IN SEARCH OF THE OPTIMAL FUNDING PROFILE: THE EFFECT OF FUNDING PROFILES ON COST AND SCHEDULE GROWTH

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Abstract – When allocating funding to NASA missions, it is very important to allocate sufficient funding to each year of development in order to properly fund the mission. Unfortunately, for many reasons, funding profiles are defined by the budget available in a given year as opposed to allocating the funding according to an optimal profile for that individual project's development. This funding shortage in a given year can result in many funding profiles being back-loaded, where limited funding is available in the early years of development for risk reduction. The end result is potential overruns in the later years of development due to unanticipated or unmitigated risks. Front-loaded funding profiles can provide substantial money in the early years of development but may also be problematic. The higher spend rate in the early years of development can lead to problems in reducing the work force and available funding in later years by consuming funding upfront that may be needed when problems arise during integration and testing. Derivation of an optimal funding profile is not straightforward, however, as it is difficult to determine which profile is more "optimal" for a given mission. This paper investigates the cost and schedule growth for over 40 different NASA missions and compares the initial funding profiles to final funding profiles to determine if a correlation exists, thereby identifying a relatively ideal funding profile. The profiles and correlations are also examined relative to mission procurement approach and mission development duration. Clarifying examples are used to help explain the different profiles. Recommendations are then made to provide guidance for determining funding profiles for developing an initial budget for future NASA missions.

Introduction

When the concept for a NASA robotic science mission is originally conceived, the funding profile for that mission, i.e., the funding required during a given year of development, is often based more on funding availability than on mission needs. This is unfortunate as the ability of NASA to afford a new mission is a function of how much annual funding is available during the development life of a new mission. Typically the funding profiles available for new start missions are a function of the remaining funding in a given fiscal year after all other missions operating or in development obligate what they require from NASA's total available budget. This approach of allocating whatever funding is leftover to new missions sometimes conflicts with the desired funding profile needed for the new mission providing too little or too much funding at inopportune times. In order to understand if there is an optimal, or at least desired, funding profile for new start missions, a study of cost and schedule growth versus different types of funding profiles, was performed. The results shown build upon a recent study performed by The Aerospace Corporation which examined the cost and schedule growth across a set of 40 NASA missions over the past decade (1992-2007).[1] By investigating the initial funding profiles of these 40 historical missions, it was hoped that greater insight could be gained into the relationship between a mission's initial funding profile and its final cost and schedule growth over baseline.

Explanation of Historical Cost and Schedule Growth and Funding Profile Data

The primary source of information for this study was the NASA Fiscal Year Budget Estimates from 1992 to 2007. These documents are publicly released in February of each year and display the cost and major milestones of NASA's major projects. Comparing the different budgets for a mission over fiscal years as well as major milestones provides a basis by which cost and schedule growth can be measured. For the purposes of this study, cost growth was measured from the initial project budget submittal to final actual cost of the mission. As defined in this paper, cost growth was only measured for the development cost of the mission, including Phase A and B cost, excluding mission operations and data analysis, launch support and tracking and data support cost. Additionally, schedule growth was measured from the schedule as defined by the start of Phase B until launch for the initial, planned project schedule as compared to final duration of the schedule based upon the actual launch date. These budget documents also provide the basis for the initial funding profile used for the analysis. For purposes of this paper, the initial funding profile is defined as the annual development budget minus the annual launch vehicle expenditures such that the funding profile represents the flight and ground segment development cost.

Table 1: List of Missions Included in the Study

• Discovery – NEAR* – Lunar Prospector – Genesis – Messenger – Mars Pathfinder* – Stardust* – Contour* – Deep Impact • Mars Exploration – MGS* – MCO/MPL* – MER* – MRO* • New Millennium – DS-1 – EO-1	• Explorer – FAST – ACE – TRACE – SWAS – WIRE – FUSE – IMAGE – MAP – HESSI – GALEX – SWIFT – HETE-II – THEMIS • ESSP – GRACE – CALIPSO – CLOUDSAT	• Great Observatory Class – Spitzer – Gravity Probe B • Flagship – EOS-Aqua – EOS-Aura – TRMM • Solar Terrestrial Probe – TIMED – STEREO • Other – LANDSAT -7 – SORCE – ICESAT * Denotes mission with a restricted launch window

An Explanation of "Standard" Funding Profiles

In order to assess the effect of initial funding profiles on cost and schedule growth, each initial funding profile must be categorized in a standard way. One way to categorize the initial funding profiles is the standard NASA "Beta Curve" profile. The Beta curve approximation for funding profiles was developed at Johnson Space Center (JSC) in the 1960s and is one technique for spreading estimated acquisition costs over time.[2] The equation is a combination of percent funding spent against percent time elapsed between two points in time. The fifth-degree polynomial, expresses the cumulative cost fraction as function of the cumulative time fraction, T:

$$\text{Cumulative Cost Fraction} = 10*T^2 (1 - T)^2 (A + BT) + T^4(5 - 4T) \text{ for } 0<=T<=1 \qquad \textbf{Eq 01}$$

Where:

A and B are parameters (with 0 <= A + B <= 1) that determine the shape of the beta curve
T is fraction of time
A=0.96, B= 0.04 gives 80% expended at 50% time
A=0, B= 1 gives 50% expended at 50% time
A=0, B= 0.04 gives 20% expended at 50% time

Figure 1 shows these standard Beta Curve profiles for different back-loaded (i.e. less than 50% expenditure at 50% time) and front-loaded (i.e. greater than 50% expenditure at 50% time) profiles versus an evenly-loaded profile (i.e. 50% expenditure at 50% time). Although there are no hard and fast rules for the application of standard Beta curve distributions, there are some commonly used values depending on the acquisition strategy of the mission. NASA's Systems Engineering Handbook suggests that JSC typically uses a 50% or 60% beta curve.[3]

