MSFC-806

Constellation Program Life-cycle Cost Analysis Model (LCAM)

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Introduction

The Constellation Program (CxP) is NASA's effort to replace the Space Shuttle, return humans to the moon, and prepare for a human mission to Mars. The major elements of the Constellation Lunar sortie design reference mission architecture are shown in Exhibit 1. Unlike the Apollo Program of the 1960's, affordability is a major concern of United States policy makers and NASA management. To measure Constellation affordability, a total ownership cost life-cycle parametric cost estimating capability is required. This capability is being developed by the Constellation Systems Engineering and Integration (SE&I) Directorate, and is called the Life-cycle Cost Analysis Model (LCAM).

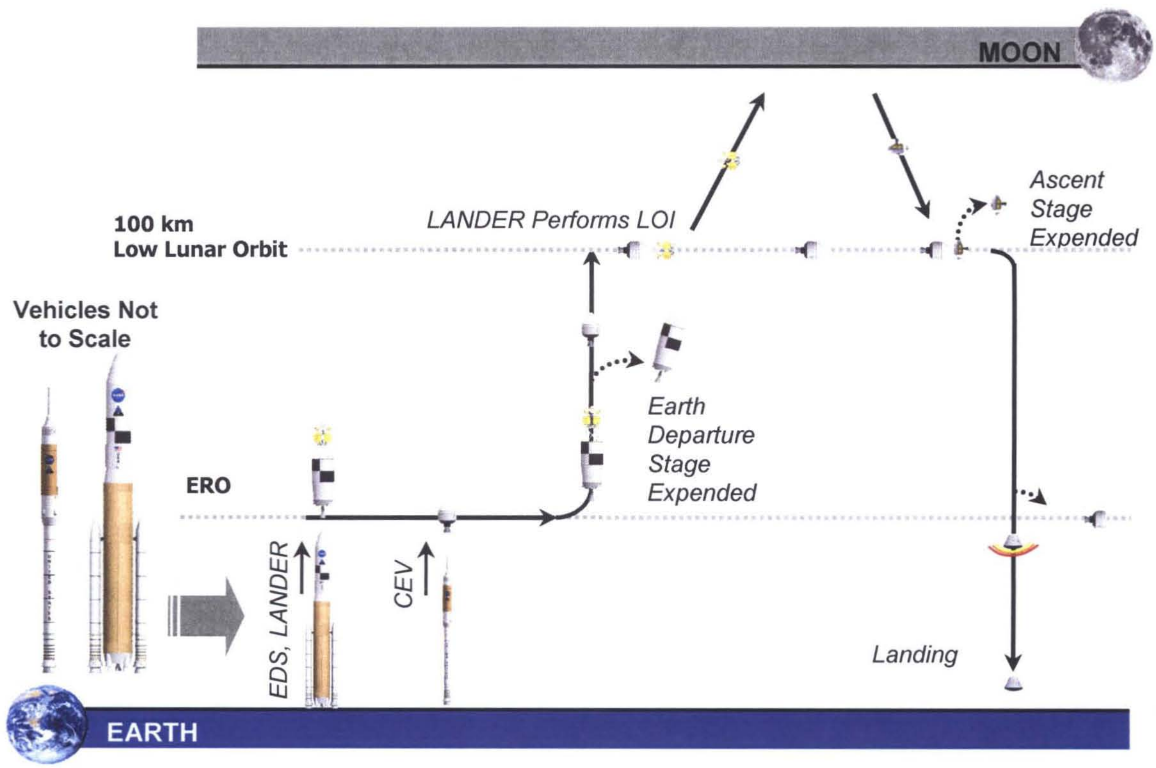


Exhibit 1. Lunar Sortie Architecture

The requirements for LCAM are based on the need to have a parametric estimating capability in order to do top-level program analysis, evaluate design alternatives, and explore options for future systems. By estimating the total cost of ownership within the context of the planned Constellation budget, LCAM can provide Program and NASA management with the cost data necessary to identify the most affordable alternatives. LCAM is also a key component of the

Integrated Program Model (IPM), an SE&I developed capability that combines parametric sizing tools with cost, schedule, and risk models to perform program analysis.

LCAM is used in the generation of cost estimates for system level trades and analyses. It draws upon the legacy of previous architecture level cost models, such as the Exploration Systems Mission Directorate (ESMD) Architecture Cost Model (ARCOM) developed for Simulation Based Acquisition (SBA), and ATLAS. LCAM is used to support requirements and design trade studies by calculating changes in cost relative to a baseline option cost. Estimated costs are generally low fidelity to accommodate available input data and available cost estimating relationships (CERs). LCAM is capable of interfacing with the Integrated Program Model to provide the cost estimating capability for that suite of tools.

LCAM Architecture

LCAM is designed with a modular architecture that can either be run in a stand alone mode, or integrated into the IPM. When implemented in the IPM, Phoenix ModelCenter provides the integrating environment. When operating as a stand alone capability, the cost models are linked by the Analysis Data Manager (ADaM). By using a modular architecture, additional tools can be incorporated depending upon the analysis.

LCAM is currently comprised of three components: an Analysis Data Manager (ADaM), an Architecture Cost Model (ARCOM) (actually one version for each major flight hardware element), and a Lifecycle Cost Integration Model (LifCIM). In addition, several in-house and commercial cost models are used to generate costs for flight hardware, operations and software cost elements. The costs estimated by these external models are passed to LifCIM for integration into the life cycle cost estimate. The current LCAM models and interfaces are shown in Exhibit 2.

