AN ASSESSMENT OF THE INHERENT OPTIMISM IN EARLY CONCEPTUAL DESIGNS AND ITS EFFECT ON COST AND SCHEDULE GROWTH

Claude W. Freaner[a]
Robert E. Bitten[b]
David A. Bearden[b]
Debra L. Emmons[b]

[a]NASA Headquarters, Science Mission Directorate, 300 E ST SW, Washington DC 20546-0001, USA
[b]The Aerospace Corporation, P.O. Box 92957, Los Angeles, California 90009-2957, USA
Claude.Freaner@nasa.gov

Abstract – When missions experience cost growth, cost estimators are often criticized for underestimating the cost of missions in the early conceptual design stage. The final spacecraft and instrument payload configuration at launch, however, can be significantly different as the project evolves, thereby leading to cost "growth" as compared to these lower initial estimates. In order to make a more robust initial estimate, historical mass, power, data rate, and growth rates can be used to provide a reasonable upper bound for inputs into the cost estimating methodologies. This paper illustrates this problem by showing examples of the evolution of a design, and its respective cost, complexity and schedule estimates, throughout its lifecycle. This paper reveals that the issues behind the cost and schedule growth are varied, but may be attributed in part to systems that have changed substantially from those examined at initial concept through to launch. In addition, historical resource growth is investigated for a variety of missions to provide guidelines for cost estimators to be used during the initial conceptual design stage.

Introduction

The history of NASA cost and schedule growth suggests that estimating the cost and schedule of future space systems early in the design life is a difficult task.[1,2,3] The results from a recent study of 40 NASA missions over the past decade (1992-2007) indicated that the average cost and schedule growth of these missions, over and above programmatic reserves, was 26.9% and 21.5%, respectively.[4] Although the study mentioned several potential reasons why cost and schedule might grow, one potential causative factor postulated was the inherent optimism in initial concept designs due to competitive pressures. This inherent optimism can translate to the underestimation of technical specifications such as mass, power, data rate, and the complexity of a system. Since most cost models use some form of system resources as a predictor of mission cost, the underestimation of these resources can lead to the underestimation of the final cost of the mission. To compound problems, the desire to launch a system as early as possible, in order to obtain science quickly, can lead to a success oriented schedule that may be shorter than historical comparisons would indicate. This combination of underestimated resources providing an optimistic cost estimate basis combined with a success oriented schedule can contribute to the observed history of cost and schedule growth. The cost estimators, in effect, are trying to estimate a moving target as the system resources grow. In order to more fully understand the relationship between these elements, the growth of mass, power, cost and schedule of ten recent NASA missions is investigated.

The Need for the Investigation of Resource Growth

In order to understand the impact of resource growth on the cost estimate of a mission, an example mission was chosen. NASA's Solar-TErrestrial Relations Observatory (STEREO) mission is designed to understand the origin and consequences of coronal mass ejections. The original concept for the mission was developed by the STEREO Science Definition Team (SDT) which presented a report in November 1997.[5] The initial SDT report is used as a basis for defining the science requirements for a mission as well as to determine a viable concept that can then be costed in order to provide input to the budgetary process. Although a mission's budget is not fixed or formally baselined until the mission goes through the confirmation process, the initial budget at the stage of an SDT is used to determine the number and type of missions that are in NASA's future science portfolio. It is important to adequately estimate the cost of these initial concepts so as not to set unrealistic expectations of the science that can be delivered in NASA's future.

Figure 1 shows a comparison of the programmatic and technical design parameters as identified in the STEREO SDT report versus those of the STEREO configuration at time of launch.[6] Notice that, in almost all parameters, the resource requirements for the final configuration more than doubled versus the initial SDT configuration.

	STEREO SDT*	STEREO Final
Programmatics		
Schedule (months)	40	70
Launch Vehicle	Taurus	Delta II
Technical		
Mass (kg)		
Satellite (wet)	211	630
Spacecraft (dry)	134	421
Payload	69	149
Power (W)		
Satellite (Orbit Average)	152	503
Payload (Orbit Average)	58	116
Other		
Transponder Power (W)	20	60
Downlink Data Rate (kbps)	150	720
Data Storage (Gb)	1	8

* Science Definition Team (SDT)

SDT Configuration

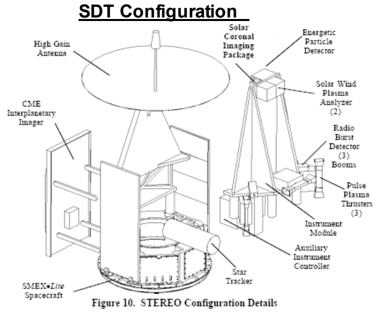


Figure 10. STEREO Configuration Details

Final Configuration

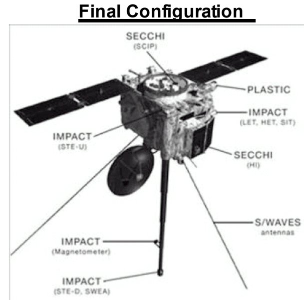


Figure 1: Comparison of Parameters from the STEREO Science Definition Team to the Final as Flown Configuration

Figure 2 shows the effect on the increase in resources as identified in Figure 1 on an independent cost estimate. The independent cost estimates utilized multiple methods including spacecraft and payload historical analogies. The figure shows the probability of achieving a given cost for the configurations analyzed. The curve on the left shows the cost cumulative distribution function ("S-curve") assuming the SDT report configuration parameters while the curve on the right shows the cost as estimated given the STEREO parameters at time of launch. As can be seen, the two S-curves are so substantially different that they do not intersect. It is important to note that the method accurately predicted the cost of the STEREO at launch configuration, showing that cost methods can provide an accurate estimate assuming that the input provided to the model is representative of the final configuration at launch.

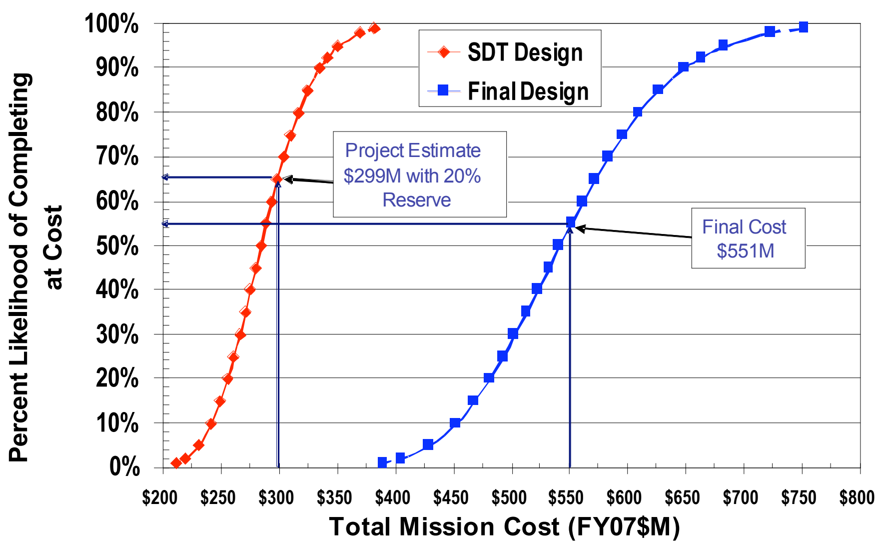


Figure 2: Comparison of an Independent Cost Estimate for the STEREO SDT vs. Final Configuration