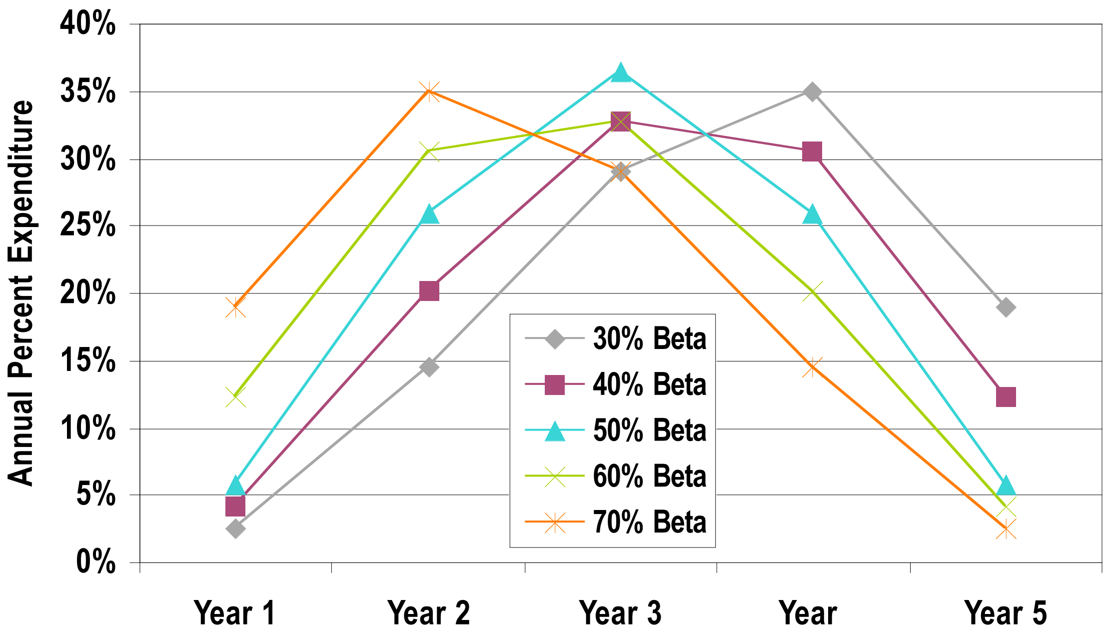

Figure 1: Distributions of the "Standard" Beta Curves

Depending on the mission acquisition strategy, certain funding profiles may be more beneficial than others. For example, front-loaded funding profiles have a primary benefit that they provide funding upfront for risk reduction for technology development or risk mitigation. An inherent limitation, however, is that such a profile reduces the amount of funding available during later phases when troubles may arise during integration and test (I&T). An additional limitation is that a project, once staffed at high spending levels in the early phases, may have a difficult time reducing staff in the later phases so as to not exceed the available budget. Back-loaded funding profiles possess the opposite attributes of front-loaded profiles with limited funding for early risk mitigation but more funding for problems that arise in I&T. The limited spending in the early phases, however, could lead to cost and schedule growth due to potentially less mature technologies or design resulting in more risk during I&T.

In reality, a mission's funding profile is a combination of funding profiles from different elements. For example instrument development is usually front-loaded to allow for readiness and delivery to environmental test and typically have roughly 60% of the funds spent by 50% of the development time. Ground system development funding cost is typically back-loaded with 30% of the cost spent at 50% time as most of the ground system is typically developed nearer to the launch readiness date after the instrument data analysis plan is more mature. Spacecraft are more evenly distributed at 50% of the funds spent by 50% of the development time as initial development is offset by a longer I&T time whereas the majority of the effort is in the detailed design phase prior to I&T. Stretching out any of the individual phases, or developing a system with either high heritage or substantial development, can substantially affect the funding profiles of any of these elements and therefore the overall mission funding profile. For the analysis presented in this paper, however, only the total mission funding profile is considered.

Distribution of Funding Profiles

Figure 2 displays a histogram showing the number of missions out of the forty mission data set that matched an initial funding profile as indicated. As can be observed, the distribution of funding profiles is fairly evenly distributed amongst front-loaded, back-loaded and evenly loaded funding profiles. Of the 40 mission data set, the initial funding profiles for 17 missions fall within the standard 45% to 55% beta curve, indicating that these profiles are essentially evenly loaded, while 14 missions have more front-loaded profiles (i.e. greater than 55% @ 50% time) and the final 9 missions are more back-loaded (i.e. less than 45% @ 50% time).

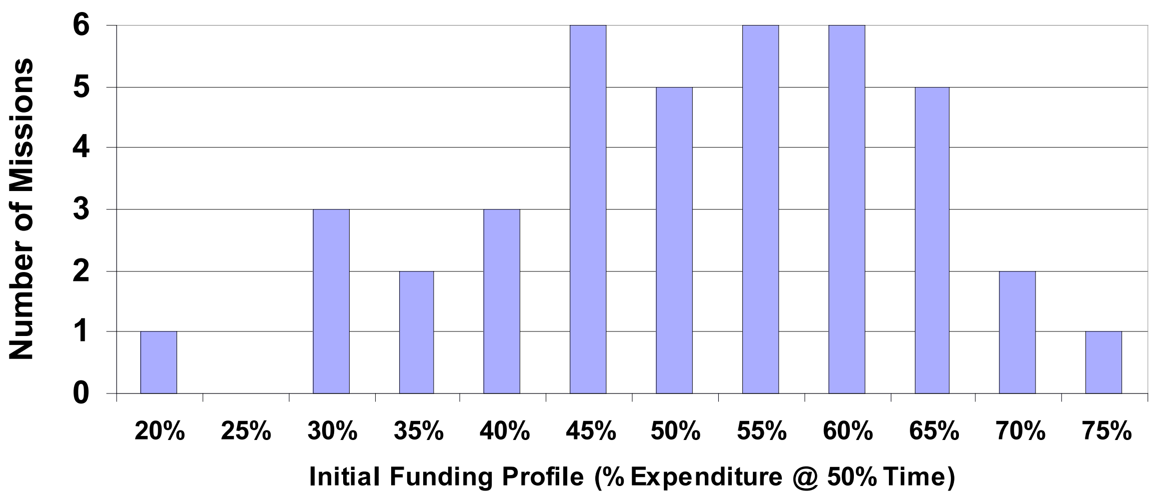

Figure 2: Distribution of Initial Funding Profiles for Mission Data Set

Comparison of Initial Funding Profiles versus Cost and Schedule Growth

For each of the missions in the study, cost and schedule growth were compared against the initial funding profile as shown in Figure 3. As can be seen, based on the results of the complete data set, the data indicates that the minimum average mission cost and schedule growth occurs for an evenly loaded schedule, with an initial funding profile between 50 and 55% expended at 50% time. Although the data points for the extremely back-loaded (i.e. 20 to 25% expended @ 50% time) and extremely front-loaded (i.e. 70 to 75% expended @ 50% time) are small, they tend to indicate that the extreme profiles may be one of the drivers leading to higher cost and schedule growth than a more balanced funding profile.

