Lockheed Martin
Missiles & Space- Huntsville

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Advanced Transportation System Studies Technical Area 2 (TA-2) Heavy Lift Launch Vehicle Development Contract

NAS8-39208
DR 4

Final Report

Prepared by
Lockheed Martin Missiles & Space
for the
Launch Systems Concepts Office
of the
George C. Marshall Space Flight Center

July 1995

Advanced Transportation System Studies
Technical Area 2 (TA-2)
Heavy Lift Launch Vehicle Development Contract

NAS8-39208
DR 4

Final Report
Volume III
Program Cost Estimates

Approved:

James B. McCurry

James B. McCurry
TA-2 Study Manager

Lockheed Martin
Missiles & Space- Huntsville

Preface

The Advanced Transportation System Studies (ATSS) Technical Area 2 (TA-2) Heavy Lift Launch Vehicle Development contract, NAS8-39208, was led by the Missile Systems Division of Lockheed Martin Missiles & Space (LMMS), and supported by principal TA-2 teammembers Lockheed Martin Space Operations (LMSO), Aerojet, ECON, Inc., and Pratt & Whitney. Addition technical task support was provided by Lockheed Martin Skunk Works (LMSW).

The ATSS TA-2 contract was managed by James B. McCurry, Lockheed Martin Missiles & Space, and performed for Mr. Gary W. Johnson, Contracting Officer's Technical Representative (COTR), of the Launch Systems Concepts Office (Organization Code PT-51), National Aeronautics and Space Administration George C. Marshall Space Flight Center (MSFC).

The purpose of the TA-2 contract was to provide advanced launch vehicle concept definition and analysis to assist NASA in the identification of future launch vehicle requirements. Contracted analysis activities included vehicle sizing and performance analysis, subsystem concept definition, propulsion subsystem definition (foreign and domestic), ground operations and facilities analysis, and life cycle cost estimation. The basic period of performance of the TA-2 contract was from May 1992 through May 1993. No-cost extensions were exercised on the contract from June 1993 through July 1995.

This document is the final report for the TA-2 contract. The final report consists of three volumes:

Volume I	Executive Summary
Volume II	Technical Results
Volume III	Program Cost Estimates

Volume I provides a summary description of the technical activities that were performed over the entire contract duration, covering three distinct launch vehicle definition activities: heavy-lift (300,000 pounds injected mass to low Earth orbit) launch vehicles for the First Lunar Outpost (FLO), medium-lift (50,000-80,000 pounds injected mass to low Earth orbit) launch vehicles, and single-stage-to-orbit (SSTO) launch vehicles (25,000 pounds injected mass to a Space Station orbit).

Per direction from the TA-2 COTR, Volume II provides documentation of selected technical results from various TA-2 analysis activities, including a detailed narrative description of the SSTO concept assessment results, a user's guide for the associated SSTO sizing tools, an SSTO turnaround assessment report, an executive summary of the ground operations assessments performed during the first year of the contract, a configuration-independent vehicle health management system requirements report, a copy of all major TA-2 contract presentations, a copy of the FLO launch vehicle final report (NASA document with contributions from TA-2), and references to Pratt & Whitney's TA-2 sponsored final reports regarding the identification of Russian (NPO Energomash) main propulsion technologies.

Volume III provides a work breakdown structure dictionary, user's guide for the parametric life cycle cost estimation tool, and final report developed by ECON, Inc., under subcontract to Lockheed Martin on TA-2 for the analysis of heavy lift launch vehicle concepts.

Any inquiries regarding the TA-2 contract or its results and products may be directed at Mr. Gary W. Johnson, NASA Marshall Space Flight Center, (205) 544-0636.

Acknowledgments

The TA-2 study manager wishes to acknowledge the outstanding working relationships that developed during the TA-2 study contract, involving a true team effort between each of the TA-2 participants. The TA-2 COTR, Mr. Gary W. Johnson, was instrumental in fostering a team-play environment between the NASA and contractor participants that resulted in an extraordinary amount of engineering analysis results being produced. The TA-2 participants were immersed in a very dynamic environment in which the scope of the launch vehicle analysis activities constantly changed, reflecting the extraordinarily dynamic events that were unfolding at NASA Headquarters during the period of March 1992 through June 1994. The following personnel, listed by participating organization, are gratefully acknowledged for their outstanding contributions to the TA-2 contract. In addition, special recognition is due Messrs. Keith Holden and Kevin Sagis for their unique and innovative contributions during the entire course of the TA-2 contract in the development of vehicle sizing tools and the assessment of vehicle performance, respectively.

NASA-Headquarters

Bob Bristow	Headquarters sponsor
Phil Sumrall	Headquarters sponsor

NASA- Marshall Space Flight Center

Gene Austin	ATSS Study Manager and Access to Space Option 3 Team Lead
Tom Byrd	Russian propulsion assessment
Steve Creech	Cost assessment
Steve Cook	Vehicle concept assessment
Joe Hammaker	Cost assessment
Uwe Hueter	Access to Space Option 2 Team Lead
Gary Johnson	TA-2 COTR
Becky McCaleb	Environmental assessment
Rick Ryan	Propulsion assessment
Ed Threat	Vehicle concept assessment

NASA- Johnson Space Center

Phil Deans	First Lunar Outpost requirements definition
Darryl Kendrick	First Lunar Outpost vehicle concept assessment
Ed Svrcek	First Lunar Outpost vehicle concept assessment
Kevin Templin	First Lunar Outpost vehicle concept assessment
Wayne Ordway	First Lunar Outpost vehicle concept assessment
Dave Weaver	First Lunar Outpost requirements definition

NASA-Kennedy Space Center

Joel Blum	Advanced Projects Group Lead, ground operations
Don Paige	Ground processing facilities and support equipment

Aerojet

Ed Bair	Advanced propulsion concepts definition
Bill Sprow	Advanced propulsion concepts definition

ECON, Inc.

