FOREWORD

This report, prepared by Martin Marietta Corporation, is submitted to George C. Marshall Space Flight Center, National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Alabama, in response to the DR-6 requirements of contract NAS8-37856, Space Transfer Vehicle Concept and Requirements. It is the DR-6 identified in Data Procurement Document No. 709.
# GLOSSARY

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<th>Definition</th>
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<tr>
<td>ACC</td>
<td>Aft Cargo Carrier</td>
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<tr>
<td>ACS</td>
<td>Attitude Control System</td>
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<td>AFE</td>
<td>Aeroassist Flight Experiment</td>
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<tr>
<td>Al-Li</td>
<td>Aluminum Lithium</td>
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<td>ALS</td>
<td>Advanced Launch System</td>
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<td>APCM</td>
<td>Advanced Programs Cost Model</td>
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<tr>
<td>ASE</td>
<td>Airborne Support Equipment</td>
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<tr>
<td>ATLO</td>
<td>Acceptance, Test, Launch, and Operations</td>
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<tr>
<td>ATR</td>
<td>Advanced Technology Roadmap</td>
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<tr>
<td>BOE</td>
<td>Basis of Estimate</td>
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<tr>
<td>C&amp;DM</td>
<td>Configuration and Data Management</td>
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<tr>
<td>CAD</td>
<td>Computer-Aided Design</td>
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<tr>
<td>CDR</td>
<td>Critical Design Review</td>
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<tr>
<td>CER</td>
<td>Cost Estimating Relationship</td>
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<tr>
<td>CG</td>
<td>Center of Gravity</td>
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<tr>
<td>CLAAS</td>
<td>Closed-Loop AeroAssist Simulation</td>
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<tr>
<td>CNDB</td>
<td>Civil Needs Data Base</td>
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<tr>
<td>COLD-SAT</td>
<td>Cryogenic Onorbit Liquid Depot Storage, Acquisition, and Transfer Satellite</td>
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<tr>
<td>CSLI</td>
<td>Civil Space Leadership Initiatives</td>
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<tr>
<td>DDT&amp;E</td>
<td>Design, Development, Test, and Evaluation</td>
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<td>DOD</td>
<td>Department of Defense</td>
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<td>DR</td>
<td>Data Requirement</td>
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<td>Design Reference Missions</td>
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<td>ETO</td>
<td>Earth-to-Orbit</td>
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<td>ETR</td>
<td>Eastern Test Range</td>
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<tr>
<td>GEO</td>
<td>Geosynchronous Earth Orbit</td>
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<tr>
<td>GN&amp;C</td>
<td>Guidance, Navigation, and Control</td>
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<tr>
<td>GPS</td>
<td>Global Positioning Satellite</td>
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<td>GSE</td>
<td>Ground Support Equipment</td>
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<tr>
<td>H/W</td>
<td>Hardware</td>
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<td>I/F</td>
<td>Interface(s)</td>
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<td>ILC</td>
<td>Initial Launch Capability</td>
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<td>IMU</td>
<td>Inertial Measurement Unit</td>
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<tr>
<td>IR</td>
<td>Interim Review</td>
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<tr>
<td>IR&amp;D</td>
<td>Independent Research and Development</td>
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<td>IRD</td>
<td>Interface Requirements Document</td>
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<td>KSC</td>
<td>Kennedy Space Center</td>
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<tr>
<td>L/D</td>
<td>Lift-to-Drag Ratio</td>
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<td>LAD</td>
<td>Liquid Acquisition Devices</td>
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<td>LCC</td>
<td>Life-Cycle Cost</td>
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<td>LEO</td>
<td>Low-Earth Orbit</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>LeRC</td>
<td>Lewis Research Center (NASA)</td>
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<tr>
<td>LEV</td>
<td>Lunar Excursion Vehicle</td>
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<td>LTV</td>
<td>Lunar Transfer Vehicle</td>
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<td>LV</td>
<td>Launch Vehicle</td>
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<td>MAP</td>
<td>Manifesting Assessment Program</td>
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<td>MDC</td>
<td>McDonnell Douglas Corporation</td>
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<tr>
<td>MLI</td>
<td>Multilayer Insulation</td>
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<td>MMS</td>
<td>Multimission Modular Spacecraft</td>
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<tr>
<td>MSFC</td>
<td>Marshall Space Flight Center</td>
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<td>MSS</td>
<td>Manned Space Systems</td>
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<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
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<td>NASP</td>
<td>National Aero-Space Plane</td>
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<tr>
<td>OTV</td>
<td>Orbital Transfer Vehicle</td>
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<tr>
<td>P/A</td>
<td>Propulsion/Avionics</td>
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<tr>
<td>PDF</td>
<td>Probability Distribution Function</td>
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<tr>
<td>PRD</td>
<td>Preliminary Requirements Document</td>
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<td>RAMP</td>
<td>Risk Assessment and Management Program</td>
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<td>RCS</td>
<td>Reaction Control System</td>
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<td>RFP</td>
<td>Request for Proposal</td>
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<tr>
<td>S/W</td>
<td>Software</td>
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<td>SE</td>
<td>Support Equipment</td>
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<td>SEI</td>
<td>Space Exploration Initiative</td>
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<td>Sh-C</td>
<td>Shuttle-C</td>
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<td>SOFI</td>
<td>Spray-On Foam Insulation</td>
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<td>SSF</td>
<td>Space Station Freedom</td>
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<td>STAS</td>
<td>Space Transportation Architecture Study</td>
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<td>STCAEM</td>
<td>Space Transportation Concepts and Analysis for Exploration Missions</td>
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<td>STIS</td>
<td>Space Transportation Infrastructure Study</td>
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<tr>
<td>STS</td>
<td>Space Transportation System</td>
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<td>STV</td>
<td>Space Transfer Vehicle</td>
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<td>STVIS</td>
<td>Space Transfer Vehicle Information System</td>
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<td>TCS</td>
<td>Thermal Control System</td>
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<td>TEI</td>
<td>Trans-Earth Injection</td>
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<tr>
<td>TMI</td>
<td>Trans-Mars Injection</td>
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<tr>
<td>TPS</td>
<td>Thermal Protection System</td>
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<tr>
<td>TT&amp;C</td>
<td>Telemetry, Tracking, and Control</td>
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<tr>
<td>TVC</td>
<td>Thrust Vector Control</td>
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<td>TVS</td>
<td>Thermodynamic Vent System</td>
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<td>UNIS</td>
<td>Unified Information System</td>
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<td>USRS</td>
<td>Upper Stage Responsiveness Study</td>
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<tr>
<td>VCS</td>
<td>Vapor Cooled Shields</td>
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<td>WTR</td>
<td>Western Test Range</td>
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1.0 INTRODUCTION