As missions develop, the usual assumption made by projects is that their overall complexity remains constant over time, but the authors assert that the missions, in fact, typically become more complex as time progresses as more is known about the mission. This increase in complexity corresponds to an increase in mass, power, schedule, and ultimately, cost. The Complexity Based Risk Assessment (CoBRA) methodology can provide insight into this progression. CoBRA was developed to determine if a system's development cost and schedule are commensurate with its relative complexity.[7] Development cost includes all cost from project start until launch but does not include the launch vehicle cost or mission operations and data analysis (MO&DA) cost. CoBRA's complexity index has been shown to be a good indicator of the ability of a mission to meet cost and schedule constraint given a set of mission parameters.[8] Figure 3 and 4 show an example of the CoBRA method that plots the actual cost and development schedule, respectively, versus the relative complexity for a variety of different missions. The red and yellow boxes indicate missions that have failed while the green triangles represent missions that have been successful. The green line in each figure identifies the regression of complexity versus development cost and schedule for successful missions. An ideal mission development cost and schedule falls on or near the green line.

Another look at Figure 3 and 4 shows the progression of the complexity index for STEREO, as indicated by the blue diamonds in each plot, from the initial SDT concept to the final at launch STEREO configuration. As can be seen, the STEREO configuration progressed from an initial complexity index of 41% to a final complexity index of 60%. This increase in complexity is consistent with the increased cost and schedule at launch.

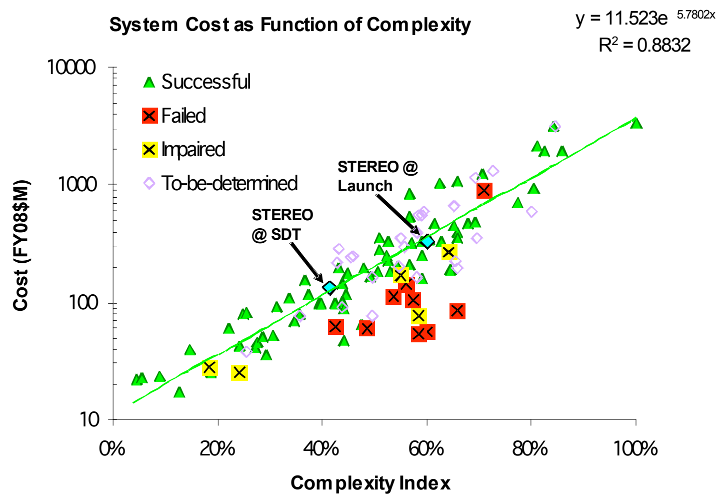


Figure 3: Comparison of the Complexity vs. Development Cost of the STEREO SDT vs. Final Configuration

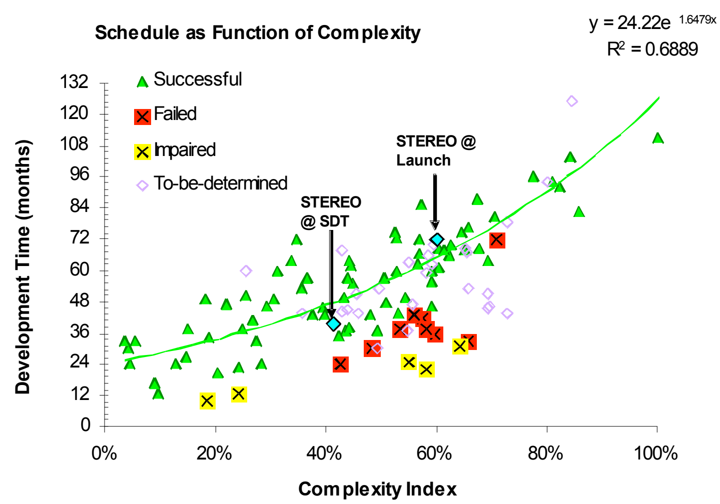


Figure 4: Comparison of the Complexity vs. Development Schedule of the STEREO SDT vs. Final Configuration

Study Approach

For each of the missions in the study, the mass, power, cost, schedule and other parameters were identified at the beginning of Preliminary Design phase (NASA Phase B) of a mission. For the competed missions within the data set, i.e. those missions that were competed and awarded using the Announcement of Opportunity (AO) process, the initial point of comparison is the Concept Study Report (CSR) that is submitted at the end of a competitive Conceptual Design phase (NASA Phase A). For other missions, the Systems Requirements Review (SRR), Preliminary Mission System Review (PMSR) or Preliminary Non-Advocate Review (PNAR) milestone information was used to determine the mission's starting point. These values were then compared to values presented at the Preliminary Design Review (PDR), Critical Design Review (CDR) and at the time of launch to understand the growth over time of each of these resources. The resource growth is then compared to industry guidelines to understand if these guidelines would have adequately predicted the growth for the mission data set studied. Additionally, the CoBRA complexity index was also calculated at the beginning of Phase B and at Launch to identify how the system complexity had changed.

Data Base Description

In the past, it has been difficult to obtain technical and cost information on NASA space flight systems. Once a mission had been launched, personnel were reassigned and development data was lost or thrown away. In December of 2003, NASA initiated a document action process that would capture technical and cost information about NASA missions at various points during the life of the mission. This document was called the Cost Analysis Data Requirement (CADRe) and was incorporated into NPR 7120.5 series NASA Space Flight Program and Project Management Requirements. Much of the data for this study was obtained from the CADRes that NASA has prepared on each of the missions studied.

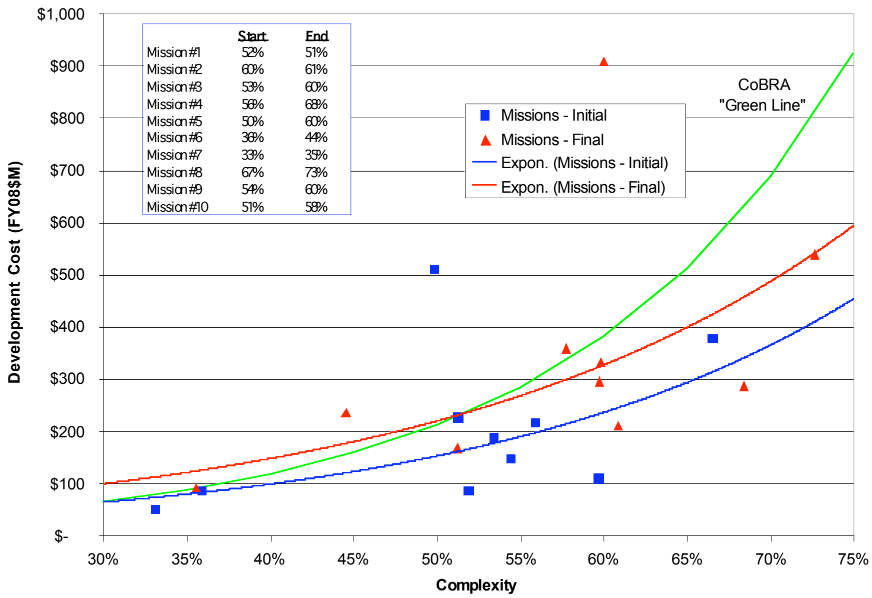
The ten missions chosen for this study represent a broad range of NASA space flight missions. Table 1 provides details. There are three missions that were assigned to a NASA Center ("Directed"), seven that were obtained with the Announcement of Opportunity process ("Competed"). Four of the missions were developed for investigating other planets ("Planetary") and six were either Earth-orbiters, or staying in the near vicinity of Earth. The missions also represented each of the NASA science themes with four from planetary science, three from astrophysics science, two from Earth science, and one from Heliophysics science. Additional missions were desired for this study, but at the time of writing, complete CADRes had not been written for any additional missions.