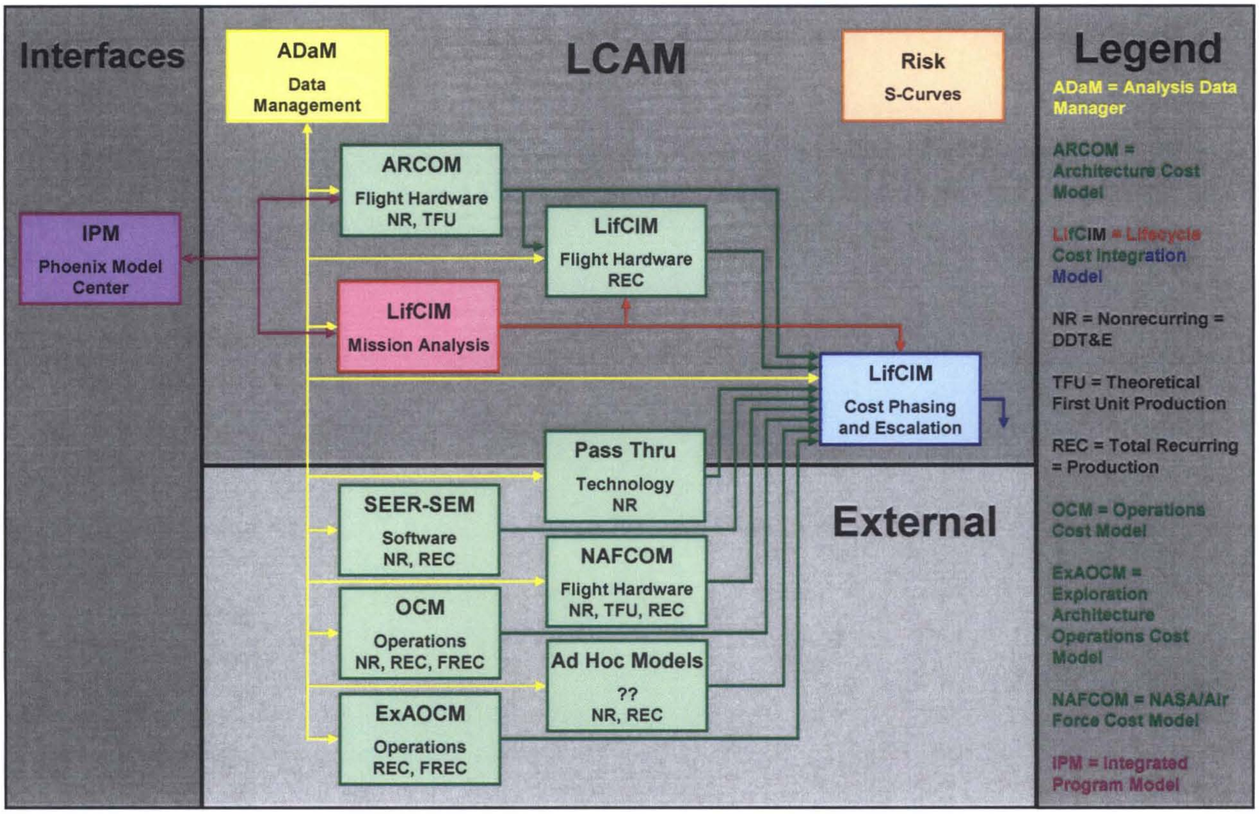


Exhibit 2. LCAM Architecture

As can be seen in Exhibit 2, LCAM is comprised of several NASA and other cost models, including but not limited to, the NASA Air Force Cost Model (NAFCOM), Architecture Cost Model (ARCOM), Operations Cost Model (OCM), Life Cycle Integration Model (LifCIM) and SEER-SEM. At this time, only ARCOM and LifCIM are integrated into Phoenix Model Center, though ADaM can be used to move data among the other models. A post-estimate risk analysis calculation capability is available.

One benefit of the modular approach is that individual Constellation Projects can provide their own parametric models. These models can be easily integrated into LCAM and be used in lieu of general purpose models like ARCOM or NAFCOM. Where necessary, new or hybrid cost models may be developed to meet the estimating needs of specific studies or analyses.

LCAM Components

The components of LCAM, as well as some of the external cost models, are further described below.

Analysis Data Manager (ADaM)

ADaM is a custom software development which stores the input data used by the ARCOMs and the external cost estimating models, as well as the outputs from them. It also can store the results from LifCIM. Trade study option cost estimates can be archived and quickly retrieved. ADaM manages multiple analysis scenarios and variations of those scenarios. It enables easy access to analysis scenarios and results and the ability to recreate results from stored model inputs and assumptions. An example of an ADaM user form is shown in Exhibit 3.

