Instrument First, Spacecraft Second (IFSS): Reducing Development Risk in NASA Science Missions

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NASA science instruments have had a history of developmental delays. These development delays can lead to cost growth for the overall mission, as shown in recent studies of NASA missions and a larger historical data set. An analysis was conducted to assess if a new mission development process, labeled instrument first, spacecraft second (IFSS), could provide reduced cost and schedule growth in future missions by minimizing the impact of instrument development issues on mission development. A cost and schedule analysis was conducted for representative Tier 2 and Tier 3 Earth Science Decadal Survey missions to quantify the benefits. The results indicate that the savings resulting from such an approach is on the order of $2B, making more funding available for future missions, while providing a less volatile and more manageable mission portfolio. This paper reviews the results of this analysis and assesses the implications of implementing such a mission development process by showing the approach on specific examples.

I. Introduction

THE development of NASA missions is difficult. Developing world class science instruments that constantly push the state of the art can present a series of developmental challenges that are difficult to both anticipate and overcome. For many NASA missions, the development of an instrument can become the primary key technological challenge for the success of a mission.[1] As such, the difficulty of developing an instrument can lead to delays in delivering the instrument to the spacecraft for system integration.[2] This delay, in turn, can lead to cost growth while the spacecraft, mission and ground system team waits for the instrument to be delivered. The subsequent "marching army" cost can be significant and is one of the primary causes of cost growth for NASA missions.[3]

This issue is addressed by hypothesizing that developing the instrument first and bringing it to an acceptable level of maturity prior to procuring the spacecraft and initiating ground system development could provide an overall cost reduction or minimize cost growth for NASA missions. To test this theory, the cost and schedule of representative missions from the recent Earth Science Decadal Survey (ESDS)[4] were analyzed to determine if potential cost and schedule growth could be minimized by developing the instrument(s) prior to starting full mission development.

Section II discusses the historic difficulties of NASA science instrument development and the associated cost and schedule growth while proposing a potential approach to reduce this growth for future missions. Section III presents the instrument first, spacecraft second (IFSS) methodology and the results when applying it to representative ESDS Tier 2 and Tier 3 missions. Section IV presents possible programmatic approaches for implementing IFSS.

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II. Background

Historically, most NASA missions have had instrument development issues.[3] Specific examples of recent problems include the development of the Cloud Profiling Radar (CPR) instrument on CloudSat, the Geoscience Laser Altimeter (GLAS) instrument on ICESat and the instrument on the Orbiting Carbon Observatory (OCO). Each of these missions experienced significantly more cost growth to the project than the cost of the instrument growth alone. As can be seen in Fig. 1, instrument development difficulties led to delays in instrument delivery which results in significant cost growth in the instrument and the subsequent total mission cost due to the marching army cost. For the examples shown, the ratio of total mission cost growth to instrument cost growth is on the order of 2:1. Although it is understood that other factors contributed to the cost growth of these missions, the instrument delivery delays were one of the primary contributors.

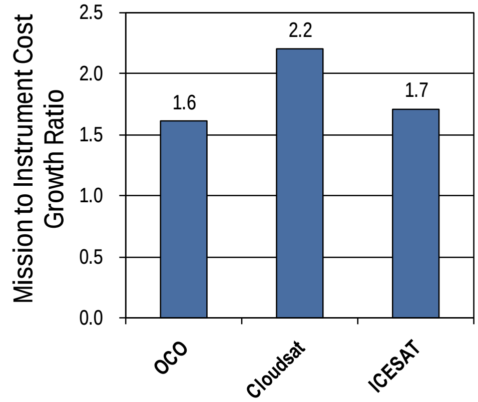

Figure 1. Ratio of Total Mission Cost Growth to Instrument Cost Growth for Recent Missions with Instrument Difficulties

To understand the impact of instrument difficulties and their contribution to cost and schedule growth relative to a larger data set, a recent investigation of the causes of cost and schedule growth for forty NASA missions shows that over two-thirds of the missions experienced instrument development difficulties.[3] Figure 2 shows the results of this study where a third of the missions had instrument problems only and another 30% of the missions had both instrument and spacecraft development problems. Figure 3 shows the associated cost growth for these missions where missions that only had instrument development problems experienced over twice the cost and schedule growth of missions that only had spacecraft development problems. It is postulated that cost growth for instrument development problems are more prevalent and have higher cost growth because instruments are the primary, challenging developmental items for NASA science missions while spacecraft have less developmental issues. With the availability of standard spacecraft busses through NASA's Rapid Spacecraft Development Office (RSDO) and commercial providers, the complexity of instruments relative to spacecraft is even greater for potential future Earth science missions.

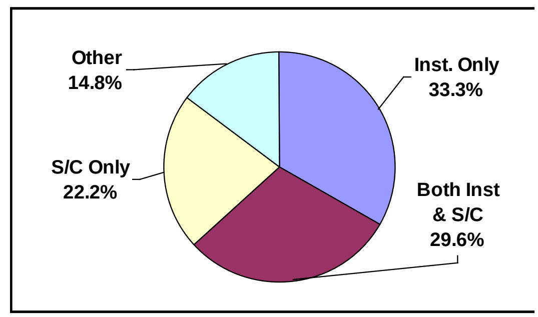

Figure 2. Distribution of Problems Identified for a Forty NASA Mission Set Studied

Another recent study examined the average delay and distribution of delays of the planned versus actual delivery times for the instrument. Figure 4 shows a plot of the planned versus actual development time for sixty-four NASA science instruments. The plot shows the planned time on the x-axis with the actual delivery time on the y-axis. The diagonal line on the graph indicates when the actual delivery time equals the planned delivery time. As can be seen, the majority of data points lie above that line, indicating that a delay has occurred. Figure 5 provides further enlightenment by indicating the distribution of the delays. The average growth of the data set is 33%, with almost half of the instruments experiencing growth greater than 30% and 14% of the instruments experiencing growth over 60% of their planned delivery duration.

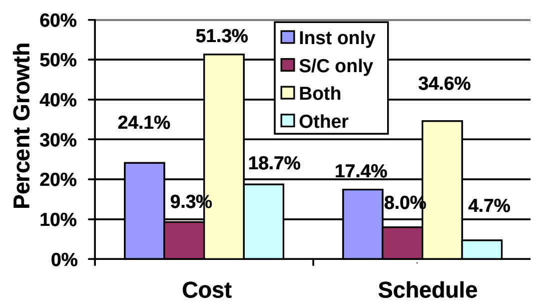

Figure 3. Associated Cost and Schedule Growth as a Function of the Problems Encountered

Follow-on work to the study in Ref. 2 was recently completed that looked at the phases where instrument schedule growth occurred.[5] Figure 6 shows a comparison of planned versus actual instrument schedules broken down by milestone. On average the schedules grew by 10 months with 7.5 months of the growth occurring between CDR and Instrument Delivery. Development issues are not identified early on in the project when plans could be reworked and resources reallocated easier. The issues arise later when it is much harder to find workarounds for delays leading to a marching army cost while waiting for delivery of the instrument.

