12. Cost

12.1 ESAS Cost Analysis Context

Current NASA cost projections for the Exploration Vision are based on the Exploration Systems Architecture Study (ESAS) recommended architecture. The estimates are based on parametric cost models, principally the NASA and Air Force Cost Model (NAFCOM). The cost analysis attempted to be conservative. For example, NAFCOM assumes the historical levels of requirements changes, budget shortfalls, schedule slips, and technical problems. If the Vision program maintains stable requirements, is provided timely funding, and incurs fewer technical issues (due to the simplicity and heritage of the approach), cost should be lower than historical norms. Cost credits were not taken for such outcomes, nor do the estimates reflect desired commercial activities that might develop needed cargo and crew services

On the other hand, the ESAS was a Phase A concept study. The designs will mature as in-house and contractor studies proceed. Costs will be revisited at Systems Requirement Review (SRR) and Preliminary Design Review (PDR), including non-advocate independent cost estimates. A firm commitment estimate is not possible until PDR.

Finally, critical procurement activity is currently underway and Government cost estimates are being treated as sensitive information. Accordingly, all cost results are provided in the procurement-sensitive appendix, **Appendix 12A**, **Procurement-Sensitive Cost Analysis**.

12.2 Major Cost Conclusions

The ESAS effort considered a wide trade space of space transportation, space vehicle, and ground infrastructure options that are discussed throughout this report. The final recommended architecture resulted, in large part, from selections made on the basis of cost. First, Shuttle-derived Launch Vehicles (LVs) were found to be more economical, both in nonrecurring and recurring cost terms, than the other major alternatives considered—various configurations of Evolved Expendable Launch Vehicle (EELV)-derived launchers. Specifically, the most economical Crew Launch Vehicle (CLV) was found to be the four-segment Solid Rocket Booster (SRB) in-line vehicle with a Space Shuttle Main Engine (SSME) upper stage. Shuttle-derived in-line Heavy-Lift Launch Vehicles (HLLVs) were also found to be more economical than their EELV-derived counterparts. The Crew Module (CM) part of the Crew Exploration Vehicle (CEV) was baselined to be reusable, which resulted in significant Life Cycle Cost (LCC) savings. Using the (CEV) and CLV combination to service the International Space Station (ISS) results in an average annual cost that is approximately $1.2B less than the current cost of using the Shuttle to service the ISS. Various lunar mission modes were considered and costed. While the direct-to-the-lunar-surface mission mode resulted in lowest overall cost, the Earth Orbit Rendezvous–Lunar Orbit Rendezvous (EOR–LOR) option was actually selected for other reasons and was only marginally higher in cost. A CEV and CLV funding profile for first flight in 2011 was recommended that offers an acceptable cost and schedule confidence level, but exceeds planned budgets in some years. Beyond 2011, the development of the lunar LV and other elements again results in a relatively modest over-budget situation in certain years that can be addressed by additional design-to-cost approaches. Subsequent to the ESAS effort, NASA baselined a 2012 first flight for CEV and CLV, which allows the program to be accomplished within available budget.

12.3 Top-Level Study Cost Ground Rules

The major ESAS cost assumptions are listed below:

- Cost is estimated in 2005 dollars in full cost (including civil service and corporate General and Administrative (G&A)).
  - Cost is converted to inflated ("real year") dollars only for the "sand chart" budget overviews.
- Cost reserves of 20 percent for Design, Development, Test, and Evaluation (DDT&E) and 10 percent for production and operation cost are included.
  - Probabilistic cost risk analysis performed later in the study verified that this reserve level is acceptable.
- Cost estimates are formulation estimates and, as such, are considered preliminary.
- Any cost estimates supplied by contractors are vetted by independent Government estimators.
- All cost estimates reflect today's productivity levels and modern engineering processes.
- The costs include all civil service salaries and overheads and all Government "service pool" costs ("full cost" in NASA terms).

The cost estimates include all LLC elements from DDT&E through operations. These elements are listed below:

- DDT&E;
- First flight unit;
- Test flight hardware costs;
- Hardware annual recurring cost (split between fixed and variable);
- Operations capability development;
- Facilities and facilities Maintenance and Operations (M&O);
- Hardware operations costs:
  - Flight operations (fixed and variable);
  - Launch operations (fixed and variable); and
  - Sustaining engineering, spares, and logistics.
- Flight and ground software;
- Full cost adds:
  - Civil servant; and
  - Support contractors.
- Reserves.

Ground test hardware, test flight hardware, and test operations were all included to be consistent with the test plan reported separately in this report. Early operations capability development at the launch and mission control sites at NASA Kennedy Space Center (KSC) and Johnson Space Center (JSC) were included. Production and operations costs were book-kept as annual fixed cost and variable cost-per-flight to properly account for rate effects across varying flight rates per year.

12.4 Cost-Estimating Participants

As shown in **Figure 12-1**, several NASA Centers and NASA Headquarters (HQ) participated in the cost-estimating activities. JSC estimated the CEV, landers, surface systems, Launch Escape System (LES), and mission operations. NASA Marshall Space Flight Center (MSFC) was responsible for all space launch and transportation vehicle development and production costs. KSC estimated the launch facilities and launch operations costs. NASA Glenn Research Center (GRC) provided the lunar surface power systems cost estimates. The costs were integrated by the ESAS team at NASA HQ, which also handled the interface with the Shuttle/ISS configuration. Final budget integration and normalization was done by NASA HQ.

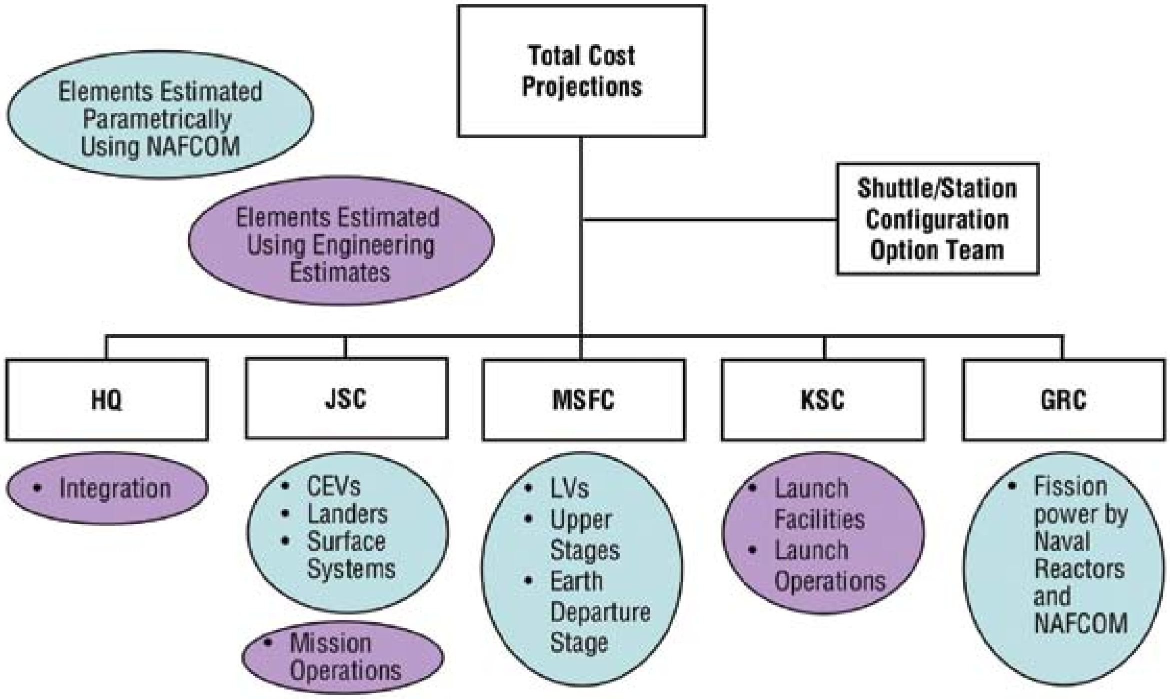


Figure 12-1. Cost-Estimating Participants and Approaches Used

12.5 Top-Level Summary of Methodologies Employed

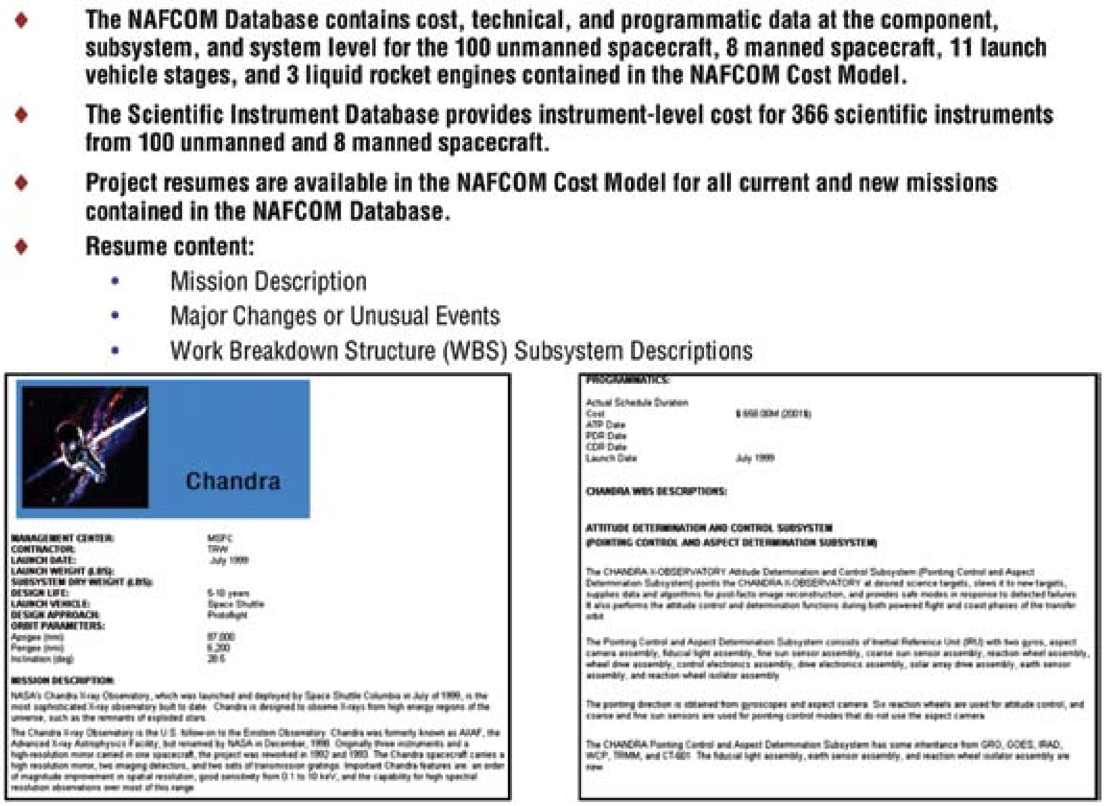
12.5.1 DDT&E and Production Costs

The cost estimates were calculated using both parametric and engineering estimating approaches. Most parametric estimates were performed with NAFCOM, which is a basic parametric cost-estimating tool widely used in the aerospace sector. NAFCOM is a NASA-managed model currently being maintained by a Government contractor for NASA. As shown in **Figure 12-2**, the model is based on a relatively large database of approximately 122 historical projects including LVs and spacecraft. Recent model improvements include changes as a result of internal statistical assessments and benchmarking activities with aerospace industry contractors.

- **Parametric cost model based on 122 NASA and Air Force space flight hardware projects**
  - Launch Vehicles
  - Robotic Satellites
  - Human-Rated Spacecraft
  - Space Shuttle
- **Recent updates based on benchmarking activity with contractors, internal assessment**
- **NAFCOM customers**
  - NASA HQ, MSFC, IPAO, other NASA centers
  - NAFCOM is used by over 800 civil servants and Government contractors

Figure 12-2. NAFCOM

The NAFCOM database is the basis for the multivariable Cost-Estimating Relationships (CERs) in NAFCOM. The model allows the user to use a complexity generator approach, which is essentially a multivariable regression CER approach or, alternately, a specific analogy approach in which the user selects the historical data points from the database for calibration purposes. Sample data from the NAFCOM database is shown in **Figure 12-3**.



- **The NAFCOM Database contains cost, technical, and programmatic data at the component, subsystem, and system level for the 100 unmanned spacecraft, 8 manned spacecraft, 11 launch vehicle stages, and 3 liquid rocket engines contained in the NAFCOM Cost Model.**
- **The Scientific Instrument Database provides instrument-level cost for 366 scientific instruments from 100 unmanned and 8 manned spacecraft.**
- **Project resumes are available in the NAFCOM Cost Model for all current and new missions contained in the NAFCOM Database.**
- **Resume content:**
  - Mission Description
  - Major Changes or Unusual Events
  - Work Breakdown Structure (WBS) Subsystem Descriptions

Chandra

MANAGEMENT CENTER: MSFC
CONTRACTOR: TRW
LAUNCH DATE: July 1999
LAUNCH WEIGHT (LBS):
SUBSYSTEM DRY WEIGHT (LBS):
DESIGN LIFE: 5-10 years
LAUNCH VEHICLE: Space Shuttle
DESIGN APPROACH: Protoflight
ORBIT PARAMETERS:
Apogee (nmi) 87,000
Perigee (nmi) 6,200
Inclination (deg) 28.5

MISSION DESCRIPTION:

PROGRAMMATICS:

Actual Schedule Duration
Cost
ATP Date
PDR Date
CDR Date
Launch Date July 1999

CHANDRA WBS DESCRIPTIONS:

ATTITUDE DETERMINATION AND CONTROL SUBSYSTEM
(POINTING CONTROL AND ASPECT DETERMINATION SUBSYSTEM)

Figure 12-3. Sample from the NAFCOM Database

12.5.2 Operations Costs

ESAS operations analysis of affordability used a combination of cost-estimation methods including analogy, historical data, subject matter expertise, and previous studies with contracted engineering firms for construction cost estimates. The operations affordability analysis relied on cost-estimating approaches and was not budgetary in nature, as budgetary approaches generally have extensive processes associated with the generation of costs, and these budgetary processes cannot easily scale to either architecture-level study trades in a broad decision-making space or to trading large quantities of flight and ground systems design details in a short time frame. The operations cost-estimating methods used in the ESAS are attempts at fair and consistent comparisons of levels of effort for varying concepts based on their unique operations cost drivers.