Table 1: Summary of Missions Investigated

Mission Set Complexity Growth

Our hypothesis was that complexity of the missions investigated grows over time. The CoBRA complexity index was used to test this hypothesis. The complexity measure itself identifies the relative complexity of any project within a database of over 150 satellites by performing a percentage ranking of each individual characteristic, i.e. mission parameter, versus the CoBRA database and then combining and normalizing these rankings into an overall complexity index.[9] The complexity of each mission investigated was assessed at the start of Phase B as well as at launch.

Figures 5 and 6 show the results of the complexity progression versus the increase in development cost (FY08$M) and schedule, respectively, for each mission. The CoBRA complexity index for the start of Phase B and at launch is show in the table in Figure 5. Except for mission #1, which had a descope during its development, the missions investigated experienced an increase in complexity according to the CoBRA complexity index. The average increase in complexity for all missions is 12% with an average increase in cost and schedule of 76% and 36%, respectively.



	Start	End
Mission #1	52%	51%
Mission #2	60%	61%
Mission #3	53%	60%
Mission #4	56%	68%
Mission #5	50%	60%
Mission #6	36%	44%
Mission #7	33%	35%
Mission #8	67%	73%
Mission #9	54%	60%
Mission #10	51%	58%

Figure 5: Change in Complexity vs. Development Cost for the Missions Investigated

The collective results, based on the number of missions that start below the green line and then move toward or above it, identify that there was some optimism in the cost and schedule of the mission relative to its complexity. A regression was performed to place best fit curves through the initial and final ten mission data points, respectively, on both the cost and schedule versus complexity figures. As can be seen in Figure 5, the red regression line, representing the regression through the final cost and complexity points, is much closer to the green line than the blue regression line, which represents the regression through the initial cost and complexity points. For the missions investigated, the initial cost was, on average, 63% from the ideal green line, while the final cost moved closer to the green line with an average 22% from the green line. A similar upward movement toward the green line, from initial to final schedule versus complexity, is also shown in Figure 6. Regarding the schedule results, the initial schedule was on average 37% from the ideal schedule green line, while the final schedule was on average 20% from the green line. These results imply an inherent optimism in cost and schedule at the start of a project while the general trend of increasing complexity implies an inherent optimism in the overall complexity of the mission.

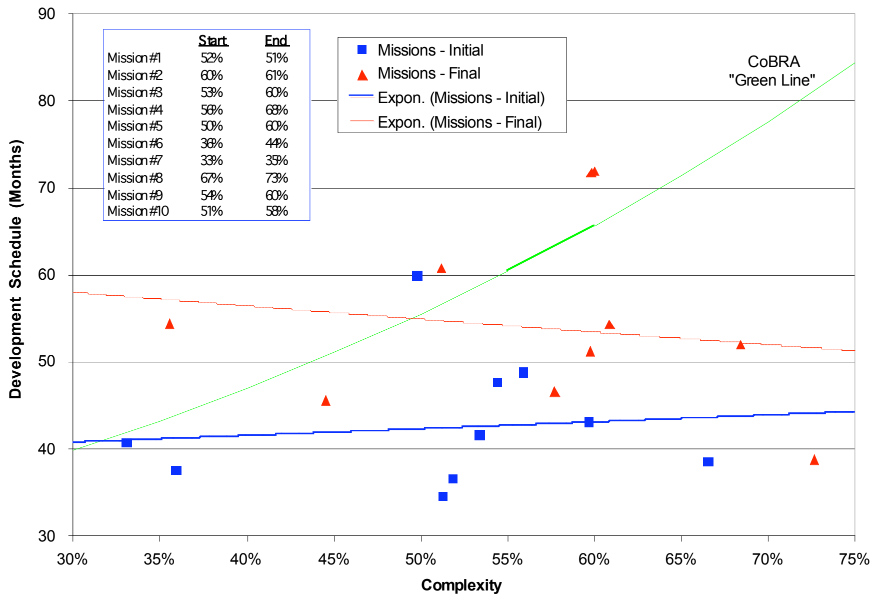


Figure 6: Change in Complexity vs. Development Schedule for the Missions Investigated

Mass & Power Growth of Missions in Data Set

As mentioned in the introduction, cost models use mission resources and technical parameters as inputs. In their simplest form, cost models take a parameter such as mass and multiply it by a factor and the result is a cost. Therefore, if the input factor changes, a resulting cost change occurs. To illustrate how these inputs change, Figure 7 shows the mass growth of the SWIFT mission, a gamma ray burst detector observatory, over the development period of nearly five years. The payload for the SWIFT mission consists of three instruments, the Burst Alert Telescope (BAT), the Ultraviolet Optical Telescope (UVOT), and the X-ray Telescope (XRT), plus the Optical Bench. Figure 7 shows the mass growth of these three instruments and the optical bench, as well as the spacecraft bus, through successive major milestones until launch.

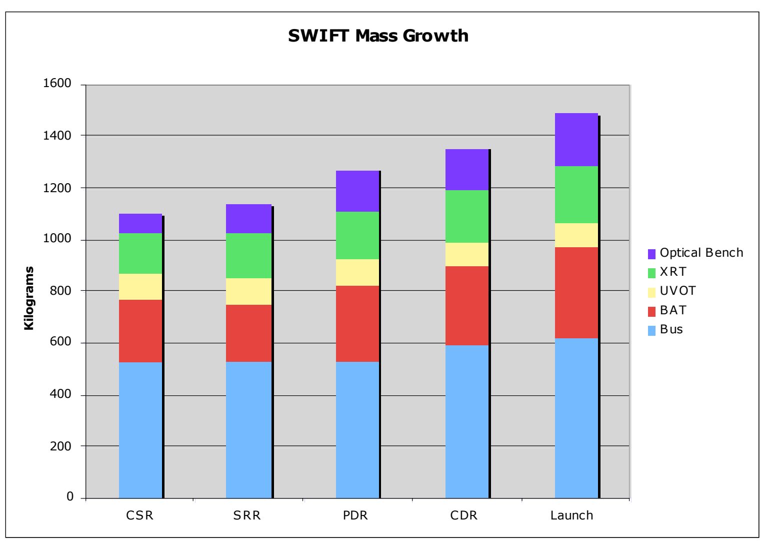


Figure 7: An Example of Mass Growth for a Selected Mission

The mass growth of SWIFT is indicative of the mass growth for the other missions investigated. Figure 8 shows the total mass growth of the ten missions in the data set. The mass growth shown is relative to the Current Best Estimate (CBE) mass at the start of Phase B. The mean, or average, total mass growth during the development cycle for the ten missions is 43%, with a sample standard deviation of 19%. The 90% confidence interval for this sample standard deviation is 10%, which means there is only a 10% chance that the population mean is outside the interval of 43% ± 10%, or 33% - 53%.