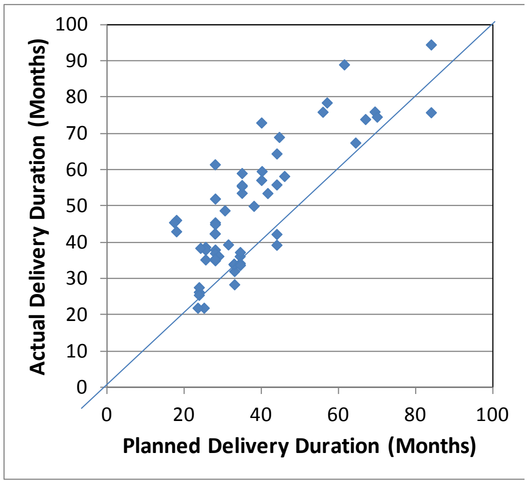

Figure 4. Planned vs. Actual Delivery Durations for 64 NASA Science Instruments

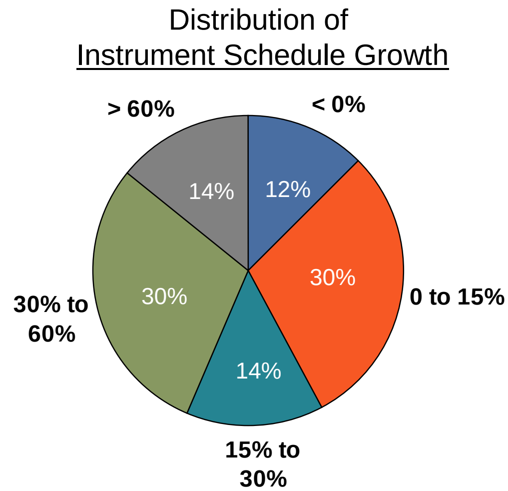

Figure 5. Distribution of Instrument Schedule Growth for 64 NASA Science Instruments

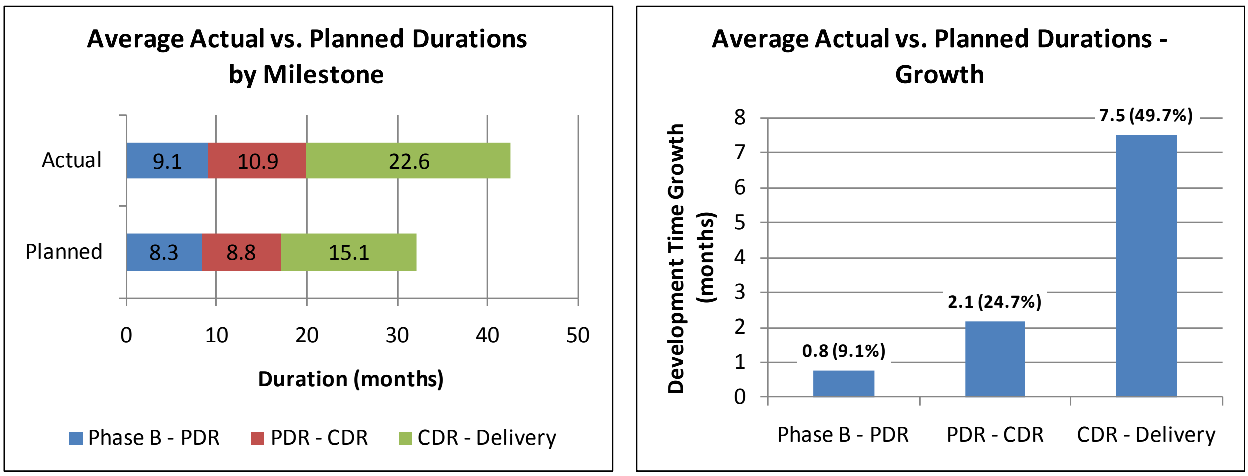

Figure 6. Instrument Schedule Growth by Milestone

The difficulty of instrument developments versus spacecraft developments can also be seen when investigating resource growth for historical NASA missions. Another study reviewing a subset of twenty NASA missions in greater detail demonstrates that instrument resources such as mass and cost grow at a significantly greater rate than spacecraft resources.[6] Figure 7 shows the average percentage mass and cost growth of the instruments and spacecraft from the start of Phase B within this twenty mission data set and shows that the growth for instruments is essentially twice the growth for spacecraft. This incongruity implies that instruments typically are less mature than spacecraft at the initiation of a project, as shown by the differences in mass growth, which leads to cost growth. Again, this additional information supports the idea of developing instruments early, prior to start of spacecraft development, in order to minimize the marching army effect of spacecraft waiting for instruments to be delivered. Based on the immaturity of the initial instrument design, the history of instrument development difficulties and the associated total mission cost growth, an approach that develops the instrument first before the other mission elements, referred to as the instrument first, spacecraft second (IFSS) mission development approach, could potentially provide a reduction in cost growth in the development of NASA missions.

Missions where the majority of instrument issues were resolved prior to the start of spacecraft development, such as QuikSCAT and QuikTOMS, are in sharp contrast to missions developed in a more traditional manner. For both of these missions, the instruments for each, SeaWinds for QuikSCAT and TOMS for QuikTOMS, had already been largely developed prior to spacecraft acquisition. Each instrument was able to be integrated with spacecraft and launched in the relatively short time of two years. The reduced development time and integration uncertainty in these missions helped to keep the cost and schedule growth relatively low compared to historical NASA mission averages.

The proposed IFSS approach is a simple idea – developing the instrument early and bringing it to an acceptable level of maturity prior to initiating full mission development. A notional example of the IFSS development approach is shown in Fig. 8 where the start of spacecraft development is delayed to more favorably match the historical instrument development delays.

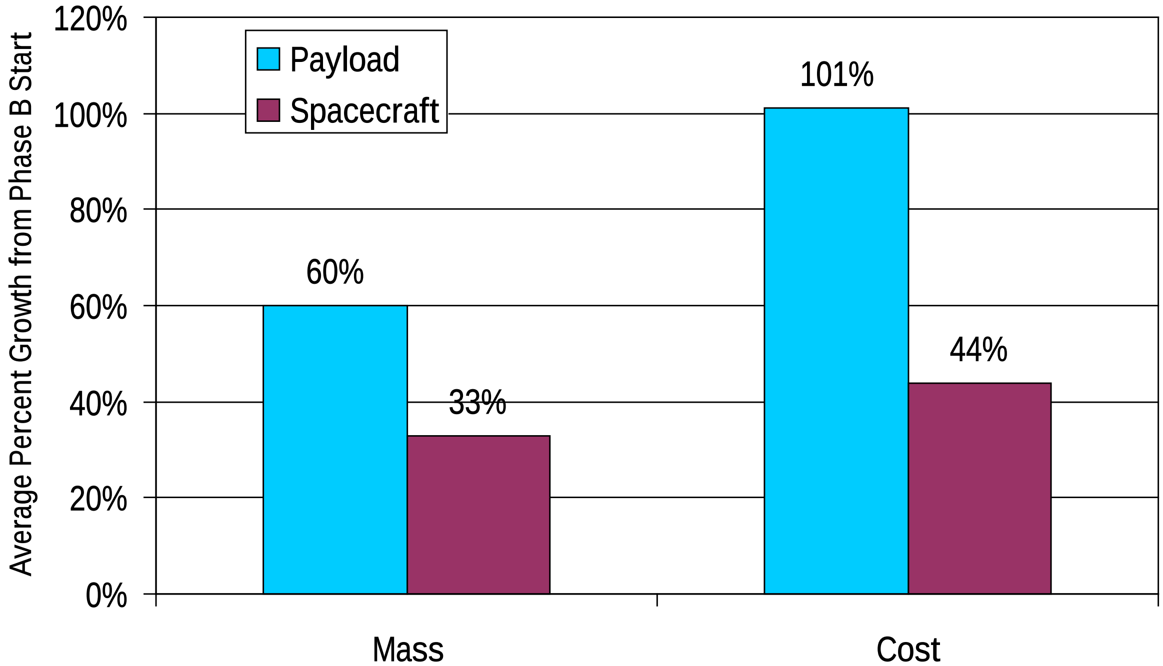

Figure 7. Relative Cost and Schedule Growth, from Phase B Start, of Instrument Payloads vs. Spacecraft