12.6 Productivity Improvements Since Apollo

ESAS cost estimates account for productivity improvements since Apollo. On average, the American economy has shown an approximate 2 percent productivity gain for the period of 1970 to 1990. Subsequent to 1990, average productivity has been higher due to the continuing effects of the Information Technology (IT) revolution.

The Bureau of Labor Statistics (BLS) has a productivity data series for “Guided Missiles & Space Vehicles (SIC Code 3761)” for the period of 1988 to 2000. Over that period, this series has shown an average productivity gain of 2.47 percent. Independently, internal NASA estimates have shown that an approximate 2.1 percent productivity gain can be derived from the data behind NAFCOM. This data includes historical Apollo hardware costs. It is reasonable to question whether the BLS data is valid for earlier years because the effects of the IT revolution began impacting costs in aerospace design and manufacture around the mid-1980s.

Assuming that the internal NASA estimates are a better estimate as to the average annual rate of productivity gain in the aerospace industry over the period of 1970 to 2005, but that the BLS data reflects trends in the period 1985 to 2005, it can be estimated that, prior to about 1985, productivity gains averaged approximately 1.58 percent. This gives an overall average productivity gain of 2.1 percent for the whole period.

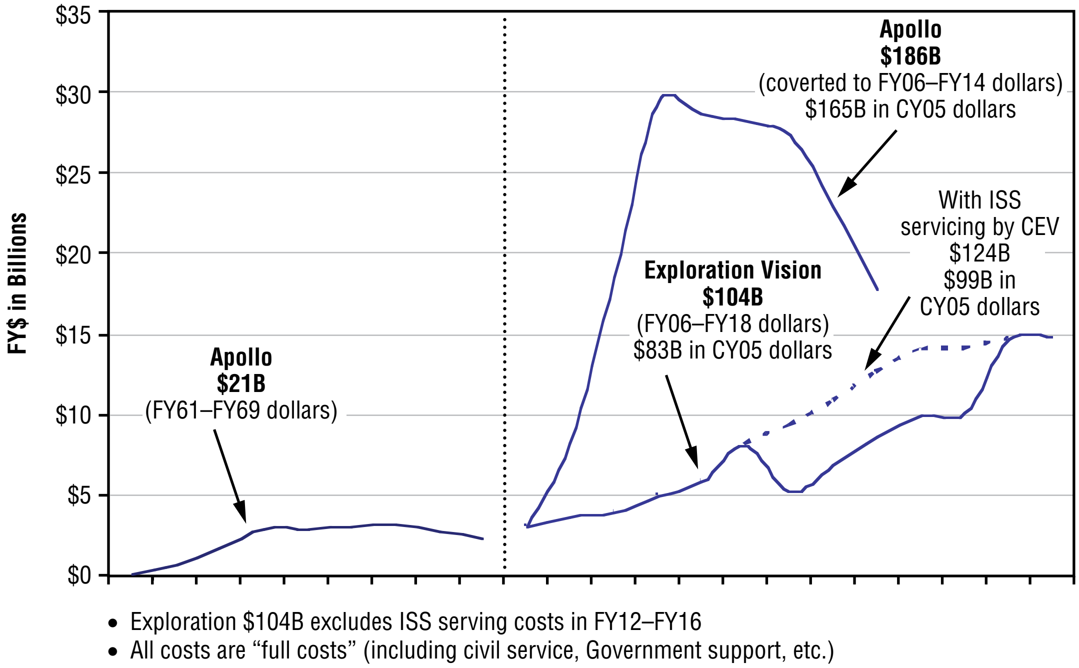
NAFCOM accounts for the productivity gains discussed above for most subsystems by embedding a time variable in the CERs, which is modeled as the development start date. Some NAFCOM CERs do not include the time variable due to statistical insignificance. For example, in the regressions for Main Propulsion System (MPS), engines, system integration, and management, the development start date was not statistically significant. With all else being equal, NAFCOM would predict that most Apollo flight hardware developed 50 years later would cost 33 percent less to develop and 22 percent less to produce than in 1967. Some subsystems, such as avionics, have an opposing trend of increasing cost over time due to increased functional requirements. In addition, NAFCOM allows the modeling of other specific engineering and manufacturing technology improvements that further reduce estimated cost.

12.7 Comparison to Apollo Costs

The cost estimates of the ESAS architecture accounted for the productivity gains previously discussed. In addition, because Shuttle-derived hardware is being used in the estimate, a cost savings is seen as compared to the Apollo Program's development of the Saturn V. Another factor to consider is that the proposed ESAS architecture is significantly more capable than the Apollo architecture. Apollo placed two crew members on the lunar surface for a maximum of 3 days, whereas the ESAS architecture places four crew members on the surface for a maximum of 7 days. This is factor of 4.6 times more working days on the lunar surface per sortie mission. The ESAS CEV also has three times the volume of the Apollo Command Module. This additional capability does not come at a great additional cost.

The historical cost in current 2005 dollars for the Apollo Program through the first lunar landing (FY61–FY69) was approximately $165B. The $165B figure includes all civil service salaries and overheads and all Government "service pool" costs. The ESAS architecture has an estimated total cost of $124B through the first lunar landing (FY06–FY18). As shown in **Figure 12-4**, costs were estimated conservatively with the inclusion of $20B for ISS servicing by CEV. Currently, NASA is planning to use commercial crew and cargo services to service the ISS which could further reduce cost.

The factor of 4.6 gain in capability and factor-of-three improvement in volume can be attained for less cost than the historical costs of Apollo. It should be noted that the ESAS architecture also allows access to the entire lunar surface, whereas Apollo was confined to the equatorial regions, and the ESAS architecture allows anytime return from any lunar location, thus providing still more capability over the Apollo capability.



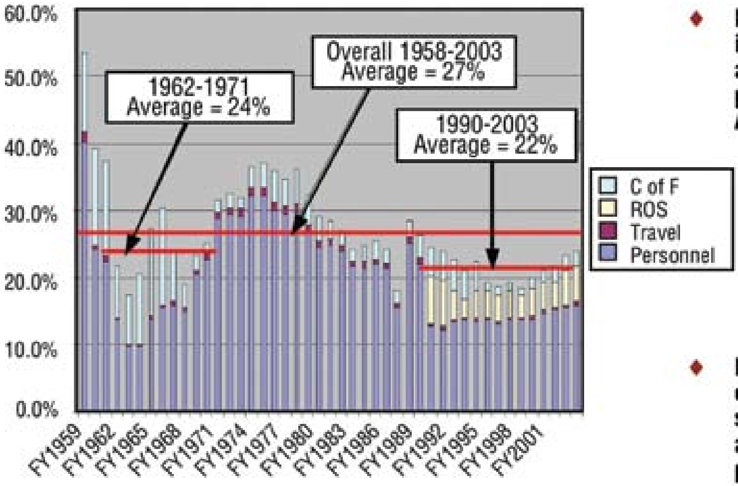
- Exploration $104B excludes ISS serving costs in FY12–FY16
- All costs are "full costs" (including civil service, Government support, etc.)

Figure 12-4. Comparison of Apollo Costs to Exploration Vision

12.8 Cost Integration

12.8.1 Full Cost “Wrap”

As shown in **Figure 12-5**, the cost of civil service and institutional costs has, over the long term of NASA’s history, equated to an approximate 25 percent “wrap factor” on procurement costs. In the ESAS, this 25 percent “parametric” factor was used where a detailed engineering estimate of civil service and institutional costs was not available.



- **Full cost (civil service and institutional costs) adds approximately 25% Agency-to-procurements costs at the total Agency level***
  - Shuttle and Station have recently been approximately 21%
  - Science has recently been 12% to 24%
  - Aeronautics research has been 50%
- **Full cost has been included in the estimates of the new exploration system to the extent they are not already covered by ongoing projects**

* Expressed as a multiplicative “wrap” factor on procurements, (equates to 20% of total budget).

Figure 12-5. Full Cost “Wrap”

12.8.2 Research and Technology Cost Estimates

The Research and Technology (R&T) budget includes Exploration Systems Research and Technology (ESRT), Human Systems Research and Technology (HSRT), and the Prometheus Nuclear Systems Technology (PNST) programs. The Prometheus program has been entirely replaced with a nuclear surface power technology program. This program is focused on a low-cost, low-mass, high-power capability for use on the Moon or Mars. The ESRT and the HSRT programs will be focused on projects with direct application to the ESAS-recommended architecture. Near-term focus for HSRT will be on ISS applications that provide information on effects of long durations in zero- or low-gravitational environments, risks due to radiation exposure, radiation protection measures, and advanced space suit technologies. Near-term focus of ESRT is on the following: heat shield applications; propulsion technologies for CEV and lander, especially Liquid Oxygen (LOX)/methane engines; Low-Impact Docking System (LIDS); airbag and parachute landing systems; precision landing Guidance, Navigation, and Control (GN&C); In-Situ Resource Utilization (ISRU) technologies; lunar surface mobility systems; and Integrated System Health Management (ISHM).

12.8.3 Systems Engineering and Integration Cost Estimate

The Systems Engineering and Integration (SE&I) cost estimate was derived by examining the costs for several previous human spaceflight programs. As a percentage of all other costs, the SE&I cost averaged approximately 7 percent in those programs. The ESAS cost is estimated as 7 percent of total cost until it reaches a staffing cap at 2,000 people. In all prior human space flight programs, the peak workforce level for SE&I was between 1,000 and 1,500 people. Capping the Exploration estimate at 2,000 people is a conservative assumption that should be attainable. There were no additional reserves added to the cost of SE&I for that reason.

12.8.4 Robotic Lunar Exploration Program (RLEP) and Other Costs

NASA's RLEP program costs are bookkept on the future ESAS budget profiles because it is an integral part of NASA's human and robotic exploration program.

12.8.5 Other Costs

Several smaller cost elements and elements that provide common support across all elements have been included in the "other" category of the ESAS cost estimates. The elements included in this category are: Mission Control Center (MCC) common systems/software, Launch Control Center common systems/software, In-Space Support Systems, crew medical operations, Flight Crew Operations Directorate support, flight crew equipment, Space Vehicle Mockup Facility (SVMF), neutral buoyancy laboratory support, nontraditional approaches for providing space flight transportation and support, ISS crew and cargo services from international partners, and Michoud Assembly Facility (MAF) support during transition from Shuttle to Exploration LV production. These costs were predominantly estimated by direct input from the performing organizations. Most are the result of assessing current expenditures for the Shuttle and ISS programs and extrapolating those results to the Exploration program. The major element within the In-Space Support Systems is the lunar communication constellation. This estimate was taken from a communication system working group study from March 2005. In the case of the nontraditional approaches, there is a set-aside in these estimates of approximately $600M to cover entrepreneurial options between 2006 and 2010. The ISS crew and cargo services were estimated by pricing Soyuz flights at $65M per flight and Progress flights at $50M per flight. The Soyuz and Progress estimates were coordinated with the ISS Program Office.

12.8.6 Cost Risk Reserve Analysis

The ESAS team performed an integrated architecture cost-risk analysis based on individual architecture element risk assessments and cost-risk analyses. Cost-risk analyses were performed by the cost estimators for each major element of the Exploration Systems Architecture (ESA). Cost estimates for the CLV, Cargo Launch Vehicle (CaLV), CEV, landers, rovers, and other hardware elements were developed using NAFCOM. Risk analysis was provided by the cost estimators using the risk analysis module within NAFCOM. NAFCOM uses an analytic method that calculates top-level means and standard deviations and allows full access to the element correlation matrix for inter- and intra-subsystem correlation values. Facility modification and development, ground support, Michoud Assembly operations, R&T, and other costs were estimated using other models or engineering buildup. Risk for some of these elements was assessed by reestimating using optimistic and pessimistic assumptions and modeling the three estimates as a triangular risk distribution. The integrated cost from these estimates was transferred to an “environment” known as the Automated Cost-Estimating Integrated Tools (ACEIT). ACEIT is a spreadsheet-like environment customized for cost estimating that has the capability to perform comprehensive cost-risk analysis for a system-of-systems architecture.

The cost-risk analysis was performed subsequent to the presentation of the cost estimate to the NASA Administrator, Office of Management and Budget (OMB), and the White House. This was due to the limited time of the ESAS and the high number of alternative configurations costed. Hence, for these initial estimates, the ESAS team decided to include a 20 percent reserve on all development and 10 percent reserve on all production costs, approximately $1.5B total, to ensure an acceptable Confidence Level (CL) in the estimate to arrive at a total estimate of $31.2B through the first lunar flight.