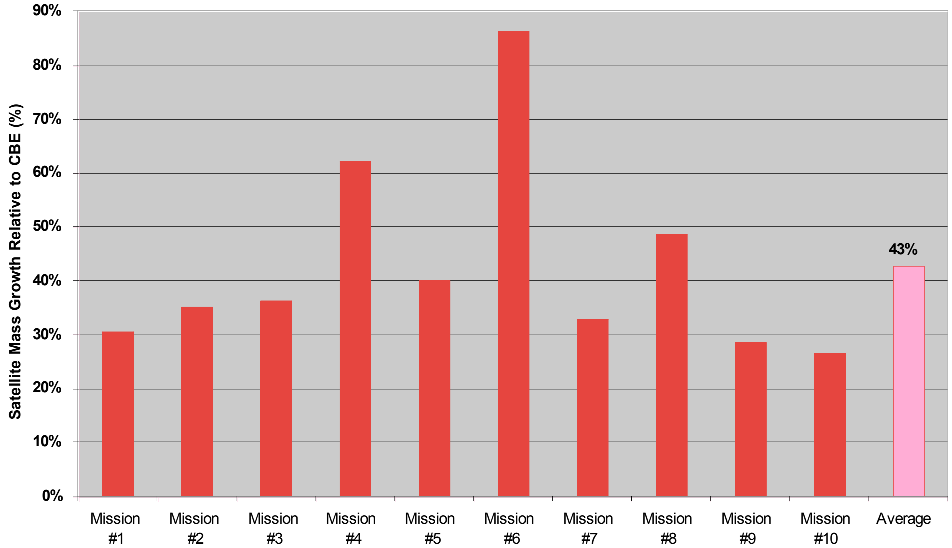


Figure 8: Comparison of Mass Growth (%) for Missions Investigated

Figure 9 shows the mass growth over time for all ten missions to identify if the trend is consistent. Although there is a wide variation in the outcome, the average growth continues to increase up until launch. As can easily be seen, the majority of the mass growth occurs after PDR.

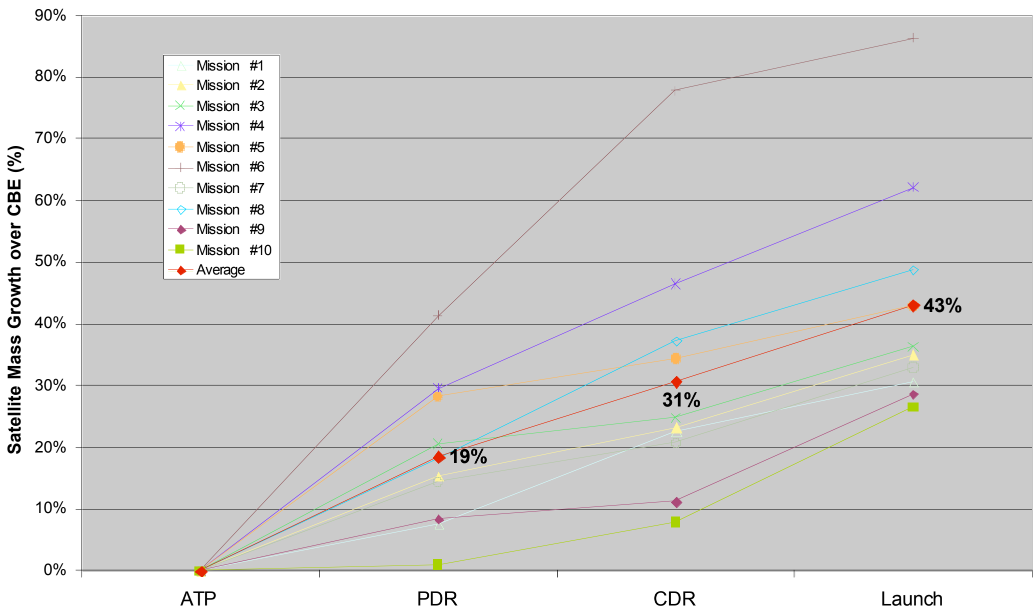


Figure 9: Comparison of Mass Growth (%) over Time for Missions Investigated

Figure 10 shows the growth in power for the missions in the data set and identifies a similar trend as the mass growth shown previously. The average power growth was 42%, with a sample standard deviation of 38%, which indicates a much wider variation in growth among the missions. The confidence interval for power growth is ± 20%. Figure 11 shows the growth of power over time and, similar to the mass growth trend, shows that the majority of growth occurs after PDR.