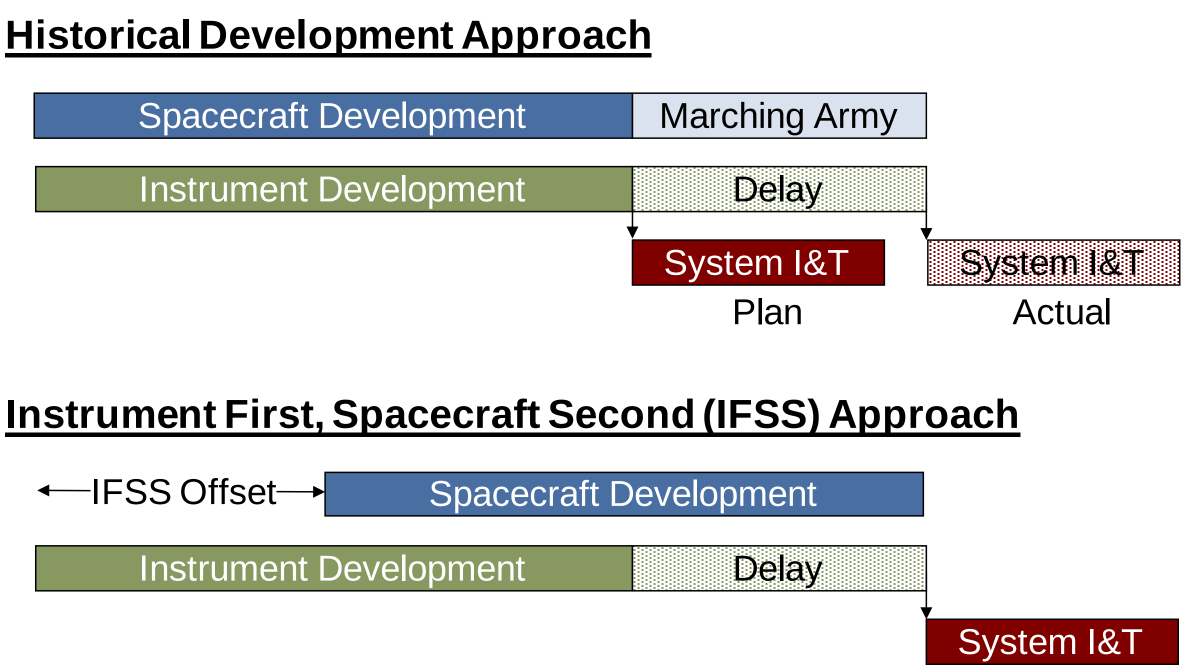

Figure 8. Notional Comparison of Traditional Development with Delays versus a Possible IFSS Approach

III. Assessment Approach and Results

A. Assessment Approach

To test the hypothesis that IFSS could lead to a decrease in cost and schedule overruns, a quantitative process was needed. Realistically, it should use plausible missions that are under investigation for future flight. It was decided that the Tier 2 and Tier 3 Earth Science Decadal Survey missions would be used. The Earth Science Decadal Survey missions were chosen because there was a good amount of public data, both cost and technical, to use in the analysis and the Tier 2 and Tier 3 mission are currently under study for flight in the next decade. A multi-step process was undertaken to generate portfolio costs to compare the development costs for the Tier 2 and Tier 3 under the current paradigm and under IFSS. Figure 9 provides an overview of the process that was used.

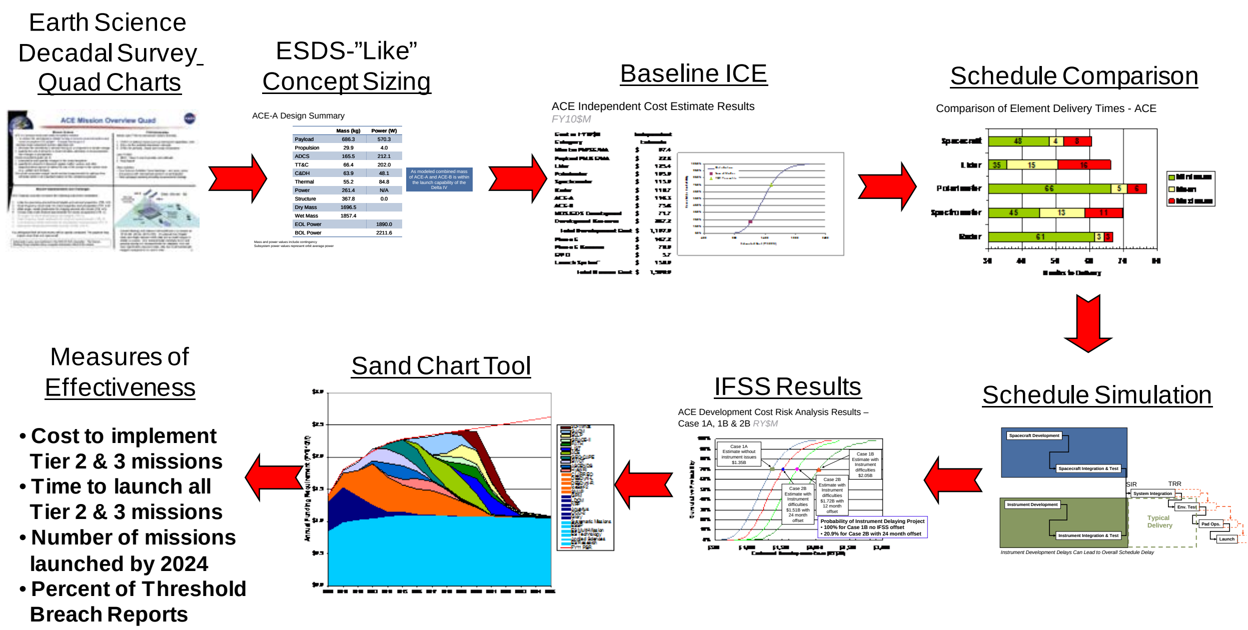

Figure 9. Process to Investigate Possible Cost Savings from the IFSS Development Approach

For each of the Tier 2 and 3 missions, the available technical data was used to develop "-like" missions. These missions are not the exact current concepts, but are representative of what would be flown. It was necessary to develop these detailed designs so that a cost estimate could be generated for each mission. The detailed designs were generated using a concurrent engineering methodology (CEM) model. The CEM model used is a single page spreadsheet that uses mission design and instrument technical parameters to size the spacecraft bus (mass, power and various technical parameters).