The cost-risk analysis identified the 65 percent CL estimate ($31.3B) as equivalent to the ESAS team’s point estimate with 20 percent/10 percent reserves. The cost-risk analysis confirmed that the cost estimate presented earlier was an acceptable confidence. Note that risk analysis was performed only through 2011; most cost risk is post-2011.

12.9 Overall Integrated Cost Estimate

In general, the cost estimates for all elements of the ESAS were provided by cost-estimating experts at the NASA field centers responsible for each element. These estimates were provided to the ESAS team in FY05 constant dollars including NASA full cost wraps. The team applied the appropriate reserve levels for each estimate to achieve a 65 percent CL and spread the costs over the appropriate time periods to complete the LLC estimates. Nonrecurring costs were provided as “Estimates at Completion” (EAC). Recurring costs were provided in fixed cost and variable cost components. In general, the nonrecurring costs were spread over time using a distribution curve based on historical cost distributions from many previous human space flight and large scientific NASA programs. The prior programs were converted to percent-of-time versus percent-of-total-cost curves. A beta distribution curve that closely traced the historical data was then used by the ESAS team for spreading the individual element nonrecurring costs.

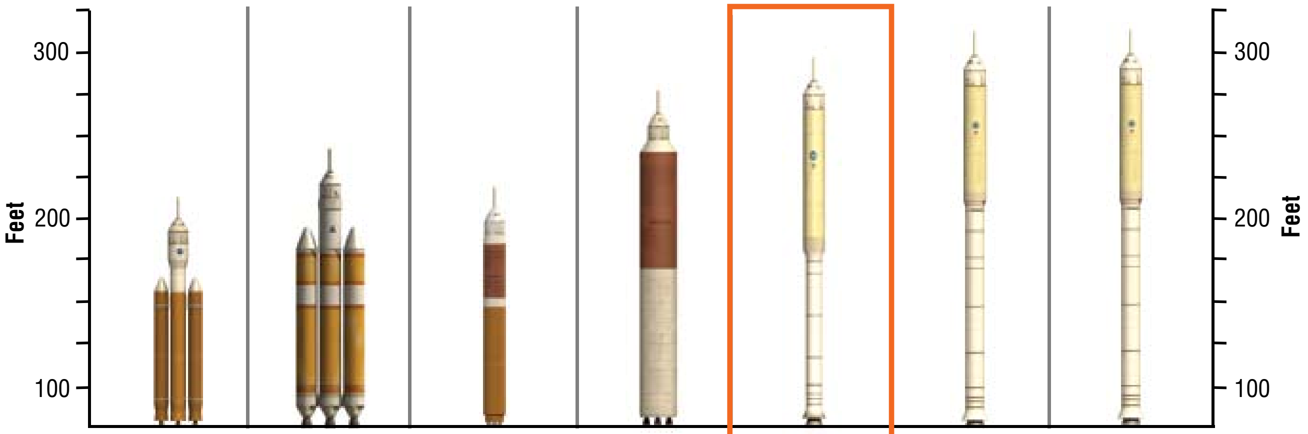
For all of the elements described below, the integrated cost estimate includes the DDT&E estimate for the hardware, production of flight hardware, provision of flight test articles, facility modifications at the NASA operational sites and engine test sites, operational costs for processing hardware at the launch site, mission operations to train crew and ground personnel, initial spares lay-in, logistics for processing the reusable components, and sustaining engineering for reusable components once production has ended.

12.9.1 ESAS Initial Reference Architecture

In order to compare various approaches and options for the study, a baseline departure point was selected by the ESAS team. This baseline was referred to as the ESAS Initial Reference Architecture (EIRA).

12.9.2 Launch Vehicle Excursions from EIRA

Excursions from EIRA were examined for both the CLV and the CaLV. **Figures 12-6** and **12-7** provide the top-level comparison of costs for the most promising LV options assessed during this study.



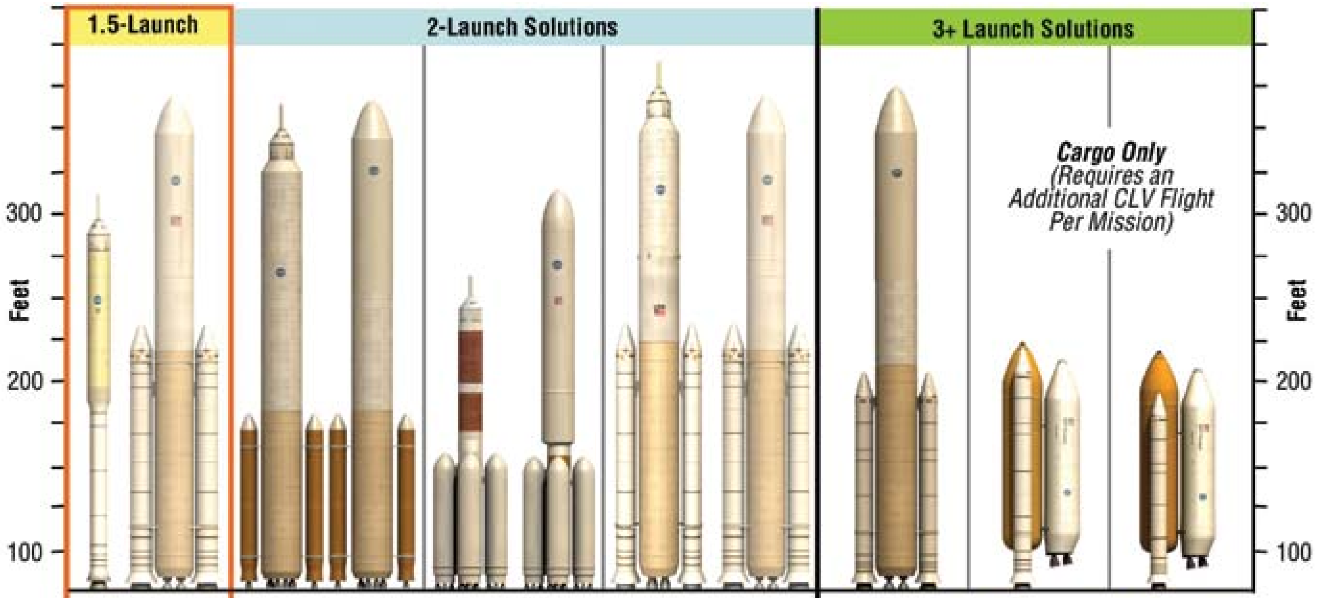
	Human-Rated Atlas V/New US	Human-Rated Delta IV/New US	Atlas Phase 2 (5.4-m Core)	Atlas Phase X (8-m Core)	4 Segment RSRB with 1 SSME	5 Segment RSRB with 1 J–2S	5 Segment RSRB with 4 LR–85
Payload (28.5°)	30 mT	28 mT	26 mT	70 mT	25 mT	26 mT	27 mT
Payload (51.6°)	27 mT	23 mT	25 mT	67 mT	23 mT	24 mT	25 mT
DDT&E*	1.18**	1.03	1.73**	2.36	1.00	1.3	1.39
Facilities Cost	.92	.92	.92	.92	1.00	1.00	1.00
Average Cost/Flight*	1.00	1.11	1.32	1.71	1.00	.96	.96
LOM (mean)	1 in 149	1 in 172	1 in 134	1 in 79	1 in 460	1 in 433	1 in 182
LOC (mean)	1 in 957	1 in 1,100	1 in 939	1 in 614	1 in 2,021	1 in 1,918	1 in 1,429

LOM: Loss of Mission   LOC: Loss of Crew   US: Upper Stage   RSRB: Reusable Solid Rocket Booster

* *All cost estimates include reserves (20% for DDT&E, 10% for Operations), Government oversight/full cost; Average cost/flight based on 6 launches per year.*

** *Assumes NASA has to fund the Americanization of the RD–180.*
Lockheed Martin is currently required to provide a co-production capability by the USAF.

Figure 12-6. Comparison of Crew LEO Launch Systems



	5 Segment RSRB In-Line with 5 SSME Core - Cargo	Atlas Phase X (8-m Core)	Atlas Phase 3A (5.4-m Core)	5 Segment RSRB In-Line with 4 SSME Core	4 Segment RSRB In-Line with 3 SSME Core	5 Segment RSRB Side-mount with 3 SSME	4 Segment RSRB Side-mount with 3 SSME
Payload to 28.5	106 mT (125 mT w/ upperstage)	95 mT	94 mT	97 mT	74 mT	80 mT	67 mT
Lunar LV DDT&E*	1.00	1.29	.59	.96	.73	.80	.75
CLV+Lunar Crew/Cargo DDT&E (family op)*	1.00 (4 Seg RSRB w/1 SSME)	1.26 (Atlas V)	1.02 (Phase 2)	.98 (4 Seg RSRB w/1 SSME)	.83 (4 Seg RSRB w/1 SSME)	1.03 (5 Seg RSRB w/J2S-LR85)	.85 (4 Seg RSRB w/1 SSME)
Lunar LV Facility DDTE	1.00	1.33	2.25	1.00			
CLV+Lunar Facilities Cost	1.00	1.12	1.56	1.00			
Lunar LV Average Cost/Flight*	1.00	1.08	1.19	.87	.78	1.13**	1.13**
LOM – Cargo (mean)	1 in 124	1 in 71	1 in 88	1 in 133	1 in 176	1 in 172	1 in 173
LOC (mean)	1 in 2,021	1 in 536	1 in 612	1 in 915	1 in 1,170	N/A	N/A

* All cost estimates include reserves (20% for DDT&E, 10% for Operations), Government oversight/full cost; Average cost/flight based on 6 launches per year.

**Production costs are higher than in-line due to production of separate side-mount cargo carrier

Figure 12-7. Lunar Cargo Launch Systems Comparison

One of the first options examined was the use of human-rated EELVs. From a cost perspective, the EELV-derived CLVs were approximately equivalent to the Shuttle-Derived Vehicles (SDVs). They were eliminated from further consideration primarily as a result of the reliability and safety analysis and because they did not offer a significant cost advantage over the more highly reliable SDVs. EELV derivatives for the CaLV were more costly than the SDVs and were eliminated on that basis.

In the case of the EIRA Shuttle-derived CLV, some of the highest cost items for development were the changes to a five-segment Reusable Solid Rocket Booster (RSRB) and the new LR–85 upper stage engine. Several options were examined to change the upper stage engine to a J–2S or an SSME. Using the SSME as an upper stage engine allows the use of the four-segment RSRB on the CLV instead of the five-segment version. This defers the cost of the five-segment development until needed for the CaLV. The lowest-cost and shortest-schedule CLV option is the current four-segment RSRB combined with a minimally changed SSME used for the upper stage. This configuration provides a highly reliable and safe vehicle. Since it is almost entirely derived from existing Shuttle components, it has the highest likelihood of meeting the desired launch date in 2011. It is the ESAS-recommended option for both ISS support and lunar missions.

For the CaLV, several excursions were examined to try to minimize the number of launches needed to complete a lunar mission and also to try to get a CaLV to pair with the highly reliable RSRB-derived CLV. In order to use the RSRB-derived CLV, the CaLV needs to provide more lift capability than the EIRA configuration. Options to add an upper stage to the vehicle were examined as well as options that use the Earth Departure Stage (EDS) during the ascent stage. The lowest cost option that allowed continued use of the RSRB CLV was the five-SSME core stage with five-segment strap-on RSRBs, while using the EDS for a burn during the ascent stage. This is the ESAS-recommended option for the CaLV. When coupled with the RSRB-derived CLV, this is called the “1.5-launch solution.”

One additional option was examined to try to reduce the total LLC of LVs. In this option, the CLV was eliminated and the HLLV was designed from the beginning for use as both a CLV and a CaLV. While this option has the best total LLC, it is very expensive in the near-term. Secondly, this option would represent excessive risk to meeting the desired 2011 launch date with many significant development activities needed. It also scores worse than the RSRB-derived CLV for reliability and safety. These results are presented in more detail in **Section 6.11**, **Conclusions**.

12.9.3 Cost Excursions from EIRA

12.9.3.1 “One Content Change at a Time” Excursions from EIRA

In addition to looking at LV options, the ESAS team looked at several other candidates to either reduce the costs in the critical periods or to improve the technical aspects of the EIRA baseline. **Table 12-1** provides a summary for several options that were examined.

Table 12-1. “One Content Change at a Time” Cases

Cost Case	Crew to ISS LV	Lunar Cargo and Crew LV	EDS	Rendezvous Option and CEV Diameter	Lunar Launches Per Mission	Lunar Program	Schedule	Technology Program
1A (EIRA) Low Tech	5-segment SRB LR-85 US	SDV 8-m Core 5-segment SRBs (with SSMEs)	Heritage Modified from US (LR-85s)	0 (LOR Split Mission) 5M CEV	2	Sorties + Base	2011 2018	Full
1E Low Tech	5-segment SRB LR-85 US	SDV 8-m Core 5-segment SRBs (with SSMEs)	Heritage Modified from US (LR-85s)	0 (LOR Split Mission) 5M CEV	2	**Sorties Only Deferred Base**	2011 2018	Full
1F Low Tech	5-segment SRB LR-85 US	SDV 8-m Core 5-segment SRBs (with SSMEs)	Heritage Modified from US (LR-85s)	0 (LOR Split Mission) 5M CEV	2	Sorties + Base	**2012** 2018	Full
1J Low Tech	5-segment SRB LR-85 US	SDV 8-m Core 5-segment SRBs (with SSMEs)	Heritage Modified from US (LR-85s)	0 (LOR Split Mission) 5M CEV	2	Sorties + Base	2011 2018	**Reduced**
1M Low Tech	5-segment SRB LR-85 US	SDV 8-m Core 5-segment SRBs (with SSMEs)	Heritage Modified from US (LR-85s)	0 (LOR Split Mission) 5M CEV	2 **Modified Test Plan**	Sorties + Base	2011 2018	Full

Changes from EIRA indicated by bold text.