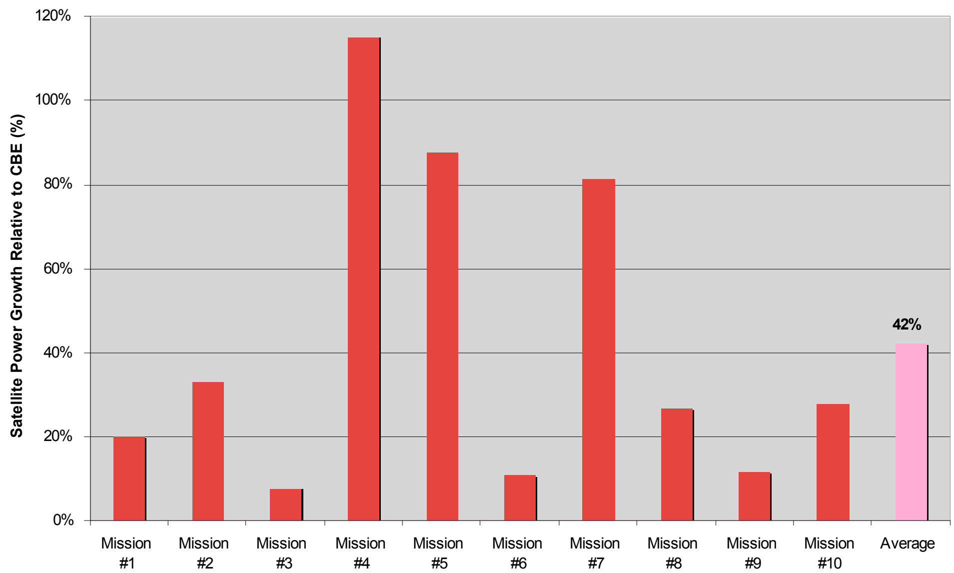


Figure 10: Comparison of Power Growth (%) for Missions Investigated

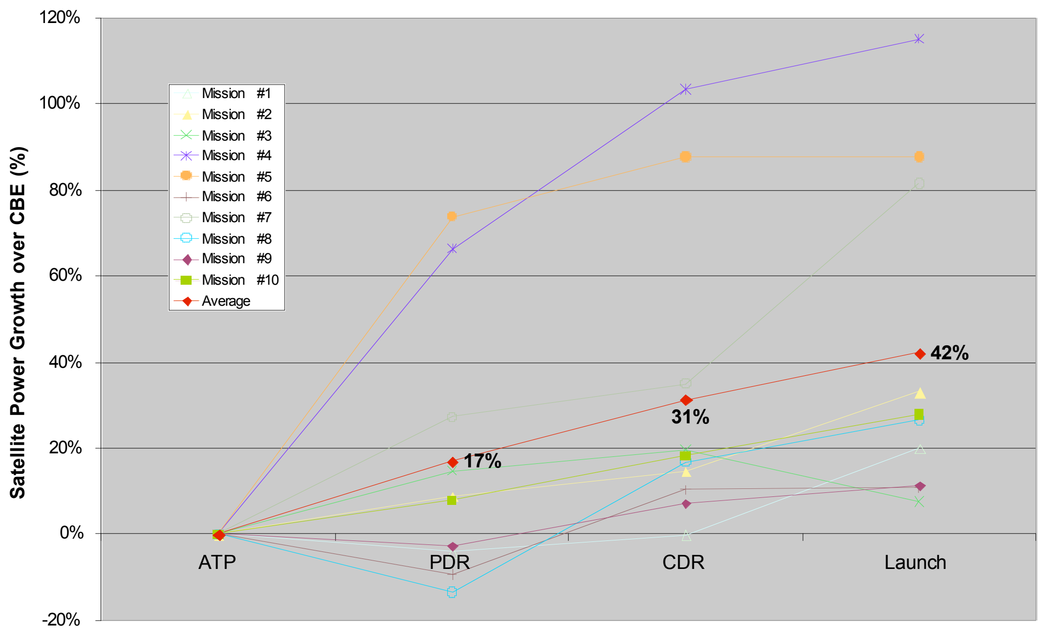


Figure 11: Comparison of Power Growth (%) over Time for Missions Investigated

Cost & Schedule Growth of Data Set

Figure 12 is a combination chart showing the total development cost growth, as measured by dollars and percentage, of the ten missions in our data set. For the purposes of our study, the development cost is defined as the Phase B/C/D cost not including the launch vehicle cost. The development cost growth shown is relative to the project cost baseline, with reserves, at the start of Phase B. The mean, or average, total cost growth during the development cycle for the ten missions is 76%, with a sample standard deviation of 51%. The percent growth of the mission data set is shown in Figure 12 by the line chart on the secondary y-axis. The 90% confidence interval for this sample standard deviation is 27%. For comparison purposes, the development cost growth was also determined relative to the project cost baseline, without reserve, at the start of Phase B. In this case, the mean total development cost growth for the ten missions is 113%, with a sample standard deviation of 63%. Figure 12 also shows similar information regarding the total development cost growth in terms of the absolute cost growth. These data for the mission set are shown by the columns plotted against the primary y-axis.

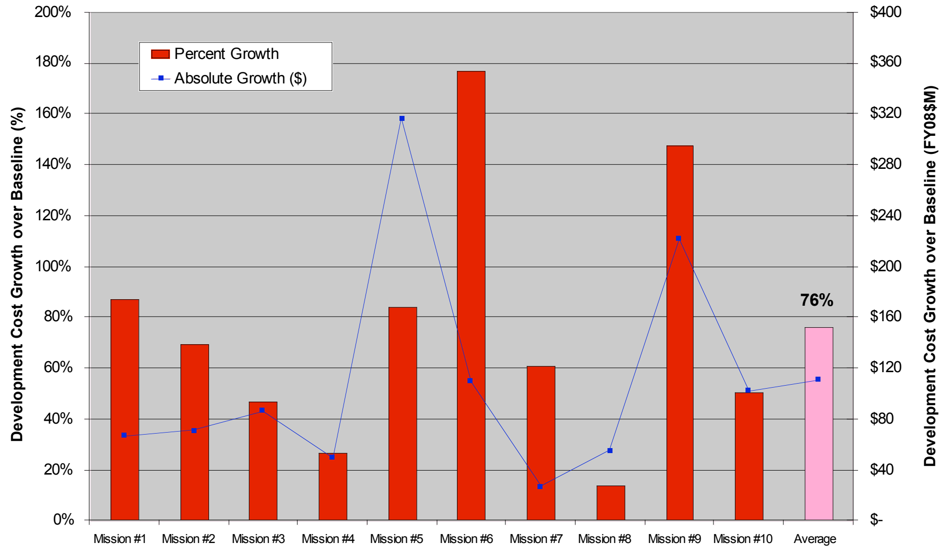


Figure 12: Comparison of Percent Cost Growth (%) and Absolute Cost Growth (FY08$M) for Missions Investigated

Figure 13 shows the growth of development cost over time. When looking at this trend, it is important to notice that, unlike the mass and power growth time trends, cost growth is typically not recognized until after CDR. This is counter to standard industry guidelines that recommend a decreasing percentage reserve on a reduced cost-to-go basis. The substantial cost growth after CDR implies that a greater percentage reserve on cost to go should be held. Alternately, it may mean that cost growth is occurring earlier in the project lifecycle, but isn't recognized until later. An earlier release of reserves to mitigate the risk of these cost drivers may be another project management approach.