Jon Graham	Cost modeling development
John Skratt	Cost analysis

Lockheed Martin Missiles & Space

Wayne Boyle	Aerodynamics generation and base heating analysis
Don Cornelius	Contract administration
Alan Chan	Structures analysis
Keith Holden	Vehicle definition/sizing and integration
Bob Kummerer	Base heating analysis
Jim McCurry	TA-2 study manager, vehicle definition and integration
Oral Prater	Subcontracts management
Louis Rustenburg	Systems engineering
Kevin Sagis	Vehicle simulation and performance assessment
Jean Walters	Data reduction, group logistics

Lockheed Martin Space Operations

Steve Black	Vehicle health management
Steve Burns	Ground facilities definition
Gary Letchworth	Ground operations assessment
Arlene Reese	CAD drawings
Pat Scott	Ground operations assessments

Lockheed Martin Skunk Works

Wally Eshelman	Reliability, maintainability, and supportability assessment

Pratt & Whitney

Paul Greasely	Russian propulsion assessment
Larry Tanner	Russian propulsion assessment

Jim McCurry, TA-2 Study Manager
Huntsville, Alabama
September 1995

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1.0 Introduction

At the inception of the TA-2 contract, it was Lockheed's expressed desire to infuse an understanding and quantification of nonrecurring and recurring cost influences on the launch system design process. Lockheed thereby employed ECON, Inc., as a TA-2 subcontract partner to become a part of the concurrent engineering design process. The ECON support was performed principally by Messrs. John Skratt and Jon Graham. ECON was directly involved during the early brainstorming sessions in helping to define HLLV design requirements and design drivers. An HLLV cost assessment work breakdown structure was defined by ECON, and is provided in Section 2. Section 3 provides a report of ECON's preliminary cost analysis findings regarding the HLLV configurations. An HLLV cost estimation tool was also developed, along with a user's guide, and is provided in Section 4.

During the course of the TA-2 contract, direction was given by the TA-2 COTR to de-emphasize the assessment of vehicle recurring and nonrecurring costs, and instead focus the limited contract funding resources on the vehicle design and operations assessments. Consequently, funding was de-allocated from ECON's TA-2 subcontract prior to ECON being able to fully complete the HLLV assessments, and ECON was unable to participate in the assessment of the SSTO concepts. The database of historic launch system costs that ECON possessed, and the understanding that ECON demonstrated regarding the assessment of advanced technologies and costing "new ways of doing business" were valuable assets to the TA-2 team that, unfortunately, were not sufficiently leveraged.

Section 2 provides a copy of the launch system work breakdown structure that was developed by ECON, and constitutes the deliverable item for TA-2 Data Requirement Number 5, as identified in the NAS8-39208 Data Procurement Document. Section 3 provides a copy of ECON's final report, which constitutes the deliverable item for TA-2 Data Requirement Number 6. Section 4 provides a copy of the user's guide that ECON prepared for the use of their HLLV cost estimation tool.

2.0 Work Breakdown Structure Dictionary

The following is the work breakdown structure (WBS) dictionary that was developed by ECON, Inc., for the TA-2 contract, to assess HLLV costs. The WBS dictionary constitutes the deliverable item for TA-2 Data Requirement Number 5, as identified in the NAS8-39208 Data Procurement Document.

ADVANCED TRANSPORTATION SYSTEM STUDIES (ATSS)

Heavy Lift Launch Vehicle Concepts

Technical Area 2

HEAVY LIFT LAUNCH VEHICLE PARAMETRIC COST ANALYSIS

Life Cycle Cost Work Breakdown Structure and Dictionary
(SDRL Item 5)

Prepared by:
ECON, Inc.

Purchase Order No. PLX8Y8670
Ref: 8670-019

27 April, 1994

Foreword

This Life Cycle Cost Work Breakdown Structure (WBS) and WBS dictionary have been prepared in response to Subcontractor Data Requirement Item 5 of Purchase Order No. PLX8Y8670; Heavy Lift Launch Vehicle (HLLV) Parametric Cost Analysis; Year 1 (Basic).

This report has been prepared by ECON, Inc. in support of Lockheed Missiles and Space Company, Inc., Huntsville.

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1.0 WORK BREAKDOWN STRUCTURE

The work Breakdown Structure utilized under the Advanced Transportation System Studies (ATSS); Task Area 2 (TA-2), Heavy Lift Launch Vehicle (HLLV) Definition Study was developed based on generally accepted cost estimating principles. The driving structure for the WBS was the Launch Vehicle Sizing routine producing the mass properties of alternative vehicle designs. The sizing routine was utilized by Lockheed Missiles and Space Company, Inc. (LMSC) personnel to generate alternative mass properties for the various vehicle designs.

The sizing routine provided the weight statement against which cost estimates were generated. This level is representative of the level of concept definition. Table 1 displays the hardware subsystems generated in the LMSC sizing routine.

These hardware end-items were then reorganized into a WBS structure grouped according to functionality and similarity. The resulting WBS is shown in Table 2.

TABLE - 1 - Subsystems generated by LMSC sizing routine

Stage 1
Fwd Skirt
LO_2 Tank
Intertank
Fuel Tank
Aft Skirt
TPS
Range Safety
TVC
Engines
Thrust Structure
Engine mount/gimbal/purge
Feed/Pressurization system
Avionics
Interstage
Contingency (@ 10%)
Dry Weight
Stage 2
Fwd Skirt
LO_2 Tank
Intertank
Fuel Tank
Aft Skirt
TPS
Range Safety
TVC
Engines
Thrust Structure
Engine mount/gimbal/purge
Feed/Pressurization system
Avionics
Stage Sep/Ullage Motors
RCS Motors
Contingency (@ 10%)
Dry Weight