Cost Case 1E was introduced to reduce the cost problem in the out-years. This option eliminated the long-stay base requirements and limited missions to short-duration sorties only. Cost Case 1F slipped the first CEV/CLV flight from 2011 to 2012. While it helps the near-term significantly, it is considered undesirable except as a last resort by the NASA Administrator because of the gap it introduces in the U.S. human space flight capabilities between Shuttle retirement and first CEV capability. Cost Case 1J significantly reduces the R&T budgets by focusing the activity on the needs of the ESAS-recommended program content. This option provides significant benefit in both the near-years and the out-years. Cost Case 1M implements a change to the flight test plan that was decided for technical reasons as a more reasonable test approach. It eliminates one of two previously planned Low Earth Orbit (LEO) tests of the CEV, lander, and the EDS. It retains both an LEO flight test mission and a lunar flight test mission, in which an unmanned lander goes to the lunar surface and returns for a rendezvous with the CEV. The deleted flight test mission saves the production of the CEV, lander hardware, and the LVs.

12.9.3.2 Rendezvous and Propulsion Technology Options

In support of the lunar architecture mission mode trade studies, several options were identified to vary the rendezvous locations for the CEV and lander. The initial rendezvous could either occur in Low Lunar Orbit (LLO) per the EIRA assumptions or they could initially rendezvous in LEO. The LEO rendezvous was preferable from an operational, safety, and reliability perspective because any problems with the rendezvous would occur in close proximity to the Earth and would allow better contingency options. The second major rendezvous occurs when the lander returns from the surface of the Moon. In the EIRA, the lander returns from the lunar surface and rendezvous with the CEV in LLO. Another option is to take the CEV to the lunar surface; then the return to Earth does not require a rendezvous at all. The CEV may go directly from the lunar surface to an Earth return trajectory. This option was referred to as a “direct return.” In the course of examining these options, additional options were introduced to change the technology level of the engines used for the CEV and lander. The EIRA assumes pressure-fed LOX/methane engines for the CEV Service Module (SM), lander descent stage, and lander ascent stage. The first set of options changed the lander descent engines to pump-fed LOX/hydrogen. The second set of options changed the CEV and lander ascent engines to pump-fed LOX/methane, in addition to using LOX/hydrogen engines for the lander descent stage. The lowest cost options were the lunar direct-return missions that required the pump-fed engines in all applications. The next lowest cost and the ESAS recommendation was the EOR–LOR case with pump-fed LOX/hydrogen engines on the lander descent stage and retaining pressure-fed LOX/methane engines for the CEV and lander ascent. The lunar direct-return cost was much lower due to the elimination of the habitable volume and crew systems on the lander ascent stage. These were replaced by the CEV going all the way to the lunar surface. The ascent stage of the lander was also eliminated by using the SM capabilities for ascent propulsion from the lunar surface. These cost advantages were offset by reduced safety and reliability due to the loss of the redundant habitable volume provided by the lander. Having both the CEV and the lander as separable crew habitation space was desirable from a crew survival perspective and for operational flexibility. The results of these rendezvous and engine technology options are shown in **Figure 12-8**. These results are presented in more detail in **Section 4.2.5**, **Analysis Cycle 3 Mission Mode Analysis**.

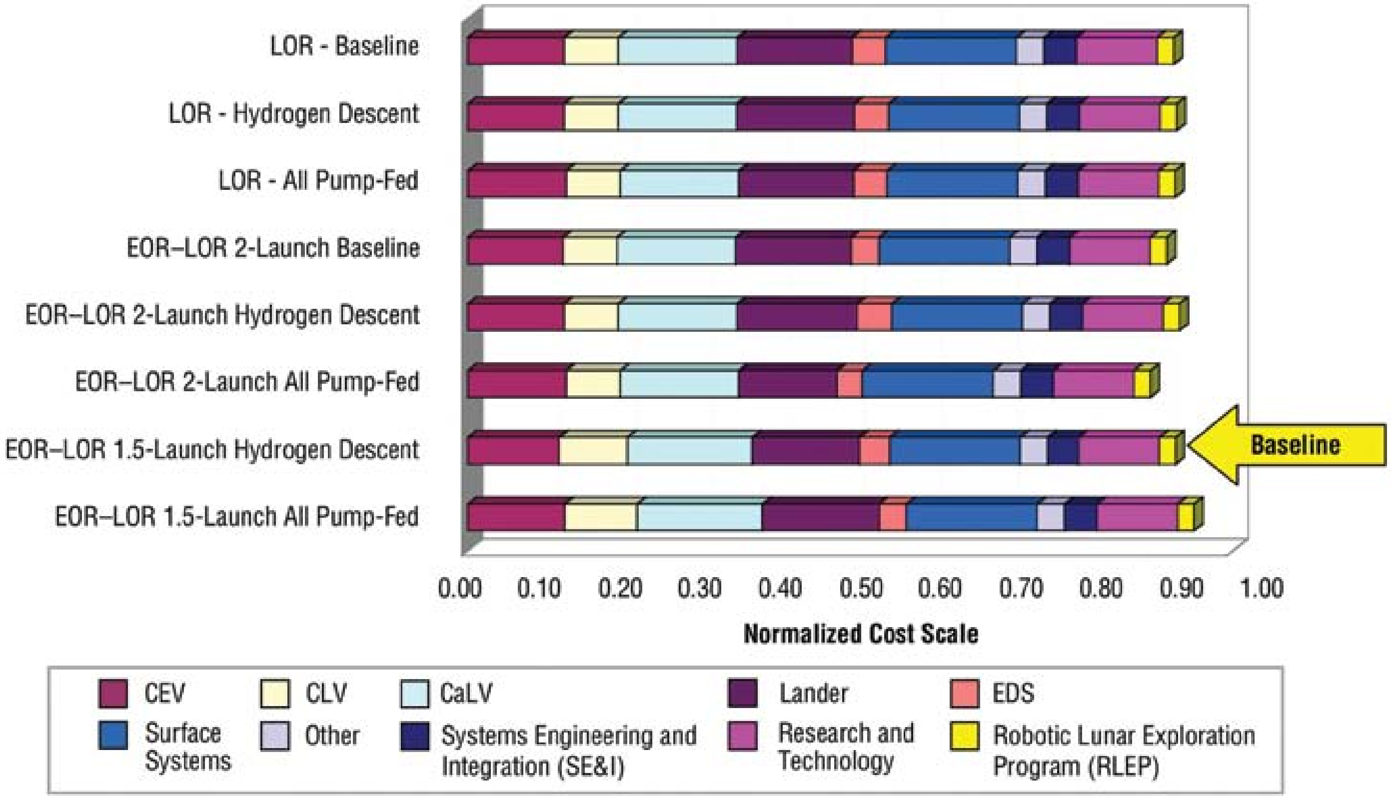


Figure 12-8. Rendezvous and Propulsion Technology Options

12.9.4 Final Cost Projections

As part of the President's Vision for Space Exploration, NASA was provided with a budget profile through FY11. The ESAS final cost recommendation assumed a funding requirement that exceeded this guideline in the years FY08–10, assuming the CEV first flight were to occur in 2011.

The ESAS recommendation retains the schedule objectives of the EIRA (i.e., 2011 first ISS mission and 2018 first human mission to the lunar surface). The recommendation includes the use of the 5.5-m CEV, the reduced R&T budget, and the modified test plan. It also includes reductions to the lunar outpost but not complete elimination of the outpost. The recommendation includes a minimal outpost consisting of both unpressurized and pressurized rovers, solar electrical power instead of nuclear power, lunar surface Extra-Vehicular Activity (EVA) suits, and small ISRU technology demonstrators. It eliminates the dedicated habitation module and large-scale ISRU production capability demonstrators. The recommended architecture is somewhat above the currently available budget in many years, but is considered a prudent achievable plan to replace human space flight capability and to begin to develop the necessary transportation infrastructure to provide a meaningful exploration capability. Subsequent to the ESAS effort, NASA baselined a 2012 first flight for the CEV and CLV, which allows the program to be accomplished within available budget.

12.10 CEV, Lunar Surface Access Module (LSAM), Lunar Surface Systems, EVA Systems, and Mission Operations Cost Estimates

12.10.1 Crew Exploration Vehicle (CEV) Acquisition Costs

12.10.1.1 Scope

The CEV cost estimates include the costs for the crewed CEV (Crew Module (CM), SM, and Launch Abort System (LAS)), the uncrewed CEV, and the unpressurized Cargo Delivery Vehicle (CDV). The CEV CM and SM have ISS and lunar variants. Because the ISS variant is the first to be developed, it carries the majority of the development cost. Lunar variants assume a significant degree of commonality with the ISS variant.

12.10.1.2 Methodology

All CEV estimates were prepared using NAFCOM. Hardware estimates were generally completed at the subsystem level or component level if detailed information was available. Cost estimates include the DDT&E cost and the production cost of the first Flight Unit (FU).

12.10.1.3 Ground Rules and Assumptions (GR&As)

The cost GR&As are included below.

- Cost estimates are in millions of FY05 dollars and include 10 percent fee and 4 percent vehicle integration.
- Hardware estimates were based on weight, selected analogies, design and development complexity, design heritage, flight unit complexity, system test hardware quantity, quantity next higher assembly, production quantity, and learning curve.
- System Test Hardware (STH) quantities were based on inputs from the Test and Verification Plan. All STH was allocated to the ISS versions of the CEV, since the lunar version was assumed to be identical. Production costs were based on a 90 percent Crawford learning curve. Production quantities were based on the projected mission manifest through 2030. For the uncrewed CEV capsule, and lunar variants of the CEV capsule and SM, the learning curve was assumed to start where the previous production run ended.
- Software estimates were based on previous estimates for the Orbital Space Plane (OSP). Software estimates for the CEV were output as a subsystem in NAFCOM to capture the additional system integration costs.
- The system integration costs were based on the average of three analogies: Gemini, Apollo Command and Service Module (CSM), and X–34. The Gemini and Apollo CSM analogies represent crewed capsule developments, while the X–34 was used to represent modern systems engineering and program management methods.

12.10.1.4 Alternative CEV Architectures

Several alternative CEV architectures were studied. These alternatives were estimated by variations from the basic EIRA cost estimate. Variations were created by changing the rendezvous mode and propulsion options. In addition, some alternatives have new technology options, such as fuel cells instead of solar arrays. The alternative architectures were assumed to perform the same number of missions.

12.10.1.5 Reusable Versus Expendable Capsule Trade Study

A trade study was performed to compare the LLC of a reusable CEV capsule to an expendable CEV capsule. The study looked at numerous variables that would influence the cost difference between the two options, including: flight unit cost, missions per vehicle, percentage of hardware replaced per mission, missions per year, and learning curve rate.

The trade study assessed the range of values for each input variable and identified the most likely values for each input. The study concluded that a reusable CEV capsule could save approximately $2.8B compared to an expendable capsule over the life of the program.

12.10.2 Lunar Surface Access Module (LSAM)

12.10.2.1 Scope

Estimates for the LSAM include the crew ascent vehicle, crew descent stage, and cargo descent stage.

12.10.2.2 Methodology

The cost-estimating methodology used for the LSAM was similar to the method used for the CEV.

12.10.2.3 Ground Rules and Assumptions

The GR&As used for the LSAM were similar to those used for the CEV.

12.10.2.4 Alternative LSAM Architectures

Several alternative LSAM architectures were studied. These alternatives were estimated by variations from the basic EIRA cost estimate. Variations were created by changing the rendezvous mode and propulsion options. In addition, some alternatives have new technology options, such as pump-fed versus pressure-fed engines. The alternative architectures were assumed to perform the same number of missions.

12.10.3 Lunar Surface Systems

12.10.3.1 Scope

The scope of the lunar surface systems includes hardware that is intended to operate primarily on the lunar surface, except for power systems, EVA systems, and crew equipment, which are addressed in later sections. The lunar surface systems include surface vehicles, surface modules, construction and mining systems and vehicles, and manufacturing and processing facilities.

12.10.3.2 Methodology

The cost-estimating methodology used to estimate the lunar surface systems was similar to the method used to estimate the CEV and LSAM. The data provided by the technical team was top-level notional design information that included system mass with functional descriptions. A Work Breakdown Structure (WBS) was developed for each surface system element with the aid of the ESAS design engineers and past studies. The estimates are preliminary and require updates as the designs mature.

12.10.3.3 Ground Rules and Assumptions

The GR&As used to estimate the lunar surface systems were similar to those used to estimate the CEV and LSAM.