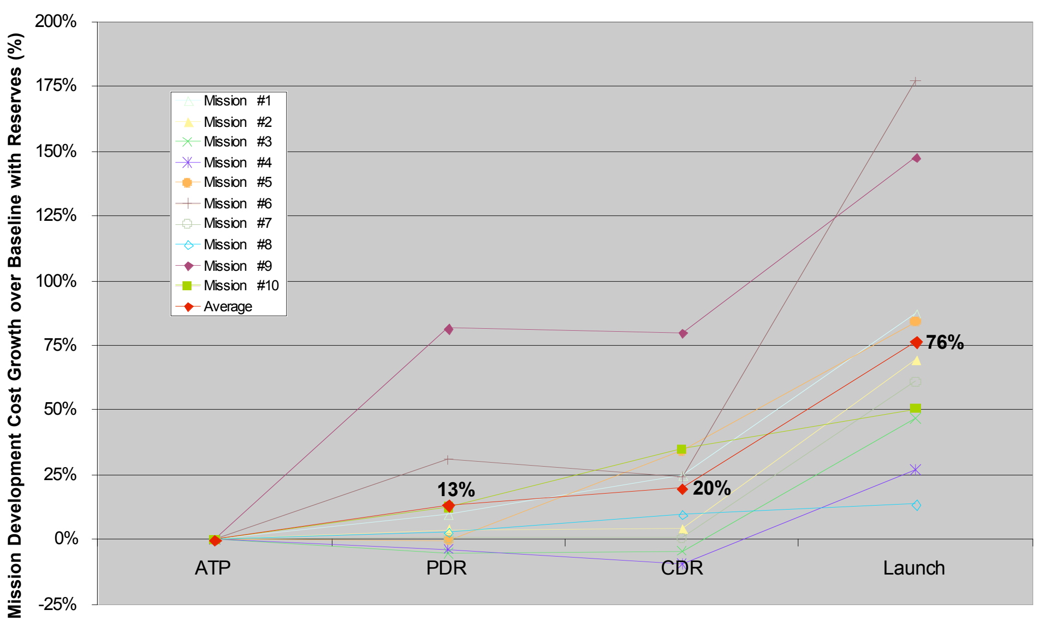


Figure 13: Comparison of Cost Growth (%) over Time for Missions Investigated

Figure 14 is a combination chart showing the total development schedule growth, as measured by months and percentage, of the ten missions in our data set. For the purposes of our study, the development schedule is defined as the Phase B/C/D schedule. The development schedule growth shown is relative to the project schedule baseline, with reserve, at the start of Phase B. The mean total schedule growth, as a percentage, for the ten missions was calculated at 36%, with a sample standard deviation of 21%. The percent growth of the mission data set is shown in Figure 14 by the line chart on the secondary y-axis. Figure 14 also shows similar information regarding the total development schedule growth in terms of the absolute schedule growth. These data for the mission set are shown by the columns plotted against the primary y-axis. The mean schedule growth is 16 months, with a sample standard deviation of 8.4 months. The 90% confidence interval for this sample standard deviation is 4.4 months.

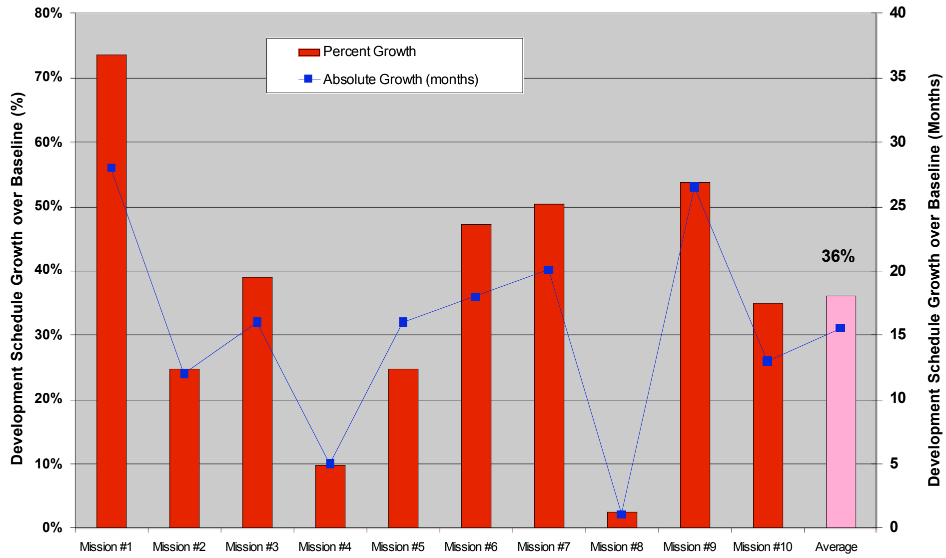


Figure 14: Comparison of the Schedule Growth (%) and Absolute Schedule Growth (Months) for Missions Investigated

Figure 15 shows the growth of development schedule over time. Similar to the development cost growth trend shown previously, the majority of schedule growth is typically not recognized until after CDR.

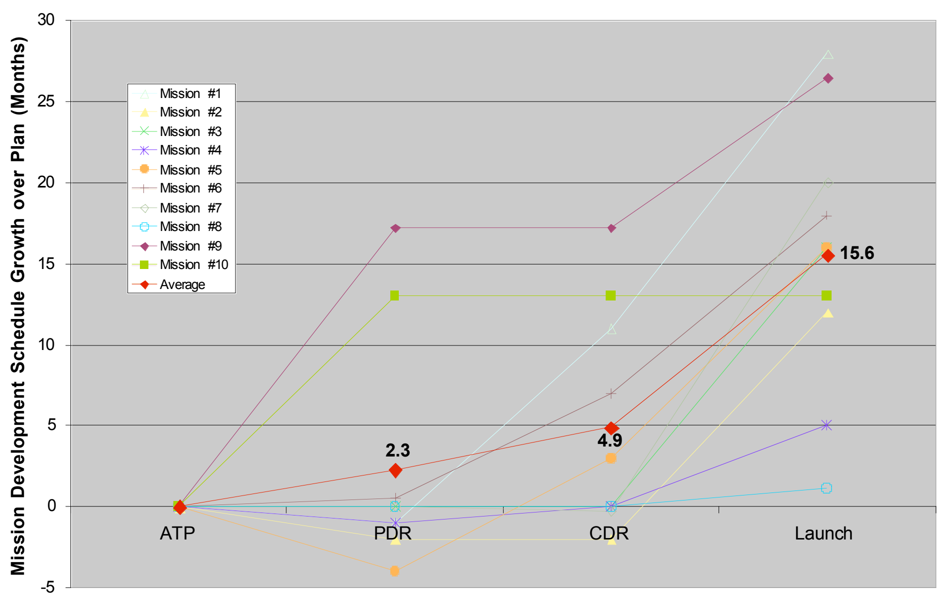


Figure 15: Comparison of Schedule Growth (Months) over Time for Missions Investigated

It is interesting to note that the average cost and schedule growth over the baseline, at 76% and 36%, respectively, is significantly higher than the 40 mission data set averages of 26.9% and 21.5%, respectively.[10] There are a few different reasons that the authors conjecture to explain why this may be the case. First, the 40 mission data set represented missions from 1992-2007, whereas this study's 10 mission data are more current, representing missions launched from 2000 onward. In the earlier timeframe there were a number of mission operating under the Faster, Better, Cheaper paradigm, like the IMAGE and Stardust missions, which had limited or much less than average cost and/or schedule growth. Another reason for the difference in the averages is that the 40 mission study generally used NASA budget data, which is New Obligation Authority (NOA), while the current study is using project cost data.

Comparison to Industry Guidelines

Although it is true that cost estimators are required to understand all technical disciplines of the scientific payload, spacecraft, launch vehicle, ground system, operations and data analysis concept, and program management and systems engineering approach, estimators should not be expected to check the validity of the designs that they are estimating. One simple way to treat this dilemma is to add a reserve value to the current best estimate (CBE) design parameters while developing a cost estimate in order to anticipate resource growth. For example, common industry guidelines recommend holding 30% mass and power reserve to account for design growth.[11] The average mass and power growth across the missions investigated of 43% and 41%, respectively, indicates that using the industry standard guidance for cost estimating purposes would underestimate the total growth, and therefore total cost, of the system.