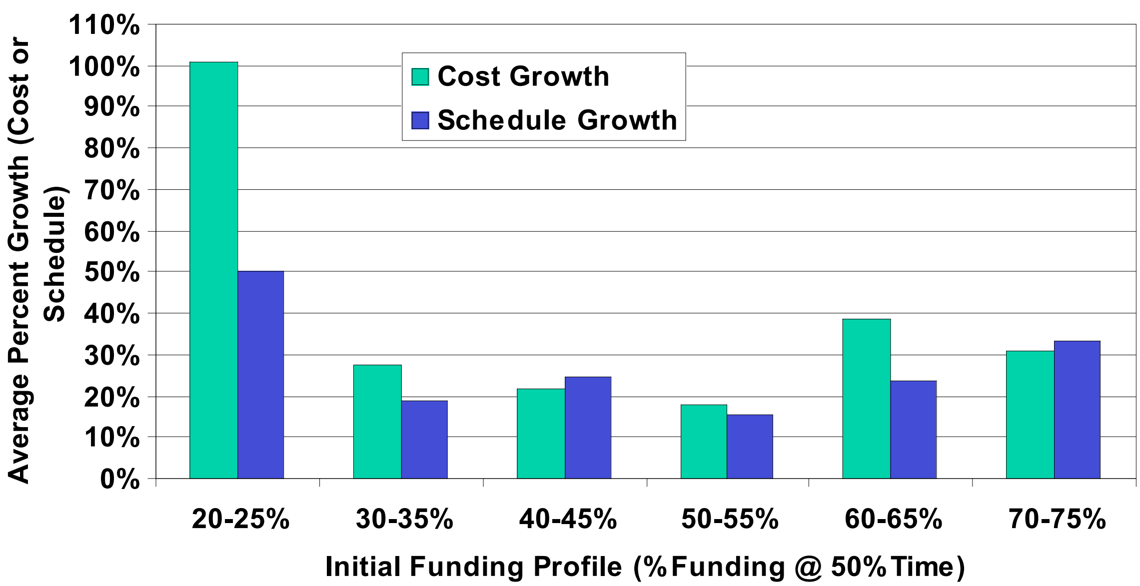

Figure 3: Distribution of Cost and Schedule Growth vs. Initial Funding Profile for All Missions

To determine if there is a predictive relationship between initial funding profiles and cost and schedule growth, the average cost and schedule growth percentages for the missions investigate were plotted against their respective initial funding profile. The results of this correlation are shown in Figure 4 where the diamonds indicate the average percent cost growth for the mission with the initial funding profile shown while the triangles indicated the average schedule growth for the respective missions. The correlation between the average cost and schedule growth and the initial funding profile indicates that the minimum cost and schedule growth occurs at the 50% beta curve which is consistent with the data shown in Figure 3.

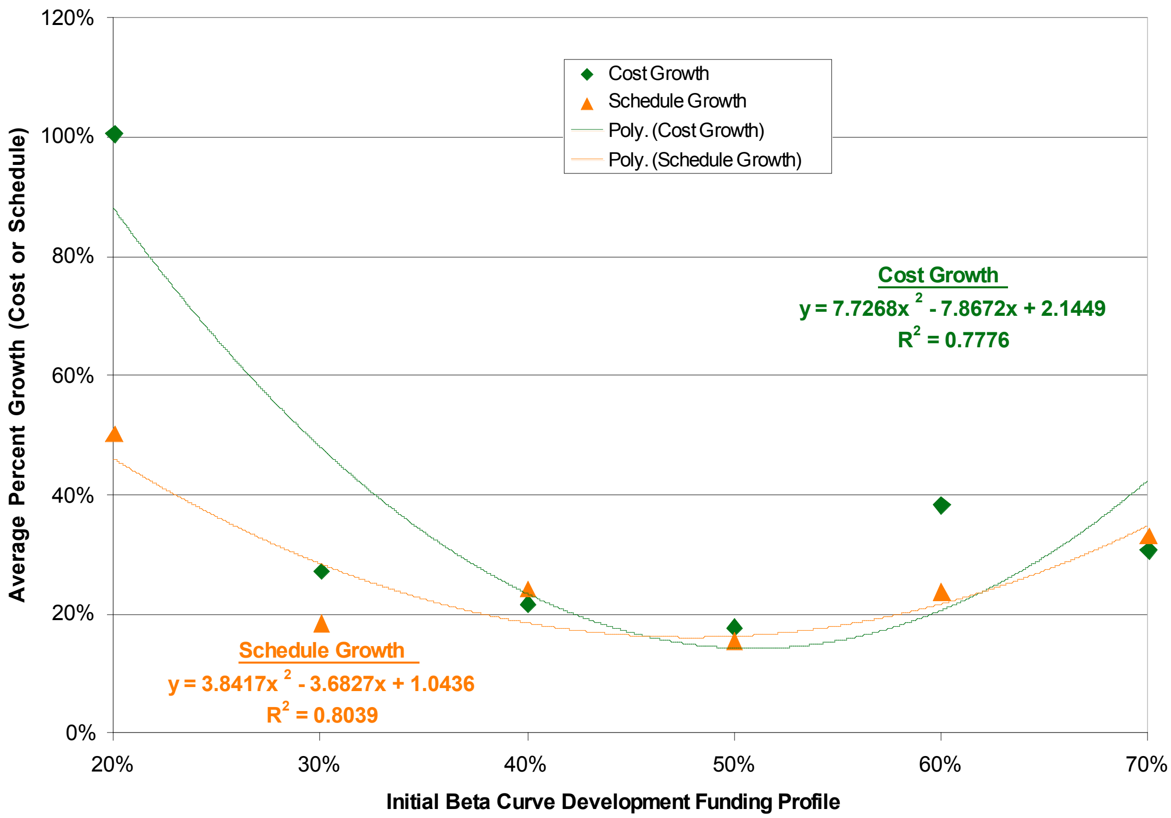

Figure 4: Correlation of Average Cost and Schedule Growth with Initial Funding Profile

The Effect of an Off-Optimal Initial Funding Profile

To demonstrate the effect that an initial prescribed funding profile has on the selection and development of a mission, the funding profile for the Mars Scout Announcement of Opportunity (AO) proposed in 2002 was investigated. The Mars Scout Program is a Discovery-like competed mission focused on investigation of Mars. Although the schedule and total mission cost are prescribed, any proposed science objectives are considered as long as they are focused on increasing the science community's understanding of Mars. Due to near term Mars Exploration Program budget constraints, the profile offered in the Mars Scout 2002 AO was severely back-loaded. The prescribed funding profile placed severe restrictions on the missions that could be selected given that the launch date could not be moved due to launch window considerations for a 2007 Mars mission. The mission that was selected, the Phoenix Lander, was considered to have minimal funding needs in the early development phase as the design was based on reuse of substantial existing hardware that was available from the cancelled Mars 2001 Lander mission. Figure 5 shows the initial Mars Scout 2002 AO development funding profile relative to the final actual development funding required by the mission. As can be seen, the mission needed additional funding in the early years to be able to overcome challenges as the ability to re-use existing hardware was overestimated and additional developmental difficulties arose on less mature elements. In the end, the Phoenix mission final funding profile looked similar to the 40% beta curve distribution as opposed to the extremely back-loaded profile of the AO.