12.10.4 Fission Surface Power System (FSPS)

12.10.4.1 Scope

The operational scenario calls for a stationary Fission Surface Power System (FSPS) power plant landed with a mobile Station Control Electronics (SCE) cart. The FSPS remains on the lander. The mobile SCE is off-loaded from the fixed power plant and drives to the designated site while deploying the power transmission cable. Startup and verification of the power system is performed prior to landing the habitat near the mobile SCE. The habitat provides the power interface to the mobile SCE.

12.10.4.2 Methodology

The design of the FSPS was based on the Prometheus FSPS-Lunar "Task 3 Report, Revision 8," dated June 10, 2005. Several power levels were studied in addition to the baseline power level of 50 kWe.

12.10.4.2.1 Reactor/Power Conversion Subsystems

Reactor and power conversion subsystem costs were derived from the Project Prometheus Naval Reactors prime contractor cost input. The estimate included costs for development, two ground test reactors, and two flight units. Costs for the second ground test reactor and flight unit have been removed and costs were converted from FY06 dollars to FY05 dollars. These costs had not been approved by Department of Energy (DoE) Naval Reactors as of the time of this estimate and are considered conservative. The estimate scope includes development and flight hardware for all reactor and power conversion subsystems/components, materials test and evaluation, and ground test reactor/facilities development and operations.

12.10.4.2.2 Balance of Power System/Mobility System

NAFCOM and GRC Boeing Task 26, CERs for Advanced Space Power and Electric Propulsion Systems, dated June 2005, were used to develop the Phase C/D cost estimates for the balance of the power system and the mobility system. NAFCOM was used to estimate the mechanical subsystem for the power plant (using manned-mission-type analogies) and the mobility system subsystems (using unmanned-planetary-type analogies and Earth-orbiting-mission-type analogies). GRC Boeing Task 26 was used to estimate the heat rejection subsystem for the power plant, transmission cable, and the station control electronics.

12.10.4.3 Ground Rules and Assumptions

The key GR&As associated with the FSPS estimate were as follows:

- The estimate was for surface power only (e.g., no nuclear propulsion related work). The costs do not include NASA HQ program management, risk communications, NASA National Environmental Policy Act (NEPA) support, KSC FSPS facility requirements, and corporate G&A.
- The reactor and power conversion subsystems were sized for 100 kWe for all power options considered.
- The mobile SCE concept mobility system was sized to transport only the power control electronics and cable from the lander to a remote location approximately 2 km away.
- Non-nuclear technology development costs were based on Prometheus requirements and do not change with a change in power level.
- Nuclear technology and facilities development costs include the ground test reactor and facilities and reactor module materials test and evaluation.
- Phase A/B DoE Naval Reactors costs were estimated at 7 percent of the Naval Reactors Phase C/D costs. Phase A/B prime contractor costs were estimated at 14 percent of prime contractor Phase C/D costs due to increased complexity associated with human-rating and integration complexity associated with multiple Government/contractor entities.
- The ground test reactor will continue to operate throughout the mission life.
- Government insight/oversight full costs were estimated at 10 percent of non-nuclear costs and 5 percent of DoE Naval Reactors costs for technology, Phase C/D, and Phase E. Government insight/oversight full costs were estimated at 30 percent of total Phase A/B costs.
- Phase C/D power system and mobility system risk ranges were based on results of a NAFCOM subsystem risk analysis. The cost estimate was the 50 percent confidence value from NAFCOM with risk turned on. Narrow risk ranges for the Phase A/B and Phase C/D are the result of using conservative estimating information and techniques.
- Cost phasing was based on assumed activities to be performed in each phase of the program. Minimum cost-level requirements that may be necessary for DoE Naval Reactors work have not been assumed. These requirements may change the phasing but not the total FY05 dollars required.
- Three test hardware items were included for all SCE subsystems/components and the heat rejection subsystem has two test hardware items.
- Mobility system power was assumed to be provided by a 3-kWe station control electronics solar array for transit and reactor startup.
- Ground test reactor facilities were assumed to be operational by 2014. Operations during the Phase C/D period were included in the Phase C/D costs.

12.10.5 Extra-Vehicular Activity (EVA) Systems

12.10.5.1 Scope

The EVA system consists of three major elements: (1) EVA suits, (2) EVA tools and mobility aids, and (3) vehicle support systems. The EVA suit system consists of the life support systems and pressure garments required to protect crew members from ascent/entry, in-space, and planetary environmental and abort conditions.

The EVA tools and mobility aids consist of the equipment necessary to perform in-space and planetary EVA tasks, and include items such as drills, hammers, ratchets, walking sticks, vehicle handrails, and foot restraints. The vehicle support system consists of the equipment necessary to interface the EVA system with the vehicles. It includes items such as mounting equipment, recharge hardware, and airlock systems.

Associated with each of the three major EVA elements are ground support systems. The ground support systems include the equipment and facilities required to test and verify the EVA development and flight systems.

For the purpose of this cost estimate, it was assumed that each phase of the exploration mission architecture will require a unique EVA system. Though these systems may be based on a common architecture, for cost purposes, they were considered separately.

12.10.5.1.1 EVA System I

The EVA System I will include the delivery, by 2011, of an in-space suit and the associated equipment necessary to support launch, entry, and abort scenarios and contingency EVA from the CEV and other Constellation vehicles. The EVA System I is required for all crewed missions, regardless of destination.

12.10.5.1.2 EVA System II

The EVA System II will include the delivery, by 2017, of a surface suit and the associated equipment necessary to support surface exploration during the lunar sortie phase. The EVA System II is required for short-term lunar missions, starting with the CEV/LSAM LEO integrated test flight.

12.10.5.1.3 EVA System III

The EVA System III will include the delivery, by 2022, of an enhanced surface suit and the associated equipment necessary to support surface exploration during steady-state lunar outpost operations. The EVA System III will be based on System II and will include those upgrades and modifications necessary for longer planetary missions.

12.10.5.2 Methodology

For each of the areas listed above, procurement costs were based on historical data from previous EVA efforts or derived from bottom-up estimates. Institutional costs were derived as a percentage of the procurement cost. The percentage chosen was dependant on the specific activity. For instance, the civil service involvement during the complicated DDT&E phase of the EVA suit was assumed to be higher (30 percent), while civil service involvement during the more straightforward ground processing phase was assumed to be lower (15 percent).

The following cost breakdowns were provided for each of the EVA systems.

- A total nonrecurring cost was provided for the DDT&E for each of the major elements (suit system, tools and mobility aids, vehicle support system, and ground support system). An estimated time required for completion was provided along with the total cost.
- A per-unit recurring cost was provided for production of each of the major elements (suit system, tools and mobility aids, vehicle support system, and ground support system).
- A yearly cost was provided for the sustaining engineering associated with the overall EVA system. This effort includes activities such as failure analysis and correction and discrepancy tracking.
- A yearly cost was provided for the ground processing associated with the overall EVA system. This effort includes ground processing for both flight and training activities.

12.10.5.3 Ground Rules and Assumptions

The key GR&As associated with the EVA systems estimate are as follows:

- All costs were estimated in 2005 dollars.
- Estimates for operations activities were not provided as part of the EVA estimate. Instead, they were provided as part of the mission operations cost estimate.

12.10.6 Mission Operations

12.10.6.1 Scope

Mission operations includes the control centers, training simulators and mockups, processes, tools, and personnel necessary to plan the missions, train flight crews and flight controllers, and support the flights and missions from the ground. Mission operations are complementary to ground operations at the launch site, which was estimated separately. Mission operations support the flight crew, the costs of which were estimated separately.

12.10.6.2 Methodology

In August 2004, budget analysts from six flight operations areas convened to develop mission operations cost estimates to support the Constellation Development Program. The product was a run-out of costs for each launch/mission and an estimated duration and spread among the following four cost categories: (1) operations support to vehicle development, (2) new or modified facility capability, (3) mission preparation, and (4) mission execution. Assumptions and results were documented and reviewed with NASA HQ management and independent groups.

The estimates presented in this report were a product of applying the mission-specific cost templates to a manifest of ESAS launches to produce an integrated cost.

12.10.6.3 Ground Rules and Assumptions

The key GR&As associated with the mission operations estimate were as follows:

- Unique operations preparation and operations support to development are required for each new space vehicle or major upgrade of a space vehicle.
- LV performance margins will be maintained to avoid significant recurring planning optimization of operational missions.
- Recurring ISS missions will use a single stable CEV and LV configuration and mission design.
- The existing NASA JSC MCC will be used with limited modification for all human missions and test flights of human-rated vehicles. Telemetry and command formats were assumed to be compatible with existing MCC capabilities.
- Recurring fixed cost for MCC use was shared by Exploration after Shuttle Orbiter stops flying, in proportion to facility utilization.
- New development was required for training simulators because the potential for reuse of existing simulators is very limited.
- Simple mission planning and operations were assumed for test flights and CEV to ISS.
- Complex, highly integrated mission plans are required for initial lunar sorties.
- Simple, quiescent surface operations are assumed for extended lunar stays.
- Crew and ground tasks are considerably simpler than for Shuttle during critical mission phases.
- Mission operations cost is largely dependent on the number of unique space vehicles and annual crewed flight rate.
- Mission operations cost is generally independent of the number of launches involved in a single crewed mission.
- Mission operations cost is generally independent of the launch architecture.

12.10.7 Neutral Buoyancy Laboratory (NBL) and SVMF Operations

12.10.7.1 Scope

For the SVMF, the estimate includes development of CEV mockups representing each of the configurations: crewed to ISS, uncrewed to ISS, and crewed to the Moon. It also includes LSAM descent stage, both crewed and cargo, and an ascent stage. A lunar rover was included in the cost estimate as well as upgrades to the partial gravity simulator for surface EVA training.

For the Neutral Buoyancy Laboratory (NBL), the mockup development includes a CEV mockup for contingency EVA training and a mockup for water egress and survival training. The NBL will need facility modifications to support the new EVA suits. Two suits were assumed: an ascent/entry/abort/contingency EVA suit and a surface EVA suit.

Training EVA and launch/entry suits for either facility were not included in this assessment. Also, science package training hardware was not included in this assessment.

12.10.7.2 Methodology

The cost estimates for the SVMF and NBL were based on experience supporting the ISS and Shuttle programs.

12.10.7.3 Ground Rules and Assumptions

The key GR&As associated with the NBL/SVMF operations estimate were as follows:

- The development and delivery schedule estimated a mockup delivery date of 2 years before the first flight and a 2-year development process.
- The fidelity for the mockups was assumed to be similar to the existing high-fidelity Shuttle and ISS mockups. This was reflected in the "most-likely" cost. The high cost estimate would be valid if more fidelity is required or if the vehicles are more complex than reflected in the initial reference architecture. The low cost estimate can be realized if engineering or qualification hardware is available to augment the training mockups.
- The cost assessment included a sustaining cost for each mockup after it was delivered that is consistent with the sustaining cost of current Shuttle and ISS mockups.
- Manpower estimates included instructor and flight control personnel for crew systems and EVA. A mix of civil servant and contractor personnel were assumed for these jobs. It was assumed that, early in the program, there would be a higher ratio of civil servants to contractors than there would be later in the program.

12.10.8 Flight Crew Operations

12.10.8.1 Scope

The cost estimate for flight crew operations includes estimates for the Astronaut Office, Vehicle Integration and Test Office (VITO), and Aircraft Operations Division (AOD). Astronaut Office personnel include astronauts, technical support engineers, astronaut appearance support, IT support, schedulers, and administrative and secretarial support. The VITO provides critical support at KSC during test and integration of flight hardware and during launch flows as representatives of the crew.

Aircraft operations include maintaining and flying the T–38 aircraft used by all astronauts to develop the mental and manual skills required to fly safely and successfully in a spacecraft. It also includes all the personnel to serve as flight instructors and as engineering support for the aircraft, as well as an Aviation Safety Office. The portion to be retained for Exploration training will most closely resemble the T–38 aircraft program of today.

12.10.8.2 Methodology

12.10.8.2.1 Astronaut Office

The number of astronauts is driven by the need to support crew mission assignments, provide flight crew support for operations development and technical issues, provide (non-crew) mission support, and support educational outreach to the public pertaining to the NASA mission and goals.

There is a minimum office size required to maintain the appropriate skill sets and experience within the Astronaut Corps. It is critical to maintain crew members with spaceflight experience, including those with experience in developing operational concepts for EVA, robotics, rendezvous, docking, controlling and maintaining a spacecraft and its systems, and other crew activities.

For this estimate, an Excel spreadsheet was used to estimate attrition, astronaut candidate selections, and military-to-civil-servant conversion. The current size of the Astronaut Office was used as the initial value. Estimates of attrition were based on historical values, and the variable of astronaut selection was used to stabilize the number of astronauts at approximately 60 by 2016. There is variation from year to year with the addition of each new astronaut class and with attrition. After 2016, classes of approximately 12 were required every 3 years to maintain the number of astronauts between 56 and 64. Until 2010, astronaut support was divided between Shuttle, ISS and Exploration programs. Following this period, the support was divided between ISS and Exploration. Beginning in 2016, only the Exploration program was supported.

The Shuttle Retirement Change Request (CR) was used to estimate the number of support engineers for the Astronaut Office. This was a convenient source of reference for procurement contractor support and civil service support for the Shuttle program. Due to the complex and multiple elements required for Exploration (i.e., support of multiple elements for lunar missions and eventual support of Mars strategy), estimates were made that support needs to begin in FY06 and ramp up to values greater than the current Shuttle support numbers by 2016. Contractor support for astronaut exploration activities will also begin in FY06. Total office support in these areas was shared with the other programs prior to FY16.