The Space Transfer Vehicle (STV) Concepts and Requirements Study has been an eighteen-month study effort to develop and analyze concepts for a family of vehicles to evolve from an initial STV system into a LTS system for use with the Heavy Lift Launch Vehicle (HLLV). The study defined vehicle configurations, facility concepts, and ground and flight operations concepts. This volume reports the program cost estimates results for the this portion of the study. The STV Reference Concept described within this document provides a complete LTS system that performs both cargo and piloted Lunar missions.

Cost estimates have been developed for reference system which meets the program planning schedule, the production buys, and the launch schedule provided by the mission model. In addition, costs have been developed for providing launch capabilities from Space Station Freedom. A description of our cost estimating approach and methodology, summary cost data, cost estimates by Work Breakdown Structure (WBS) element, a funding schedule, and an economic analysis for the STV/LTS have also been included.

The current life cycle cost (LCC) estimate for the recommended concept for the initial STV (summarized in Section 3.1 and discussed in detail in Volume II) which meets the requirements stated in the Systems Requirements Document (SRD) is $10,247.3 M. This includes $624.4 M for the Design Development Test and Evaluation (DDT&E) program, $1205.2 M for the production of 22 vehicles, and $8417.7 M for launch operations for 22 missions. The average mission cost is $437.4 M.

The current LCC estimate for the recommended concept for the LTS (summarized in Section 3.2 and discussed in detail in Volume II) is $88,620.4 M. This includes $23,385.4 M for the Design Development Test and Evaluation (DDT&E) program, $6375.8 M for the production of 9 vehicles, and $58,859.2 M for launch operations for 25 missions. The average mission cost is $2610 M. Details of these estimates are discussed in Sections 2.0 and 4.0.
2.0 APPROACH, METHODOLOGY, AND RATIONALE

2.1 COST ESTIMATING METHODOLOGY

Engineering Economic Analysis (EEA) is an integral decision factor utilized in the STV system definition process. EEA decision support ensures that the cost in each of the program phases, Design, Development, Test, and Evaluation (DDT&E), Production, and Operations and Support (O&S), are all optimized to meet program goals and requirements. Figure 2.1-1 shows that the EEA approach begins early in a program. Cost avoidance studies are utilized in the requirements allocation process to assure interaction among design engineers in all disciplines so that a cost-effective system is derived. The Life Cycle Cost (LCC) of the system is estimated and then analyzed for affordability, cost containment, and cost reduction potential. The entire process is iterated until the cost in each phase is optimized.

![Diagram](image)

**Figure 2.1-1 EEA Project Support Activities**

The Martin Marietta STV cost estimating approach utilizes multiple independent estimates, as shown in Figure 2.1-2. These independent estimates are used to cross check and verify each other. The estimating techniques vary, depending on the amount and type of design or operations data available. The techniques used in this study are:
- Parametric Cost Estimating Relationships
- Historical Analogy
- Industrial Engineering Estimates
- Expert Analysis (Tops-down, Bottoms-up, or Supplier Quotes)

Parametric Cost Estimating Relationships (CERs) were derived for new systems where there was historical data from existing systems that were functionally similar. These CERs take the form of mathematical equations (as shown below) that can be derived through curve fitting techniques applied to historical cost, performance, timelines, and physical parameter data.

1988 $ in millions = 0.135 \times WT (LBS)^{0.868}

The design parameters for the new system (weights, volumes, power requirements, etc.) were estimated and the calculations, with appropriate complexity factors, are made. Project support factors (for Systems Engineering, Program Management, etc.) were added to produce a total program cost estimate.

