Results from the NASA Instrument Capability Study

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Abstract - *Numerous National Aeronautics and Space Administration (NASA) projects have had difficulties in developing science instruments for application to their missions, affecting projects across the NASA mission directorates. NASA's Office of the Chief Engineer (OCE) chartered a comprehensive cross-cutting study to evaluate instrument development capability across the Agency. The National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DoD) also participated in this Study. This study, titled the NASA Instrument Capability Study (NICS), was chartered to determine if NASA instrument developments are facing challenges that impact the capability to design and build quality instruments, or if there are flaws in the acquisition strategy evidenced by schedule delays, cost overruns, and increased technical risk via design deficiencies. This paper provides an overview of the process used to collect and analyze the data as well as a summary of the findings and recommendations.*

Keywords: Instruments, instrument development, NASA, NOAA, DoD, payloads, science.

1 Introduction

In July 2007, NASA OCE chartered the NICS team to determine whether NASA instrument developers are facing challenges that impact the capability to design and build quality instruments or whether there are flaws in the acquisition strategy evidenced by schedule delays, cost overruns, and increased technical risk via design deficiencies. The Study team was also chartered to determine if occurrences seen recently are coincident but isolated cases, or if there were generic issues causing such degradation. If the issues were found to be generic, the team was to offer solutions to recover such capability.

The NICS Team, led by John Leon of the NASA Goddard Space Flight Center (GSFC), conducted a 14 month study to:

1. Obtain a macro-level understanding of problem areas within the instrument development processes (not root cause analysis);
2. Determine factors that impact primary success indicators (i.e., cost, schedule, and technical performance);
3. Determine factors that impact instrument development processes;
4. Identify potential issues for higher risk or more complex instrument developments;
5. Identify common, overarching themes spanning the instrument development processes; and
6. Recommend options for solutions that address Study themes.

The study results, which were documented in a final report, can be downloaded from the NASA Office of Chief Engineer public website [1].

2 Study Approach and Implementation

Figure 1 is a graphical representation of the study implementation. The approach involved four major steps: establishment of the team; development of the study tools; data collection, processing, and analysis; and, identification of options for solutions. These steps are discussed in detail in the following sections.

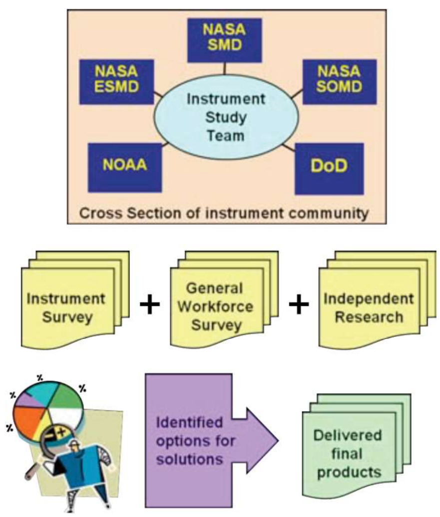

Figure 1. Study implementation.

2.1 Establishment of the Study Team

The NASA GSFC led the Study and a cross-agency team was formed to implement it. Three of the current four NASA Mission Directorates participated in the study: Exploration Systems (ESMD), Science (SMD), and Space Operations (SOMD). Since science instruments are also developed by NOAA and by DoD, the NASA OCE invited their participation in the Study to provide a broader perspective of instrument development. The team was made up entirely of civil servants and obtained support from NASA contractors in their areas of expertise. A Review Board was also formed to assist the team by providing the Board members' individual reactions, comments and suggestions to the team throughout the conduct of the Study.

2.2 Development of the Study Tools

The Study team implemented a comprehensive survey development process that resulted in two surveys: an Instrument Survey (IS) and a General Workforce Survey (GWS). The two surveys were designed to provide an assessment of instrument development challenges as they related to eight cross-cutting processes or areas: 1) Acquisition, 2) Complexity Factor, 3) Management Control, 4) Project Staffing, 5) Project Reviews, 6) Requirements and Design, 7) Verification and Validation, and 8) Safety and Mission Assurance Processes. Additionally, a wide-ranging Independent Research (IR) effort was established to cross-reference with survey results and to support formulation of recommendations.

The IS, which consisted of approximately 50 questions, was aimed at specific instruments identified by the OCE and core team. The survey was given to project managers and instrument managers (not floor-level personnel) in order to provide a "top-down" assessment of instrument development. The questions were often multi-part so they would yield the most information. The questions were also designed such that the respondent did not have to research the answer. The Instrument Survey could be completed in an hour.

Conversely, the GWS, which consisted of three broad questions, was aimed at the general instrument workforce personnel across NASA, NOAA, and DoD. This particular survey was not targeted to any specific instrument. The goal was to gain "floor" level insight into the perceptions regarding instrument development. Similar to the IS, the GWS targeted the same cross-cutting processes and included easy to answer questions (no research required). The GWS took about 20 minutes to complete.

The third study tool included data mining of IR conducted by other sources. The goal of the IR was to provide additional insight to the IS and GWS findings (data correlation). The team searched for similar studies that had been performed by NASA, NOAA, DoD, or industry to gain an understanding of past efforts relevant to NICS. Additionally, in an attempt to discover threads related to instrument development problems, the team performed a general review of instruments, not on the IS list, via existing databases (e.g., Aerospace CADres) and open source material. The team also researched public media, lessons learned, and mishap investigation data to gather information.