Expedition Readiness Training (ERT) for exploration astronauts is currently in the planning stages. It is envisioned that there will be challenging training situations to hone leadership and survival skills and to provide a basis for serious evaluation of the astronaut candidates and assigned crew members. This will include travel to outdoor leadership field exercises to assess leadership skills, travel to Mars analog sites to assess operational concepts, hardware concept development, and suitability for training and further expedition leadership training. There are numerous site possibilities for these activities.

12.10.8.2.2 Vehicle Integration and Test Office (VITO)

The Vehicle Integrated Test Team (VITT) has a long history of providing critical support at KSC during test and integration of flight hardware and during launch flows as representatives of the crew. This support will begin to ramp up to support CEV in FY07. VITT members also travel to contractor sites to inspect hardware under development to provide critical input regarding hardware crew interface standards while changes can be made more easily.

12.10.8.2.3 Aircraft Operations Division (AOD)

A percentage of aircraft operations support that includes maintaining and flying the T–38 aircraft should be shared by the Exploration Program. This cost estimate shows it beginning at a low level in FY06 and ramping up in proportion to the percentage of astronauts dedicated to Exploration support.

Discussions are underway concerning aviation analog training, with the objective of providing situations requiring time-critical and, perhaps, life-critical decisions in a real-life environment. This may include a variety of aircraft; however, details were not yet available as the planning is in the very preliminary stages. The goal is to stay within the T–38 portion of the AOD operations budget as it exists today. Based on the Shuttle Retirement CR numbers, the current T–38 program costs were prorated based on the percentages of astronauts dedicated to exploration activities from FY06 through FY25.

Support includes civil servants who serve as instructors and research pilots and who provide other engineering support. Contractor procurement support includes engineering support, aircraft maintenance, and other support staff. The total procurement costs based on the Shuttle Retirement CR estimates also include T–38 operating costs. Annual funding was included for aircraft modifications and other uncertainties.

12.10.8.3 Ground Rules and Assumptions

The key GR&As associated with the flight crew operations estimate were as follows:

- All costs are in FY05 dollars.
- All contractor travel was included in procurement costs.

12.10.9 Medical Operations

12.10.9.1 Scope

Medical operations include the following functions:

- Medical operations (direct mission support);
- Astronaut health (rehabilitation and conditioning, as well as Flight Medicine Clinic (FMC) and human test support);
- Flight surgeons;
- Shuttle-Orbiter-Medical-System- (SOMS-) like support;
- Crew-Health-Care-System- (CHeCS-) like support;
- Training;
- Contingency;
- Radiation health office;
- Behavioral health and performance;
- Documents and requirements integration;
- Flight medical testing;
- Environmental monitoring;
- Clinic laboratory; and
- Pharmacy.

12.10.9.2 Methodology

Driving assumptions for the basis of this estimate are:

- Lunar sortie missions are similar to Shuttle missions with respect to medical operations level of effort (MCC support, systems complexity, training templates, etc.).
- Similarly, lunar outpost missions are similar to ISS missions for medical operations.
- CEV missions between 2011 and 2016 are only for ISS crew rotation (no non-ISS CEV missions). Therefore, minimal medical operations support is required for CEV MCC console support, training, contingency, environmental and crew medical testing, and documentation support.
- Medical kit provisioning for CEV-to-ISS and lunar sorties will be similar in scope to the SOMS.
- The complement of medical supplies and equipment at the lunar outpost will be similar in scope (complexity, capabilities, consumables, etc.) to the ISS CHeCS.

12.10.9.3 Ground Rules and Assumptions

The key GR&As associated with the medical operations estimate were as follows:

- Costs were estimated initially in FY05 dollars (based on Space Transportation System (STS) and ISS experience), and then a 3.5 percent inflation rate was applied.
- Medical operations costs will begin in 2017 for pre-mission activities and for bridging staff and capabilities after ISS program termination.
- Costs assume little international participation. An international partnership arrangement similar to ISS would add costs for medical coordination with partners.
- ISS ends in 2016.
- The astronaut corps will be reduced in size after 2011, which affects outside medical bill costs.
- Supporting laboratories are assumed to continue to have multiple funding sources such that operations products can be purchased as required.
- Food provisioning was not included.
- Development, production, certification, and sustaining engineering of medical hardware was not included.
- For CEV to ISS, preflight environmental monitoring is performed similar to Shuttle. In-flight and post-flight support is reduced to less than half. The net result when combined with ongoing ISS support is 40 percent of the cost of Shuttle environmental monitoring.

12.10.10 Flight Crew Equipment (FCE)

12.10.10.1 Scope

Flight Crew Equipment (FCE) includes the following crew escape equipment: the pressure suits, hardware processing costs, training events, and other associated content. It also includes the provisioning (food) and associated integration requirements. The estimate includes crew equipment requirements such as electronics, cameras, medical kits, and laptop computers. The estimate includes the parachute packing and testing requirement, including laboratory calibration. The FCE estimate also includes allowances for subsystem management support and new development/modifications (lockers, cables, batteries, etc).

12.10.10.2 Estimating Methodology

The estimates were derived from analogies of existing expenditures for the Space Shuttle and ISS programs.

12.10.10.3 Ground Rules and Assumptions

Based on FY05 planning values provided from the Flight Crew Equipment (FCE) Office personnel at NASA JSC, the value of the annual Space Shuttle Program (SSP) support was assumed as a base value. The current assumption for the SSP requirements is seven crew times five flights per year. While this would infer some fluctuation in supporting the ISS/lunar manifest, a significant portion of this capability was considered fixed and, therefore, applicable fidelity required for the ESAS effort.

A set of values was then added to the base for the ISS variable requirements. The initial value was consistent with the ISS-supported portion of the ESAS manifest and later was doubled to account for lunar outpost operations, including provisioning requirements for lunar crew for 6-month periods.

The current budget baseline values associated with SSP non-prime content such as parachute packing were added. Finally, a wedge was included to approximate the subsystem management/sustaining engineering requirements including a small value for new development items. This value was based in part on current Internal Task Agreement (ITA) support for the NASA JSC Engineering Directorate and estimates provided by the NASA JSC FCE manager.

12.11 Launch Vehicles (LVs) and Earth Departure Stages (EDSs) Cost Estimates

12.11.1 Scope

The LV estimates include the cost for the core booster stage, the upper stage, and any strap-ons applicable to the configuration. Both CLVs and CaLVs were estimated. EDSs were also estimated. There was an extensive trade assessment performed with regards to the LVs and EDSs. Concerning the LV alone, over 36 different variations were assessed during the study. The LV trade space represented a large cross-section of alternatives consisting of both EELVs and SDV configurations. Potential EELV-derived families included the Delta IV and Atlas V Heavy and Atlas Phase 2/Phase 3/Phase X growth vehicles. Shuttle-derived families include four- and five-segment SRBs with new upper stages, External Tank (ET) with side-mounted cargo carriers, and new heavy-lift launch families based on the diameter of the ET.

In support of the 36+ vehicles and 12 EDSs that were evaluated during this study, various engine trades were performed. The scope of engine trades ranges from maximum reuse of existing engines to newly developed engines. The EDS is part of the mass the LV must lift to orbit, and, therefore, is viewed as a payload to the LV. The selected EDS configuration has two J–2S+ engines. EDS estimates were performed adhering to the same GR&As as used for the LV crew upper stages. EDS configurations with no heritage were assessed primarily for cost sensitivities with regard to the type of engine used. With regards to nonrecurring cost, appropriate heritage gained from the crew vehicle upper stage was identified at the subsystem level.

The details of these trades, vehicle descriptions, and study results are contained in **Section 6, Launch Vehicles and Earth Departure Stages**.

12.11.2 Methodology

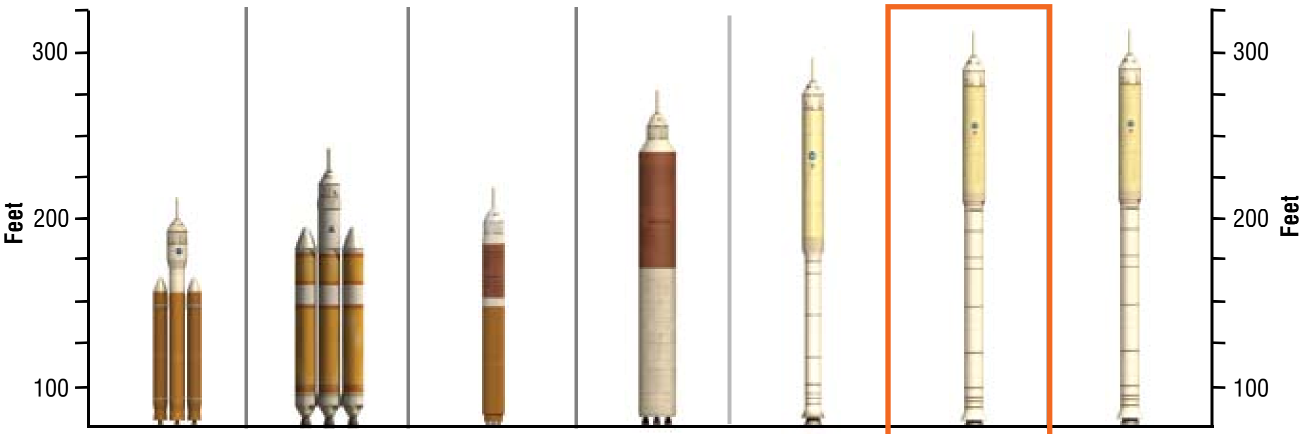
All LV and EDS acquisition cost estimates were prepared using NAFCOM. Hardware estimates were generally performed at the subsystem level or component level if detailed information was available. Software estimates were performed using SEER, with estimates for lines of code based on required functionality. Acquisition cost estimates include the DDT&E cost and the production cost of the first Theoretical Flight Unit (TFU). TFU cost is defined as the cost to produce one unit at a rate of one per year.

12.11.3 Ground Rules and Assumptions

The total LV was estimated, except for the crew LES. Shuttle program and contractor inputs for Shuttle elements and engines were used where applicable, after verification and adjustment for content by program and engineering assessments. All LV option costs include a Structural Test Article (STA) and a main propulsion test article. Total DDT&E also includes three test flights for crewed vehicles and one test flight for cargo vehicles. Required facilities are included for both crew and cargo vehicles. Vehicle physical integration of stages into a complete LV was an additional 4 percent of DDT&E, based on NASA experience. A standard fee of 10 percent was used, and a 20 percent reserve was added to each vehicle estimate. U.S. Government oversight of 25 percent was included for the full cost accounting factor. The full cost accounting factor includes civil service salaries, travel, infrastructure upkeep, utilities, security, cost of facilities, and corporate G&A. Facilities costs are based on engineering assessments of infrastructure requirements. When contractor inputs were available, Government estimates were compared and reconciled with those inputs.

12.11.4 Results

The cost estimates for the most promising lunar CLVs/CaLVs are presented in **Figures 12-9** and **12-10**. The seven crew LEO launch systems consist of four EELV-derived configurations and three Shuttle-derived configurations. The selected CLV (Vehicle 13.1) utilizes Shuttle Reusable Solid Rocket Boosters (RSRBs) as the core stage, with a new upper stage utilizing the SSME. This selection provides a low-cost solution for the crew LEO mission elements and meets the primary consideration in the selection of the CLV for safety/reliability of the system. It also has the ability to meet the early schedule dictated by the need to support ISS beginning in 2011.