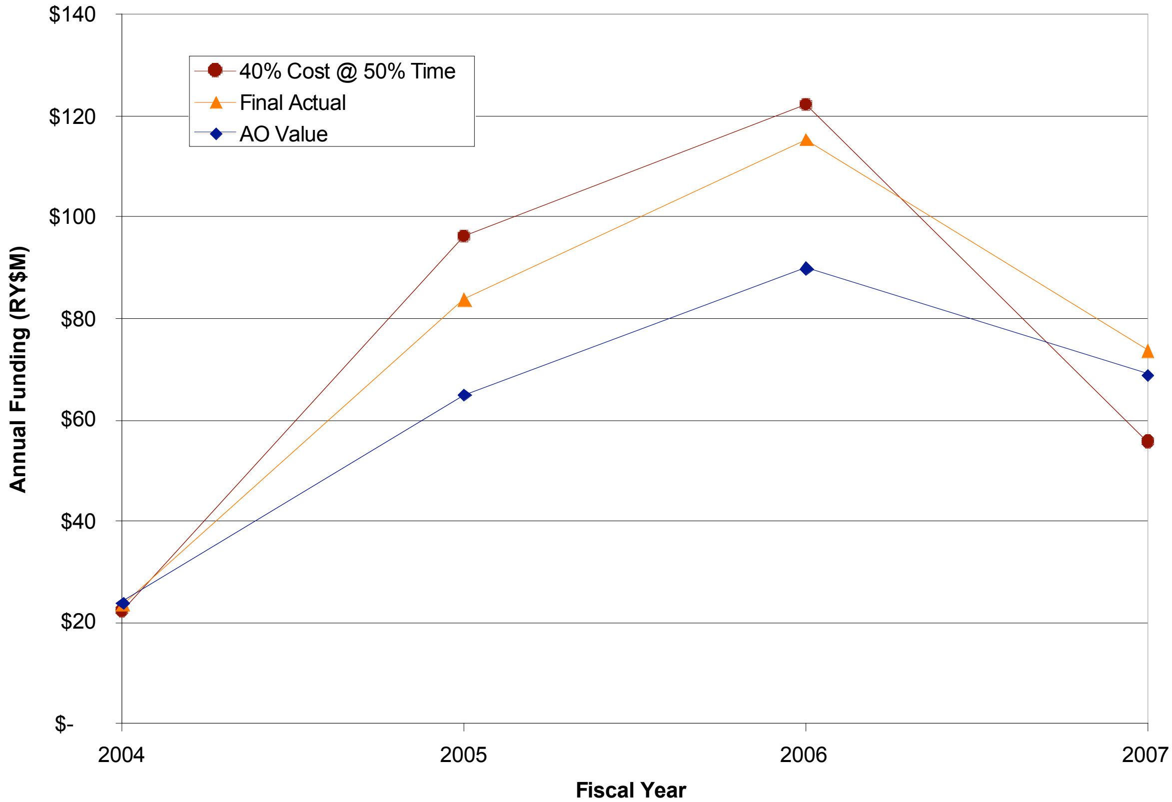

Figure 5: Comparison of Mars Scout 2002 AO Development Funding Profile and Final Profile for Implemented Mission

Comparison of Results as a Function of Acquisition Approach

To investigate the data at a deeper level, the data was further segregated as a function of acquisition approach and as a function of development duration. It was hypothesized that competed missions, those missions that are selected in response to an AO in which science objectives are proposed to NASA, may need a different initial funding profile as compared to missions in which they are directed by a program to fulfill a given science objective (i.e., Directed Mission). The data was segregated in this manner, AO (or Competed) vs. Directed missions, in order to determine if there is a difference in funding profiles between the respective acquisition approaches.

As a starting point, the average cost and schedule growth of the eighteen Directed and twenty-two Competed missions in the data set were compared to the average of all missions. Figure 6 shows the results of this comparison and indicates that, overall, the Competed missions experienced a greater cost and schedule growth than the Directed missions. Given this difference between the cost and schedule growth of Directed and Competed missions, it can be postulated that there is also a difference in the relationship between the initial funding profile and cost and schedule growth.

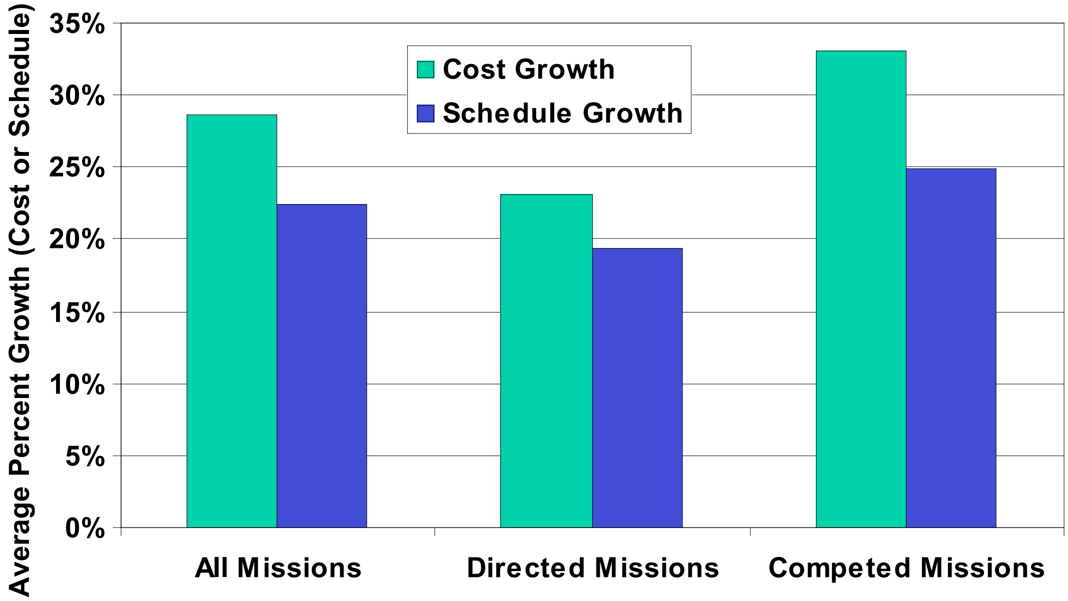

Figure 6: Comparison of Cost and Schedule Growth for Directed vs. Competed Missions

Figure 7 shows the results of comparing the average cost and schedule growth vs. initial funding profiles for Competed missions. As seen in Figure 7, the distribution is similar to the distribution shown in Figure 3 for all missions where a balanced funding profile shows the minimum cost and schedule growth and extremely front or back loaded funding profiles are associated with the largest cost and schedule growth. This result may indicate that Competed missions, which typically have limited technology development but still some development and integration risk, could benefit the most from a balanced funding profile.