The historical analogy to existing design uses the historical cost data of a point design to establish the cost of a new item. This technique is normally used where design data is available on a component or at an assembly level. The estimate is accomplished by relating the two designs in terms of technical characteristics and by making a judgement as to the degree of similarity.

Industrial Engineering estimates are production costs built up in terms of material usage and labor operations. Individual piece parts are analyzed to determine the quantity and type of material needed; and the specific operations, such as cutting, grinding, welding, cleaning, and inspection, are identified along with the manpower for conducting each operation. Standard labor, overhead, and General and Administrative rates are then applied to determine the cost. Such an estimate requires a great amount of detail and is therefore more suited to a more firm type of estimate.

The Tops-down expert analysis is often the only means of estimating available, especially if back up data is scarce or nonexistent. This process involves estimates made by the engineers that are the most familiar with the system. A thorough understanding of the rationale involved in the estimate, as well as any assumptions made, are documented and evaluated.

The Bottoms-up expert analysis is the most complete type of cost estimate and involves the most detail. The estimate takes a detailed listing of the tasks to be performed and applies the manpower, labor skill mix, computer units, number of trips, tooling materials, supplies, etc. to them. Specific labor, overhead, and General and Administrative rates are then applied to give a complete estimate.
Supplier quotes are obtained by soliciting experienced suppliers to estimate the cost of an item using specifications of performance and design requirements and definitions of production quantities, rates, and schedules. Wraparound factors are applied to these quotes to include the internal effort to checkout, package, assemble, and ship the hardware.

In the early phases of this STV program, no single estimating technique can be used to cover all aspects of a program cost. Table 2.1-1 lists the primary estimating techniques that were used in developing the STV estimate. For the most part, the costs were based on data contained in a proprietary Martin Marietta database. Also listed in Table 2.1-1 are the techniques that were used to check the reasonableness of the costs. These techniques were used for the work breakdown structure (WBS) elements that historically drive cost such as avionics, software, and operations and they would be used for all elements in the detailed estimates that Martin Marietta prepares for actual hardware development and production.

We have used our vehicle definitions, preliminary development plans and schedules, and the developed WBS (including MSFC inputs) to prepare system cost estimates. All phases of the LCC of the system have been addressed, including DDT&E, facilities, production, and operations costs. We have used our PC-based Advanced Programs Cost Model (APCM) as the tool to develop our estimates. APCM has been used for cost analysis on Phase A programs such as STAS, USRS,
Table 2.1-1 STV Costing Methodology

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<th>Basis of Estimate</th>
<th>Comparative Method</th>
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<td>Historical $/lb, Vendor Quotes</td>
<td>Engineering Estimate</td>
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<tr>
<td>Software</td>
<td>Bottoms-Up, Engr Estimate</td>
<td>Engineering Estimate</td>
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<td>Support Equipment</td>
<td>Analogy, Historical Factor</td>
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<td>Facilities</td>
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<tr>
<td>Operations</td>
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<tr>
<td>Growth and Fee</td>
<td>NASA Supplied Factors</td>
<td>N/A</td>
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</table>

and ALS. It uses historical data from such flight hardware programs as Titan, External Tank, Shuttle, Peacekeeper, Small ICBM, Transtage, and the candidate MLV-II stage to develop cost estimating relationships (CER) based on system parameters. As shown in Figure 2.1-3, the design aspects of the vehicle system elements were used to determine the design and development and first unit costs. Projected flight rates were used to determine the production rates and the number of processing facilities required to maintain the launch schedule. Synergism and commonality between the vehicle elements were accounted for in the production and operations costs by taking advantage of learning and rate efficiencies for larger quantities. Facility costs have been estimated based on size and processing capability. Manpower and work shifts have been varied to simulate a true launch processing environment.

Using the estimates developed by the APCM, STV analyses concentrated on defining the cost driving requirements. Understanding the difference between a high-cost area and a cost driver is critical. Knowing only the high cost areas aids little in reducing costs. The engineers must also know which requirements are influencing the cost so that the design will avoid the costly requirements.

In order to understand which requirements are influencing cost, sensitivity analyses are conducted on various requirements, such as responsiveness. Sensitivity analyses serve to define the magnitude a variation makes on the cost. If cost is highly sensitive to a requirement, the requirement is termed a cost driver. Sensitivity analyses often will define a "knee" in the cost curve below which a change in the requirement does not affect cost greatly.
The results of the cost driver and sensitivity analyses, along with the cost and schedule risk have been used to identify cost uncertainties and estimate their range of uncertainty. They have been applied to specific system and subsystem trades to ensure that the cost-effective alternatives were identified.

Figure 2.1-3 STV Cost Analysis Methodology

2.2 GROUNDRULES AND ASSUMPTIONS

Groundrules and assumptions were established so all cost estimates could be developed with a common basis. This section documents these in subsections for the general groundrules and assumptions provided by the government (Section 2.2.1), the additional assumptions Martin Marietta found necessary as analysis proceeded (Section 2.2.2), and the groundrules and assumptions for the program phases of non-recurring, production, and integration and operations (Sections 2.2.3, 2.2.4, and 2.2.5 respectively).