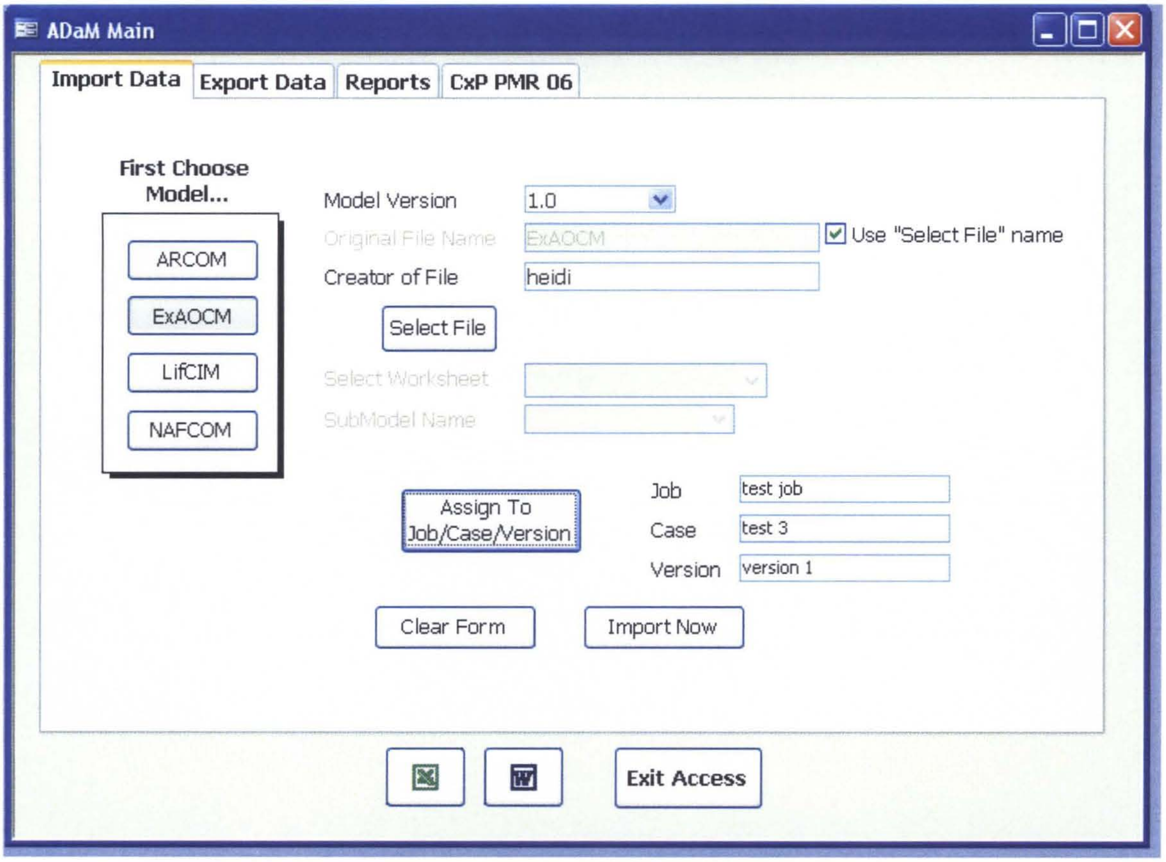
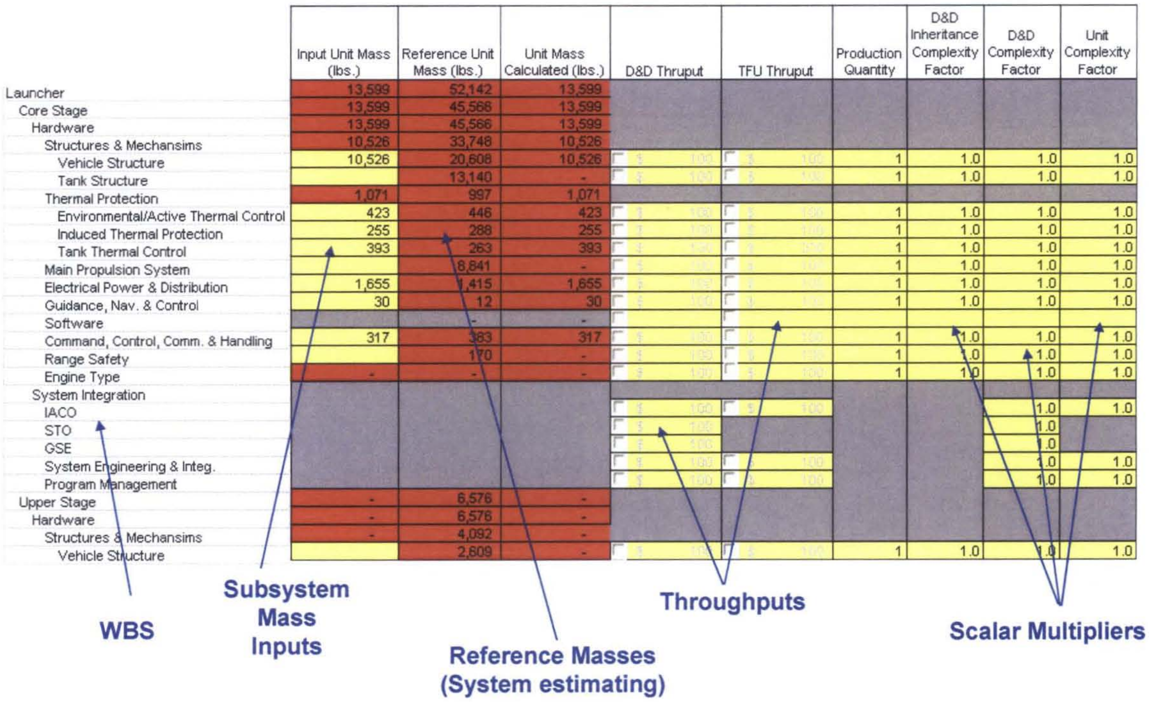


Exhibit 3. ADaM User Form

Architecture Cost Model (ARCOM)
ARCOM is a spreadsheet based technical derivative of NAFCOM which estimates flight hardware costs. A version of ARCOM has been created for each of the major cost elements of the CxP, including the CEV, CLV, LSAM, CaLV, and Lunar Habitation Module. Each version is tailored to the cost elements of the hardware along with appropriate CERs from NAFCOM or based on NAFCOM data. These models generate costs at the system, subsystem, or component levels, depending on the data available for the hardware. A sample screen shot of a portion of an ARCOM spreadsheet is shown in Exhibit 4.