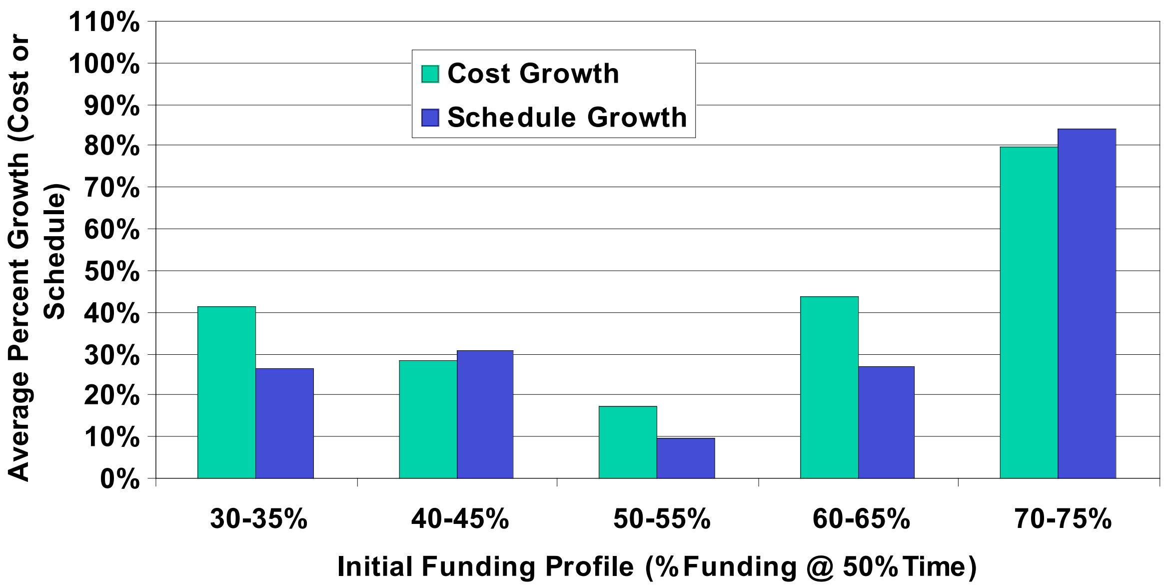

Figure 7: Distribution of Cost and Schedule Growth vs. Initial Funding Profile for Competed Missions

An example of a Competed mission that demonstrates this characteristic is the NASA Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission which experienced cost and schedule growth substantially less than average. Figure 8 displays that percentage annual funding of the IMAGE mission compared to the standard 55%

beta curve and shows a very good fit.

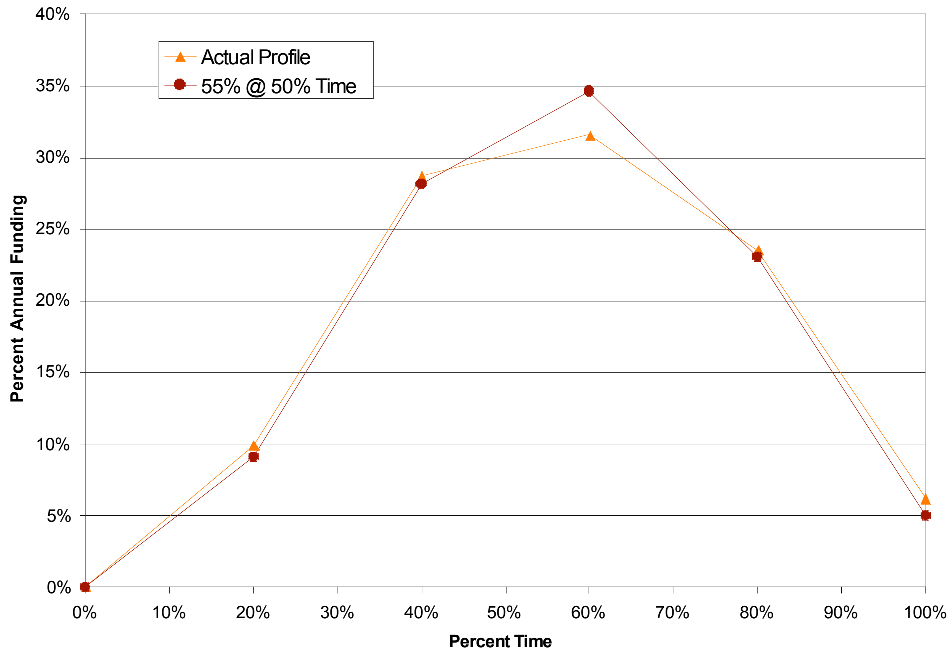

Figure 8: Comparison of the IMAGE Mission Initial Funding Profile to the Standard 55% Beta Curve

Figure 9 shows a similar plot as Figure 7 although it compares the average cost and schedule growth vs. initial funding profiles for Directed missions. Figure 9 results indicate that a more back-loaded funding (30-45% funding spent at 50% time) profile results in minimum cost and schedule growth for the Directed missions. This result may indicate that Directed missions, which typically have more extended Phase B studies and more technology development than Competed missions, could benefit the most from a back-loaded funding profile in which additional trade studies and risk mitigation activities are conducted prior to full scale mission development. In the end, this approach may also contribute to the reduced overall cost and schedule growth experienced by Directed missions.

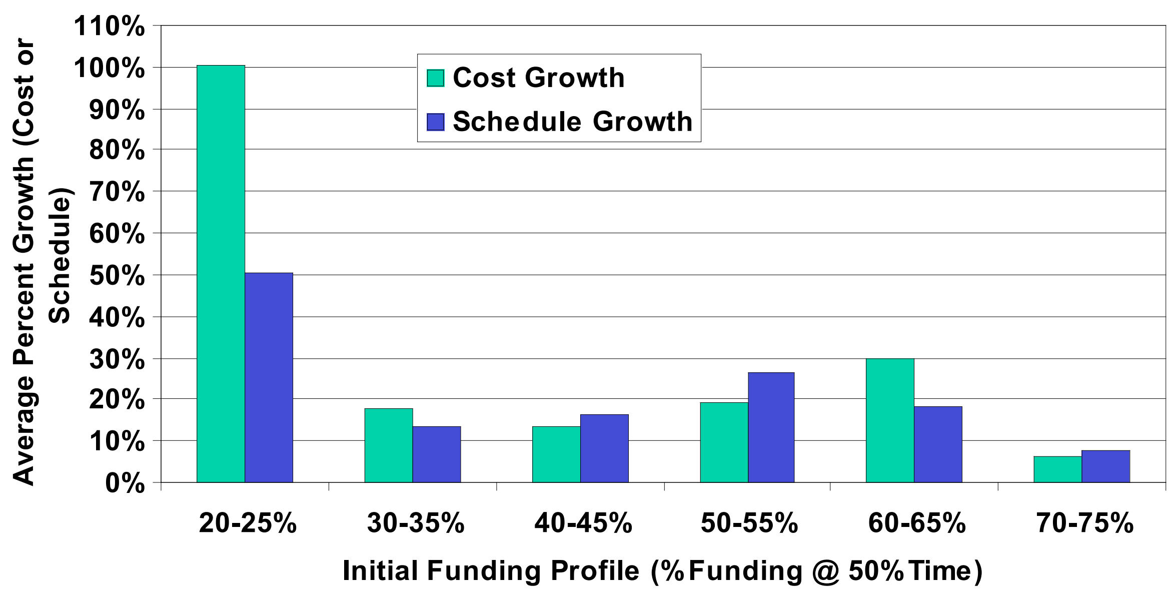

Figure 9: Distribution of Cost and Schedule Growth vs. Initial Funding Profile for Directed Missions

An example of a Directed mission that demonstrates this characteristic is the NASA Earth Observing System (EOS) Aura (EOS-Aura) Mission which also resulted in cost and schedule growth substantially less than average. Figure 10 displays the percentage annual funding of the EOS-Aura mission compared to the standard 40% beta curve and also shows a very good fit.