Unfortunately, it is difficult to develop a uniform mass or power reserve number to apply to CBE estimates as the variability of the data investigated is substantial. Figure 16 shows the range of mass growth seen from the missions investigated for the instrument payload and for each major spacecraft subsystem. Each bar represents the range of values where the red value represents the range below the mean while the green value represents the range above the mean. The range shows that cost estimators may want to use a greater range in their inputs than standard industry guidance would suggest when generating the range of estimates used for cost risk analysis. It is also interesting to note that for some subsystems the average growth is less than the 30% standard reserve guidance.

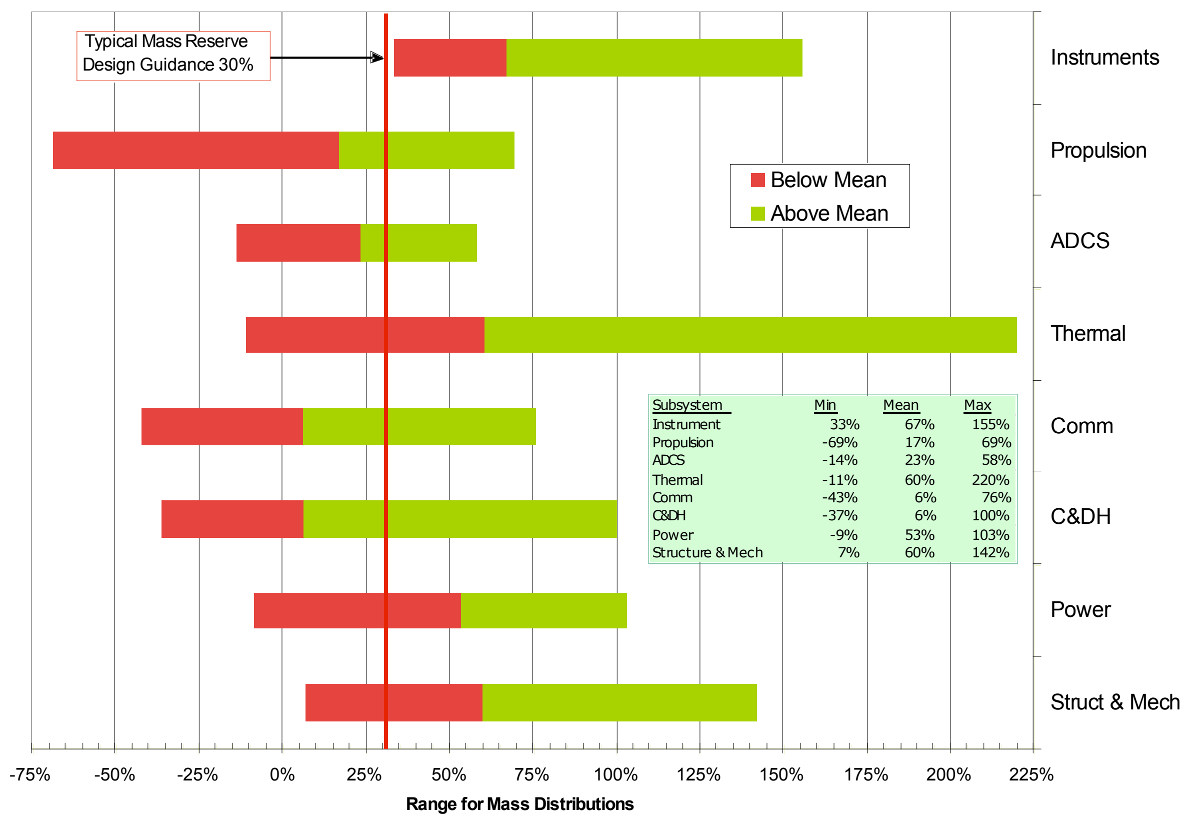


Figure 16: Range of Instrument and Subsystem Mass Growth Identified for Missions Investigated

To show the potential effect of these expanded guidelines on a cost estimate, a cost risk analysis was developed using the industry standard NASA/Air Force Cost Model (NAFCOM). Design parameters for the STEREO configuration at SRR were used as the baseline and subsystem and instrument mass values for the minimum, most likely and maximum case were varied using the percent mass ranges specified in Figure 16. The results of this analysis can be seen in Figure 17 where the curve on the left represents a traditional mass variation of -10% to plus 30% of the CBE mass whereas the curve on the right shows the results using the ranges from Figure 16. As can be seen, the curve on the left shows that the cost estimate at SRR would have had only a 19% chance (i.e. 100% minus 81% probability of the final cost of $551M) of being less than the final STEREO cost whereas the cost estimate with expanded mass reserves would have had a 42% (i.e. 100% minus 58%) chance of being less than the final cost. Although this example is not conclusive, it does provide an example of how increased design reserves used for cost risk estimating could provide a more realistic assessment of the potential design, and therefore, final cost of a system.

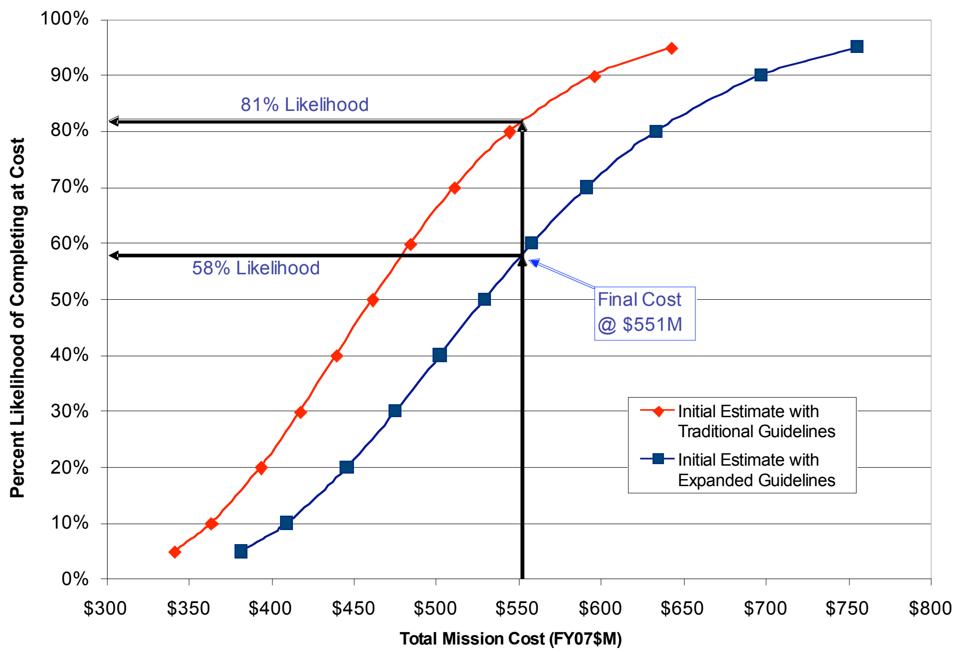


Figure 17: Estimate of System at Start of Phase B with Traditional and Expanded Design Reserve Guidelines

Recommendations

It is a given that the goal of cost estimating is to accurately predict the eventual future cost of something. In the case of space mission estimating, using early and uncertain technical parameters such as mass, power, pointing accuracy, data transmission rates, etc., the cost estimator is expected to provide an early accurate estimate of the final design that actually launches – a moving target, at best.

