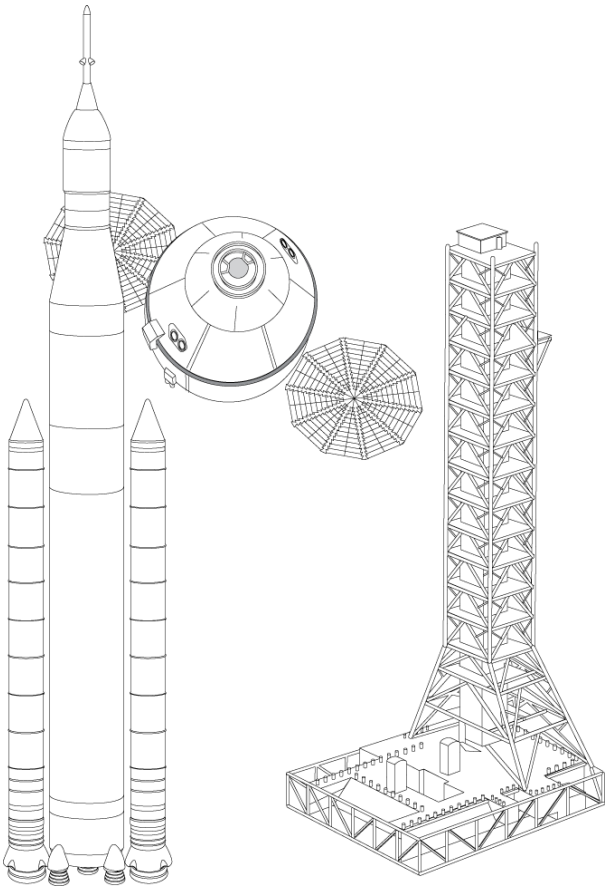
INDEPENDENT COST ASSESSMENT OF THE SPACE LAUNCH SYSTEM, MULTI-PURPOSE CREW VEHICLE AND 21ST CENTURY GROUND SYSTEMS PROGRAMS

EXECUTIVE SUMMARY OF FINAL REPORT

AUGUST 19TH, 2011



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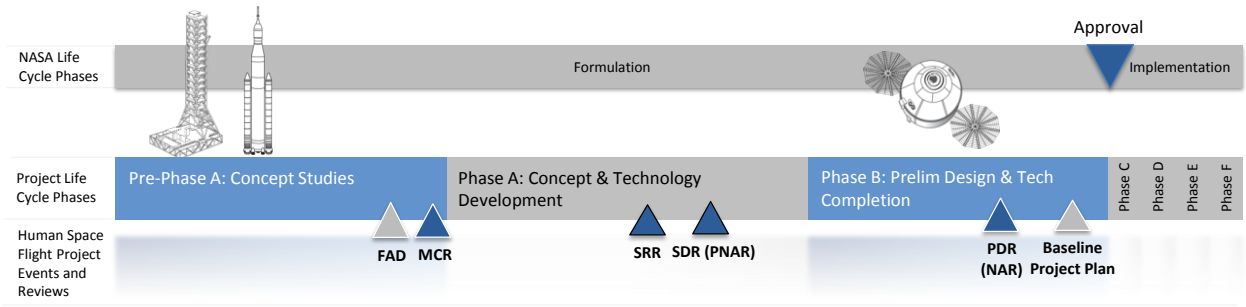
Executive Summary

Task Overview

NASA engaged Booz Allen Hamilton to perform independent assessments of cost and schedule estimates (hereafter referred to as Independent Cost Assessments, or ICAs) developed by the Space Launch System (SLS), Multi-Purpose Crew Vehicle (MPCV), and 21st Century Ground System (21CGS) Programs, and to assess the sufficiency of reserves contained in the estimates. It is important to note that an ICA is not a cost estimate, but rather, it is an assessment of existing cost estimates and the documentation and practices used to generate them.

The estimates of this assessment were generated by the three Programs as part of their response to an Analysis of Alternatives (AoA). The AoA was commissioned by the Human Exploration and Operations Directorate (HEO) to evaluate candidates for NASA's post-Space Shuttle manned space flight architecture.