TABLE 2 Hardware End-Item Work Breakdown Structure

1.	INTEGRATED VEHICLE
1.1	FIRST STAGE ELEMENT
1.1.1	STRUCTURES & MECHANISMS
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1.1.1.2	OXIDIZER TANK
1.1.1.3	FWD SKIRT
1.1.1.4	INTERTANK
1.1.1.5	AFT SKIRT
1.1.1.6	THRUST STRUCTURE
1.1.1.7	INTERSTAGE
1.1.2	ELECTRICAL POWER & DISTRIBUTION
1.1.3	AVIONICS
1.1.4	THERMAL PROTECTION
1.1.5	RANGE SAFETY
1.1.6	MAIN PROPULSION
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1.1.6.2	FEED/PRESSURIZATION SYSTEM
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1.2.1.6	THRUST STRUCTURE
1.2.1.7	INTERSTAGE
1.2.2	ELECTRICAL POWER & DISTRIBUTION
1.2.3	AVIONICS
1.2.4	THERMAL PROTECTION
1.2.5	RANGE SAFETY
1.2.6	MAIN PROPULSION
1.2.6.1	ENGINE MOUNT/GIMBAL/PURGE
1.2.6.2	FEED/PRESSURIZATION SYSTEM
1.2.6.3	MAIN ENGINES
1.2.7	AUXILIARY PROPULSION
1.2.7.1	AUXILIARY PROPULSION - RCS
1.2.7.2	AUXILIARY PROPULSION -TVC
1.2.7.3	AUXILIARY PROPULSION - Ullage motors

2.0 WBS DICTIONARY

Following is the WBS dictionary for each of the hardware end-items contained in the HLLV Work Breakdown Structure.

1.0 INTEGRATED VEHICLE

This hardware element contains the hardware related efforts and materials required for the Research, development test and evaluation (RDT&E), and production of the total vehicle which cannot be allocated to individual hardware elements below the vehicle level. The element also includes elements associated with the integration, test system engineering and management of the total launch vehicle.

1.1 FIRST STAGE ELEMENT

This hardware element sums the hardware related efforts and materials required for the Research, development test and evaluation (RDT&E), and production of the initial stage of the launch vehicle which cannot be allocated to individual hardware elements below the first stage level. The element also includes elements associated with the integration, test system engineering and management of the total launch vehicle.

1.1.1 STRUCTURES & MECHANISMS

This hardware element sums all efforts and materials required for the RDT&E, and production of the structure subsystem of the launch vehicle's first stage. This elements includes primarily the fuel tank, oxidizer tank, forward skirt, intertank, aft skirt thrust structure and interstage

1.1.1.1 FUEL TANK

This hardware element sums all efforts and materials required for the RDT&E, and production of the fuel tank used by the launch vehicle's first stage.

1.1.1.2 OXIDIZER TANK

This hardware element sums all efforts and materials required for the RDT&E, and production of the oxidizer tank used by the launch vehicle's first stage.

1.1.1.3 FORWARD SKIRT

This hardware element sums all efforts and materials required for the RDT&E, and production of the forward skirt used by the launch vehicle's first stage.

1.1.1.4 INTERTANK

This hardware element sums all efforts and materials required for the RDT&E, and production of the intertank used by the launch vehicle's first stage.

1.1.1.5 AFT SKIRT

This hardware element sums all efforts and materials required for the RDT&E, and production of the aft skirt used by the launch vehicle's first stage.

1.1.1.6 THRUST STRUCTURE

This hardware element sums all efforts and materials required for the RDT&E, and production of the thrust structure used by the launch vehicle's first stage.

1.1.1.7 INTERSTAGE

This hardware element sums all efforts and materials required for the RDT&E, and production of the thrust structure used by the launch vehicle's first stage.

1.1.2 ELECTRICAL POWER & DISTRIBUTION

N/A - The electrical power and distribution subsystem was not separated out in this analysis. The weights and costs associated with the electrical power and distribution subsystem were instead allocated to the specific subsystems (e.g., avionics, main engines) based on their specific power requirements.

1.1.3 AVIONICS

This hardware element sums all efforts and materials required for the RDT&E, and production of the avionics used by the launch vehicle's first stage. This element includes guidance and control, instrumentation, and data management components

1.1.4 THERMAL PROTECTION

This hardware element sums all efforts and materials required for the RDT&E, and production of the thermal protection system used by the launch vehicle's first stage.

1.1.5 RANGE SAFETY

This hardware element sums all efforts and materials required for the RDT&E, and production of the range safety system used by the launch vehicle's first stage.

1.1.6 MAIN PROPULSION

This hardware element sums all efforts and materials required for the RDT&E, and production of the main propulsion system used by the launch vehicle's first stage. Included in this element are the engine mount/gimbal and purge system, the feed and pressurization system and the main engines of the launch vehicle's first stage.

1.1.6.1 ENGINE MOUNT/GIMBAL/PURGE

This hardware element sums all efforts and materials required for the RDT&E and production of the engine mount; gimbal; and purge system used by the launch vehicle's first stage.

1.1.6.2 FEED/PRESSURIZATION SYSTEM

This hardware element sums all efforts and materials required for the RDT&E and production of the feed and pressurization system used by the launch vehicle's first stage.

1.1.6.3 MAIN ENGINES

This hardware element sums all efforts and materials required for the RDT&E and production of the main engines used by the launch vehicle's first stage.

1.1.7 AUXILIARY PROPULSION - TVC

This hardware element sums all efforts and materials required for the RDT&E and production of the auxiliary propulsion system or thrust vector control system used by the launch vehicle's first stage.

1.2 SECOND STAGE ELEMENT

This hardware element sums the hardware related efforts and materials required for the Research, development test and evaluation (RDT&E), and production of the second stage of the launch vehicle which cannot be allocated to individual hardware elements below the second stage level. The element also includes elements associated with the integration, test system engineering and management of the second stage of the launch vehicle.

1.2.1 STRUCTURES & MECHANISMS

This hardware element sums all efforts and materials required for the RDT&E, and production of the structure subsystem of the launch vehicle's second stage. This elements includes primarily the fuel tank, oxidizer tank, forward skirt, intertank, aft skirt, and thrust structure.

1.2.1.1 FUEL TANK

This hardware element sums all efforts and materials required for the RDT&E, and production of the fuel tank used by the launch vehicle's second stage.

1.2.1.2 OXIDIZER TANK

This hardware element sums all efforts and materials required for the RDT&E, and production of the oxidizer tank used by the launch vehicle's second stage.

1.2.1.3 FORWARD SKIRT

This hardware element sums all efforts and materials required for the RDT&E, and production of the forward skirt used by the launch vehicle's second stage.

1.2.1.4 INTERTANK

This hardware element sums all efforts and materials required for the RDT&E, and production of the intertank used by the launch vehicle's second stage.