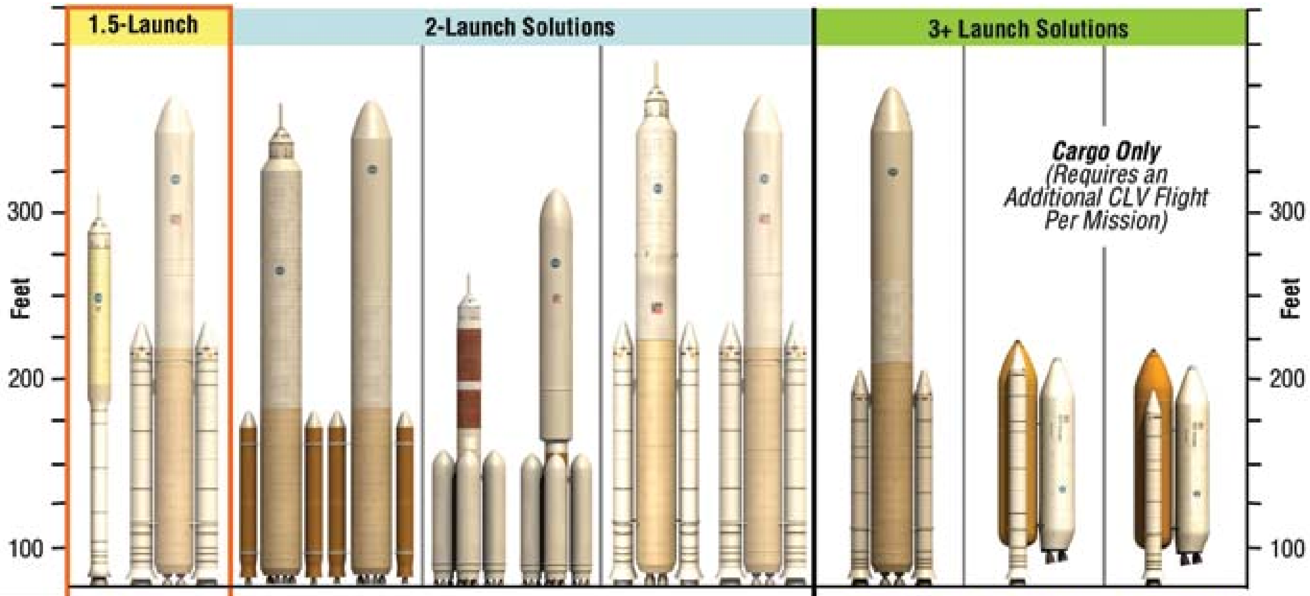
	Human-Rated Atlas V/New US	Human-Rated Delta IV/New US	Atlas Phase 2 (5.4-m Core)	Atlas Phase X (8-m Core)	4 Segment RSRB with 1 SSME	5 Segment RSRB with 1 J–2S	5 Segment RSRB with 4 LR–85
Payload (28.5°)	30 mT	28 mT	26 mT	70 mT	25 mT	26 mT	27 mT
Payload (51.6°)	27 mT	23 mT	25 mT	67 mT	23 mT	24 mT	25 mT
DDT&E*	1.18**	1.03	1.73**	2.36	1.00	1.3	1.39
Facilities Cost	.92	.92	.92	.92	1.00	1.00	1.00
Average Cost/Flight*	1.00	1.11	1.32	1.71	1.00	.96	.96
LOM (mean)	1 in 149	1 in 172	1 in 134	1 in 79	1 in 460	1 in 433	1 in 182
LOC (mean)	1 in 957	1 in 1,100	1 in 939	1 in 614	1 in 2,021	1 in 1,918	1 in 1,429

LOM: Loss of Mission LOC: Loss of Crew US: Upper Stage RSRB: Reusable Solid Rocket Booster

* *All cost estimates include reserves (20% for DDT&E, 10% for Operations), Government oversight/full cost; Average cost/flight based on 6 launches per year.*

** *Assumes NASA has to fund the Americanization of the RD–180. Lockheed Martin is currently required to provide a co-production capability by the USAF.*

Figure 12-9.
Comparison of Crew LEO Launch Systems



	5 Segment RSRB In-Line with 5 SSME Core - Cargo	Atlas Phase X (8-m Core)	Atlas Phase 3A (5.4-m Core)	5 Segment RSRB In-Line with 4 SSME Core	4 Segment RSRB In-Line with 3 SSME Core	5 Segment RSRB Side-mount with 3 SSME	4 Segment RSRB Side-mount with 3 SSME
Payload to 28.5	106 mT (125 mT w/ upperstage)	95 mT	94 mT	97 mT	74 mT	80 mT	67 mT
Lunar LV DDT&E*	1.00	1.29	.59	.96	.73	.80	.75
CLV+Lunar Crew/Cargo DDT&E (family op)*	1.00 (4 Seg RSRB w/1 SSME)	1.26 (Atlas V)	1.02 (Phase 2)	.98 (4 Seg RSRB w/1 SSME)	.83 (4 Seg RSRB w/1 SSME)	1.03 (5 Seg RSRB w/J2S-LR85)	.85 (4 Seg RSRB w/1 SSME)
Lunar LV Facility DDTE	1.00	1.33	2.25	1.00			
CLV+Lunar Facilities Cost	1.00	1.12	1.56	1.00			
Lunar LV Average Cost/Flight*	1.00	1.08	1.19	.87	.78	1.13**	1.13**
LOM – Cargo (mean)	1 in 124	1 in 71	1 in 88	1 in 133	1 in 176	1 in 172	1 in 173
LOC (mean)	1 in 2,021	1 in 536	1 in 612	1 in 915	1 in 1,170	N/A	N/A

* All cost estimates include reserves (20% for DDT&E, 10% for Operations), Government oversight/full cost; Average cost/flight based on 6 launches per year.

**Production costs are higher than in-line due to production of separate side-mount cargo carrier

Figure 12-10. Lunar Cargo Launch Systems Comparison

The most promising CaLV configurations are shown in **Figure 12-9**. The selected configuration for heavy lift (Vehicle 27.3) has several advantages. First, the 1.5-launch solution evolves from the CLV, using an updated SRB and the existing SSMEs. It also reduces the total amount of launches per mission. This selection keeps alternate access to space by maintaining the CLV. In addition, the five-segment RSRB in-line SSME core option offers substantially greater lift capacity over four-segment options at modest additional DDT&E.

12.11.5 Operations Cost Model and Recurring Production Costs

12.11.5.1 Operations Cost Model (OCM)

OCM is an Excel-based, parametric model developed for the estimation of space launch systems operations costs. For the purpose of modeling in OCM, launch system operations are defined as those activities that are required to deliver a payload from a launch site on the Earth's surface to LEO. The OCM WBS cost elements represent the full complement of products and services potentially required to operate an LV. The cost elements are arranged into four segments: Program (P), Vehicle (V), Launch Operations (L), and Flight Operations (F). The individual WBS cost elements are assigned to one of these four segments. Estimating cost for every WBS cost element is not required, nor is it necessarily expected. For instance, an unmanned vehicle would not be expected to have costs for F7 Crew Operations or V2 Reusable Hardware Refurbishment. **Figure 12-11** shows the WBS cost element arrangement.

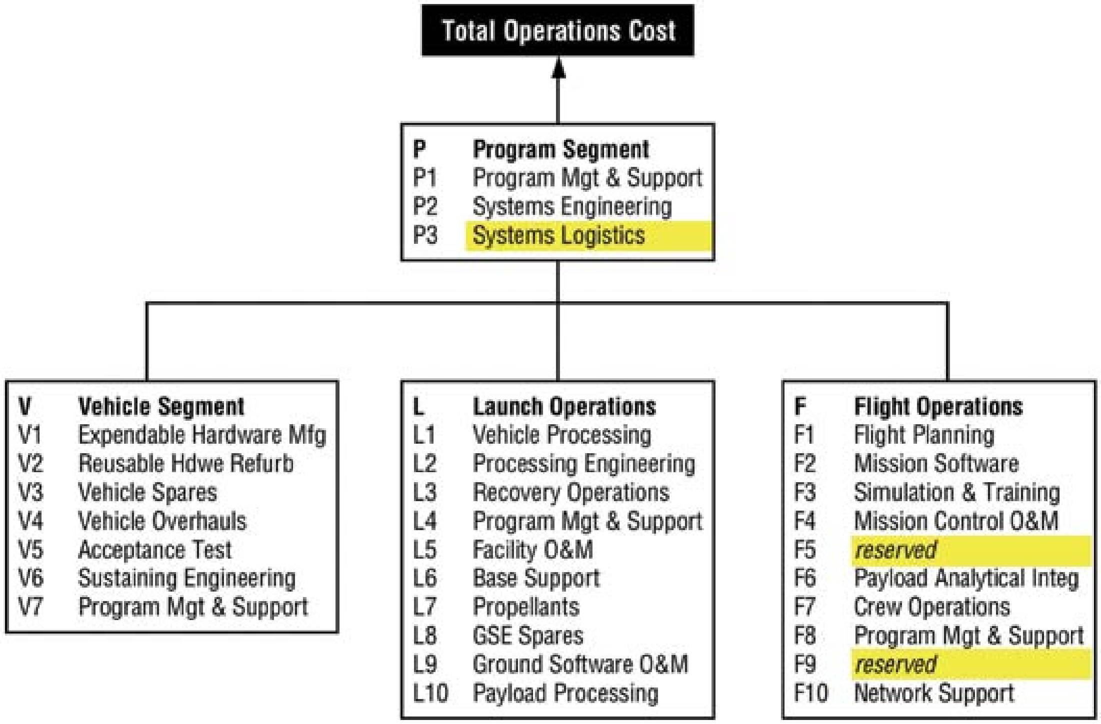


Figure 12-11. OCM Cost Element WBS

For this analysis only, the Vehicle Segment of OCM was used to estimate the recurring production costs of flight hardware elements. Launch operations costs, as defined above, were estimated by NASA KSC personnel, while flight operations costs were estimated by NASA JSC personnel. Program segment costs and full cost accounting were included by adding 25 percent wraps and 10 percent reserve to the other operations cost estimates. The detailed cost estimates for new or modified launch facilities and Ground Support Equipment (GSE) were prepared also by NASA KSC personnel.

12.11.5.2 General Assumptions and Ground Rules

In general, a conservative approach was adopted. Production of hardware for all architectural configurations was estimated as for manned systems, whether the vehicle was designated as “crew” or “cargo.”

Production costs include both those for the manufacture of new expendable hardware and the refurbishment of reusable hardware. Production costs are estimated using a TFU cost, either obtained from NAFCOM or derived from historical or vendor data, and applying rate curves using the OCM to estimate the annual production costs. The use of rate curves in these estimates is critical to capture the effects of variances in production (or flight) levels in the launch industry. The entire Shuttle program is an example of how fixed costs can dominate. Regardless of the actual flight rate, the budget remains constant, in large measure because the extensive staff of trained, skilled, and experienced personnel at all levels must be retained during periods of low activity in order to sustain the capacity of the system. Expendable systems behave in a similar manner. When fixed costs predominate, they must be spread over the units produced to recoup the expenditures with revenue. Lower production levels mean higher prices for the items produced. The spread is not linear but is best reflected by a power function model called the rate curve. This is entirely different from a learning curve in which the effects over time cease to have much impact. The cost of a single production unit is found by the following equation:

Average Unit Cost = TFU x (number of units produced/unit of time) ^ (Log$_2$(Rate Curve %)).

However, a more useful equation is a linear approximation of the power curve. In the OCM, this is derived by estimating the annual operations/production cost at four production levels (e.g., 2, 4, 6, and 8 units per year) which are plotted as Cost on the Y-axis and Number of Units Produced on the X-axis. A “best-fit” linear approximation is then constructed through these four points. The Y-intercept is the fixed production/operations cost, and the slope of the line is the variable cost per unit of output (or marginal cost.) The linear approximation of the rate curve power function is useful because an analyst can then estimate the annual operation cost for any output for any year of operation using the following equation:

Annual Cost = Fixed Cost + Number of Units of Output x Variable Cost Per Unit.

Fixed and variable costs may be aggregated at the segment level if desired. The annual cost for any production or flight rate for any hardware element can be estimated from the fixed and variable costs using the above equation. This allows the analyst to estimate annual production costs in the face of variations in production or flight rates from year to year.

12.11.6 Flight Hardware Production (Manufacturing and Refurbishment)

Flight hardware production costs, including both the manufacture of new expendable hardware (core, upper stage, engines) and the refurbishment of reusable hardware Solid Rocket Motor (SRM)/SRB, part of the interstage), were estimated using the OCM as described above. Cost estimates were based on the concept of the "ongoing" concern, that is, for the period of time under analysis, production facilities would operate from year to year with the same capacity regardless of how many items were actually produced. Implicit in this assumption is the idea that the staff of trained, experienced, and skilled technicians, engineers, and managers does not vary with changes in demand. This assumption allows the use of fixed and variable costs to estimate the annual cost of production and the average unit cost of hardware for a given year.

12.11.7 Family Assessment for Reference 1.5-Launch Solution Architecture (LV 13.1 Followed by LV 27.3)

The cost estimates developed for the family assessments used NAFCOM for calculation of the DDT&E and TFU costs. However, rather than costing each vehicle as an independent standalone concept, the family approach assumed an evolved methodology. Each family develops a CLV first. The first LV in the family will lift crew and a limited amount of cargo per launch. The second vehicle developed within the family will be used to lift cargo and, in some families, crew also. Its development takes credit, wherever possible, for any development costs already paid for by the crew vehicle (i.e., engine development, software development, etc.). If full development costs cannot be applied to the CLV, the second CaLV in the family may take some heritage credit, where the subsystem is similar to the CLV (i.e., thermal), thus reducing the development cost of the CaLV. The discussion below deals with the DDT&E costs of the vehicle only. Facilities and test flight costs are not included in the provided dollars. All other GR&As remain the same.

In the 1.5-launch solution family, the CLV is the four-segment RSRB used as the booster, with a new upper stage using the SSME. DDT&E costs were estimated at $3.4B. The evolved vehicle in this family is an in-line heavy-lift CaLV. The ET-based core uses five eSSMEs, with two five-segment RSRBs as strap-ons. As an evolved vehicle from the CLV, the CaLV pays the development cost to make the SSME fully expendable. The CLV paid for altitude start and minimal changes to lower cost. In addition, some of the CLV software can be either modified or reused. Test software, database software, and time/power management are a few of the functions that fall into this category. These savings are somewhat offset by the fact that the CaLV must incur the development cost of the five-segment RSRB. The evolved CaLV saves $0.9M in development costs as compared to stand-alone estimates. It should be noted that the CaLV uses an EDS as an upper stage. This EDS is not included in the costs.

12.12 Launch Site Infrastructure and Launch Operations Cost Estimation

12.12.1 Purpose

The purpose of this subtask of the ESAS was to estimate launch site operations nonrecurring infrastructure costs, such as facilities and GSE, and future recurring launch operations costs. The ESAS team developed numerous potential architectures, which included detailed assessments and descriptions of systems and subsystems for the major elements of the architectures. Launch operations insight was provided by the ESAS team to allow decision-making to proceed with architecture-level launch operations factors properly analyzed and integrated into the life-cycle perspective of the study.

