INSTRUMENT SCHEDULE DELAYS: POTENTIAL IMPACT ON MISSION DEVELOPMENT COST FOR RECENT NASA PROJECTS

Robert E. Bitten, Eric M. Mahr

The Aerospace Corporation, El Segundo, CA

ABSTRACT

NASA space-borne instruments, while trying to pursue world class science, 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 $2.5B, making more funding available for future missions, while providing a less volatile and more manageable mission portfolio.

Index Terms— Cost, Schedule, Instrument development

1. INTRODUCTION

NASA continually improves its ability to deliver world class science by constantly pushing the state of the art in developing technologically challenging instruments. The inherent difficulty of developing these instruments, however, can lead to development difficulties. A number of recent studies have shown that these instrument development difficulties can have a significant impact on the overall mission cost. Instrument delivery delay can lead to mission cost growth through “marching army” costs as personnel await instrument delivery to complete the integration and test phase of the mission development. Missions that have mature or existing instruments, however, have substantially loss cost and schedule growth due to less uncertainty about the instrument development. For this reason, a new development paradigm, called instrument first, spacecraft second (IFSS) was proposed that would plan for maturing the instrument ahead of the rest of the hardware in order to experience minimal cost and schedule growth. For this study, the ability of the concept to reduce cost growth and schedule delays and provide a less volatile and more manageable mission portfolio is quantified using the Tier 2 and Tier 3 missions from the most recent Earth Science Decadal Survey.

2. HISTORICAL INSTRUMENT DELAY IMPACTS

Historically, most NASA missions have had instrument development issues [1]. 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. For each of these missions, instrument development difficulties led to delays in instrument delivery which resulted in significant cost growth in the instrument and the subsequent total mission cost due to the marching army cost. For the examples stated, 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.

To understand the impact of instrument difficulties and their contribution to cost and schedule growth relative to a larger data set, an 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 [1]. Figure 1 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 2 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 most NASA science missions while spacecraft typically have less developmental issues.

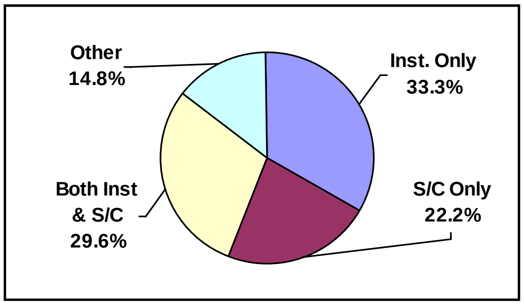

Figure 1: Distribution of Problems Identified for a Forty NASA Mission Set Studied

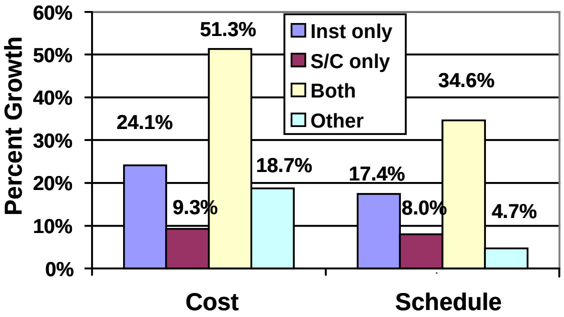

Figure 2: Associated Cost and Schedule Growth as a Function of the Problems Encountered

Another recent study looked at the phases where instrument schedule growth occurred [2]. Figure 3 shows a comparison of planned versus actual instrument development 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 typically 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.

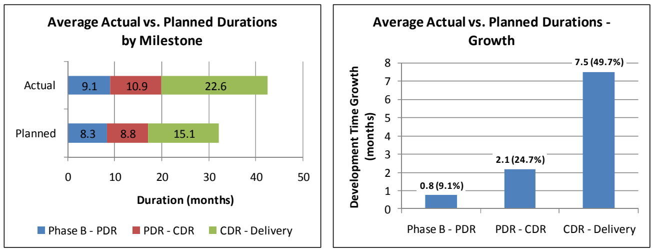

Figure 3: Instrument Schedule Growth by Milestone

The difficulty of instrument developments versus spacecraft developments can also be seen when investigating resource growth for historical NASA missions. Another study reviewing twenty NASA missions in greater detail shows that instrument resources, such as mass and cost, grow at a significantly greater rate than spacecraft resources [3]. Figure 4 shows the average percentage mass and cost growth of the instruments and spacecraft from the start of Phase B. As can be seen, 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 and supports the idea of developing instruments first to reduce uncertainty.

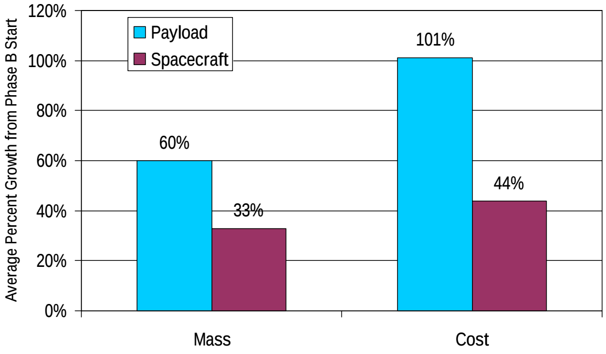

Figure 4: Instrument/Spacecraft Mass & Cost Growth

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 QuickTOMS, 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 Figure 5 where the start of spacecraft development is delayed to more favorably match the historical instrument development delays.