	Input Unit Mass (lbs.)	Reference Unit Mass (lbs.)	Unit Mass Calculated (lbs.)	D&D Thruput	TFU Thruput	Production Quantity	D&D Inheritance Complexity Factor	D&D Complexity Factor	Unit Complexity Factor
Launcher	13,599	52,142	13,599						
Core Stage	13,599	45,566	13,599						
Hardware	13,599	45,566	13,599						
Structures & Mechansims	10,526	33,748	10,526						
Vehicle Structure	10,526	20,608	10,526	$ 100	$ 100	1	1.0	1.0	1.0
Tank Structure		13,140	-	$ 100	$ 100	1	1.0	1.0	1.0
Thermal Protection	1,071	997	1,071						
Environmental/Active Thermal Control	423	446	423	$ 100	$ 100	1	1.0	1.0	1.0
Induced Thermal Protection	255	288	255	$ 100	$ 100	1	1.0	1.0	1.0
Tank Thermal Control	393	263	393	$ 100	$ 100	1	1.0	1.0	1.0
Main Propulsion System		8,841	-	$ 100	$ 100	1	1.0	1.0	1.0
Electrical Power & Distribution	1,655	1,415	1,655	$ 100	$ 100	1	1.0	1.0	1.0
Guidance, Nav. & Control	30	12	30	$ 100	$ 100	1	1.0	1.0	1.0
Software		-	-						
Command, Control, Comm. & Handling	317	383	317	$ 100	$ 100	1	1.0	1.0	1.0
Range Safety		170	-	$ 100	$ 100	1	1.0	1.0	1.0
Engine Type	-	-	-	$ 100	$ 100	1	1.0	1.0	1.0
System Integration									
IACO				$ 100	$ 100			1.0	1.0
STO				$ 100				1.0	
GSE				$ 100				1.0	
System Engineering & Integ.				$ 100	$ 100			1.0	1.0
Program Management				$ 100	$ 100			1.0	1.0
Upper Stage	-	6,576	-						
Hardware	-	6,576	-						
Structures & Mechansims	-	4,092	-						
Vehicle Structure		2,609	-	$ 100	$ 100	1	1.0	1.0	1.0

Exhibit 4. ARCOM Input Data Area

Life-cycle Cost Integration Model (LifCIM)

LifCIM is a spreadsheet based tool which performs three functions. First, it does mission analysis to collect the schedule of missions and determine the major hardware elements required to fulfill the campaign. This includes determining the development and production start dates and schedule spans for each cost element. Second, it calculates hardware total recurring costs based on the Theoretical First Unit (TFU) costs received from the hardware cost models and the number of units required based on the mission analysis. Third, it sums, time-phases and inflates all the cost elements. The LCCE for a given trade study option can be quickly compared to a baseline option. A sample screen shot of a portion of a LifCIM spreadsheet is shown in Exhibit 5.

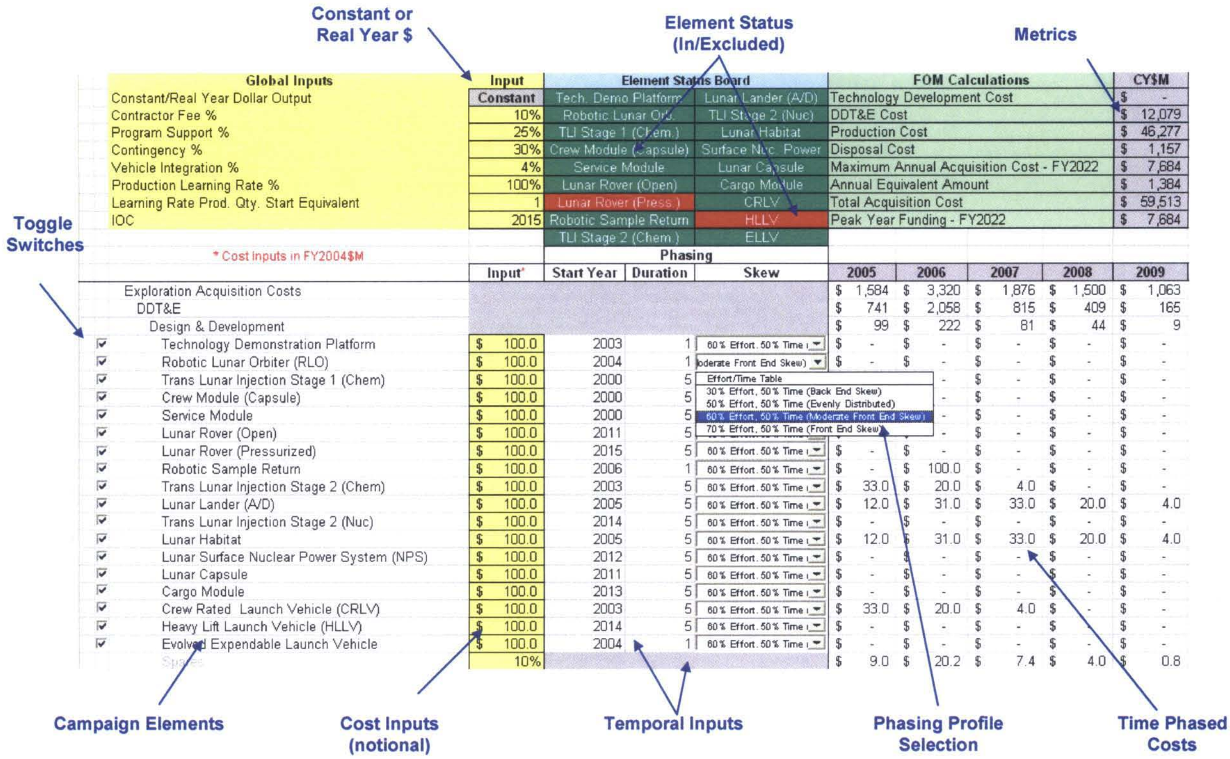


Exhibit 5. LifCIM Main Input Area

External Cost Models

In-house cost models, including NASA / Air Force Cost Model (NAFCOM) for flight hardware costs and the Operations Cost Model (OCM) for ground operations costs, the Exploration Architecture Operations Cost Model (ExAOCM) for mission operations costs, as well as commercial cost estimating models such as the Galorath, Incorporated SEER-SEM cost model for software cost estimating are used as required and their outputs are passed to LifCIM for integration into the LCCE.