With the detailed designs in hand, the cost estimates for each mission were developed. Though cost estimates for each mission are available publically, the available information is only the system-level cost and is not at a low enough level to be useful in the study. For this study, costs at the level of the spacecraft and individual instruments were required to understand the cost impact of delays for each of these elements. These costs were then laid out over a baseline schedule. This provides a funding profile from which expenditures by phase can calculated and used in the simulation that was run to quantify possible schedule delays. The baseline schedule was a notional timeline based on the planned development time for each mission. To quantify possible overruns for the instrument developments, historical development times for analogous instruments were needed. Analogies for each instrument to be flown on a mission were identified and the range of times used in the simulation.

In order to assess the impact of potential instrument delays on the cost of a mission, a simulation was developed that uses a distribution of historical development durations for analogous spacecraft compared to the distribution of historical development durations for analogous instruments for the missions to be investigated.

Figures 10 and 11 show the primary basic test which drives the simulation. For each, a Monte Carlo draw is made for both the spacecraft development duration and instrument development duration(s) to determine if the spacecraft will be ready for system testing prior to the instruments' availability for integration to the spacecraft. Figure 10 shows a case in which the instrument development duration is greater than the spacecraft development duration. In this case, a “marching army” cost, identified as the average monthly cost expenditure (i.e., “burn rate”) from the time of initial assembly to test, is incurred by the complete project until the instrument is ready to be integrated. Figure 11 shows the case where the instrument development is started earlier than the spacecraft – by the corresponding “IFSS Offset” – and the instrument is delivered prior to the spacecraft being ready for test. In this case, a burn rate associated with the instrument integration and test team, which is much smaller than that for the complete project, is applied as a penalty for early instrument development. The simulation is run for 10,000 cases providing a statistical distribution of potential outcomes allowing for an assessment of the benefit or penalty of different IFSS offsets.

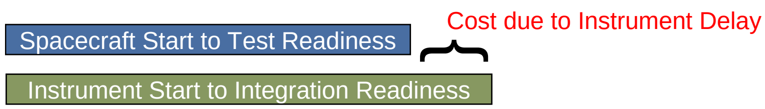

Figure 10. Typical Development Leading to “Marching Army” Cost Due to Instrument Delays

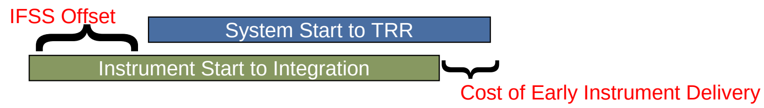

Figure 11. Applying the IFSS Offset to Reduce the Potential Cost Due to Instrument Delays

Once all the simulations were complete, the results from the current development paradigm could be compared to those from the IFSS approach to see if there is any savings from starting the instrument development early. The individual mission results were then used in a tool called the Sand Chart Tool. This tool provides the ability to visualize the portfolio as a whole and use metrics other than cost (such as total time to launch all missions) to compare the performance of the two different approaches.

B. Assessment Results

The simulation was applied to representative designs of the eleven Tier 2 and Tier 3 Earth Science Decadal Survey missions. For each of the missions, public documentation was used to identify instrument resources, such as mass, power, pointing requirements, data rate, etc., and a spacecraft sizing routine was used to size the spacecraft to satisfy the mission and instrument resource requirements. The goal was to develop ESDS-like missions for which an independent cost estimate could be developed for use in the simulation. The independent cost estimate was developed to assess the baseline cost of the mission assuming that the instruments could be delivered on time with no developmental difficulties. Table 1 shows that the “-like” missions are representative of the proposed ESDS missions.

Table 1. Comparison of Tier 2 & 3 Mission Public Costs vs. Independent Estimate for ESDS-like Missions

Mission	Public Cost (FY10$M)	Aerospace Estimate (FY10$M)	Difference
Tier 2			
HySPIRI-like	$ 433	$ 451	4.2%
ASCENDS-like	$ 455	$ 510	12.1%
SWOT-like	$ 652	$ 808	24.0%
GEO-CAPE-like	$ 1,238	$ 677	-45.3%
ACE-like	$ 1,632	$ 1,285	-21.2%
Tier 2 Total	*$ 4,409*	*$ 3,731*	*-15.4%*
Tier 3			
LIST-like	$ 523	$ 683	30.7%
PATH-like	$ 459	$ 387	-15.7%
GRACE-II-like	$ 454	$ 280	-38.3%
SCLP-like	$ 449	$ 552	22.9%
GACM-like	$ 988	$ 830	-16.0%
3D-Winds-like	$ 760	$ 856	12.6%
Tier 3 Total	*$ 3,632*	*$ 3,587*	*-1.2%*
Total	**$ 8,042**	**$ 7,319**	**-9.0%**

Costs do not include Launch Vehicle and Public Costs come from NASA Earth Science Decadal Survey Implementation inflated to FY10$M

Historical development times for instruments analogous to those for each of the specific Tier 2 or Tier 3 missions investigated were gathered and used in the simulation to provide the basis for the instrument development durations. These historical instrument development durations should therefore be representative of the challenges facing these types of instrument developments. The cost of the baseline mission, with and without instrument difficulties, was compared to similar conditions for missions developed with an IFSS offset to determine if savings could be realized.

Figure 12 shows the results of the simulation for a HyspIRI-like mission using the historical development times. Case 1A shows the baseline cost distribution assuming that no instrument developmental difficulties arise (i.e., that the instruments are delivered on schedule). Case 1B shows the same case when historical instrument developmental difficulties are introduced using the instrument development duration distribution based on historical analogous instruments. The cost difference between Case 1A and Case 1B indicates a potential $115M cost growth could occur if the mission was planned such that the spacecraft and instrument developments were started at the same time. Applying an IFSS offset of 18 months in Case 2B results in a potential cost growth of only $6M or a savings of $109M over Case 1B. This same methodology and approach was used for all eleven Tier 2 and Tier 3 missions to identify the total cost growth savings that could be achieved for a portfolio of missions. Based on the simulation