One means of producing a more accurate estimate is to have better input data up front. Independent validation of instrument resources and resulting spacecraft resources needed to meet mission requirements would allow more accurate estimates. For Directed missions, requirements should be set, a preliminary design should be developed that meets these requirements with conservative assumptions on resources (mass, power, data rate, etc.) and THEN an independent cost estimate should be conducted as the basis of budget. For competed missions, this becomes more difficult, as the missions vary widely in the science they are trying to achieve, the orbits they need, and the launch constraints imposed by planetary alignments. Competed missions, in essence, set their own requirements, and develop just enough of a preliminary design that they can claim it will meet their science objectives while remaining within the resource constraints imposed by the budget. During the source selection process, independent estimators attempt to create cost estimates of the proposed missions to check for reasonability and realism. These independent estimates are used, in part, to determine the risk of each proposed mission. As can be seen in the preceding data, the resource requirements generally grow significantly beyond those allotted which directly results in underestimating the final mission cost.

We mentioned previously that standard industry guidelines may be inadequate or inappropriate for predicting the growth of resource requirements. Another way of saying this is that industry guidelines do not in general adequately predict the uncertainty in the initial physical and programmatic parameters claimed in the proposals. One method to identify the uncertainty in the data driving the cost estimate would be for estimators to prepare their uncertainty distributions using the variations we have shown in Figure 16. For example, the triangular distribution for structures and mechanisms could use the mean shown of 60% growth over Current Best Estimate (CBE), a lower bound of one standard deviation (60% - 39%) of 21% growth over CBE, and an upper bound of the maximum in Figure 16, 142%. Where the project input data is higher than this lower bound, the project data should be used as the lower bound. In the case where project data is higher than the mean in Figure 16, the lower bound should be set equal to the mean shown here. Although the data gathered from these ten missions cannot provide definitive guidelines, consideration should be given for allocating more design growth allowance when providing input to cost risk analysis.

Another place where industry guidelines may need to be revisited is in the area of reserves. Guidelines in general begin with 30% reserves needed at PDR, and decrease as a percentage of cost to go as the project approaches launch. As shown previously in Figure 13, the majority of growth in cost occurs after CDR. This means that the guidelines should be increasing the reserves as a percentage of cost to go, not decreasing them.

Future Work

As CADRes are developed on additional NASA missions, the subsystem data base should be expanded to include new missions to provide more of a statistical basis for the preliminary recommendations made in this paper. In addition, the Instrument subsystem needs to be expanded to identify which instrument types have had the highest historical resource growth. Figure 16 highlights that the Instrument subsystem has the highest mean mass growth of all the subsystems areas examined. Moreover, the 40 mission data study had previously shown that Instrument challenges were the single largest contributor to cost and schedule growth. Therefore, an expanded Instrument study will be required to better understand these issues, and help refine any recommendations.

Summary

The missions investigated for this report demonstrate that power and mass resource growth was significant and increased throughout the design lifecycle. Complexity, as measured by the CoBRA methodology, increased for 9 out of 10 missions while cost and schedule increased for 10 out of 10 missions. The reduced complexity of the one mission that had a major descope is also identified by the CoBRA methodology. Industry guidelines do not, in general, adequately predict the uncertainty in the initial physical and programmatic parameters identified at the start of a mission when compared to the data from this study. Current cost risk process appears to be underestimating the resource growth, which essentially implies an underestimation of the S-curve (mean and slope). Estimators cannot be expected to check the validity of the designs that they are estimating so it is important that an independent validation of instrument resources, and the resulting spacecraft resources needed to meet mission requirements, is undertaken. That would allow more accurate estimates as more robust design parameters would be used as the input to the cost models. Until more robust parameters are developed as a standard practice, cost estimators can use wider ranges on parameters for estimating the input values used for cost risk analysis. Although the results of this paper indicate a wider range of parameters should be used for the cost risk process, a more detailed study of a larger mission set is required to develop more substantive guidelines.

Biography

Mr. Claude Freaner has worked in the cost estimating field in industry and at NASA Headquarters for the last 30 years. As part of his duties, Claude is responsible for independent cost assessment of proposed and ongoing missions within NASA's Science Mission Directorate. Claude recently received the 2006 NASA Cost Estimating Leadership Award which is given "to provide recognition to an individual who has brought leadership and inspiration to the space cost community in activities such as championing a cause, leading and mentoring others in the space cost community, acting as a strong cost advocate, and garnering the respect of his cost peers." Claude has a Bachelor of Science in Mathematics from the University of Idaho, a Masters in Business Administration (MBA) in Management Science from San Diego State, several certifications in Cost Analysis and Program Management and is a Certified Parametric Practitioner.

Mr. Bob Bitten works at The Aerospace Corporation and has conducted independent cost estimates for NASA proposal evaluations and independent assessments for a variety of different NASA missions and organizations. Bob is a winner of the President's Award, The Aerospace Corporation's highest honor, for his effort in assessing the cost effectiveness of different alternatives in the in the Hubble Space Telescope Remote Servicing Module (HST RSM) Analysis of Alternatives (AoA). Bob also recently won the NASA Cost Estimating Support Contractor of the Year Award for 2007 that is awarded to recognize an individual who has provided "outstanding contractor support to the NASA cost estimating community and significantly contributed to the field of cost estimating." Bob has a Bachelors degree in Industrial and Systems Engineering from the Georgia Institute of Technology, and an MBA from Pepperdine University.

Ms. Debra Emmons works at The Aerospace Corporation where she has developed a unique, quantitative schedule analysis tool using historical data. She has used this tool on several NASA proposal evaluations and independent assessments. In 2006, Ms. Emmons was also a winner of The Aerospace Corporation's President's Award, for her part in utilizing her unique methodology to conduct schedule analysis that was critical to the conclusions drawn in the HST RSM AoA. Debra is also a winner of The Aerospace Corporation's Woman of the Year (WOTY) Award for 2007 which is awarded to Aerospace women who "demonstrate outstanding professional achievement, leadership, community involvement, and initiative". Debra has a Bachelors and Masters Degree in Electrical Engineering from Cornell University and an MBA from the Imperial College of London.

Dr. David Bearden works at The Aerospace Corporation where he developed the Complexity Based Risk Assessment (CoBRA) methodology which earned Dave a nomination for the Aviation Week & Space Technology Annual Aerospace Laurels. He has continued to develop the CoBRA method and has used this tool on several NASA proposal evaluations and independent assessments. Dr. Bearden was also a part of the award winning HST RSM AoA team and was recently selected by the National Academy of Sciences to be part of the Beyond Einstein Program Assessment Committee. Dr. Bearden has a Ph.D. and Masters degree in Aerospace Engineering from the University of Southern California and a Bachelors degree in Mechanical Engineering and Computer Science from the University of Utah.

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