NASA / Air Force Cost Model (NAFCOM)

NAFCOM is a custom software tool which estimates flight hardware costs using historical data from previous space programs to predict the development and production costs of new space programs. It uses parametric relationships to estimate subsystem or component level costs for any space hardware including: earth orbital spacecraft, manned spacecraft, launch vehicle, upper stages, liquid rocket engines, scientific instruments, and planetary spacecraft. It uses a single variable (mass) or a multivariable CER method. The NAFCOM database contains data from over 120 NASA and Air Force missions. Mission, hardware, and programmatic descriptions are included for referencing and to aid in CER analogy selections. A sample input form for NAFCOM is shown in Exhibit 6.

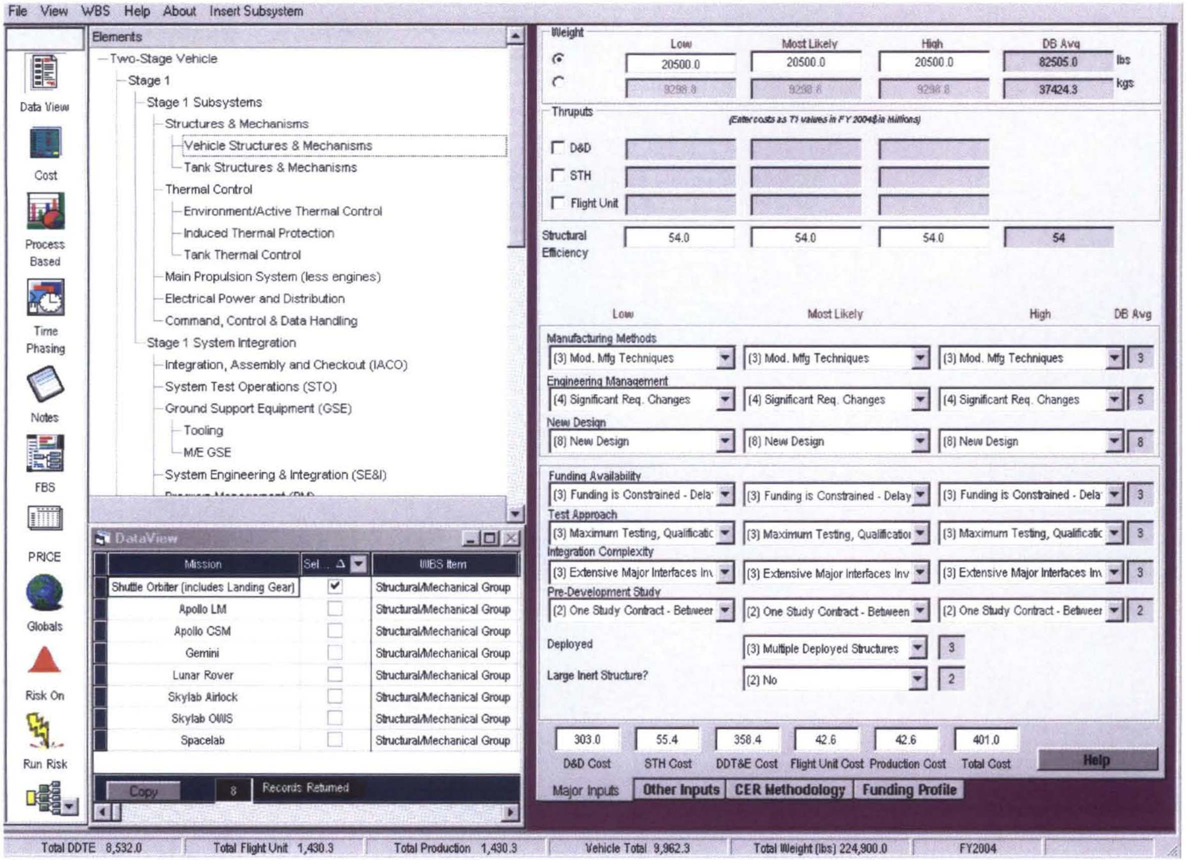


Exhibit 6. Sample NAFCOM Input Form

Operations Cost Model (OCM)

OCM is a spreadsheet based cost model which estimates recurring operations costs, including vehicles, launch operations, flight operations, and program level wraps. It also estimates the acquisition costs for facilities. OCM estimates the variable costs per flight, plus the fixed costs per year. A sample screen shot from OCM is shown in Exhibit 7.

OPERATIONS COST MODEL

Program Database

PARAMETRIC DATABASE

P1 Program Management & Support

	b =	0.7		
	A=	0.28496		
	Rating:	1		
		Man	Reus	Factor
1	Man/Reus	1.0700	1.2125	1.2974
2	Unman/Reus	1.0000	1.2125	1.2125
3	Man/Expend	1.0700	1.0000	1.0700
4	Unman/Expend	1.0000	1.0000	1.0000
	Use:	1.2974		
	Rate Curve:	51.0%	-0.971431	
	c (Num Orgs)	0.1000	1.1487	
FPY	3	6	8	10
Base	$2,615	$2,870	$3,001	$3,116

P2 Systems Engineering

	b =	0.7		
	A=	0.21991		
	Rating:	1		
		Man	Reus	Factor
1	Man/Reus	1.0700	1.2125	1.2974
2	Unman/Reus	1.0000	1.2125	1.2125
3	Man/Expend	1.0700	1.0000	1.0700
4	Unman/Expend	1.0000	1.0000	1.0000
	Use:	1.2974		
	Rate Curve:	51.0%	-0.971431	
	Num Orgs	0.1000	1.1487	
FPY	3	6	8	10
Base	$2,533	$2,781	$2,909	$3,021