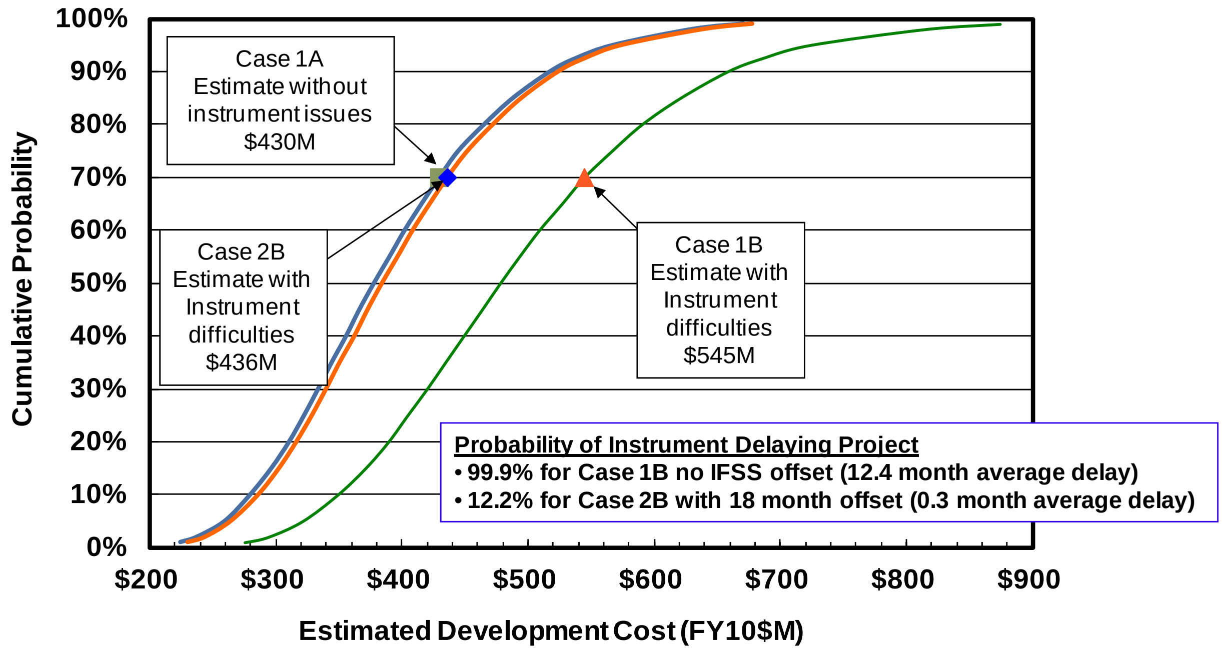

Figure 12. **HyspIRI-like Development Cost Risk Analysis Results**

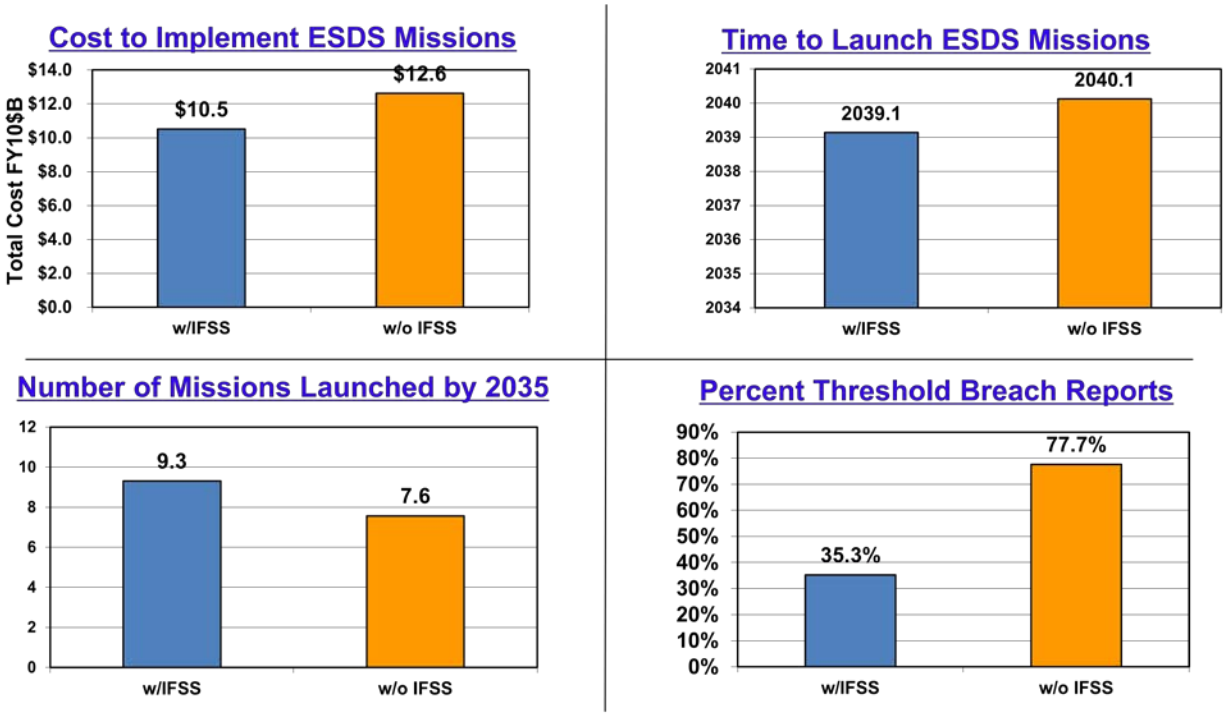

Figure 13. **Comparison of Sand Chart Tool Portfolio Analysis with and without IFSS**

results over all Tier 2 & 3 missions, the IFSS approach saves on the order of 35% compared to the typical development approach.

Additionally, the potential cost savings for the portfolio of Tier 2 and Tier 3 missions that use an IFSS approach was assessed. This assessment used The Aerospace Corporation Sand Chart Tool (SCT) which simulates the effect of cost and schedule growth of missions on subsequent missions in a mission portfolio.[7] SCT is a dynamic simulation that uses heuristic algorithms to fit projects into an annual budget profile by delaying projects that have been planned and haven't started yet or projects that have started but are currently in the preliminary design phase

(Phase B). This simulation emulates historical cases like the effect of cost and schedule growth of missions such as CloudSat and CALIPSO causing the cascading cost growth and initial schedule delay of the Aquarius and Orbiting Carbon Observatory (OCO) missions. SCT was used for the two cases of development with and without IFSS. Four measures of effectiveness were developed to compare the SCT results: 1) Cost to implement ESDS missions, 2) Time to launch ESDS missions, 3) Number of missions launched by 2035, and 4) the percent of time that missions exceed their baseline cost by 15% resulting in a threshold breach report. The results for each measure are shown in Fig. 13 and indicate that, for all four measures, IFSS provides better results.

The results of the SCT portfolio simulation show the effect of the traditional approach of developing the instrument and spacecraft concurrently in a compressed time and the inefficient cascading effect this approach has on future missions. The IFSS approach allows for late instrument delivery thereby realizing less "marching army" cost growth within a mission and subsequently less impact on future missions. The implications of the analysis are significant in that the results show that the Tier 2 and Tier 3 ESDS missions could be implemented at less cost, allowing more missions to be executed earlier while maintaining the projects within their agreed upon development funding. Although the analysis only considered the Tier 2 and Tier 3 missions, the ability to fund the missions at a $2B savings allows for future missions to be funded at an accelerated pace which will increase future science return.

Taking these results into account, a comparison of the current, traditional development process can be made relative to the IFSS approach. The pros and cons of these approaches are shown in Table 2.

Table 2. Comparison of the Traditional and IFSS Development Approaches

Approach	Pros	Cons
Traditional	-Typical project development that is the current paradigm -Complete project staff available to work any issues/questions in early development	-Potential for standing army costs waiting for instruments to be delivered to Integration and Test (I&T)
IFSS	-Focus early resources on development of instruments to mitigate delays in I&T -Various approaches exist that can be tailored to mission and instrument development requirements	-Change from known and understood development environment -Reduced personnel for interaction with instrument developers to trade spacecraft design choices in early development

IV. Implementation Approaches

Although the benefits of an IFSS approach appear clear, there is a question on how this approach may be implemented relative to NASA's current development approach. To answer this question, NASA policy was investigated to determine if current NASA policies would have to be modified or separate guidance provided. In addition, implementation recommendations such as schedule guidance are provided. Finally, different organizational constructs are assessed to determine the potential pros and cons of each approach to identify if a single best implementation approach exists.