Figure 1: Program Project Milestones



Not all of the estimates have the same level of maturity due to each program's respective lifecycle phase. Both 21CGS and SLS can be characterized as Pre-Phase A programs, whereas MPCV can be characterized as Phase B since it has held portions of its Preliminary Design Review (PDR) process, but has not completed it due the changes in the other parts of the architecture. Due to the numerous alternatives considered as part of the AoA which began in March, and a final determination of the Planning, Programming, Budgeting & Execution (PPBE) architecture in June, each Program was limited in the time they had available to develop their estimates. In many cases, the documentation was being created in parallel with the ICA review and was updated from previous estimates due to time constraints. The Booz Allen ICA Team (subsequently referred to as the ICA Team) worked as closely as possible with program personnel to obtain and evaluate all appropriate documentation. Since the AoA estimates form the basis of NASA's long-term PPBE submission they have been reviewed according to standards typically associated with full life-cycle cost estimates.

Key Findings

In general, the estimates prepared by SLS, MPCV, and 21CGS are consistent with Analysis of Alternative (AoA) level estimates and are reasonable point estimates for budget planning in the near-term 3-5 year budget horizon. They are serviceable in that they represent the basis to build upon for future life-cycle cost estimates of the quality required for long-term budget formulation and the development of program baselines. None of the estimates reviewed by the ICA Team support establishment of long-term budgets or detailed baselines consistent with NPR 7120.5 requirements. They are, however, reasonable AoA estimates appropriate for supporting trade studies and comparative analyses. All three Program estimates assume large, unsubstantiated, future cost efficiencies leading to the impression that they are optimistic. A scenario-based risk assessment, which excludes cost estimating uncertainty and unknown-unknown risks (historically major sources of cost and schedule growth), reveals all three Programs' reserves are insufficient.

Below are the seven key findings common to all three programs:

Finding: The Programs' estimates are serviceable and can be used for near-term budget planning in the current 3- to 5-year budget horizon. Beyond this horizon, the inclusion of large expected cost savings in the estimates, the beginning of development activities, and the potential for significant risk events decreases the ICA Team's confidence in the estimates.
Recommendation: The ICA Team recommends that NASA initiate full Program life-cycle cost estimates (LCCEs) for SLS, MPCV, and 21CGS immediately upon approval of SLS architecture. Further, the ICA Team recommends that an Independent Cost Estimate be conducted at the next program milestone as a cross-check to the Program estimates.

Finding: The BOEs provided by the Programs are not fully traceable or documented. An independent organization could not replicate Program estimates using the data sets provided by SLS, MPCV, or 21CGS without additional explanation from Program staff.
Recommendation: The ICA Team recommends that HEO/ESD use the occasion of a selection of a new SLS architecture to establish a common practice across Programs for generating cost and schedule estimates; establish documentation standards for BOEs; and create and disseminate BOE, cost, and schedule estimate templates to Programs.

Finding: There are many instances of unjustified cost reductions in the Program estimates. This exposes the Programs to cost risk and undermines the credibility of the estimate. Cost reductions were generally observed in either of two categories: scope reductions where the removed work will likely be required, or the application of anticipated efficiencies (production, competition, etc.) that NASA has not historically achieved. In some cases the efficiencies leading to cost reductions are not explicitly identified. Both of these categories lower the estimates below what historical data suggests and indicate that the estimates are optimistic.
Recommendation: The ICA Team recommends HEO/Exploration Systems Development (ESD) require that adjustments exceeding +/- 5% from historical data provide written justifications for such adjustments and take countervailing reserve positions for items where justifications are not sufficient.

Where the source of cost reductions are not identified, NASA should describe the rationale for such reductions and develop a management plan to increase the probability that NASA achieves these efficiencies.

Finding: Programs lack sufficient reserves to cover their Protect Scenarios. Program reserves were applied independent of the level of cost and schedule risk. Quantitative risk/sensitivity analyses have not been performed on any estimates.
Recommendation: The ICA Team recommends quantitative risk/sensitivity analyses be performed on all three Programs in conjunction with their full-scale life-cycle cost estimates (recommended above) and that reserve positions be established based on risk analysis findings.

Finding: There is little observed evidence of formal cross-Program coordination or integrated schedule development, although the Programs do interact on a working level. Lack of formal integration among the Programs diminishes each program manager's ability to manage cost and schedule risk proactively.
Recommendation: The ICA Team recommends HEO/ESD enhance PMO functionality by assigning a core group of dedicated staff, working independent of the individual Programs, to coordinate and integrate schedules, milestones, technical reviews, and cross-program risks.

Finding: Individual Program cost and schedule estimates are managed separately and are not in alignment. Lack of cost and schedule alignment makes it difficult to estimate the cost impact of schedule slips and vice-versa. Non-integrated cost and schedule estimates are sufficient for trade studies, but do not facilitate ongoing baseline management.
Recommendation: The ICA Team recommends that HEO/ESD establish a common WBS/CES as a foundation for future integration of cost and schedule.