P3 Systems Logistics

not available

RATIO FACTOR DATABASE

A, B, C Coefficients

		SET 1 (M/R)				SET 2 (U/R)			
		A	B	C		A	B	C	
P1	Program Mgt & Support	0.000010	-0.000900	0.045600		0.000020	-0.001100	0.048100	
P2	Systems Engineering	0.000009	-0.000700	0.034400		0.000010	-0.000800	0.034400	
P3	Systems Logistics	0.000000	0.000000	0.000000		0.000000	0.000000	0.000000	
	Base	-0.000020	0.001600	0.920000		-0.000030	0.001900	0.917600	
SOP SUPPORT FACTORS		* SET 1 * Manned/Reusable				* SET 2 * UnManned/Reusable			
		Flights per Year				Flights per Year			
		3	6	8	10	3	6	8	10
P1	Program Mgt & Support	4.3%	4.1%	3.9%	3.8%	4.5%	4.2%	4.1%	3.9%
P2	Systems Engineering	3.2%	3.1%	2.9%	2.8%	3.2%	3.0%	2.9%	2.7%
P3	Systems Logistics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Base	92.5%	92.9%	93.2%	93.4%	92.3%	92.8%	93.1%	93.4%
		100%	100%	100%	100%	100%	100%	100%	100%

		SET 3 (M/E)				SET 4 (U/E)			
		A	B	C		A	B	C	
P1	Program Mgt & Support	0.000200	-0.007700	0.119000		0.000200	-0.009600	0.145600	
P2	Systems Engineering	0.000050	-0.002000	0.030500		0.000040	-0.001800	0.027100	
P3	Systems Logistics	0.000000	0.000000	0.000000		0.000000	0.000000	0.000000	
	Base	-0.000300	0.009700	0.850500		-0.000300	0.011400	0.827200	
SOP SUPPORT FACTORS		* SET 3 * Manned/Expendable				* SET 4 * UnManned/Expendable			
		Flights per Year				Flights per Year			
		3	6	8	10	3	6	8	10
P1	Program Mgt & Support	9.8%	8.0%	7.0%	6.2%	11.9%	9.5%	8.2%	7.0%
P2	Systems Engineering	2.5%	2.0%	1.8%	1.6%	2.2%	1.8%	1.5%	1.3%
P3	Systems Logistics	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Base	87.7%	89.8%	90.9%	91.8%	85.9%	88.5%	89.9%	91.1%
		100%	100%	100%	100%	100%	100%	100%	99%

Exhibit 7. Sample Screen Shot from OCM

Exploration Architecture Operations Cost Model (ExAOCM)

ExAOCM is a spreadsheet based cost model with VBA macros to execute complex data model relationships and logistics cost equations. It provides a node based model of an interplanetary supply chain in order to estimate mission operations costs. The main user interface for ExAOCM is shown in Exhibit 8.

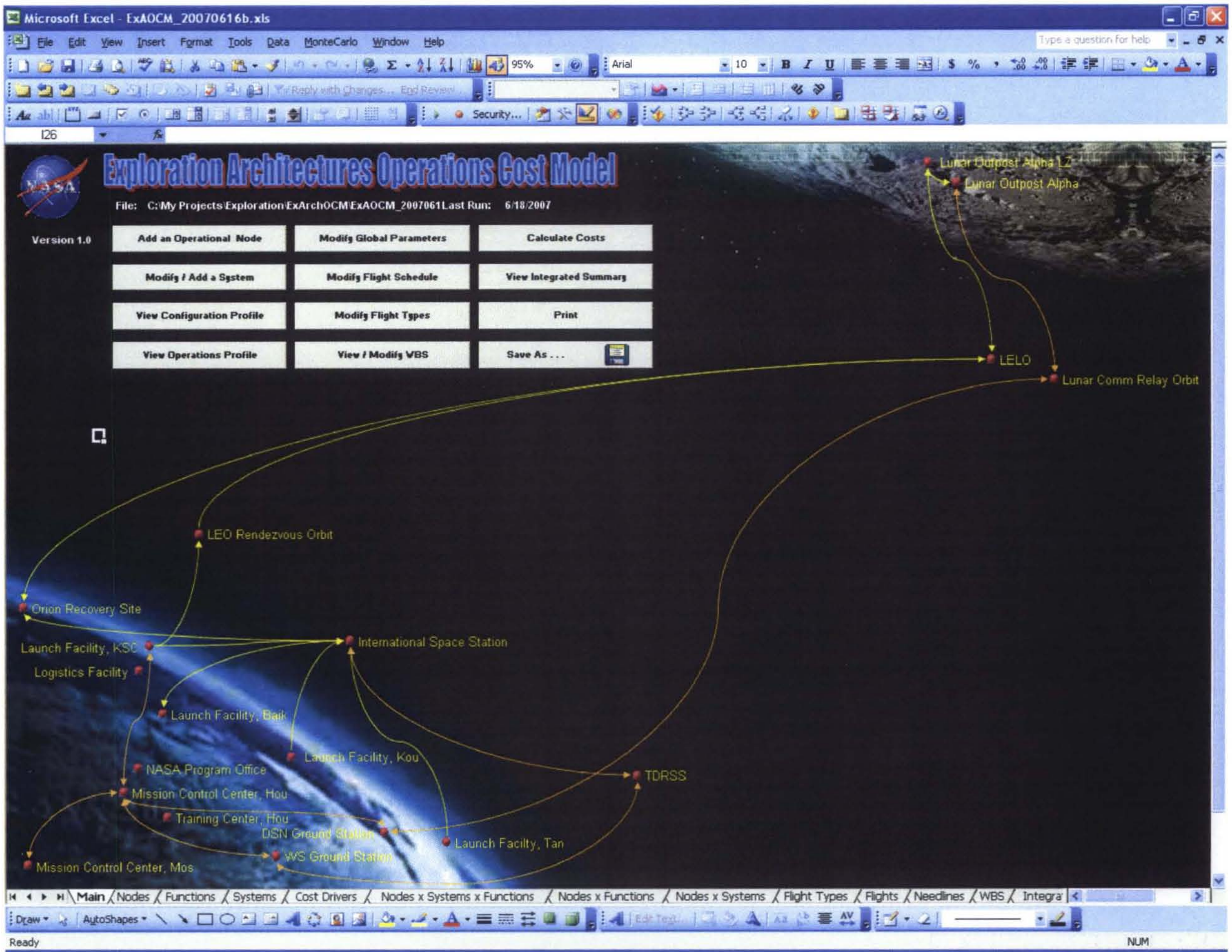


Exhibit 8. ExAOCM Main User Interface

SEER-SEM

Galorath's SEER-SEM is a powerful decision-support tool that estimates the cost, labor, staffing, schedule, reliability, and risk for all types of software development and/or maintenance projects. SEER-SEM is effective for all types of software projects, from commercial IT business applications to real-time embedded aerospace systems. Organizations use SEER-SEM on their software projects to manage and control costs, meet schedules, deliver quality and manage project risk.