A. NPR 7120.5 Compatibility

One possible issue with implementing an IFSS approach is the compatibility with NASA policy. If NASA policy precludes instrument development prior to full mission development, then this would present a severe obstacle to the implementation of an IFSS approach relative to NASA missions. The primary policy that governs requirements for mission development is NASA Procedural Requirement 7120.5E (NPR7120.5E) entitled "NASA Space Flight Program and Project Management Requirements".[8] NPR7120.5E identifies the requirements for NASA science missions at specific points in a project's development. Reviewing this document shows that the policy does no forbid early instrument development leading to a mission implementation. Further, although baseline project-level and system-level requirements are required at the Systems Requirements Review (SRR) in Phase A,[8] preliminary subsystem requirements are not required until the start of Phase B. In addition, although the baseline mission and spacecraft. architecture is required at SRR,[8] the full architecture including payload and ground system are not required until the start of Phase B. The spacecraft acquisition approach for the ICESat-2 mission recently demonstrated that a spacecraft design/developer does not have to be chosen by the start of Phase B, i.e., Key Decision Point-B (KDP-B), as the ICESat-2 spacecraft bus competition was still on-going at the time of its KDP-B decision.

It is clear from the documents, however, that the spacecraft design and/or procurement approach must be fully in place by the mission Preliminary Design Review (PDR) leading to the KDP-C, mission confirmation milestone decision. This requirement doesn't preclude an IFSS approach as the instrument(s) could still be developed to a heightened level of maturity prior to KDP-C allowing individual projects to make a decision to use an IFSS approach prior to mission confirmation.

Modification to 7120.5E would not be necessary although it may be beneficial to separately identify "IFSS Acquisition Approach" guidance in the form of a handbook or other document. In addition, it may be worthwhile to institute requirements for "demonstrated instrument maturity" and more clearly define guidelines for maturity demonstration such as developing an engineering model demonstrated in a relevant environment. As part of this guidance, the approach to identifying the proper lead time to start instrument development should be outlined to ensure that the IFSS approach is robust.

B. Schedule Guidance

To implement an IFSS approach, the timing for instrument development start relative to mission development should be optimized. The development schedule for a mission using an IFSS approach can be based on the duration and variance of historical instrument developments to stagger instrument procurement and spacecraft procurement/mission development. Using historical data, the mean and variance of instrument development durations can be identified by instrument type and destination. Unique characteristics/challenges of instrument development can also be identified to lay out specific instrument development plans that can then be compared with spacecraft development durations.

Based on the historical instrument delivery and delay data and the analysis results, the typical "IFSS Offset" for instrument development is on the order of two years. This provides instruments with a two year head start prior to a three to four year mission development phase. For most instrument development efforts, this is after the instrument Critical Design Review (iCDR) but prior to instrument integration and test. At this point, the instrument should be fairly mature and most instrument problems should be identified but, even if not, ample time remains to recover prior to delivery to the spacecraft for system environmental test. Instrument CDR should occur prior to the mission KDP-B decision so as to ensure that the mission starts with a fairly mature instrument that can categorize its known risks.

There are obviously several considerations when determining when to apply an IFSS development approach, one of which is how isolated the instrument requirements are from spacecraft requirements. It is recognized that an IFSS approach may not be suitable for all mission types as it may not apply to instruments that are fully integral to a spacecraft or otherwise impose significant design restrictions on the spacecraft. For those instruments that are compatible, the availability of standard spacecraft busses from the Rapid Spacecraft Development Office (RSDO) facilitates the IFSS approach by providing a spacecraft bus of known capability in an acquisition time on the order of 20 to 36 months.[9] This approach could apply to both missions directed by NASA Headquarters as well as those missions that are competitively procured as both could benefit from the potential reduction in cost risk that could be realized by an IFSS approach.

C. Organizational Implementation Approaches

During the time of early instrument development, it is assumed that mission systems engineers and spacecraft contractors would be involved, at some level, to ensure future mission requirements and potential spacecraft accommodations are considered. Typically, multiple organizations covering multiple functions are needed to develop a mission. Different organizational structures can be set up to allow involvement by these organizations at various phases of development. To assess this involvement, three organizational implementation approach alternatives were investigated, as shown in Fig. 14, to take any science and instrument requirements from conception to launch using an IFSS approach. Alternative 1 represents a Mission Project Office where Directed missions are awarded to a NASA Center and the individual project determines if an IFSS acquisition approach would be best

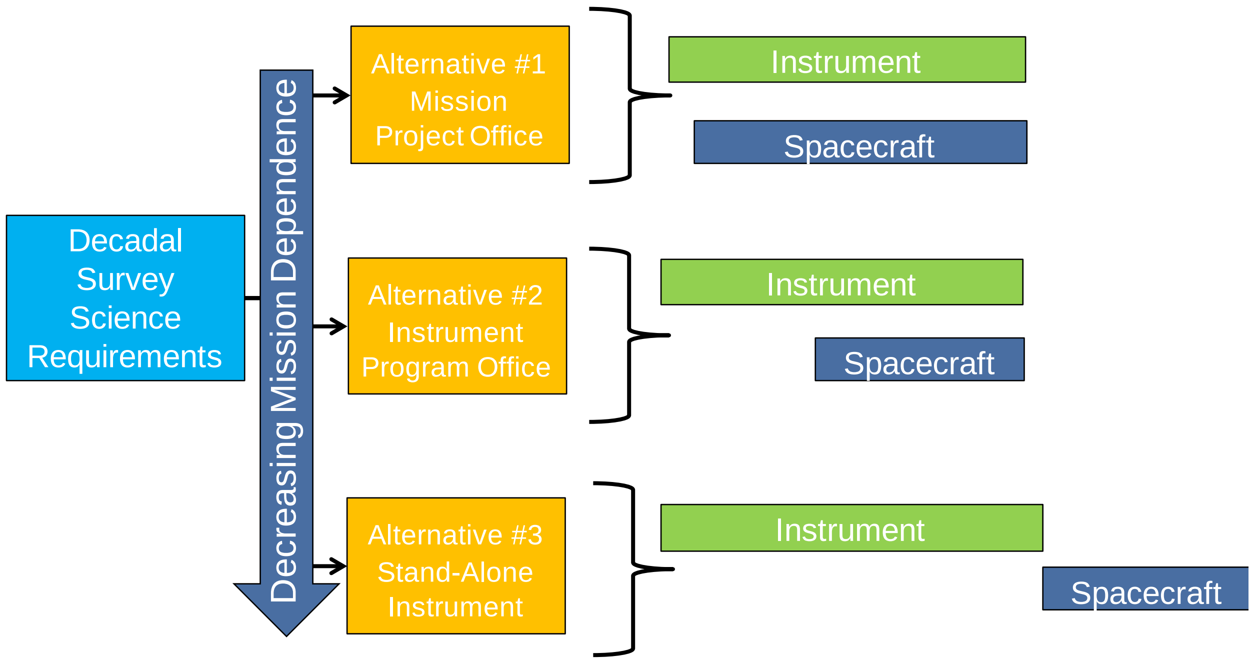

Figure 14. Comparison of Different Organizational Approaches Implementing IFSS

suited for development. Alternative 2 consists of a dedicated Instrument Program Office where instruments are started within an instrument office embedded in a flight projects division and handed off to a mission project office after instrument CDR. Alternative 3 represents a Stand-Alone Instrument project where a competed instrument is awarded to a supplier, reporting to a larger Program Office, where the spacecraft "ride" may or may not be determined at the time of award. Each of these alternatives represents a different level of involvement from a future mission with decreasing dependence as the alternatives progress from Alternative 1 to Alternative 3. A further description of each approach is included in the following sections while inherent strengths and weaknesses of each alternative are discussed.