2.2.1 Government Furnished Groundrules and Assumptions (MSFC)

1) All cost estimates will be reported in millions of constant FY91 dollars. Only Office of Secretary of Defence (OSD) inflation indices shall be used to develop an FY91 cost base.
2) A 15% weight contingency will be included for cost estimates derived from weight based cost estimating relationships (CER).

3) A 35% allowance will be used to account for growth and changes in the program requirements

4) An 8% allowance will be used for prime contractor fee.

5) A 15% allowance will be used to account for government support beyond the scope of the prime contract.

6) A 0.5% allowance will be used to account for Defense Contractor Administration Service (DCAS) taxes.

7) No separate management reserve or risk cost is to be identified as a separate cost element. All cost risks and uncertainties are to be reflected in appropriate WBS costs.

8) Major cost risks and cost uncertainties are to be identified separately along with the rationale explaining what costs are included or excluded from the WBS baseline.

9) Any additional groundrules and/or assumptions used by the contractor should be explicitly stated.

10) Any deviations from the above groundrules and assumptions should be explicitly stated.

2.2.2 Overall Program Groundrules and Assumptions

These assumptions are in addition to the government groundrules and assumptions presented in Section 2.2.1. The following groundrules and assumptions were used in preparing the cost estimates for the STV Program. They apply regardless of program phase, WBS element, or subsystem allocation.

1) The cost estimates include overhead and general and administrative (G&A) costs.

2) The cost estimates include contractor costs only. No major government support has been included.
3) The schedule used in preparing the cost estimates for the STV included the DDT&E phase from October 1995 to April 2001 (67 months), the production buy of 22 units beginning in April 2000, and vehicle processing at KSC beginning in October 2000.

4) The schedule used in preparing the cost estimates for the LTS included the DDT&E phase from October 1997 to April 2004 (79 months), the production buy of 9 units plus recurring hardware beginning in April 2002, and vehicle processing at KSC beginning in October 2003.

2.2.3 Non-recurring Groundrules and Assumptions


2) Baseline costs are provided for the scenario requiring four Lunar expendable cargo launches and 21 piloted missions over 25 years for the LTS based on the Option 5 requirements, dated December 1989, and the PSS Reference Architecture Document 90-2, dated May 1990.

3) The non-recurring costs associated with the STV/LTS consist of the Design, Development, Test, and Evaluation (DDT&E) costs.

4) No flight hardware is included in the non-recurring costs. The hardware included is that hardware built for developmental and qualification test purposes only.

5) System Test and Evaluation costs include the qualification test vehicle hardware and the thermal vacuum, acoustics, and vibration tests as well as flight operations for those vehicles.

6) Developmental and testing spares costs are included in each subsystem cost.

7) No direct Independent Validation and Verification (IV&V) effort is included, but the contractor support effort is included.

8) The cost of real estate and environmental impact assessments are not included.
9) Main engine development costs include the work for development and qualification of the Advanced Space Engine (ASE).

10) STV Initial Launch Capability (ILC) occurs in 2000 with LTS ILC occurs in 2002.


12) STV/LTS Operational phase is 25 years in duration.

2.2.4 Production Groundrules and Assumptions

1) Production consists of the recurring costs associated with the fabrication and assembly of the STV/LTS flight vehicles.

2) The first STV build will be completed in 2000.

3) Sustaining engineering and program management costs are included.

4) Manufacturing and Qualification spares are included in the vehicle production costs.

2.2.5 Operations Groundrules and Assumptions

1) STV/LTS launches will be supported by a Martin Marietta team.

2) Operations costs are for STV/LTS processing, payload integration, LEO node operations, flight operations, spares, and ETO.

3) Space Station IVA costs are assumed to be $150K per hour.

4) Space Station EVA costs are assumed to be $300K per hour.

5) ETO costs are assumed to be $2500 per pound delivered.
2.3 WORK BREAKDOWN STRUCTURE AND DICTIONARY

The Work Breakdown Structure and Dictionary were used as a baseline to define the elements of the STV/LTS program. This WBS was used as a guideline in developing the STV/LTS cost estimates discussed in this volume. The details of the WBS and WBS Dictionary are contained in DR-5, MCR-91-7505.
3.0 RECOMMENDED CONCEPT TECHNICAL DESCRIPTIONS

The STV family of vehicles that came out of the Concept Selection Trade Study analysis shows that the Lunar missions impose the most stringent requirements on the STV. The design approach taken has been to develop a vehicle that meets these design requirements and then evaluates the design to identify the elements that best satisfy the mission requirements for an initial Ground Based STV, a later Space Basing of the STV, and finally the Mars mission profile.

3.1 INITIAL STV CONCEPT

A common set of engines, tanksets, cores, aerobrakes, crew modules, subsystems, etc. were found to be applicable in the development of various ground- or space-based, expendable or reusable STV configurations including the Lunar transportation system.

