lift capability approximately double that required for the lunar missions. The vehicle concepts shown in Figure 6 are candidates to support the Mars mission. The STS-derived HLLV option is considered the reference and is capable of delivering 140t (300,000 lbs) to SSF with a payload envelope of 12.5m diameter by 30m long. This vehicle uses four ASRB’s as first stage boosters and five SSME’s in a recoverable P/A module mounted to a 10m diameter core stage. After main engine cut-off, the core stage will separate from the payload and a small kick-stage will transfer and circularize the payload at the required orbit. Following core separation, the P/A module will separate from the core stage and return to Earth for subsequent reuse.

Other Mars HLLV’s considered include two additional versions of STS evolution, both sidemounted and inline, and three liquid-booster vehicle concepts. The two STS evolution vehicles utilize a third stage of approximately 79t (175,000 pounds) propellant load to boost the quoted payload mass into orbit. The STS/ALS evolution vehicle consists of an ALS-type core stage with four STS-compatible liquid boosters. The candidate ALS vehicle utilizes three liquid boosters strapped around a core stage. The final vehicle, from a previous study exercise, represents a large LOX/hydrocarbon booster HLLV.
The Mars HLLV (MHLLV) requires substantial launch site enhancements (Figure 7) including building a new launch complex; two new-design MLP’s; reactivation of VAB high bay 4; an HLLV core-stage processing facility to assemble the large vehicle and to turnaround the reusable propulsion/avionics module; a Mars payload processing and integration facility; a vertical transporter to
deliver the cargo/shroud assembly to the VAB; and a new crawler-transporter to deliver the vehicle to the launch pad. A launch rate varying from 2 to 5 Mars HLLV launches per year (beginning in 2013) is required to support the currently defined Mars missions. Total launches per year of STS, Shuttle C, and Mars HLLV never exceed 21 in any one year.

Development of the reference, shuttle-derived, Mars HLLV requires a significant investment in new vehicle hardware and launch facilities, with the large core stage being the major new hardware item. In an attempt to minimize the initial development costs, an alternate approach was investigated which builds on the lunar HLLV through the addition of a third stage that is subsequently used as a Mars transfer vehicle. This approach, as depicted in Figure 8, results in approximately a 30 percent total ETO vehicle cost savings over the reference lunar/Mars ETO vehicle, with the lunar HLLV now being the major development item. The new third stage costs are charged to the Mars transfer vehicle development. For delivery of large, low-density Mars vehicle elements, a 10-meter diameter by 30-meter long shroud will also be developed.

The development of a liquid rocket booster (LRB) to replace the STS solid booster would provide additional capability and mission flexibility to the STS and the shuttle-derived vehicle family, such as increased safety and reliability, increased payload capability, enhanced mission operations/abort capability, and improved environmental conditions. Additionally, the LRB would be directly applicable to the ALS and new stand-alone-type launch vehicles.

![Figure 8. Shuttle Derived Launch Vehicle Approach for Lunar/Mars Initiative](image-url)

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<tr>
<th>Pre-Lunar</th>
<th>Lunar</th>
<th>Mars</th>
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<td>Shuttle-C</td>
<td>Shuttle-C Blk I</td>
<td>2 Stage HLLV</td>
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<td>• 7.6m x 27m P/L Envelope</td>
<td>• 12.5m x 30m P/L Envelope</td>
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<td>• 3rd ET</td>
<td>• Mod. ET</td>
<td>• 4 x ASRM’s</td>
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<tr>
<td>• 3 x SSME’s</td>
<td>• 61t P/L Cap.</td>
<td>• New LOX/LH Core Stage</td>
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<td>• 4.6m x 25m P/L Envelope</td>
<td>• 711 P/L Cap.</td>
<td>• 5 x SSME’s</td>
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<tr>
<td>Shuttle-C</td>
<td>SDV (Inline)</td>
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<tr>
<td>• 7.6m x 27m P/L Envelope</td>
<td>• ET Derived Core Stage</td>
<td>• 3 Stage Common w/MTV</td>
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<td>• 3 SSME’s</td>
<td>• 3 SSME’s</td>
<td>• 4 x SSME’s Core Sig</td>
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Figure 8. Shuttle Derived Launch Vehicle Approach for Lunar/Mars Initiative
Summary

Several vehicles were investigated in support of the lunar/Mars initiative. The shuttle derived vehicle approach provides a clean evolutionary path for launch vehicles for the next twenty-five years, while offering operational commonality with established national investments, thus minimizing the near-term costs which will likely be an important factor as a number of programs may be vying for the available funds during this period. For these reasons, shuttle-derived launch vehicles are an excellent choice to support President Bush's commitment to space exploration.