Ad Hoc High Fidelity Cost Models

Where necessary to capture cost impacts of trade-off details, higher fidelity cost models will be developed "on-the-fly" to support CxP studies or analyses. Cost estimates from these models may be passed through an ARCOM or directly to LifCIM. A sample screen shot of an ad hoc cost model developed for a trade study is shown in Exhibit 9.

SM Case 1: NTO/MMH, Pressure Fed, Integrated OMS/RCS

Version 08 - Based on Performance Team Results Summary v22		Cost Element Inputs											
Cost Elements		Recurring										N	
EBS	EBS Element Title	Predicted Weight (lb)	Included Weight Growth %	Raw Weight (lb)	Adjusted Weight Growth %	Adjusted Weight (lb)	Number Per Subsys	Raw Wt Per Subsys	Adj Wt Per Subsys	Major Sub %	PDF	% Unique Design	% New Design
1.0	**Propulsion Subsystem Total**												
1.1	Prime's Fee												
1.2	**Subsystem Subtotal**							2,537.85	3,299.20				
1.2.1	Subsystem SEIT/PM												
1.2.2	**Subsystem Hardware Subtotal**							2,537.8	3,299.2				
1.2.2.1	OMS Group							1,661.6	2,160.1				
1.2.2.1.1	OMS Oxidizer Pressurization Tank	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	100	0.00	0	0
1.2.2.1.2	OMS Fuel Pressurization Tank	125.6	0.0	125.6	30.0	163.3	2	251.2	326.5	100	1.00	61	100
1.2.2.1.3	OMS Oxidizer Tank	199.6	0.0	199.6	30.0	259.5	2	399.2	518.9	100	1.00	61	100
1.2.2.1.4	OMS Fuel Tank	195.4	0.0	195.4	30.0	254.0	2	390.8	508.0	100	1.00	61	40
1.2.2.1.5	OMS Pressurization Feed System	154.6	0.0	154.6	30.0	201.0	1	154.6	201.0	0	1.00	35	100
1.2.2.1.6	OMS Propellant Feed System	158.8	0.0	158.8	30.0	206.4	1	158.8	206.4	0	1.00	30	100
1.2.2.1.7	OMS Engine	307.1	0.0	307.1	30.0	399.2	1	307.1	399.2	100	0.78	79	100
1.2.2.2	RCS Group							427.2	555.4				
1.2.2.2.1	RCS Pressurization Tank (Separate RCS only)	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	100	0.00	0	0
1.2.2.2.2	RCS Oxidizer Tank (Separate RCS only)	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	100	0.00	0	0
1.2.2.2.3	RCS Fuel Tank (Separate RCS only)	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	100	0.00	0	0
1.2.2.2.4	RCS Pressurization Feed System (Separate RCS only)	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	0	0.00	0	0
1.2.2.2.5	RCS Propellant Feed System	187.2	0.0	187.2	30.0	243.4	1	187.2	243.4	0	1.00	21	100
1.2.2.2.6	RCS Engine	10.0	0.0	10.0	30.0	13.0	24	240.0	312.0	100	0.82	90	100
1.2.2.3	Passive Thermal							364.0	473.2				
1.2.2.3.1	Insulation	364.0	0.0	364.0	30.0	473.2	1	364.0	473.2	0	1.00	49	100
1.2.2.4	Broad Area Cooling (LO2/LH2 only)							0.0	0.0				
1.2.2.4.1	Cryocooler System	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	100	0.00	0	0
1.2.2.4.2	Radiator	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	0	0.00	0	0
1.2.2.4.3	Shield	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	0	0.00	0	0
1.2.2.4.4	Tubing, Valving, Integration	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	0	0.00	0	0
1.2.2.4.5	MLI	0.0	0.0	0.0	30.0	0.0	0	0.0	0.0	0	0.00	0	0
1.2.2.5	Electrical							85.0	110.5				
1.2.2.5.1	Signal Conditioning	20.0	0.0	20.0	30.0	26.0	2	40.0	52.0	0	1.00	80	100
1.2.2.5.2	Instrumentation	11.0	0.0	11.0	30.0	14.3	2	22.0	28.6	0	1.00	80	100
1.2.2.5.3	Heaters, Thermostats, Controls	11.5	0.0	11.5	30.0	15.0	2	23.0	29.9	0	1.00	40	100

Exhibit 9. Ad Hoc Cost Model for Propellant Options Study

Operational Considerations

LCAM will time phase costs across a life cycle of up to twenty years but can be modified to accommodate longer analysis time frames if needed. The model is capable of spreading cost automatically via a selectable beta distribution function (e.g., 60% cost/50% time) or manually, and display results in both graphic and tabular formats. In addition, where feasible, Visual Basic for Applications (VBA) controls are employed to facilitate user selection functions such as drop down menus, check boxes, and or toggle switches. Macro code can also be written to assist in repetitive processes or for data flow control purposes.

LCAM Output

LCAM supports manifest, design, and requirements trade studies by calculating changes in cost relative to the Program Baseline life-cycle cost estimate (LCCE) as maintained by the Constellation Program Planning and Control Office. LCAM does not change or update the baseline. Rather LCAM gives key decision makers the LCCE impacts so that informed decisions can be made. Examples of LCAM output are shown in Exhibits 10, 11 and 12.