Finding: Program estimates were shaped to fit within an anticipated budget profile. While this is common practice, it is not consistent with GAO cost estimating best practices. Shifting costs to later years to fit upcoming budget caps decreases each Program's availability of funds for risk reduction, technology maturation, and exposes the Programs to out-year cost growth.
Recommendation: The ICA Team recommends that time-phased results from the full LCCE be used to determine whether or not the AoA estimates, phased to fit into a budget profile, are executable. If not, the ICA Team recommends Programs identify specific plans to move work between years to fit into the budget cap.

Methodology

The ICA Team focused on assessing the quality of individual Bases of Estimates (BOEs). BOEs are documents describing the justification and rationale for a cost estimate. In a step away from doctrine, the technical lead allowed information collected in interviews with Programs to be considered when written documentation was not available. As discussed in the findings, this is due to the fact that the documentation required to substantiate the estimates was not always available or sufficient. This further investigation was necessitated by the fact that the ICA Team believes NASA's intent is to understand the quality of the estimates, more so than the quality of their documentation. The results of the assessments and a full description of the rating system used are contained in the main body of this report.

The ICA Team also recognized that summary-level observations could subsequently be provided for each Program. To facilitate the characterization of such observations, the team referenced the *GAO's* four properties of quality cost estimates (U.S. Government Accountability Office, 2009). These are:

> *Well-Documented: By well documented is meant that an estimate is thoroughly documented, including source data and significance, clearly detailed calculations and results, and explanations of why particular methods and references were chosen. Data can be traced to their source documents.*
>
> *Comprehensive: An estimate is comprehensive if it has enough detail to ensure that cost elements are neither omitted nor double counted. All cost-influencing ground rules and assumptions are detailed in the estimate's documentation.*
>
> *Accurate: An estimate that is accurate is unbiased, the work is not overly conservative or overly optimistic, and is based on an assessment of most likely costs. It has few, if any, mathematical mistakes; its mistakes are minor.*
>
> *Credible: As for credibility, any limitations of the analysis because of uncertainty or bias surrounding data or assumptions are discussed. Major assumptions are varied, and other outcomes are recomputed to determine how sensitive they are to changes in the assumptions. Risk and uncertainty analysis is performed to determine the level of risk associated with the estimate.*

Additionally, the team leveraged the *NASA Schedule Management Handbook* (NASA, 2011) to establish two rating criteria for quality schedule estimates. These are:

> *Traceable:* Schedule estimates are traceable when they are based on well-founded and/or previously accepted schedule information of established programs with comparable scope. Strong estimates will be derived from schedule information developed using industry best practices and standards. Lastly, traceable estimates should include adjustments and justifications for variations from reference material.
>
> *Executable:* Estimates are executable when they are founded on clearly defined work packages consistent with progress within the program lifecycle. Valid estimates will contain realistic

schedule durations based on projected work hours and program deliverables. Executable schedule estimates will also demonstrate reasonable integration with cost estimates and include considerations for programmatic risk.

The narrative of the report is structured to align with the above cost and schedule rating criteria. Furthermore, the ICA Team used Harvey Balls, as defined below, to standardize presentation of qualitative program-level observations based on these defined rating criteria.

Table 1: Program Level Observation Reference

Qualitative Observation Reference		
All		All BOEs meet all criteria
Most		Most BOEs meet criteria, or BOEs meet most criteria
Some		Some BOEs meet the criteria, or BOEs meet some of the criteria
Few		Few BOEs meet the criteria, or BOEs meet a few of the criteria
None		No BOEs meet the criteria, or BOEs meet none of the criteria.

SLS Cost and Schedule Assessment Summary

The ICA Team performed a thorough review of all BOEs, information, and data the SLS team provided in support of their PPBE submission. The ICA Team concludes that the estimate is acceptable to serve as the basis for near-term, 3-5 year, AoA and Program decisions, although there are several areas noted in this report where documentation, assumptions, and methodologies did not meet GAO standards. The estimate is not suitable for long-term budget planning or the development of a program baseline. The SLS cost estimate assumes several cost efficiencies that have not been realized on previous NASA programs. These efficiencies represent cost risk to the program as it is unclear whether they are realistic and leads to the impression that the estimate is optimistic. Local NASA in-house cost estimating resources were leveraged in production of some, but not all, of the SLS estimates.