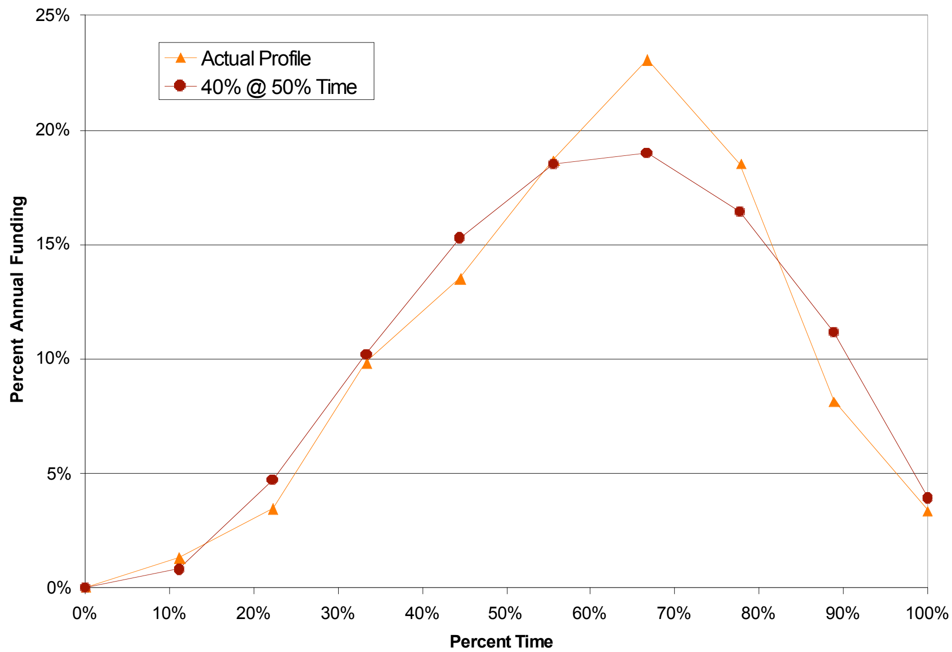

Figure 10: Comparison of the EOS-Aura Mission Initial Funding Profile to the Standard 40% Beta Curve

Comparison of Results as a Function of Development Duration

A secondary hypothesis is that missions with a longer development time (greater than four years) may also need a different funding profile than missions with development times of four years or less. The data was segregated by missions with development times of greater than 4 years vs. development times of four years or less to determine if there is a difference between the respective funding profile needs.

To determine the effect of longer development times, the average cost and schedule growth of the twenty-two missions with a development duration of four years or less and the eighteen missions with a development duration greater than four years in the data set were compared to the average of all missions. Figure 11 shows the results of this comparison and indicates that, overall, there is little differentiation between the missions from a cost and schedule growth perspective. Given that there is no difference between the cost and schedule growth for different development durations, it can be postulated there is no difference in the initial funding profile vs. cost and schedule growth.

Figure 12 shows the results of comparing the average cost and schedule growth vs. initial funding profiles for missions with development times of four years or less. As seen in Figure 12, the distribution is similar to the distribution shown in Figure 3 for all missions where a balanced funding profile shows the minimum cost and schedule growth and extremely front or back loaded funding profiles are associated with the largest cost and schedule growth. This result may indicate that missions with shorter development times, which typically have limited technology development but still some development and integration risk, could benefit the most from a balanced funding profile.

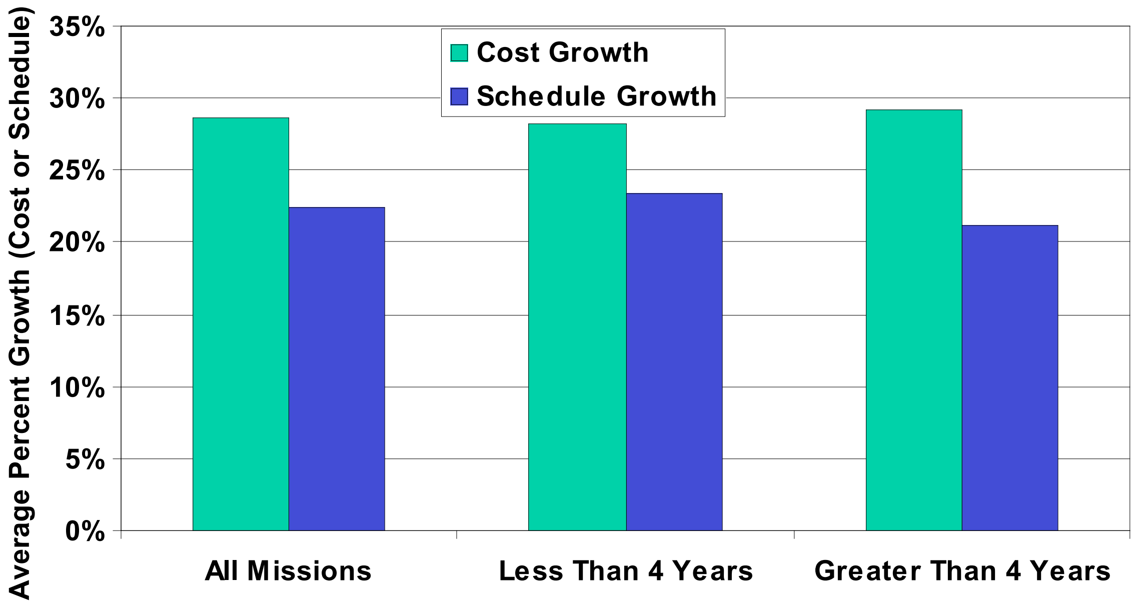

Figure 11: Comparison of Cost and Schedule Growth for Different Development Durations

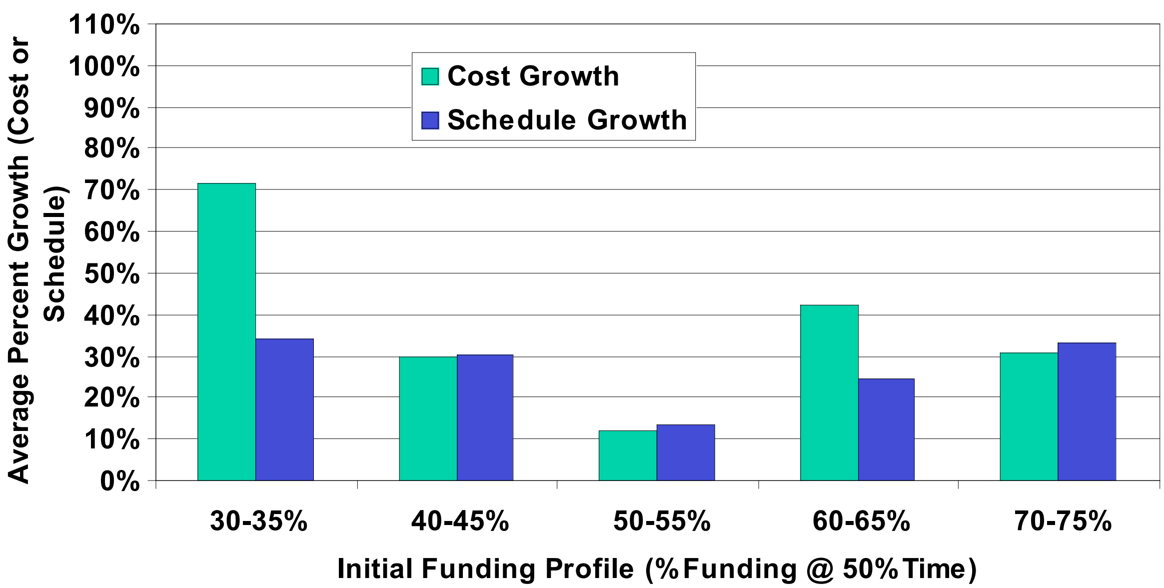

Figure 12: Distribution of Growth vs. Initial Funding Profile for Missions with Development Time 4 Years or Less