The ability of the baseline vehicle or elements of the baseline vehicle to perform the other DRM cargo requirements was evaluated and is depicted in Table 3.1-1. All DRM cargo requirements can be met by either the initial STV or the baseline core vehicle with only one set of drop tanks. The capability of the stages was determined using the RL10A-4 cryogenic engine at 449.5 seconds of Isp and the various pieces of the LTS as listed in the table. The table shows the minimum needs of the core vehicle to meet the DRM cargo requirements in terms of extra propellant and subsystems, e.g. the crew module for the manned mission.

<table>
<thead>
<tr>
<th>DRM</th>
<th>Description</th>
<th>Cargo Requirement</th>
<th>LTS/STV Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>E - 1</td>
<td>Manned GEO Servicing</td>
<td>4.0 t delivery &amp; return</td>
<td>4E-5B Core w/AB, Crew Module, &amp; 43 t Prop in Drop Tanks</td>
</tr>
<tr>
<td>E - 2</td>
<td>10 t GEO Platform Delivery (DELETED IN CNDB '90)</td>
<td>10.0 t delivery</td>
<td>Interim Vehicle (12.9 t maximum capability)</td>
</tr>
<tr>
<td>E - 3</td>
<td>6.4 t GEO Payload Delivery (DoD)</td>
<td>6.4 t delivery</td>
<td>Interim Vehicle (12.9 t maximum capability)</td>
</tr>
<tr>
<td>E - 4</td>
<td>Unmanned Polar Platform Servicing</td>
<td>3.5 t delivery &amp; return</td>
<td>4E-5B Core w/AB, &amp; 26.3 t Prop in Drop Tanks</td>
</tr>
<tr>
<td>P - 1</td>
<td>Comet Nucleus Sample Return (DELETED IN CNDB '90)</td>
<td>16.9 t delivery</td>
<td>4E-5B Core &amp; 5.1 t Prop in Drop Tanks</td>
</tr>
</tbody>
</table>

DRM Propellant Loads Are Based on the Use of RL10A-4 Engines (449.5 sec)
The initial STV, shown in Figure 3.1-1 is a ground-based expendable version and can be built from the common set of elements and subsystems. A common tankset and two engines with limited subsystems form the basis for this vehicle. It is sized to fit within a 4.6 m (15 ft) diameter payload shroud for delivery to orbit. The dry weight of the vehicle is about 3 t with a length of nearly 12 m. With approximately 28 tonnes of LOX/LH₂ propellant in the tankset, the vehicle can deliver 12.9 tonnes of payload to a geosynchronous orbit.

![Figure 3.1-1 Ground-Based Expendable Version](image)

### Mass Properties

<table>
<thead>
<tr>
<th>Components</th>
<th>Mass (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>0.68</td>
</tr>
<tr>
<td>Propellant Tanks</td>
<td>0.52</td>
</tr>
<tr>
<td>Propulsion System</td>
<td>0.31</td>
</tr>
<tr>
<td>Main Engines</td>
<td>0.31</td>
</tr>
<tr>
<td>RCS System</td>
<td>0.09</td>
</tr>
<tr>
<td>GN&amp;C</td>
<td>0.07</td>
</tr>
<tr>
<td>Communication &amp; Data Handling</td>
<td>0.15</td>
</tr>
<tr>
<td>Electrical Power</td>
<td>0.25</td>
</tr>
<tr>
<td>Thermal Control System</td>
<td>0.38</td>
</tr>
<tr>
<td>Contingency (15%)</td>
<td>0.41</td>
</tr>
<tr>
<td>Total Dry Weight</td>
<td>3.17</td>
</tr>
</tbody>
</table>

**Performance** - 12.9 t Max to GEO

### 3.2 LTS CONCEPT

The STV concept definition for a vehicle that is configured for the Lunar mission is based on the requirements set out in the STV Statement of Work (SOW), with additional derived requirements from the Option 5 Planetary Surface System (PSS) documents, and the system trade studies and analyses. These studies and analyses recommend that the orbital mechanics designated as Lunar Architecture #1 (LA#1) is the best at meeting these requirements. Briefly stated LA#1 uses a LEO node as the start and finish of the Lunar mission for both crew and cargo flights. The LEO node is used for assembly, checkout, and refurbishment of the Lunar STV concept. Additional elements of the orbital mechanics require the vehicle orbit in Low Lunar Orbit (LLO) before lunar descent, have a lunar trajectory that encompasses a free earth return for an abort.
scenario, and returns to the LEO node via an aerobraking pass through the atmosphere.

Once the Lunar mission profile shown in Figure 3.2-1, was selected, the following key design drivers were integrated into the development and definition of vehicle configuration candidates:

a) The system shall deliver 14.6 tonnes of cargo and 4 crew to Lunar surface and return
b) The system shall deliver 33.0 tonnes of cargo on unmanned flight to the Lunar surface
c) LEO transportation node shall be Space Station Freedom (SSF)
d) The propulsion system shall utilize cryogenic propellant
e) The system shall be reusable for a minimum of five missions

These design drivers were also filtered through the subsystems trade study analysis and finally incorporated into the vehicle design.

\[\text{Figure 3.2-1 Lunar Mission Profile}\]

3.2.1 LTS VEHICLE

The STV consists of a family of vehicles which share common elements performing both cargo and piloted/cargo missions such as GEO delivery, lunar, and planetary (Mars mission). That portion of the STV family that deals with the lunar missions is called the Lunar STV or the Lunar Transportation System (LTS). The LTS is comprised of two mission profiles: (1) the Cargo mission capable of delivering 33 tonnes to the lunar surface and (2) the Piloted/cargo mission capable of delivering a crew of 4 plus 14.6 tonnes to the lunar surface. These mission profiles reflect the flights and cargo manifesting schedules developed from the Option 5 Lunar Exploration Requirements Levels I - III.