1.2.1.5 AFT SKIRT

This hardware element sums all efforts and materials required for the RDT&E, and production of the aft skirt used by the launch vehicle's second stage.

1.2.1.6 THRUST STRUCTURE

This hardware element sums all efforts and materials required for the RDT&E, and production of the thrust structure used by the launch vehicle's second stage.

1.2.2 ELECTRICAL POWER & DISTRIBUTION

N/A - The electrical power and distribution subsystem was not separated out in this analysis. The weights and costs associated with the electrical power and distribution subsystem were instead allocated to the specific subsystems (e.g., avionics, main engines) based on their specific power requirements.

1.2.3 AVIONICS

This hardware element sums all efforts and materials required for the RDT&E, and production of the avionics used by the launch vehicle's second stage. This element includes guidance and control, instrumentation, and data management components.

1.2.4 THERMAL PROTECTION

This hardware element sums all efforts and materials required for the RDT&E, and production of the thermal protection system used by the launch vehicle's second stage.

1.2.5 RANGE SAFETY

This hardware element sums all efforts and materials required for the RDT&E, and production of the range safety system used by the launch vehicle's second stage.

1.2.6 MAIN PROPULSION

This hardware element sums all efforts and materials required for the RDT&E, and production of the main propulsion system used by the launch vehicle's first stage. Included in this element are the engine mount/gimbal and purge system, the feed and pressurization system and the main engines of the launch vehicle's second stage.

1.2.6.1 ENGINE MOUNT/GIMBAL/PURGE

This hardware element sums all efforts and materials required for the RDT&E and production of the engine mount; gimbal; and purge system used by the launch vehicle's second stage.

1.2.6.2 FEED/PRESSURIZATION SYSTEM

This hardware element sums all efforts and materials required for the RDT&E and production of the feed and pressurization system used by the launch vehicle's second stage.

1.2.6.3 MAIN ENGINES

This hardware element sums all efforts and materials required for the RDT&E and production of the main engines used by the launch vehicle's second stage.

1.2.7 AUXILIARY PROPULSION

This hardware element sums all efforts and materials required for the RDT&E and production of the auxiliary propulsion system used by the launch vehicle's second stage. Included in this element are the reaction control system, the thrust vector control system and the ullage motors.

1.2.7.1 AUXILIARY PROPULSION -RCS

This hardware element sums all efforts and materials required for the RDT&E and production of the reaction control system used by the launch vehicle's second stage.

1.2.7.2 AUXILIARY PROPULSION -TVC

This hardware element sums all efforts and materials required for the RDT&E and production of the thrust vector control system used by the launch vehicle's second stage.

1.2.7.3 AUXILIARY PROPULSION - Ullage motors

This hardware element sums all efforts and materials required for the RDT&E and production of the ullage motors used by the launch vehicle's second stage.

3.0 Heavy Lift Launch Vehicle Cost Estimation Final Report

This section provides a copy of ECON's final report, which constitutes the deliverable item for TA-2 Data Requirement Number 6, as identified in the NAS8-39208 Data Procurement Document.

ADVANCED TRANSPORTATION SYSTEM STUDIES (ATSS)

Heavy Lift Launch Vehicle Concepts

Technical Area 2

HEAVY LIFT LAUNCH VEHICLE PARAMETRIC COST ANALYSIS

Final Report

(SDRL Item 4)

Prepared by:
ECON, Inc.

Purchase Order No. PLX8Y8670
Ref: 8670-019

27 April, 1994

Foreword

This Final Report has been prepared in response to Subcontractor Data Requirement Item 4 of Purchase Order No. PLX8Y8670; Heavy Lift Launch Vehicle (HLLV) Parametric Cost Analysis; Year 1 (Basic).

This report has been prepared by ECON, Inc. in support of Lockheed Missiles and Space Company, Inc., Huntsville.

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1.0 INTRODUCTION & EXECUTIVE SUMMARY

This report documents the cost model and estimating activities conducted by ECON, Inc. in support of Lockheed Missiles & Space Company, Inc. under Purchase Order PLX8Y86 70 F, Heavy Lift Launch Vehicle Parametric Cost Analysis; Year 1 (Basic).

Under the Purchase Order, ECON was assigned four primary tasks:

- Assist Lockheed in identification of subsystem requirements and selection criteria that affect advanced transportation system life cycle costs
- Assist Lockheed in the identification of candidate advanced transportation configurations
- Conduct parametric engineering cost estimates
- Assist Lockheed in the selection of the most favorable vehicle configurations.

Toward this end, ECON personnel participated in concurrent systems engineering session with other team members and conducted a series of studies for alternative launch vehicle configurations. Two primary concurrent systems engineering sessions were conducted. The first involved general launch vehicle design objectives from both an acquisition and operations viewpoint. The second involved the design and operations of alternative Single Stage to Orbit (SSTO) configurations.

Cost Estimates provided to Lockheed under this effort included Heavy Lift First Lunar Outpost configurations; a variety of 50k vehicle configurations; an assessment of stage diameter impact on a selected 50k concept, and an analysis of minimal DDT&E as a primary goal in development of a new launch system.

Additionally, ECON participated in and contributed to regular briefings and weekly teleconferences concerning the TA-2 study.

For a number of reasons, a thorough analysis and firm conclusions are not possible from the cost analysis carried out under this effort. Part way through the effort, the funding under this Purchase Order was significantly reduced, leaving few remaining funds for further analysis and documentation.

Among other reasons for the lack of conclusions were several redirection's from the customer which prevented scrubs and iterations of the system concepts and data or trade studies to be conducted. Additionally, ECON was required to use cost estimates provided by outside sources with no independent verification or data normalization other than adjusting for the year of economics. Because these outside estimates are generally produced under significantly different groundrules, assumptions and methodologies, the resulting answers are generally not comparable. In most cases, the outside estimates were provided for the main propulsion systems (MPS) of alternative concepts. The MPS is the primary cost contributor to new systems. Hence, the answers and results of the cost estimates produced under this study are most likely skewed in manners unknown to the analyst and no firm conclusions can be drawn.