1. Alternative 1: Mission Project Office

Implementing the IFSS approach within the construct of a typical mission would not be a fundamental change from how missions are managed currently. The concept would keep the look and feel of a typical project development while allowing for the early development of the instruments. All the typical functions of a project (Project Management, Systems Engineering, Spacecraft, Instruments, etc.) would be staffed from initiation, but most would be staffed at a minimal level until the instruments reached maturity. Early resources would be used primarily for the development of the instruments. The other functions would be used as needed to conduct trade studies/sensitivity analyses to understand the impact of instrument design choices on the mission architecture (e.g., operations complexity, spacecraft mass, spacecraft pointing requirements). This staffing could either work out of the traditional offices or be part of the systems engineering group. The organizational construct for this type of organization is shown in Fig. 15 and follows a traditional project organizational chart.

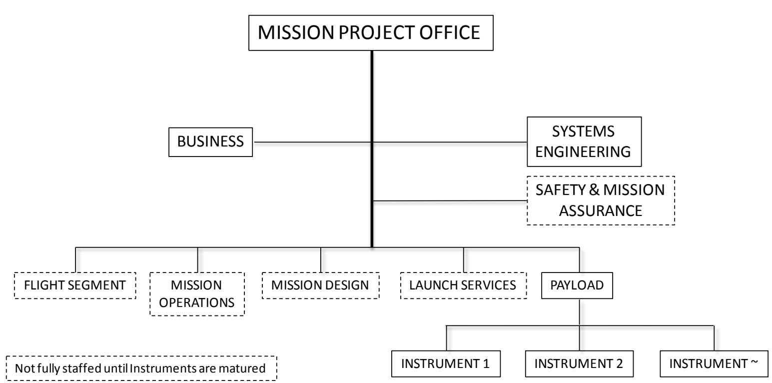

Figure 15. Mission Project Office Organization

A recent example of a mission that attempted this type of implementation was ICESat-2 (an Earth Science Decadal Survey Tier 1 mission). The instrument development started early and a spacecraft vendor was not selected until the time of Confirmation. The resource allocation for ICESat-2, however, was as normally would occur with time and money spent on all other mission functions as opposed to strictly focusing on the instrument development.

This is one potential drawback of the mission project office approach as the mission development approach may revert to the traditional approach.

2. Alternative 2: Instrument Program Office

A dedicated instrument program office would be another way to implement the IFSS approach from an institutional perspective. The concept of an Instrument Program Office (IPO) is to allow the development of science instruments outside of a classical flight project environment. It would provide some of the functions of a typical flight project but without the encumbrances and size of a normal flight project. The IPO could be part of the flight projects division of an institution and would consist of a dedicated program office staffed by instrument managers experienced in instrument development as well as systems engineers that would provide mission experience with spacecraft, launch vehicles and mission operations. It is assumed that personnel from the IPO would rotate to the missions as each instrument transitioned to a dedicated mission while others from missions recently launched would transition into the IPO to ensure the proper experience base in each organization. Figure 16 displays a proposed Instrument Project Office organizational chart and shows a much leaner organization as opposed to Alternative 1.

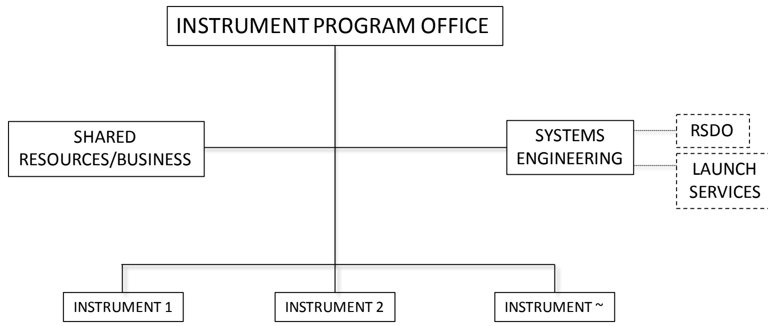

Figure 16. Instrument Program Office Organization

3. Alternative 3: Stand-Alone Instrument

A third approach for implementing IFSS would be the Stand-Alone Instrument approach. In this case, the instrument development would be led by a Principal Investigator (PI) who would report to a Program Office (PO). The PO would provide business office, safety & mission assurance and systems engineering support. It is assumed that flight selection could be one of multiple opportunities: hosted payload, free-flyer (domestic or international), or a combination of complimentary instruments to comprise a full mission. This approach is typically used for smaller, more resource constrained instruments, but could be used to compete Decadal Survey instruments as well. The primary drawback of such an approach is the possible detachment of the instrument development from future mission and spacecraft requirements that could potentially result in "hanger queen" instruments that cannot find an appropriate mission/spacecraft/launch vehicle on which to fly. Figure 17 displays the reporting of a stand-alone instrument PI reporting to a PO. Depending on the construct, the PI may be reporting into a PO which has both developmental and operational full missions, requiring a sharing of resources between these potentially higher priority missions and the stand-alone instrument development.

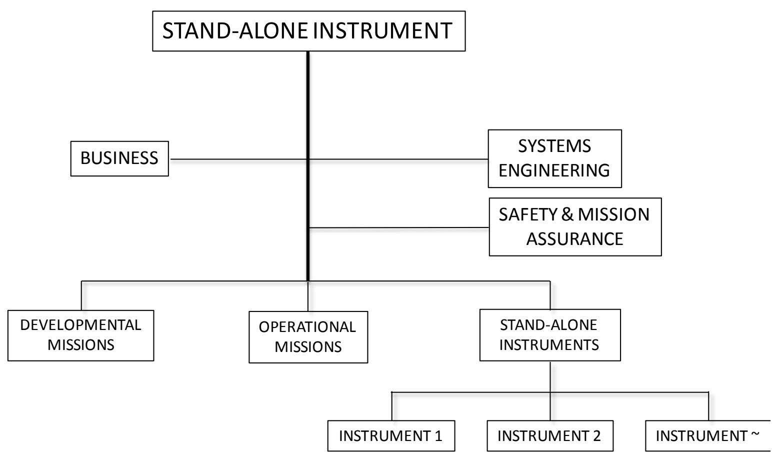

Figure 17. Stand-Alone Instrument Organization

4. Comparison of Different Approaches

Each of the proposed alternatives has its strengths and weaknesses relative to meeting an IFSS approach while still providing a robust development plan. Alternative 1 has the benefit of having the familiarity of the current mission project office construct but may make it difficult to break the current paradigm of staffing all mission