A derived requirement was developed from the studies that the final cargo and piloted vehicles would share common elements, producing a family of vehicles that have common structural core, propulsion and avionics equipment, drop tanks, and can be configured for either type of mission with no major modification to these elements. The detail definition of each vehicle configuration, performance, mass properties, structure, subsystem, cargo and crew handling, and operations will

3-3
be discussed in the following section. The evolutionary aspects of the configuration to perform the initial STV mission and the planetary mission are detailed at the end of this section.

3.2.1.1 Piloted Concept Overview—The LTS piloted configuration for the single propulsion system concept is shown in Figure 3.2.1.1-1. A crew module, six drop tanksets, and an aerobrake with its associated equipment are added to the propulsion/avionics core. The piloted vehicle dry mass is 27.58 tonnes. The configuration can deliver 15.26 tonnes of cargo (14.6 tonnes cargo plus cargo supports) in addition to the crew of 4 to the Lunar surface and return the vehicle and crew to LEO using approximately 174 tonnes of LOX/LH2 propellant. TEI and LOI propellant is housed in the drop tank sets, ascent and descent propellant is found in the core, and the return propellant is housed in two sets of tanks within the aerobrake. The 13.72 m rigid aerobrake has been designed to protect the crew during the aeroassisted maneuver before returning to Space Station Freedom.

![Image of Piloted LTS Configuration]

Figure 3.2.1.1-1 Piloted LTS Configuration

3.2.1.2 Cargo Concept Overview—The LTS cargo expendable configuration for the single propulsion system concept is shown in Figure 3.2.1.2-1. To form the cargo expendable configuration, a cargo platform (10.5 m x 14.8 m) and six drop tanksets have been added to the
propulsion/avionics core. The cargo vehicle dry mass is 18.75 tonnes and can deliver 33 tonnes of cargo to the Lunar surface using 146.5 tonnes of LOX/LH2 propellant loaded into the drop tanks and core tanks. The Flight 1 cargo manifest shown in the plan view is a typical arrangement for the four cargo missions.

![Figure 3.2.1.2-1 Cargo LTS Configuration](image)

3.3 LAUNCH PROCESSING

Based on the above defined LTS configuration, the LTS operations concept that will be addressed in this section identifies the ground processing requirements to prepare elements for launch to LEO, the Earth-To-Orbit (ETO) transportation of the configuration elements, assembly & checkout of the system at LEO, flight operations from LEO to LLO, decent and ascent and LLO rendezvous and docking, flight operations from LLO to LEO, and post flight checkout and refurbishment of the system. Figure 3.3-1 shows an overview of the elements required to perform the lunar mission. Other elements of this concept that currently have not be defined include, direct injection (ground based) systems and GEO and polar flight operations.

This scenario is designed to support the current "Option 5" mission as defined in the Space Exploration Initiative plan an supplement in the STV DRM requirements. Volume II of this report
provides the manifesting plan to support both the Lunar and near Earth missions, which is the baseline for the details defined by the STV operations scenario.

**Figure 3.3-1 STV Operations Scenario**
4.0 SUMMARY COST PRESENTATION

4.1 TOP LEVEL COST SUMMARY

Table 4.1-1 shows the STV top level cost by program phase and by major WBS element. It includes the production and launch of 22 vehicles with a LCC of $9809.9 M. The DDT&E cost is $624.4 M, the production cost is $1205.4 M ($55 M average unit cost), and the Operations cost is $8417.7 M.

Table 4.1-1 also shows the overall cost for the LTS program, including the production of 9 vehicles and launch of 25 missions, is $88,620.4 M. The DDT&E cost is $23,385.4 M, the production cost is $6,375.8 M ($708 M average unit cost), and the Integration and Operations cost is $58,859.2 M.

<table>
<thead>
<tr>
<th>Table 4.1.1 Top Level Cost Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td>Space Transfer Vehicle</td>
</tr>
<tr>
<td>Growth and Fee</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
</tr>
<tr>
<td>Lunar Transportation System</td>
</tr>
<tr>
<td>Growth and Fee</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
</tr>
<tr>
<td>STV/LTS TOTAL</td>
</tr>
</tbody>
</table>

Costs Reported in Millions of 1991 Dollars

4.2 COST BY WBS

Table 4.2-1 shows the STV LCC breakout by major WBS element. The total DDT&E cost for the LTS program is projected to be $624.4 M. The total Production cost for the STV program is projected to be $1205.2 M. The total Operations cost for the STV program is projected to be $8417.7 M.