Table 2: SLS Cost and Schedule Assessment Summary

Cost Estimates		
Well-documented		BOEs meet some of the GAO criteria. Cost estimates and corresponding BOEs exist for all major cost elements with system descriptions, ground-rules and assumptions, as well as detailed diagrams, visual mock-ups, or pictures of major elements. However, most of the BOEs do not reveal the calculations performed or the estimating methodology and rationale
Comprehensive		BOEs meet all GAO criteria. Documentation and corresponding estimates account for all major development and production activities, as well as expected testing, insight and oversight
Accurate		BOEs meet most of the GAO criteria. The estimates are based on an assessment of the most likely costs, are adjusted for inflation, and are verified by cross checks. However, the review team is unable to verify the accuracy of several vendor cost suggestions or engineering build up estimates
Credible		BOEs meet few GAO criteria. SLS personnel took steps to enhance the credibility of estimates by providing cross-checks for various elements as a part of the documentation, but there was no quantified sensitivity or risk analysis
Schedule Estimates		
Traceable	N/A	No viable schedule or corresponding BOE was available for the elements of the SLS architecture. The NASA Schedule Management Handbook does not require detailed schedules for Pre-phase A programs
Executable	N/A	No schedule was provided for evaluation

MPCV Cost and Schedule Assessment Summary

The ICA Team performed a thorough review of all BOEs, information and data the MPCV team provided in support of their PPBE submission. MPCV uses an atypical form of extrapolation from actuals, in which costs are divided into fixed and variable costs and are phased to fit the schedules of each alternative. Typical methods of extrapolation from actuals, per the GAO Cost Estimating and Assessments Guide, include averages, learning curves, and estimates at completion from earned value management systems (EVMS), as opposed to fixed and variable cost breakouts. As such, BOEs were not developed in accordance with a standardized WBS. Phasing of costs using this fixed/variable methodology was driven by technical requirements and the need to meet annual cost targets. No breakout of fixed/variable costs into their component activities was provided and no detailed plan exists for how work can be re-ordered to fit variable costs into the constrained baseline. Without this plan it is questionable whether the current estimate is executable. The resulting assessment revealed an estimate appropriate to the task of analyzing alternatives but not of sufficient rigor for long term budgeting or baseline development. Local NASA in-house cost estimating resources were not leveraged to develop the MPCV estimates.

Table 3: MPCV Cost and Schedule Assessment Summary

Cost Estimates		
Well-documented		Few BOEs meet GAO criteria. Prime contractor costs from the Update and Verification (U&V) session are well documented, but the bases of estimates modifying those costs are not well documented
Comprehensive		All BOEs meet GAO criteria. Costs comprising DDT&E, production, and upgrades are estimated, and those costs already incurred are documented
Accurate		BOEs meet some of the GAO criteria. Not all estimates are grounded in documented assumptions. Inflation was incorporated consistently, but using out of date inflation tables
Credible		Some BOEs meet the GAO criteria. U&V data used to form the base of the Prime estimate is credible. Some modifications made to the Prime U&V data to establish the Start Point are not as credible, lacking assessment of risk and uncertainty and verification by independent estimates
Schedule Estimates		
Traceable		Schedule BOEs were founded on a previously approved PDR schedule as well as work-hour estimates by the contractor, however EVA and MOD were added to the MPCV program after the initial estimate and not a part of the BOE assessment
Executable	N/A	Schedule not available for assessment

21CGS Cost and Schedule Assessment Summary

The ICA Team performed a thorough review of all BOEs, information and data that 21CGS provided in support of their PPBE submission. The ICA Team concludes that the estimate is reasonable and acceptable to serve as the basis for near-term, 3-5 year, AoA and Program decisions. Much of the 21CGS budget submission is based on in-depth design studies, although there are several areas noted in this report where documentation and assumptions did not meet GAO standards. The 21CGS PPBE submission assumes a reduction in cost in comparison to historical Shuttle and Constellation figures, primarily due to the limited launch manifest. Several technical risks exist that could have significant cost and schedule impacts. Local NASA in-house cost estimating resources developed the 21CGS estimate. Due to last minute changes in architecture and the corresponding late delivery of BOEs, 21CGS was the only Program with which the ICA Team was not able to perform an additional round of estimator interviews. This same Ground Operations team has a history of delivering on-cost and on-schedule and a portion of the ICA Team's ratings reflects the lack of time to perform a second round of estimator interviews rather than the quality of the estimates themselves.