An example of a mission that was developed in less than four years that demonstrates this characteristic is the NASA Stardust mission which also had cost and schedule growth substantially less than average. Figure 13 displays the percentage annual funding of the Stardust mission compared to the standard 55% beta curve and also shows a very good fit.

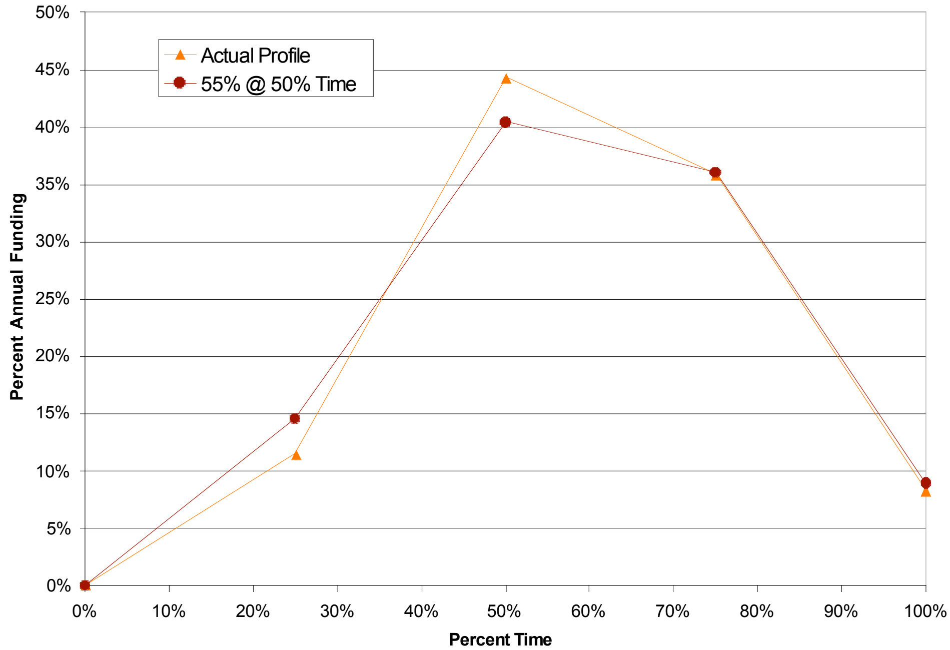

Figure 13: Comparison of the Stardust Mission Initial Funding Profile to the Standard 55% Beta Curve

Figure 14 shows the same plot comparing the average cost and schedule growth vs. initial funding profiles for missions with development times greater than four years. As seen in Figure 14, the results indicate that a more back loaded funding profile is associated with minimum cost and schedule growth, similar to the Directed mission result shown in Figure 8. This is influenced by the data set, as shown in Figure 15, in which 11 of the 18 missions that had development times greater than four years are Directed missions. The data set is not the same, however, as 7 of the missions were Competed and do influence the result. The result indicates that missions with longer development times, which typically have more extended Phase B studies and more technology development than missions with shorter development times, could benefit the most from a back loaded funding profile in which additional trade studies and risk mitigation activities are conducted prior to full scale mission development.

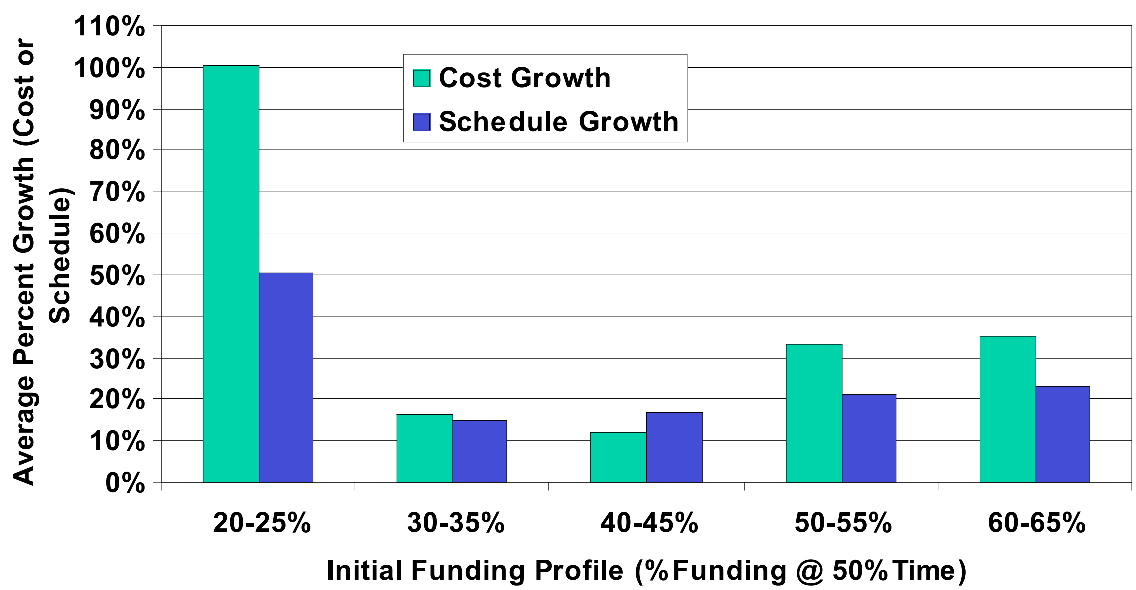

Figure 14: Distribution of Growth vs. Initial Funding Profile for Missions with Development Time Greater than 4 Years