2.0 COST METHODOLOGY

2.1 Cost Methodology Rationale

There are two primary methods of cost estimation: bottoms-up and parametric. The parametric method was selected for use in this study as it was deemed much more appropriate for conceptual definition studies than the bottoms-up approach.

There are a number of reasons for selecting parametric costing. First and foremost, downstream costs can grow rapidly after a system is defined. The best leverage for these costs is early in the program before major design and programmatic decisions have been cast in stone. The conduct of trade studies can identify bad or costly approaches before the dollars are committed.

However, early in a program, the system definition is particularly vague and the schedule uncertain.

Parametric costing provides a sophisticated tool to scope the most likely runout of costs using available system definition. It also permit trade studies to evaluate and compare alternative design options, thus improving the ultimate concept. Finally, it provides a method to establish a traceable link between the product, the schedule and the cost.

ECON, in discussions with Lockheed personnel, decided to utilize it internal parametric cost models for this study. This decision was based on the fact that:

- It has been used successfully in many previous efforts
- There is no subscription or use fee thus minimizing cost
- It is appropriate for concept definition studies
- ECON personnel are familiar with it's use

- ECON possessed an existing calibrated data base for this model of launch vehicle and other applicable subsystems, thereby minimizing the cost and effort required to estimate costs of new concepts.

2.2 The Heavy Lift Launch Vehicle Cost Model (HLLVCM)

The point of departure for the cost model used in this study is the ECON proprietary Technology Forecasting Cost Model (TFCM) TFCM is a general-case acquisition cost model that was originally derived by ECON for the NASA Johnson Space Center (JSC). The term general-case model refers to the fact that the product range for the model is not limited. That is , TFCM can estimate the cost of any manufactured product be applying its costing algorithms against a product that is specified by a set of input variables. ECON has spent a significant amount of its internal resources refining the basic premise and algorithms that were developed under the original JSC contract.

A general-case model can be narrowed down to a special-case model by restricting the product focus. ECON focused and revised the original TFCM algorithms to more suit the historical launch vehicle data to arrive at a launch vehicle specific cost model. Due to the definition of the systems available to ECON, only the acquisition cost was estimated. Acquisition cost includes both the DDT&E and production costs of a system.

Under this contract effort, portions of the launch vehicle cost forecasting module were ported from Lotus 1-2-3 to Excel for the Macintosh and renamed the Heavy Lift Launch Vehicle Cost Model (HLLVCM). Contract fund limitations prevented any further cost model development (e.g., incorporation of operations costs).

The TFCM was designed to provide cost estimates early in the conceptual phase of a program and hence requires relatively sparse system definition. The model operates with a minimum input. The model is structured to generate valid cost estimates when provided input data sets at any of three typical levels:

- At the total stage level
- At the major subsystem level
- At the subsystem level

The choice of which level to select depends on the depth of the vehicle design and also on the availability of corroborative historical data.

Central to the use of this parametric model is the process of data normalization. The process of data normalization is the extrapolation of an input parameter to a neutral point in the cost hyper plane. This appropriate neutral point is dependent on the model being used. This normalization involves the neutralization of items such as economics (e.g. same year dollars), quantity produced to account for economies of scale and production efficiencies, weight, state-of-the-art, schedule, and culture or environment. When all these factors have been neutralized, the analyst arrives at a comparable reference point. For this model, we refer to this neutral point as the complexity factor or difficulty index. This point is then used by the model as a seed for the generation of similar technologies where the cost parameters lie at different distances on each dimension of the cost hyper plane.

2.2.1 HLLVCM Description

Following is a description of the cost model, it's algorithms and inputs required to use the HLLVCM. For additional information on the use of the model, please see SDRL Item 11; Life Cycle Cost Models.

2.2.2 HLLVCM Algorithms

Five principle algorithms perform the computations in the HLLVCM model. Four of these determine recurring (production) costs, and the fifth, non recurring (DDT&E) costs. These algorithms are described below and listed in Table 1. The Factors described are arbitrary interim values used to help isolate the calculation logic.

	Factor E1 (Recurring Production)
1	Establish cost from product difficulty (complexity) Index
2	Modify cost for culture (specification) index
	Factor E2 (Recurring Production)
1	Modify cost for technology/process improvement
	Factor E3 (Recurring Production)
1	Modify cost for weight influences
2	Modify cost for percent electronics
	Factor E4 (Recurring Production)
1	Modify cost for quantity in production.
	Factor DDT&E (Non-recurring)
1	Modify costs for State-of-the-art
2	Modify cost for quantity of test-articles

Table 1 - HLLVCM Algorithms

Factor E1: This factor initially calculates the recurring cost of a theoretical first pound of the first unit produced. This is a hypothetical cost with no intrinsic interest. E1 estimates this cost based on product *complexity* and also the program *culture*. (all input variables are discussed later). Next, factor E1 is modified for technology years that are earlier or later than the model base year (1987). This technology down factor, attributed to production improvements, generates the **Factor E2**.

In the next step, factor E2 is modified for the influence of weights either greater than or less than one pound. the outcome of this step is **Factor E3**, which is the models theoretical first production unit. In **Factor E4** calculations, a learning slope is determined and the cost of all production units is estimated. This provides the total recurring acquisition cost.

RDT&E costs are derived by modifying Factor E3 to account for state of development (state-of-the-art) and the quantity of non recurring test units required.

2.2.3 HLLVCM Inputs

The HLLVCM input variables are listed in Table 2. One variable, weight, is a physical quantity.. Two others, quantity and IOC date, are measurable programmatic factors. The remaining variables are model peculiar and may be explained as follows. The state-of-the-art variable is an integer covering a linear scale from 1 (off the shelf) to 12 (highly conceptual) This is a dimensionless variable, that is, there are no units of measure.

NAME	EXPANSION
Weight	Dry Weight Including Contingency
Culture	Acquisition and Operational environment; similar to the GE PRICE model's Platform variable
SOTA	State-of-the-Art (see explanation below)
Quantity	1. Numbers of Whole Flight Articles Delivered in Prod Phase 2. Equivalent units used in test
IOC	Year of initial operational capability
Difficulty	Degree of Product Sophistication, as Measured at the IOC Date
Slope	Historical Rate of Annual Complexity Growth

Table 2 - HLLVCM Inputs

Weight is an input variable used as an indicator of the relative size of the item under study. Weight, when properly used in the context of this model, provides an indicator for cost tendencies. The impact of weight on cost has been established to vary greatly with the type of item being analyzed.