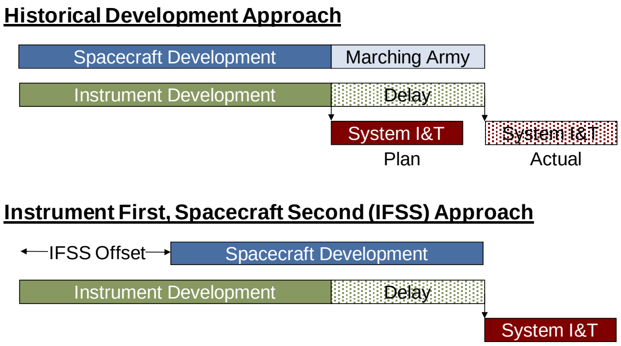

Figure 5: Notional Comparison of Traditional Development with Delays versus a Possible IFSS Approach

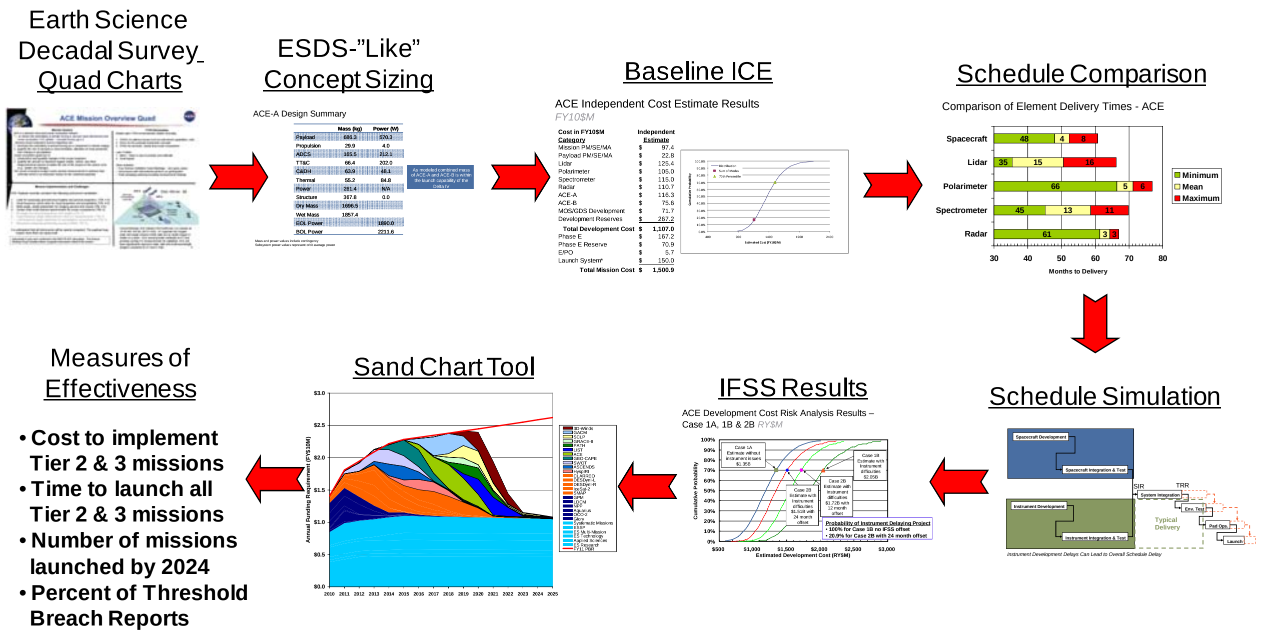

Figure 6: IFSS Assessment Process Overview

3. IFSS ASSESSMENT APPROACH AND RESULTS

To test the hypothesis that IFSS could lead to a decrease in cost and schedule overruns, a quantitative process was developed. Figure 6 shows an overview of the assessment process used for the analysis that assesses the cost risk for each individual mission with and without and IFSS approach and then rolls these results into an overall mission portfolio assessment. To increase realism, the process 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. For each of the Tier 2 and 3 missions, the available technical data was used to develop "-like" missions since complete technical data was not available. These missions are not the exact current concepts, but are representative of what would be flown. Cost estimates for each "-like" mission were developed and then spread 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 development durations was 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. 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. Figures 7 and 8 show the basic tests that drive the simulation. Figure 7 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 8 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.

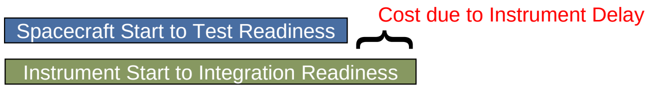

Figure 7: "Marching Army" Cost Due to Delay

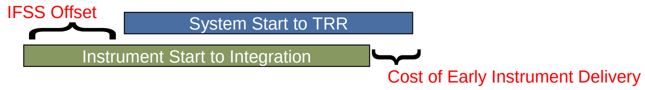

Figure 8: IFSS Offset to Reduce the Cost Due to Delay

Figure 9 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. Table 1 shows the simulation results for each "-like" mission. Based on the simulation results over all Tier 2 & 3 missions, the IFSS approach saves on the order of 30% compared to the typical, traditional development approach.