12.12.2 Team

The ESAS team members that contributed or generated costs had the support of numerous other KSC personnel depending on the insight required and the tasks at hand. Team member backgrounds included Level 4 cost estimation competency and experience in previous NASA advanced studies and projects, and Apollo, Shuttle, ISS, or ELV past and current subsystem management or technical experience. Work experience in advanced projects included OSP, Next Generation Launch Technology (NGLT), Space Launch Initiative (SLI), diverse X-vehicle projects, and numerous other architectural studies going back through NASA history into the 1980–90s. Additionally, membership experience included product lifecycle management and obsolescence management.

12.12.3 Approach

ESAS operations analysis of affordability used a combination of cost estimation methods including analogy, historical data, subject matter expertise, and previous studies with contracted engineering firms for construction cost estimates. The operations affordability analysis relied on cost-estimating approaches and was not budgetary in nature, as budgetary approaches generally have extensive processes associated with the generation of costs, and these budgetary processes cannot easily scale to either architecture-level study trades in a broad decision-making space or to trading large quantities of flight and ground systems design details in a short time frame. The operations cost-estimating methods used in the ESAS are attempts at fair and consistent comparisons of levels of effort for varying concepts based on their unique operations cost drivers.

12.12.4 Risks

Numerous risks exist that (1) might alter an ESAS cost estimate, (2) could be significant but were not addressed within the ESAS charter, or (3) reasonably warrant attention in future refinements. These risks include:

- Numerous Space Shuttle Program deferred infrastructure maintenance costs.
- Operational deployment costs for providing for water landing/abort recovery capability for each CEV flight. Margin was allowed in the current operations cost estimate for these operations, but detailed analysis is required to add confidence to eventual operational cost expectations.

- Failure modes may add operational complexities, e.g., an upper stage sizable leak/rupture that would endanger the SRB casings and structural integrity. The identification of such modes as a design evolves and the subsequent operational “mitigation” can drive operational costs upwards in unexpected ways.
- The cost behavior for center institutional costs as Space Shuttle elements retire (Orbiters), are modified (SRBs, SSMEs), and, in some cases, reappear years later (ET-derived core stages) introduces the risk that certain costs will surface in implementation as having a heavier component of fixed costs transferred to the new systems than has been estimated. The conservatism and methodology of the current estimate addresses this but cannot entirely eliminate such risks.

12.12.5 Analysis

12.12.5.1 Launch Site Infrastructure

Cost included in the launch site infrastructure cost estimates are:

- Architectural and Engineering (A&E) and design contract costs and the construction contract costs through construction acceptance (i.e., motor bump tests, wiring ring out, Heating, Ventilating, and Air Conditioning (HVAC) test and balance, etc.); SE&I costs; building outfitting costs (i.e., telephone and communication systems, furniture, movable office partitions, building IT cable distribution systems); and facility activation (facility turned over to operations). GSE and Command, Control, and Checkout systems and consoles are not included. The only additional costs to be added at a higher level are the Other Burden Costs (OBCs) (i.e., Center service pool distributions, Center G&A, and Corporate G&A).

12.12.5.2 Launch Site Operations

Costs included in the launch site recurring or “operations” cost estimates are:

- Civil service and contractor (prime and subcontractors) for (1) logistics and GSE, (2) propellant, and (3) launch operations, inclusive of the following: processing; systems engineering support; facility Operations and Maintenance (O&M); command, control, and checkout center O&M, inclusive of instrumentation; modifications (as an annual allotment, used as required); sustaining engineering; program support (procurement, etc.); communications; base operations support/O&M; weather support; payload integration; and (4) payload processing and Multi-Element Integrated Test (MEIT).

The launch site recurring costs estimation methodology approaches are as shown in **Figures 12-12** and **12-13** for Shuttle-derived and EELV-derived systems, respectively.

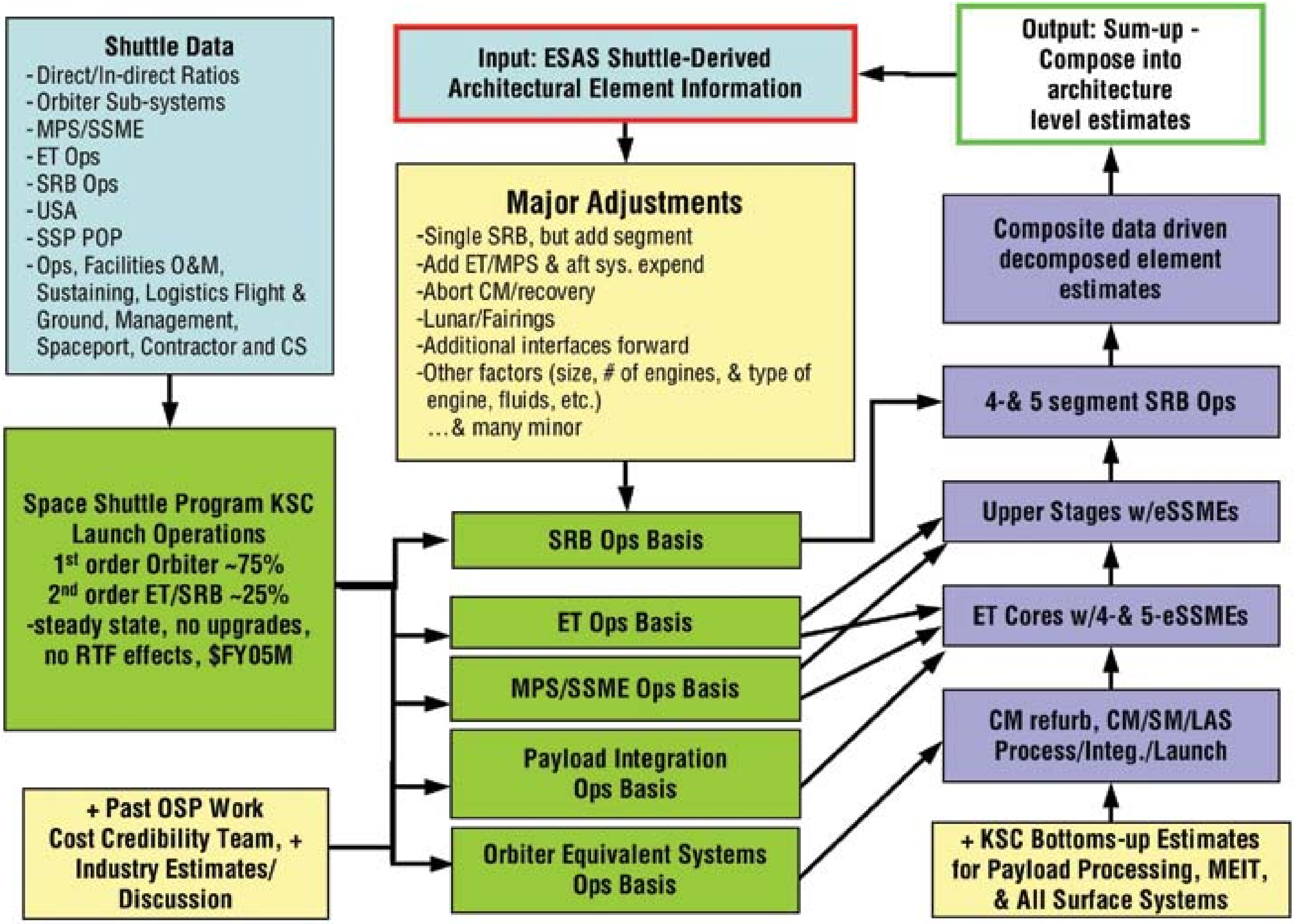


Figure 12-12. Launch Site Operations Cost-Estimating Methodology for Shuttle-Derived ESAS Architectures

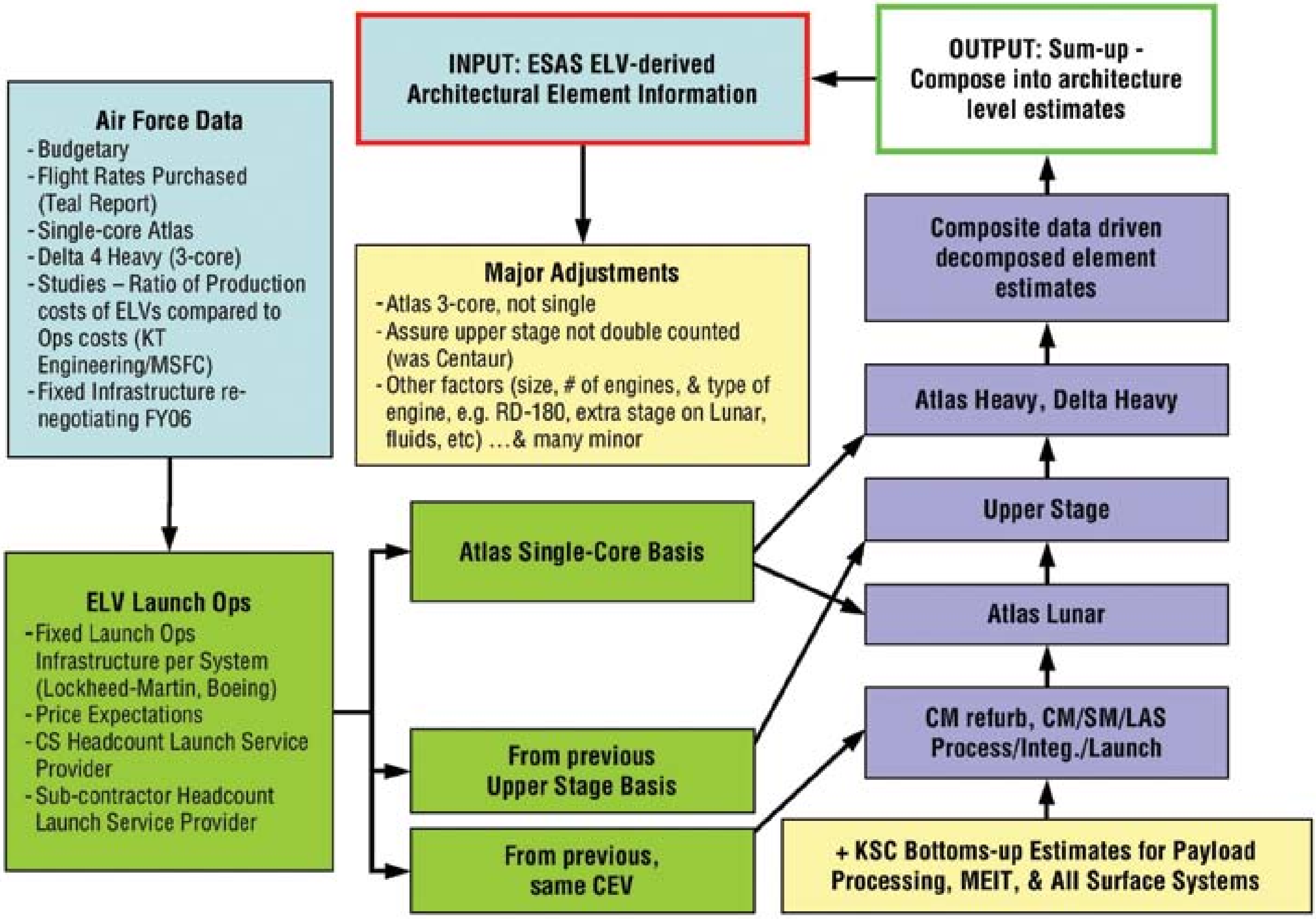


Figure 12-13. Launch Site Operations Cost-Estimating Methodology for EELV-Derived ESAS Architectures

12.12.6 Recommended Opportunities for Improvement in Operations Costs

The full cost estimates developed have not considered some areas that offer opportunities for significant improvements.

- Hypergols should be eliminated at an architectural level across the CEV and LV elements. The need is to create highly operable systems that improve over current systems operations in regard to costs, safety of ground personnel, and overall responsiveness of the system to flight rate demands. A generation of systems has evolved that has deferred such an evolution to nontoxic systems. The elimination of hypergols would begin with newer elements such as the CEV and the upper stage, and would continue as upgrades to SRB- and SSME-related systems (power systems). Then, eventual elimination of hydraulic systems and the implementation of simpler electric actuated systems would become possible, leading to further operability improvements.
- A supply chain improvement study and initiative should be pursued to better understand opportunities and define better ways of doing business. Such an initiative should be based on established Business Process Reengineering (BPR) and IT that are widely employed in the private sector. Improvements in supply chain management would address the areas and the interactions among Integrated Logistics Concepts (ILC) material and information flows, requirements management systems, work control and verification, ground process scheduling, program-level manifesting, corrective action systems, improvement systems, data management systems, sustaining and technical support, procurement, and financial systems. Together, BPR and IT advances and an improved integration of the host of other common network operations and enabling functions, an initiative looking across all supply chain functions, may offer significant opportunities for improvement that must be quantified and defined.
- A hardware-, subsystem-, and system-level reliability improvement initiative is required. An initiative is immediately required to control and improve on the nature of aerospace “small unit buy” (high variance) systems, while still maintaining and meeting unique requirements.
- A much more detailed review of the CEV ground processing activities, including refurbishment and reuse of the CM, is required. Such an analysis would go below architecture into potential subsystems at least to a level 4 of “what-if” definition. Such analysis would feed directly into SRRs and PDRs in 2006–07.