Table 4: 21CGS Cost and Schedule Assessment Summary

Cost Estimates		
Well-documented		BOEs meet some of the GAO criteria. Cost estimates and corresponding BOEs exist for all major cost elements with system descriptions, ground-rules and assumptions, as well as detailed diagrams, visual mock-ups, or pictures of major elements. However, most of the BOEs do not reveal the calculations performed or the estimating methodology and rationale
Comprehensive		BOEs meet all GAO criteria. Documentation and corresponding estimates account for all major development and production activities, as well as expected testing, insight and oversight.
Accurate		BOEs meet all GAO criteria. The estimates accounted for inflation, and were verified by cross checks. The program has a historical record of cost accuracy
Credible		BOEs meet few GAO criteria. KSC personnel took steps to enhance the credibility of estimates by providing cross-checks for various elements as a part of the documentation, but did not perform quantified sensitivity or risk analysis.
Schedule Estimates		
Traceable	N/A	No basis for schedule information was provided for 21CGS. A high-level management planning calendar (Power Point) was provided, however it did not contain any information regarding work breakdown on program milestones. Advanced schedule materials are not required for Pre-Phase A programs. The NASA Schedule Management Handbook does not require detailed schedules for Pre-phase A programs.
Executable	N/A	Schedule not available for estimate.

Reserve Sufficiency Assessment

To perform a sufficiency check on the Program reserves the ICA Team applied the *Scenario Based Method (SBM)* (Paul Garvey, The MITRE Corporation, 2005) for risk analysis. The SBM is one of three primary risk analysis methods recognized by the cost community (AFCCA, 2007) and cited within the *NASA Cost Estimating Handbook* (NASA, 2008). SBM, while subjective, provides each program with a list of potential cost and schedule risks against which they can develop actionable mitigation plans. Additionally, it provides each program a quick sufficiency check of their reserves in the absence of a detailed, quantified risk analysis.

To conduct the reserve assessment, cost/schedule risks were identified by the ICA Team and were added to technical and programmatic risks determined by Booz Allen SMEs to develop an independent risk list for each Program. From this, a subset of risks, chosen in proportion to their likelihood of occurrence, was selected by the ICA Team and Booz Allen SMEs to create the "Protect Scenario" (PS) for each program. A Protect Scenario represents a set of potential risks a program should reasonably be able to cover with its reserves. The combined cost impact, by year, of risks contained in the PS was then compared to the Program reserves. The Protect Scenario is not intended to be comprehensive, a worst-case scenario, or the definitive list of highest impact risks nor does it include estimating uncertainty or unknown-unknowns, both of which have historically been major sources of cost and schedule growth on programs. For these reasons this assessment is only useful for conducting a spot-check of the sufficiency of Program reserves. It is not appropriate for use in determining appropriate program reserve levels.

Since the protect scenarios exclude estimating uncertainty and unknown-unknown risks, which history indicates are major sources of cost and schedule growth on programs, the reserve sufficiency assessment described in this report cannot be used to determine appropriate Program reserve levels. Until a quantified risk analysis has been performed on each estimate the ICA Team can make no recommendation of appropriate Program reserve levels

Conclusion

The cost estimates prepared by the SLS, MPCV, and 21CGS Programs are consistent with pre-concept, AoA-phase estimates and thus are not suitable for long-term budget formulation or the development of Program baselines. NASA should treat the estimates as serviceable point estimates for budget planning in the near-term 3-5 year budget horizon as they represent the basis upon which future estimates can be constructed. Due to unjustified, sometimes substantial, assumed future cost savings; the ICA Team views each Program's estimate as optimistic. Reserve levels were not based on a quantitative risk analysis and do not cover each Program's Protect Scenario. Furthermore, each Protect Scenario excludes estimating uncertainty and unknown-unknown risks, which history indicates are major sources of cost growth on programs. Due to procurement of items still in development and large cost risks in the out years, NASA cannot have full confidence in the estimates for long-term planning.

Effective application of program management best practices will help the human space flight concept remain viable beyond the near-term budget window. NASA should endeavor to understand the true lifecycle cost of each program, work to integrate the programs through a master schedule, and ensure that documentation practices improve to facilitate future cost. Upon selection of a new architecture, NASA should perform a full scale life cycle cost estimate, complete with a quantitative risk analysis, to ensure each program has a long-term budget appropriate to its mission. This estimate should be validated with an independent cost estimate per NASA policy and GAO best practices.

There is little evidence of formal inter-program coordination of cost, schedule and risk. Entities that used to be individual Projects in a tightly-coupled Program are now each stand-alone Programs. NASA should establish and enforce standards for documenting, integrating, and reporting on cost, schedule, and risk at the Mission Directorate or Division level (HEO or ESD).

The SLS, MPCV and 21CGS estimates are serviceable as they represent the foundation for a future life-cycle cost estimate of the quality necessary for long-term budget development and program planning. The ICA Team believes that the recommendations contained within in this report and its appendices provide NASA an actionable framework to produce the quality estimates required to ensure the financial success of NASA's next generation of human space exploration programs.