Table 3. **Comparison of the Pros and Cons of IFSS Implementation Approaches**

Approach	Pros	Cons
#1: Mission Project Office	-Looks and feels like typical project -Staff available from all subject matter areas to support work on development issues -Reduced initial staffing relative to traditional mission approach	-Inability to develop integrated mission baseline (cost, schedule, etc.) early on -Standing army for other project elements that aren't necessary to directly support instrument development
#2: Instrument Program Office	-Avoids large staffing associated with a flight project when only instrument development is going on -Provides a core group with instrument-specific expertise and focus -Provides efficiency as some functions such as CM and scheduling may be used regularly whereas some functions such as the RSDO interface may be very infrequently used	-Being removed from a flight project could provide the chance for unanticipated problems later -Would need to guard against instrument "overdevelopment" to ensure that mission requirements are met without building "gold-plated" instrument
#3: Stand-Alone Instrument	-Competitive process allows "best" science to be selected within program constraints -Common instrument interface ensures that all instruments are uniformly compatible -Allows multiple possible launch opportunities	-May result in instruments without a launch opportunity - i.e. "hanger queens" -Can increase risk as is decoupled from institutional instrument expertise and mission & spacecraft requirements

elements from the outset. Alternative 2 provides the benefit of a separate instrument program office, possibly reporting to a flight projects division, staffed with instrument development expertise as well as spacecraft and launch vehicle shared support which would mature the instrument before handing off for full mission development. Although this organization fully supports an IFSS development approach, it could result in an instrument that may be "gold-plated" and over developed for its mission need if not closely monitored. Alternative 3 would provide the least interface with a future mission and could potentially lead to instruments that are developed that cannot find the appropriate spacecraft or launch opportunity. Table 3 summarizes the pros and cons for each approach to allow the reader to assess which is the best approach for a given application.

One additional consideration for each alternative is the funding profile that could result. Figure 18 shows a comparison of postulated funding profiles for each of the alternatives considered. For Alternative 1, it is assumed that the mission development would start earlier than Alternative 2, and therefore require more funding in the initial years. Alternative 2 also decreases the overall peak funding requirement of the mission, as shown in Figure 18, such that it is easier to more evenly load a portfolio of missions within a fixed annual budget scenario. This is important given the Earth Science requirement to implement multiple Decadal Survey missions simultaneously. Alternative 3 would provide a much more

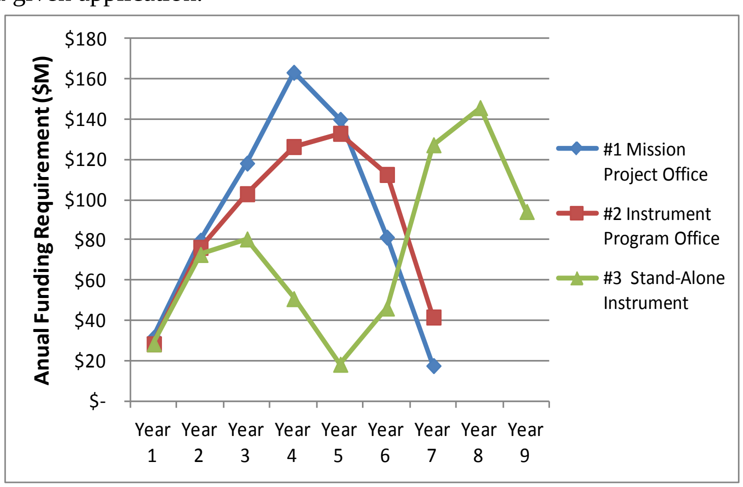

Figure 18. Funding Profile Considerations

back-loaded funding profile assuming that a dedicated spacecraft and launch vehicle would be required to eventually implement the mission. Based on the funding profiles identified, Alternative 2 would provide the best balance which would reduce the early year and peak funding requirement to provide a more stable funding posture that typically would fit more easily into a portfolio of missions. Overall, Alternative 3 would be the most costly because of the length of time needed to implement and the instrument support required throughout.

Additionally, Alternative 2 also has the lowest overall cost, as shown in Figure 19. Because of the small program office represented by the shared resources within the Instrument Program Office, the project management, systems engineering and mission assurance costs for Alternative 2 are less that that of the traditional Mission Project Office in Alternative 1. Additionally, because of the introduction of the instrument at iCDR to the mission development team, there should be limited change to the instrument as would likely happen in Alternative 3 where a completed instrument is developed without/with limited knowledge of the host spacecraft bus. Overall Alternative 2 provides the least overall cost and peak funding requirement while providing the best balance of the three alternatives emphasizing the instrument development while including spacecraft and launch vehicle considerations.

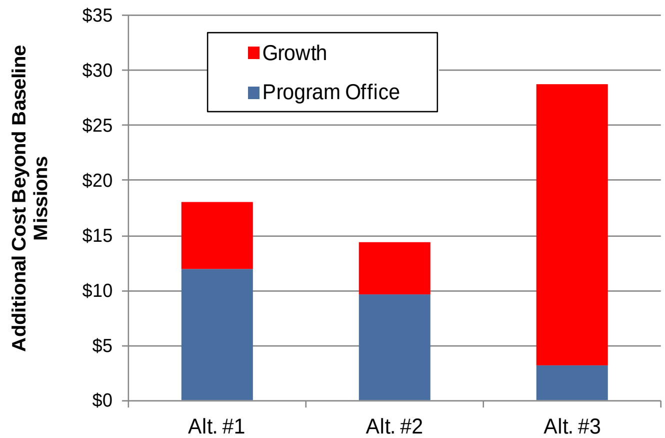

Figure 19. Comparison of Cost of Different Alternatives

V. Conclusion

The need for an instrument first, spacecraft second (IFSS) mission development approach was addressed. Based on historical data, over two-thirds of NASA missions experience significant difficulty in developing science instruments. These instrument development difficulties are due in part to the immaturity of the instruments at the start of Phase B as can be seen in historical missions where the mass and cost growth of instrument developments is twice the growth experienced by the spacecraft. The corresponding instrument delivery delays result in mission cost growth at a ratio on the order of two to one due to the “marching army” cost experienced by the other mission elements awaiting instrument delivery. By adopting an IFSS development approach, the marching army cost penalty can be addressed by allowing more time for the instrument to develop prior to initiating full mission development which can provide the potential for decreasing total mission cost growth.

To look at the viability of the IFSS development approach, a methodology was developed to assess the potential cost savings in implementing the new paradigm. Representative designs and project cost for the eleven Earth Science Decadal Survey Tier 2 and Tier 3 representative missions were assessed to determine if cost savings could be achieved. In addition, the savings for the total portfolio of Tier 2 and 3 missions was assessed. The results of the study show, using historical spacecraft and instrument development durations, that savings on the order of $2.0B can be achieved by implementing an IFSS approach. In addition, these missions can be launched a year earlier while decreasing the instances of threshold breaches from 7-in-9 to 1-in-3. Based on the results of the analysis, serious consideration should be given to developing missions using an IFSS approach.

Additionally, an IFSS approach is not precluded by current NASA policy although it would be prudent to develop an “IFSS Approach” handbook to provide guidance in developing a schedule consistent with a robust IFSS development. Multiple organizations could implement an IFSS approach, all with different strengths and weaknesses, although a dedicated instrument program office would provide the most focus for an IFSS approach and would result in the most balanced funding profile of the alternatives considered.

The potential for savings warrants a pilot project implementation of an IFSS pathfinder mission to assess if the hypothesized savings and reduction in schedule growth can be realized and if the organizational constructs outlined would provide a robust home for future instrument development.

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