Table 3 displays the available and appropriate values for the "Culture" Variable. This variable is similar to the GE PRICE Model's Platform. It has also been called the paper trail variable. It captures the influence on cost the specifications, oversight, and documentation required to develop systems in alternative environments. Additionally, it reflects the amount of reliability built into a system.

Through data normalization and the calibration process, cost differences for respective environments are neutralized so that data obtained from various environments can be utilized as analogies in all other environments.

Table 4 displays a description of appropriate State-of-the-art variables. The State-of-the-Art parameter indicated the relative differences in the complexity of the engineering task. The HLLVCM uses a twelve level scale to differentiate between off-the-shelf at one extreme, and "principles observed" at the other. Examples for each category are also provided as well as the equivalent NASA/OAST technology readiness equivalent where applicable..

Variable	Content	Equiv PRICE Platform
1.00	Ground Based Equipment	1.0
1.15	Ship borne or Ground Mobile	1.4
1.30	Airborne, Mil-SPEC	1.8
1.67	Space borne, Unmanned	2.0
1.80	Space borne, Manned	2.5

Table 3 - Culture Variable Values

IOC, or year of initial operational capability, indicates the maturity of a product's development in terms of improvements in methods and processes as well as performance between time now and the IOC of the system. It is utilized to calculate both the Technology Advancement slope and the productivity improvement impact inherent in the model's logic.

The difficulty or complexity parameter is the link between the inherent difficulty in the design of an item and its cost. In previous efforts, ECON has demonstrated a pattern of time-dependent complexity growth. ECON has found that each individual system, as well as specific subsystems, demonstrate unique slope and shape if the difficulty index is plotted over time.

Rank	Explanation	Equiv NASA Tech rating
1	Virtually 100% of drawings exist and need not be renumbered; this is a continuation of an existing product. Example: OV-105 as derived from OV-104	No Parallel
2	Predominant number of drawings exist; drawings may have been renumbered. Example: Saturn S-IVB stage as derived from S-IVB/1B	No Parallel
3	Majority of drawings exist; minor resizing of hardware is possible. Example: Gemini Spacecraft Structure as derived from Mercury	No Parallel
4	Roughly half of drawings exist; significant resizing of hardware is possible. Example: Gemini crew systems as derived from Mercury	No Parallel
5	Only a minority of drawings exist; however, drawings that do not exist are based on a familiar product line. Example: Gemini electrical power system, as derived from Mercury.	No Parallel
6	Drawing are essentially new; however a design point-of-departure is known to exist. Example: Apollo environmental control system as derived from Gemini	7
7	Drawings are new; the mission or the design concept are, in part, unfamiliar. Example: Apollo Lunar Module landing structure, as derived from Surveyor.	6
8	Drawings are new; either the mission or the design concept is unfamiliar. Example: Gemini Fuel Cells	5
9	Drawings are new; both the mission and the design concepts are unfamiliar. Example: Apollo Command Service Module/Lunar Module guidance, navigation, as an extrapolation from Gemini guidance.	4
10	Drawings are new and the design concepts transcend the state-of-the-art. Example: Apollo Command Module thermal protection	3
11	Drawings are new & the design concepts transcend state-of-the-art. In addition; multiple design paths are to be followed. Example: Apollo mission as envisioned at the time the manned lunar landing goal was announced	2
12	Drawings are new and the design concepts transcend state-of-the-art. In addition; only the principles of the mission are known. Example: manned lunar landing mission as viewed before Sputnik.	1

Table 4 - State-of-the-Art Variable

Unlike the GE PRICE models Complexity Factor, which is highly correlated to other inputs such as specification level and weight, the CF used in HLLVCM is a completely isolated and dimensionless factor.

An important features result from the use of this complexity factor as structured in the model. . By creating for any given technology a complexity-time plot, the extrapolation of this curve to future operational dates produces a prediction of how complexity - and hence cost - will be experienced in the future. This extrapolation is referred to as the complexity slope, or growth of complexity over time.

ECON utilized its existing data base of complexities and slopes generated from analogous subsystems for use in this study. The hardware end-items used correspond to the Work Breakdown Structure provided in SDRL Item 5, Life Cycle Cost WBS and Dictionary. Included in the historical analogous systems and subsystems used in this study were:

- STS Orbiter
- STS External Tank
- Centaur D-1A
- Centaur D-1T
- Agena-Gemini
- Agena-Standard
- Agena-Ascent
- Saturn IV-B Stage
- Saturn II Stage
- Titan IIID
- Delta 3920
- RL-10 Engine
- J-2 Engine
- F-1 Engine
- SSME engine

2.2.4 Model Outputs

The HLLVCM generates acquisition costs for the selected system. It breaks acquisition cost into both Design, Development, Test and Evaluation (DDT&E) and recurring production. Further, costs are divided into direct and indirect. The indirect costs include items such as Systems engineering, program management. system level test , and system and subsystem integration/assembly and checkout.

2.3 GROUNDRULES AND ASSUMPTIONS

Following are the Groundrules and Assumptions used for the cost estimates conducted during this study.

- All costs presented in FY 92$s
- NASA Code B New Start Escalation table used to Normalize $s
- Current Estimated Costs include DDT&E and Production
- Weights based on Mass Properties supplied by Mr. Keith Holden of LMSC
- Mission Model for 50K vehicle based on STS/PLS Model supplied by Mr. Gene Austin. Model includes: 101 50K vehicle flights over 2003-2010 Time Horizon
- Specification level set at manned space due to PLS Mission
- With the exception of Engines, all Subsystems Assumed two equivalent Test Articles.
- Engines test articles handled on case by case basis to "match" Government or Aerojet) supplied DDT&E costs
- When directed, ECON utilized Government Cost figures and conducted no independent verification or data normalization other than for constant year economics.
- No "technology up" used for engines (see HLLVCM description)
- Schedule impact not used in costing
- State-of-the-art ranking assumed to be new drawings with know point-of-departure.
- No government "wraps" included in cost estimates

3.0 CONCLUSIONS

For a number of reasons, a thorough analysis and firm conclusions are not possible from the cost analysis carried out under this effort. Part way through the effort, the funding under this Purchase Order was significantly reduced, leaving few remaining funds for further analysis and documentation.