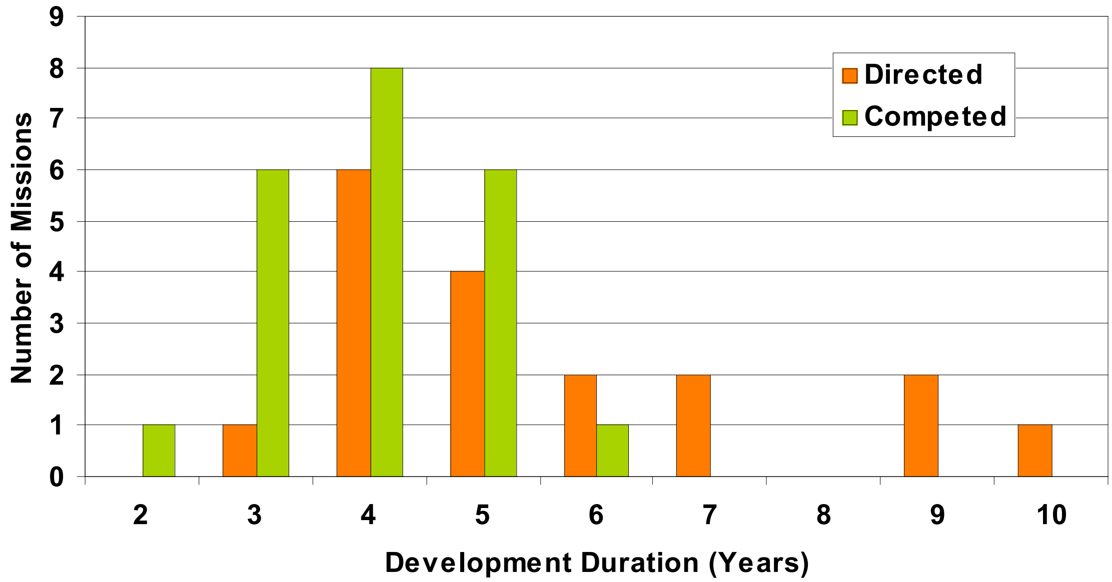

Figure 15: Distribution of Type of Mission Relative to Development Time

An example of a mission that was developed in greater than four years that demonstrates this characteristic is the NASA Competed Wilkinson Microwave Anisotropy Probe (WMAP) mission which had resulted in cost and schedule growth substantially less than average. Figure 16 displays the percentage annual funding of the WMAP mission compared to the standard 40% beta curve and also shows a relatively good fit.

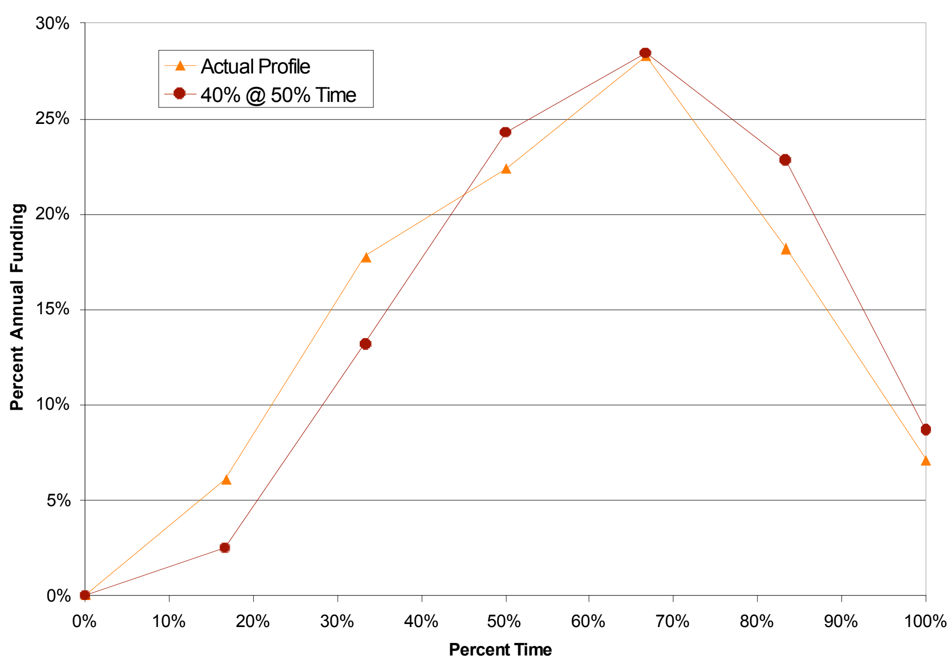

Figure 16: Comparison of the WMAP Mission Initial Funding Profile to the Standard 40% Beta Curve

Recommendations

It is difficult to say which is definitively the "optimal" funding profile but the results of this study, based on a 40 mission data set, suggest that a more balanced funding profile (45%-55% beta curve) are associated with minimal cost and schedule growth. This is not true for all acquisition approaches however, as for Directed missions and missions with development times of greater than 4 years, a more back-loaded funding profile may limit cost and schedule growth and may allow higher risk elements such as science instruments to be developed earlier. For Competed missions and missions with development times of 4 years or less, a more balanced funding profile is associated with lower cost and schedule growth and allows for early procurement of longer lead items.

Alternatively, a front loaded profile has the advantage, if managed correctly, to provide the most flexibility for early risk mitigation and provide for adequate phased reserves assuming that early funding is held in reserve for later developmental issues. Front loaded profiles do run the risk of having all funds spent early, however, since the project may spend all available funding in an effort to reduce all perceived risks. Consideration should be given to having the Program or Directorate, as opposed to the Project, hold some funding in early years in reserve and only provide the project early reserve funding based on risk mitigation proposals that have the most leverage for later cost and schedule growth avoidance. This would require the project to be initially funded at lower level in early phases with the expectation that ample reserve would be available during the integration and test phase if problems arise. Providing the Project with a balanced funding profile, while having the Program or Directorate budget for a more front loaded profile so as to hold additional reserve in the early years, may provide the most flexibility and best risk reduction leverage for future missions.

Summary

The initial funding profile provided by a mission is one of many factors that can contribute to the cost and schedule growth of a mission. Although the initial funding profile cannot be an accurate predictor of the magnitude of the cost and schedule growth, the results of this study indicate that certain initial funding profiles may help minimize cost and schedule growth. For Directed missions and missions that require more than four years to develop, a more back loaded funding profile may be best while for Competed missions and missions that require four or less years to develop, a more balanced funding profile may be most appropriate. Alternatively, a Program may want to budget a more front loaded funding profile while funding the Project in a more balanced manner so as to hold reserves to distribute as needed for risk reduction in the early phases of development or to counter difficulties in integration and test in the later phases. The best choice is made after fully understanding the development challenges of the mission, the mission development time required to successfully implement the mission, and the mission acquisition approach.

Biography

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."

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 won The Aerospace Corporation's highest honor, The President's Award, for 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 Award for 2007 which is awarded to Aerospace women who "demonstrate outstanding professional achievement, leadership, community involvement, and initiative".

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."

[1] Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines, Presented at the SCAF/SSCAG/EACE International Conference on Cost Forecasting, September 19-21, 2006, Royal Institution of Naval Architects (RINA), London, UK, Bob Bitten, Debra Emmons, Claude Freaner

[2] NASA Systems Engineering Handbook, Systems Analysis and Modeling Issues, June 1995, SP-106S, Chapter 5.2.3 Cost Estimating, Page 96

[3] Ibid.