Table 4.2-2 shows the LTS LCC breakout by major WBS element. The total DDT&E cost for the LTS program is projected to be $23,385.4 M. The total Production cost for the LTS program is projected to be $6,375.8 M. The total Operations cost for the LTS program is projected to be $58,859.2 M.
Table 4.2-1 STV Cost by WBS Element

<table>
<thead>
<tr>
<th>Element</th>
<th>DDT&amp;E</th>
<th>Prod</th>
<th>Ops</th>
<th>LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>117.8</td>
<td>689.2</td>
<td>0.0</td>
<td>807.0</td>
</tr>
<tr>
<td>Software</td>
<td>50.0</td>
<td>0.0</td>
<td>0.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Support Equipment</td>
<td>17.7</td>
<td>0.0</td>
<td>0.0</td>
<td>17.7</td>
</tr>
<tr>
<td>System Test</td>
<td>67.1</td>
<td>0.0</td>
<td>0.0</td>
<td>67.1</td>
</tr>
<tr>
<td>Facilities</td>
<td>50.0</td>
<td>0.0</td>
<td>0.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Operations</td>
<td>13.0</td>
<td>0.0</td>
<td>0.0</td>
<td>466.4</td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>95.1</td>
<td>103.4</td>
<td>70.0</td>
<td>268.5</td>
</tr>
<tr>
<td>Program Management</td>
<td>41.1</td>
<td>79.3</td>
<td>53.6</td>
<td>174.0</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>451.8</td>
<td>871.9</td>
<td>590.0</td>
<td>1913.7</td>
</tr>
<tr>
<td>ETO Costs</td>
<td>0.0</td>
<td>0.0</td>
<td>5500.0</td>
<td>5500.0</td>
</tr>
<tr>
<td><strong>Growth and Fee</strong></td>
<td>172.6</td>
<td>333.3</td>
<td>2327.7</td>
<td>2833.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>624.4</td>
<td>1205.2</td>
<td>8417.7</td>
<td>10,247.2</td>
</tr>
</tbody>
</table>

Costs Reported in Millions of 1991 Dollars

Table 4.2-2 LTS Cost by WBS Element

<table>
<thead>
<tr>
<th>Element</th>
<th>DDT&amp;E</th>
<th>Prod</th>
<th>Ops</th>
<th>LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Stage/Lander (w/ Crew Cab)</td>
<td>2038.9</td>
<td>2538.7</td>
<td>0.0</td>
<td>4577.6</td>
</tr>
<tr>
<td>TLI Tanks</td>
<td>68.8</td>
<td>646.6</td>
<td>0.0</td>
<td>715.4</td>
</tr>
<tr>
<td>LOI Tanks</td>
<td>60.8</td>
<td>461.1</td>
<td>0.0</td>
<td>521.9</td>
</tr>
<tr>
<td>Software</td>
<td>500.0</td>
<td>0.0</td>
<td>0.0</td>
<td>500.0</td>
</tr>
<tr>
<td>Support Equipment</td>
<td>867.4</td>
<td>0.0</td>
<td>0.0</td>
<td>867.4</td>
</tr>
<tr>
<td>System Test</td>
<td>2965.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2965.0</td>
</tr>
<tr>
<td>Facilities</td>
<td>2550.0</td>
<td>0.0</td>
<td>0.0</td>
<td>2550.0</td>
</tr>
<tr>
<td>Operations</td>
<td>295.0</td>
<td>0.0</td>
<td>8108.3</td>
<td>8403.3</td>
</tr>
<tr>
<td>Systems Engineering</td>
<td>2398.4</td>
<td>547.0</td>
<td>1216.3</td>
<td>4161.7</td>
</tr>
<tr>
<td>Program Management</td>
<td>1174.4</td>
<td>419.3</td>
<td>932.4</td>
<td>2526.1</td>
</tr>
<tr>
<td><strong>Sub Total</strong></td>
<td>12918.7</td>
<td>4612.7</td>
<td>10257.0</td>
<td>27788.4</td>
</tr>
<tr>
<td>ETO Costs</td>
<td>0.0</td>
<td>0.0</td>
<td>32,326.1</td>
<td>32,326.1</td>
</tr>
<tr>
<td>LEO Node Costs</td>
<td>4000.0</td>
<td>0.0</td>
<td>0.0</td>
<td>4000.0</td>
</tr>
<tr>
<td>Growth and Fee</td>
<td>6466.7</td>
<td>1763.1</td>
<td>16,276.1</td>
<td>24,505.5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>23,385.4</td>
<td>6375.8</td>
<td>58,859.2</td>
<td>88,620.4</td>
</tr>
</tbody>
</table>

Costs Reported in Millions of 1991 Dollars

Figure 4.2-1 shows the breakdown of the LTS DDT&E costs in ranked order. Figure 4.2-2 shows the breakdown of the LTS DDT&E costs by percentage. The LEO node cost makes up the largest single cost at $4000 M (23.6%), followed by the System Test cost ($2965 M, 17.5%), Facilities costs ($2550 M, 15.1%), the Systems Engineering costs ($2398.4 M, 14.2%), and the
Core Vehicle costs ($2038.9 M, 12.8%). Support Equipment, Software, Operations planning, and site activation make up the remaining costs.