Among other reasons for the lack of conclusions were several redirection's from the customer which prevented scrubs of the data or trade studies to be conducted. Additionally, ECON was required to use cost estimates provided by outside sources with no independent verification or data normalization other than adjusting for the year of economics. Because these outside estimates are generally produced under significantly different groundrules, assumptions and methodologies, the resulting answers are generally not comparable. In most cases, the outside estimates were provided for the main propulsion systems (MPS) of alternative concepts. The MPS is the primary cost contributor to new systems. Hence, the answers and results of the cost estimates produced under this study are most likely skewed in manners unknown to the analyst.

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1	Virtually 100% of drawings exist and need not be renumbered; this is a continuation of an existing product. Example: OV-105 as derived from OV-104	No Parallel
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3.0 INSTALLING HLLVCM

Running this cost model requires a Macintosh Computer equipped with sufficient space on the hard disk and Microsoft Excel 4.0. Simply drag the folder entitled HLLVCM onto the hard drive. To access the cost model, please see Section 5 - Typical steps to Generate a Cost Estimate.

4.0 ITEMS FROM THE HLLVCM MENU & TOOLBAR ICONS

Following is a description of the HLLVCM Menu items and the functionality of the customized Toolbar associated with HLLVCM. These items have been provided to improve the ease of use of the model. For additional information on using menu and toolbar items, refer to your Excel User's Manual.

ADD NEW ELEMENT - Adds a new element to the WBS. Select the line above the spot to insert the new element. An input dialog box will appear prompting the user for inputs. **The Work Breakdown Structure (WBS) name is required!**

DELETE ELEMENT - Deletes elements from the WBS. Select the line or lines to be deleted. **There is no confirmation or undo!**

MOVE ELEMENT TO THE RIGHT - Moves elements up one level in the WBS. Select the element(s) to be raised. The WBS will be renumbered. Families will automatically be moved.

MOVE ELEMENT TO THE LEFT - Moves elements down one level in the WBS. Select the element(s) to be lowered. The WBS will be renumbered. Families will automatically be moved

EDIT INPUT - Allows user to edit element inputs. Select element to be edited.

HIDE/VIEW INPUT COLUMNS - Hides or unhides input columns

UPDATE COST FORMULAS - Creates all the cost formulas on the worksheet. **Select this to calculate the cost estimate.**

PRINT COST REPORTS - Prints out cost report

CALIBRATE HISTORICAL DATABASE - "Calibrates the worksheet" “HLLVCM historical database”. The worksheet must first be opened. (**Not Operational**)

VIEW LEAST SQUARES GRAPH - Given a set of data points, calculates the least squares fit and displays the graph and statistics (**Not Operational**).

VIEW SPREAD COST - Calculates and displays costs spread by phase by year (**Not Operational**).

5.0 TYPICAL STEPS TO GENERATE COST ESTIMATE

Following is a description of the typical steps the user would go through to generate a cost estimate. The user can utilize the model in an iterative fashion to generate appropriate Complexity values over time based on their own historical data. No historical database development was conducted under this study. For additional information concerning complexity values, please refer to the Final Report submitted under SDRL Item #4 of this study.

1) Open the Excel worksheet named "HLLVCM.MACROS"

2) Select new file
   - A template worksheet will appear.

"3) Select the menu item "ADD NEW ELEMENT" from the "HLLVCM MENU:" or click once on the add element icon.
   - An input data dialog box will be displayed
   - Enter data inputs and click DONE
   - The worksheet will be updated and the WBS will be automatically renumbered

4) To manipulate the WBS select an element and choose the "MOVE ELEMENT RIGHT" or "MOVE ELEMENT LEFT" item from the HLLVCM MENU or click the ARROW icons
   - The selected element(s) will be moved one level up or down in the WBS.

"5) To edit data, either enter it on the worksheet or select An Element and choose "EDIT INPUT" from the HLLVCM MENU.
   - An input data dialog box will be displayed.
   - Enter the data and click DONE.
   - The selected Element will be updated.

"6) Once the data in entered, the cost estimating formulas need to be updated. Choose "UPDATE COST FORMULAS" from the HLLVCM MENU or click the UPDATING Icon.
   - All of the formulas are updated and calculated generating the cost estimate.

7) If any inputs are changed or the WBS is modified the user must update the formulas.

"8) To print results choose “PRINT COST REPORT” from the HLLVCM MENU or click the REPORT Icon.
   - The printout is the WBS and cost results.

Description of the HLLVCM Menu Items & Icons

Following is a desription of the selectable items from thje HLLVCM Menu and HLLVCM peculiar icons.

- Add New Element]- Adds a new element to the WBS. Select the line above the spot to insert the new element. An input dialog box will appear, prompting the user for inputs. The WBS Name is required.

- Delete Element []- Deletes elements from the WBS. Select the line or lines to be deleted. **THERE IS NO CONFIRMATION OR UNDO!**

- Move Element to the Right [->]- Moves element up one level in the WBS. Select the Element(s) to be raised. The WBS will be renumbered. The entire family will automatically be moved.

- Move Element to the Left [<-]- Moves elements down one level in the WBS. Select the element(s) to be lowered. The WBS will be renumbered. Entire Families will automatically be moved.

- Edit Input [I] - Allows user to edit element inputs. Select element to be edited

- Hide/View Input Columns [the eyeball icon]- Hides or unhidesd input columns in spreadsheet

- Update Cost Formulas - Creates all the cost formauls on the worksheet. Select this option to calculate cost estimate.

- Print Cost Reports]- Prints out preformatted cost report.

- View Spread Costs [not functional] - Calculates and displaysd costs spread by phase by year.

