INSTRUMENT FIRST, SPACECRAFT SECOND: A NEW PARADIGM IN SPACE MISSION DEVELOPMENT

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1. 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 which, 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 [2]. This paper addresses this issue 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 [3] were analyzed to determine if potential cost and schedule growth could be minimized by developing the instrument(s) prior to starting full mission development. The results of the study show that significant cost savings could potentially be achieved by applying the instrument first, spacecraft second (IFSS) mission development paradigm.

2. METHODOLOGY

A recent NASA cost and schedule growth study indicates that over two-thirds of NASA missions have experienced instrument development difficulties leading to cost growth [4]. Reviewing these missions in more detail demonstrate that instrument resources such as mass, power and cost, grow at a significantly greater rate than spacecraft resources implying that instruments typically are less mature than spacecraft at the initiation of a project [5]. 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 1 and 2 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 1 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 2 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.

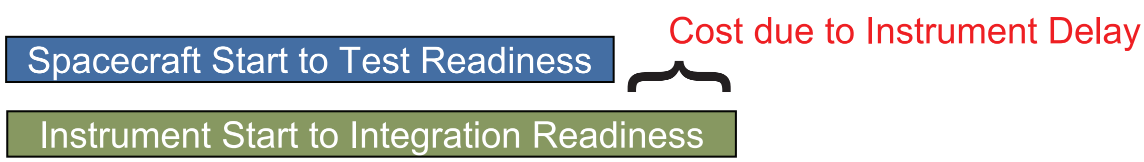

Figure 1: Typical Development Leading to "Marching Army" Cost Due to Instrument Delays

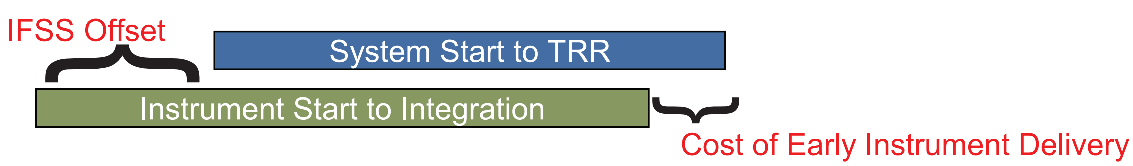

Figure 2: Applying the IFSS Offset to Reduce the Potential Cost Due to Instrument Delays

3. RESULTS

This 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. An independent cost estimate was then developed to assess the baseline cost of the mission assuming that the instruments could be delivered on time with no developmental difficulties. Historical development times for instruments analogous to those for each of the specific Tier 2 or Tier 3 mission 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 3 shows an example of the results of the simulation. 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 indicate a potential $700M 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 in Case 2B in Figure 3, as shown in two instances of a 12 month and 24 month offset, results in a potential cost growth of $370M and $160M, respectively, which results in a potential savings over Case 1B of over $500M. For the development of this example mission, which is representative of the two spacecraft, Aerosols/Cloud/Ecosystems (ACE) Tier 2 mission, a significant savings could be achieved by implementing an IFSS approach. This same methodology and approach is 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.

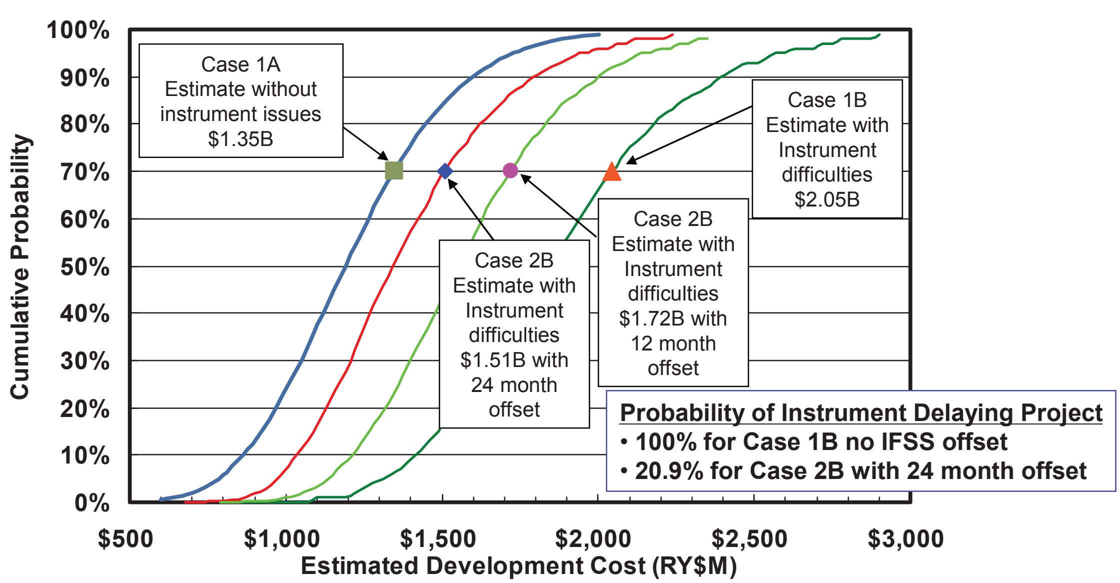

Figure 3: The Potential Savings for a Representative Earth Science Decadal Tier 2 Mission

Additionally, the potential cost savings for the portfolio of Tier 2 and Tier 3 missions that use an IFSS approach will also be assessed. This assessment will use 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. SCT is a dynamic simulation that uses heuristic algorithms to fit project 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 Calipso and

Cloudsat cost and schedule growth caused the "waterfall" cost growth and schedule delay of the Aquarius and Orbiting Carbon Observatory missions. SCT will be used to assess this effect to identify the additional savings for executing missions using an IFSS approach that experience less cost growth than those that don't.

4. CONCLUSION

A methodology was developed to assess the potential cost savings for implementing a new instrument first, spacecraft second (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. In addition, the savings for the total portfolio of Tier 2 and 3 missions will also be assessed. The results of the study show, using historical spacecraft and instrument development durations, that significant savings can be achieved by implementing an IFSS approach.

5. REFERENCES

[1] NASA Office of the Chief Engineer, NASA Instrument Capability Study (NICS) Final Report, December 2009

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[3] National Research Council Committee on Earth Science and Applications from Space, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", National Academies Press, 2007

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[5] Freaner C., Bitten R., Bearden D., and Emmons D., "An Assessment of the Inherent Optimism in Early Conceptual Designs and its Effect on Cost and Schedule Growth", 2008 SSCAG/SCAF/EACE Joint International Conference, Noordwijk, The Netherlands, 15-16 May 2008.