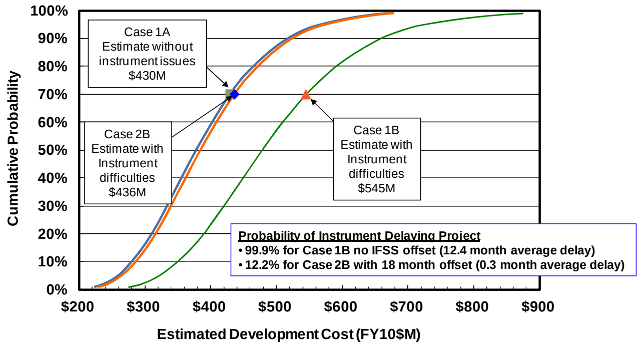

Figure 9: HyspIRI-like Development Cost Risk Analysis

Table 1: Summary of Simulation Results (FY10$M)

Mission	Planned Case 1A	"Actual" w/o IFSS Case 1B	"Actual" with IFSS Case 2B	Percent Increase	
				w/o IFSS	w/IFSS
HySPIRI-like	$ 541	$ 653	$ 556	20.7%	2.8%
ASCENDS-like	$ 599	$ 882	$ 636	47.2%	6.2%
SWOT-like	$ 866	$ 1,038	$ 880	19.9%	1.6%
GEO-CAPE-like	$ 759	$ 1,129	$ 816	48.7%	7.5%
ACE-like	$ 1,318	$ 1,663	$ 1,360	26.2%	3.2%
LIST-like	$ 759	$ 1,093	$ 800	44.0%	5.4%
PATH-like	$ 480	$ 628	$ 505	30.8%	5.2%
GRACE-II-like	$ 313	$ 374	$ 325	19.5%	3.8%
SCLP-like	$ 635	$ 900	$ 681	41.7%	7.2%
GACM-like	$ 886	$ 1,333	$ 959	50.5%	8.2%
3D-Winds-like	$ 900	$ 1,320	$ 952	46.7%	5.8%
Total	**$ 8,056**	**$ 11,013**	**$ 8,470**	**36.0%**	**5.2%**

Additionally, the potential cost savings and other benefits of an IFSS approach was assessed for the portfolio of Tier 2 and Tier 3 missions. This assessment used The Aerospace Corporation's Sand Chart Tool (SCT) which simulates the effect of cost and schedule growth of missions on subsequent missions in a portfolio of missions. SCT was used for the two cases of development with and without IFSS. Four measures of effectiveness, as shown in Figure 10, 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 2024, and 4) the percent of time that missions exceed their baseline cost by 15% resulting in a threshold breach report. The results indicate that, for all four measures, IFSS provides better results.

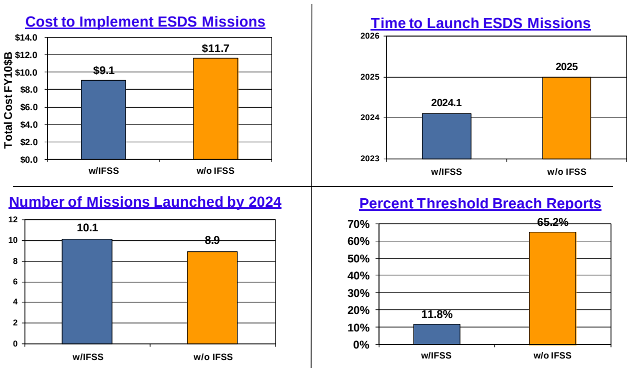

Figure 10: Summary of Portfolio Benefits of IFSS

4. 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. Given this data, a methodology was developed to assess the potential cost savings for implementing an IFSS mission development paradigm. Representative designs and project cost for the eleven Tier 2 and Tier 3 missions were assessed to determine if cost savings could be achieved. The results of the study show that savings on the order of $2.5B can be achieved by implementing an IFSS approach. In addition, implementing an IFSS approach for these missions would allow the missions to be launched a year earlier while decreasing the instances of threshold breaches from 2-in-3 to 1-in-8.

5. REFERENCES

[1] Bitten R., Emmons D., Freaner C., "Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines", IEEE Aerospace Conference, Big Sky, Montana, 3-10 March 2007

[2] Kipp K., Ringler S., Chapman E., Rinard L., Freaner C., "Instrument Schedule Delays Potential Impact on Mission Development Cost for Recent NASA Projects (Follow-on Study)", 2011 ISPA/SCEA Joint Annual Conference & Training Workshop, Albuquerque, New Mexico, 7-10 June 8, 2011

[3] Bitten R., Freaner C., Emmons D., "Optimism in Early Conceptual Designs and Its Effect on Cost and Schedule Growth: An Update", 2010 IEEE Aerospace Conference, Big Sky, Montana, 7-12 March 2010