Figure 4.2-1 LTS DDT&E Cost

Figure 4.2-2 LTS DDT&E Cost
Figures 4.2-3 and 4.2-4 show the breakdown of the LTS Production costs for 9 vehicles. The Core Vehicle makes up the largest single cost at $2538.7 M (55.0%), followed by the TLI tank costs ($646.6 M, 14.0%), and the Systems Engineering costs ($547.0 M, 11.9%). Other costs including the LOI tanks and Project Management make up the remaining costs.

**Figure 4.2-3 LTS Production Cost**

**Figure 4.2-4 LTS Production Cost**
Figures 4.2-5 and 4.2-6 show the breakdown of the LTS Operations costs for 25 missions. The ETO costs of these missions makes up the largest single cost at $32,326.1 M (75.9%), followed by the Operations cost ($8108.3 M, 19.0%). The Systems Engineering and the Program Management make up the remaining costs.

Figure 4.2-5 LTS Operations Costs

Figure 4.2-6 LTS Operations Costs
4.3 LTS TALL POLE ANALYSIS

A Tall Poles analysis serves to identify and rank the cost elements that make up 80% of the LCC of a system. The Tall Poles associated with the LTS program are shown in Figure 4.3-1.

![LTS System Tall Poles](image)

*Figure 4.3-1 LTS System Tall Poles*
5.0 LTS ECONOMIC ANALYSIS

5.1 LTS COST SENSITIVITIES

The cost analysis associated with the STVC&R Study focused on the overall system support required for point design estimates as well trade study support. Many cost studies were performed during the course of the program and those associated with specific trade studies are documented in Volume II, MCR-91-7503, Final Report. The sensitivities discussed in this volume are those related only to the cost of the Recommended Concept.

5.1.1 Earth To Orbit Cost Sensitivity

The Earth To Orbit (ETO) cost is the single largest element in the LCC of the LTS. Variations in this cost can make a significant difference in the overall cost of the program. Figure 5.1.1-1 shows the sensitivity of the Recommended Concept to variations in the ETO cost. The basic estimates presented in the preceding sections of this report utilized an ETO cost of $2500 per pound of mass delivered to LEO resulting in a LCC of $88.6 B. This cost is representative of a moderately priced vehicle such as the Heavy Lift Launch Vehicle (HLLV). If a more expensive vehicle such as the STS were used, the LCC could be driven as high as $130 B. Conversely, if a
low cost vehicle such as the Advanced Launch System (ALS) were used, the LCC could be driven as low as $50 B.

### 5.1.2 Number of Test Units Sensitivity

Another driving factor in the LCC of the LTS is the requirement for dedicated flight tests of the system prior to any cargo being flown. The Recommended Concept utilizes a single flight test vehicle to perform an equivalent piloted mission to collect data on the performance of the system. This data is analyzed and evaluated to ensure that the system is operating properly, thus reducing the risk of losing valuable cargo. Figure 5.1.2-1 shows the sensitivity of the Recommended Concept to variations in the number of dedicated test flights. If the requirement for a dedicated flight test is removed, the LCC could be lowered to approximately $85 B. If, however, the philosophy used for previous NASA programs such as Apollo were imposed, three dedicated flights would be required. This could drive the LCC to approximately $95 B. Even more stringent requirements could be placed on the system and drive the number of test flights to five. The resulting LCC would be about $100 B.

![Figure 5.1.2-1 Number of Flight Test Units Versus LTS Life Cycle Cost](image)

*Figure 5.1.2-1 Number of Flight Test Units Versus LTS Life Cycle Cost*
6.0 CONCLUSIONS

The recommended concept LTS system can perform the missions efficiently and cost effectively. The current estimate for an average mission is $2609 M (excluding DDT&E costs). Timelines have shown that the system is capable of launching the missions from Space Station Freedom in within the allocated schedule.

The cost estimates for the STV/LTS have been developed utilizing proven cost estimating relationships and calibration factors to account for the enhanced productivity and efficiency introduced by our design approach.
Appendix A

This appendix provides the detailed cost estimating data for the 15' diameter Initial STV. The costs are divided into Development/Validation, Full Scale Development, First Unit, Production, and Integration and Operations.
<table>
<thead>
<tr>
<th>Cost Elements</th>
<th>DOT&amp;OE</th>
<th>First Unit</th>
<th>Production</th>
<th>Operations</th>
<th>LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicles</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer Vehicle</td>
<td>117.8</td>
<td>44.8</td>
<td>689.2</td>
<td>807.0</td>
<td>807.0</td>
</tr>
<tr>
<td>Core Vehicle</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Tanke</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Structure</td>
<td>0.0</td>
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<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Propulsion</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Engines</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Aero brake</td>
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<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Crew Module</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other Subsystems</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>TLI Tanks (4 per Vehicle)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanks</td>
<td>117.8</td>
<td>44.8</td>
<td>689.2</td>
<td>807.0</td>
<td>807.0</td>
</tr>
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Appendix B

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