4.0 Heavy Lift Launch Vehicle Cost Estimation Tool User's Guide

This section provides a copy of the user's guide that ECON prepared for the use of their HLLV cost estimation tool. An electronic copy of the tool may be obtained from the TA-2 COTR, Mr. Gary Johnson, at MSFC.

ADVANCED TRANSPORTATION SYSTEM STUDIES (ATSS)

Heavy Lift Launch Vehicle Concepts

Technical Area 2

HEAVY LIFT LAUNCH VEHICLE PARAMETRIC COST ANALYSIS

Life Cycle Cost Model Instructions
(SDRL Item 11)

Prepared by:
ECON, Inc.

Purchase Order No. PLX8Y8670
Ref: 8670-019

27 April, 1994

Foreword

These instructions and descriptions accompany the delivery of the Heavy Lift Launch Vehicle Cost Model (HLLVCM). The HLLVCM has been developed in response to Subcontractor Data Requirement Item 11 of Purchase Order No. PLX8Y8670; Heavy Lift Launch Vehicle Parametric Cost Analysis; Year 1 (Basic).

This report has been prepared by ECON, Inc. in support of Lockheed Missiles and Space Company, Inc., Huntsville.

Table of Contents

List of Tables

1.0 INTRODUCTION

The following is submitted, in conjunction with the accompanying Cost Model Software under SDRL Item 11, Life Cycle Cost Models. The model used for this study has been title the Heavy Lift Launch Vehicle Cost Model (HLLVCM).

Some activity under this contract was used to port the existing model algorithms from Lotus 1-2-3 to Microsoft Excel, generate Excel macro statements and improve the user interface of the cost model. No model functional or algorithm development or historical data research, normalization or calibration was conducted under this Purchase Order.

The accompanying cost model should be treated as proprietary property of ECON, Inc.

2.0 The Heavy Lift Launch Vehicle Cost Model (HLLVCM)

The point of departure for the cost model used in this study is the ECON proprietary Technology Forecasting Cost Model (TFCM) TFCM is a general-case acquisition cost model that was originally derived by ECON for the NASA Johnson Space Center (JSC). The term general-case model refers to the fact that the product range for the model is not limited. That is , TFCM can estimate the cost of any manufactured product be applying its costing algorithms against a product that is specified by a set of input variables. ECON has spent a significant amount of its internal resources refining the basic premise and algorithms that were developed under the original JSC contract.

A general-case model can be narrowed down to a special-case model by restricting the product focus. ECON focused and revised the original TFCM algorithms to more suit the historical launch vehicle data to arrive at a launch vehicle specific cost model. Due to the definition of the systems available to ECON, only the acquisition cost was estimated. Acquisition cost includes both the DDT&E and production costs of a system.

Under this contract effort, portions of the launch vehicle cost forecasting module were ported from Lotus 1-2-3 to Excel for the Macintosh and renamed the Heavy Lift Launch Vehicle Cost Model (HLLVCM). Contract fund limitations prevented any further cost model development (e.g., incorporation of operations costs).

The TFCM was designed to provide cost estimates early in the conceptual phase of a program and hence requires relatively sparse system definition. The model operates with a minimum input. The model is structured to generate valid cost estimates when provided input data sets at any of three typical levels:

- At the total stage level
- At the major subsystem level
- At the subsystem level

The choice of which level to select depends on the depth of the vehicle design and also on the availability of corroborative historical data.

Central to the use of this parametric model is the process of data normalization. The process of data normalization is the extrapolation of an input parameter to a neutral point in the cost hyper plane. This appropriate neutral point is dependent on the model being used. This normalization involves the neutralization of items such as economics (e.g. same year dollars), quantity produced to account for economies of scale and production efficiencies, weight, state-of-the-art, schedule, and culture or environment. When all these factors have been neutralized, the analyst arrives at a comparable reference point. For this model, we refer to this neutral point as the complexity factor or difficulty index. This point is then used by the model as a seed for the generation of similar technologies where the cost parameters lie at different distances on each dimension of the cost hyper plane.

2.1 HLLVCM Description

Following is a description of the cost model, it's algorithms and inputs required to use the HLLVCM. For additional information on the use of the model, please see SDRL Item 11; Life Cycle Cost Models.

2.2 HLLVCM Algorithms

Five principle algorithms perform the computations in the HLLVCM model. Four of these determine recurring (production) costs, and the fifth, non recurring (DDT&E) costs. These algorithms are described below and listed in Table 1. The Factors described are arbitrary interim values used to help isolate the calculation logic.

	Factor E1 (Recurring Production)
1	Establish cost from product difficulty (complexity) Index
2	Modify cost for culture (specification) index
	Factor E2 (Recurring Production)
1	Modify cost for technology/process improvement
	Factor E3 (Recurring Production)
1	Modify cost for weight influences
2	Modify cost for percent electronics
	Factor E4 (Recurring Production)
1	Modify cost for quantity in production.
	Factor DDT&E (Non-recurring)
1	Modify costs for State-of-the-art
2	Modify cost for quantity of test-articles

Table 1 - HLLVCM Algorithms

Factor E1: This factor initially calculates the recurring cost of a theoretical first pound of the first unit produced. This is a hypothetical cost with no intrinsic interest. E1 estimates this cost based on product *complexity* and also the program *culture*. (all input variables are discussed later). Next, factor E1 is modified for technology years that are earlier or later than the model base year (1987). This technology down factor, attributed to production improvements, generates the **Factor E2**.

In the next step, factor E2 is modified for the influence of weights either greater than or less than one pound. the outcome of this step is **Factor E3**, which is the models theoretical first production unit. In **Factor E4** calculations, a learning slope is determined and the cost of all production units is estimated. This provides the total recurring acquisition cost.

RDT&E costs are derived by modifying Factor E3 to account for state of development (state-of-the-art) and the quantity of non recurring test units required.

2.3 HLLVCM Inputs

The HLLVCM input variables are listed in Table 2. One variable, weight, is a physical quantity.. Two others, quantity and IOC date, are measurable programmatic factors. The remaining variables are model peculiar and may be explained as follows. The state-of-the-art variable is an integer covering a linear scale from 1 (off the shelf) to 12 (highly conceptual) This is a dimensionless variable, that is, there are no units of measure.

NAME	EXPANSION
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