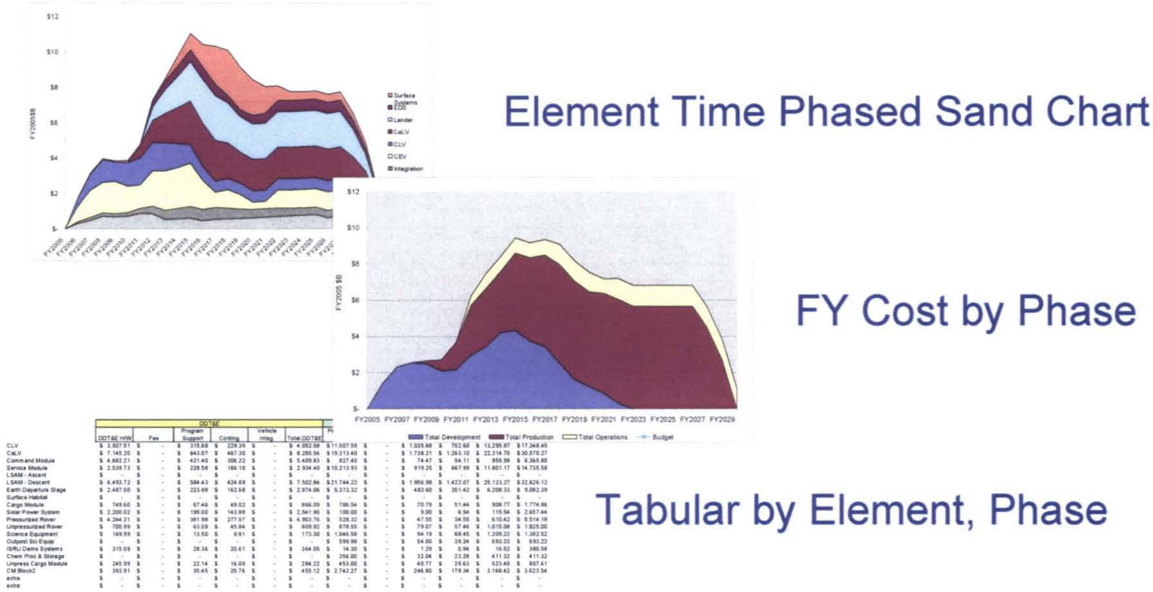


Exhibit 10. Example LCAM Sand Charts and Tables

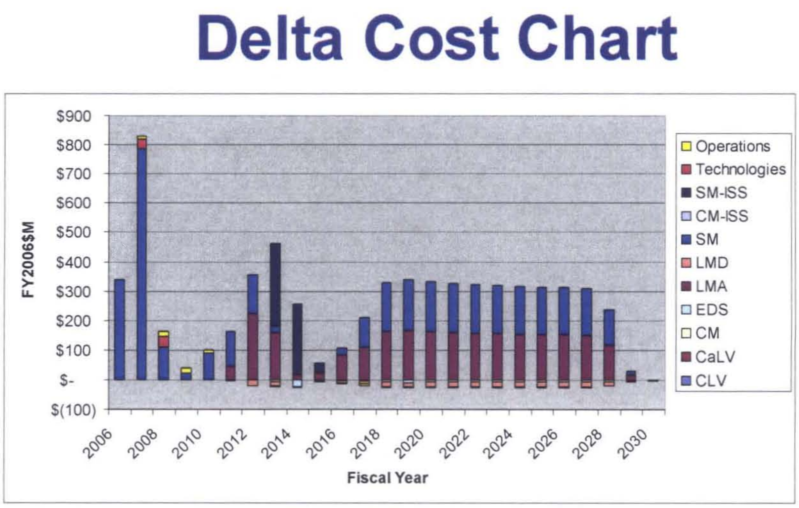


Exhibit 11. Example LCAM Time Phased Delta Cost

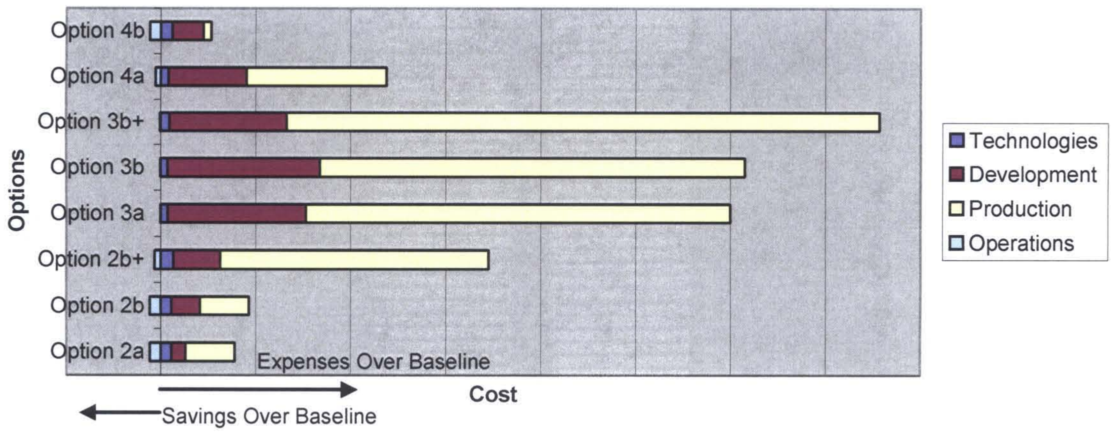


Exhibit 12. Example LCAM Delta Cost by Study Option

Summary

LCAM gives the Constellation Program the parametric estimating capability needed to provide cost data for key technical and programmatic issues. If Constellation cannot be executed affordably, it will hamper NASA's ability to fulfill the United States Space Policy for Exploration. Good life-cycle cost estimates are key to making the most cost effective decisions. Without the capability to assess the life-cycle cost impact of decisions, management effectiveness will be impaired.