2.3 Data Collection, Processing, and Analysis

A layered approach was used in the collection, processing, and analysis of the data. As shown in Figure 2, this period, which spanned six months, was broken up into three phases: preliminary data analysis, intermediate data analysis, and final data analysis. The data analysis approach involved a myriad of data tables and plots. During the preliminary data analysis phase, the team examined over 1,000 plots/tables and developed 12 preliminary findings. These 12 findings were shared with the aerospace industry at a workshop held in June 2008.

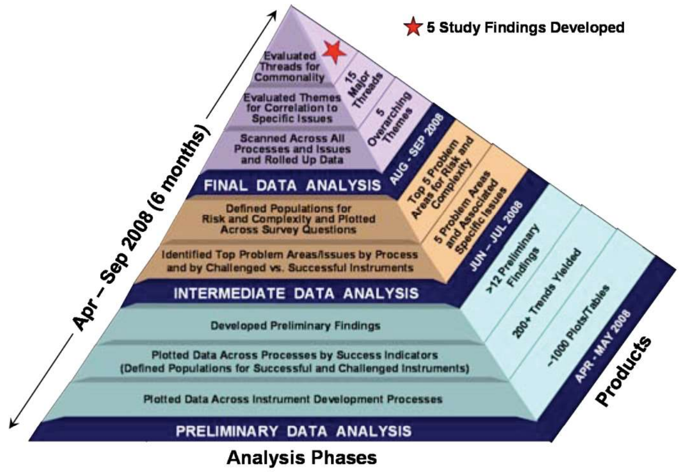

Figure 2. Data collection and processing.

During the intermediate phase, the team defined instruments that were deemed to be successful, challenged, higher/lower risk developments, and more/less complex developments. The team was then able to identify the top problem areas or issues found in each of the eight cross-cutting processes as well as for the various populations of instruments.

2.4 Identification of Options for Solutions

Once the team scanned across all of the rolled-up data, they found five overarching themes. Each of those themes was evaluated for correlation to specific issues. The outcome was the identification of 15 major threads. Next, the threads were evaluated for commonality. The result was five study findings. The team then worked to develop recommendations. These recommendations were formed by government individuals only. IR was also reviewed to provide corroborative support for the recommendations. This process was reviewed and approved by the Study team, the Review Board, the GSFC Office of Chief Counsel, and the NASA OCE.

3 Results

3.1 Bottom Line

The NICS team developed a Study approach that included a top-level assessment of instrument development processes and success indicators (cost, schedule, and technical performance). The data clearly showed that there are global challenges that impact the capability to design and build quality instruments. A significant percentage of instruments reported problems with cost, schedule, and technical performance:

1. ~70% of the instruments reported ≥25% cost overruns
2. ~60% of the instruments reported ≥5 months schedule delay
3. ~60% of the instruments reported design deficiencies that contributed to cost growth or schedule delays
4. ~80% of the instruments reported workmanship issues that contributed to cost growth or schedule delays.

3.2 Demographics

A total of 71 managers across 41 instruments completed the IS. The instrument participation by sponsoring organization was: NASA (68.3%), DoD (19.5%), and NOAA (12.2%). Although the majority of the instruments were sponsored by NASA, the instrument set included a diverse set of developers across Government, industry, and academia. The instruments spanned a broad budget, under $10 Million to over $100 Million, and schedule range, less than three years to over six years. The instruments were assessed at varying points of the development cycle, from Preliminary Design Review (PDR) through delivery. Most of the instruments were in Phase A (Concept and Technology Development) through Phase D (System Assembly, Integration & Test, or Delivery) at the time of the survey.

For the GWS, 164 survey responses were received. NASA requested only civil servants and contractors, in the performance of their official responsibilities, to complete the survey. NASA informed industry and academia of the conduct of the Study and there were individuals from industry and academia who, on their own initiative, completed the survey. The team, of course, included their responses. The respondents represented multiple organizations and a broad range of skill sets. Finally, the Independent Research consisted of over 200 studies/reports, "lessons-learned", mishap investigation reports, and media sources that resulted in approximately 1,000 entries relevant to the Study.

3.3 Top Cross-Cutting Problem Areas

Both the instruments and the general workforce identified problems within the cross-cutting processes. The top five problem areas most reported are shown in Tables 1 and 2, respectively.

Table 1. Top 5 Problem Areas Reported by Instruments.

Cross-Cutting Area	Percent
Test Failures	95
Staffing	93
SMA Functional Areas	90
Schedule Management	90
Organizational Interface	88

Table 2. Top 5 Problem Areas Reported by General Workforce.

Cross-Cutting Area	Percent
Acquisition	93
Staffing	92
Requirements Management	43
Schedule Management	42
Contract Management	36

Please note that Staffing and Schedule Management were common problems reported by both instruments and the general workforce.

3.4 More versus Less Complex Instrument Developments

Instrument developments are often found to be complex not only due to their cutting edge technology or difficult technical requirements, but also because of their risk posture and complex interfaces. Additionally, the lack of flight heritage can make instrument developments more challenging. Given these factors, the objective of this assessment was to determine whether complex instrument developments were more or less likely to have cost overruns, schedule delays, or technical problems.

The first step the Study team took was to consider what constituted a more complex instrument development. After much consideration and discussion, more complex instrument developments were defined as those that reported:

- Complex interfaces; or
- Requirements too complex; or
- Low Technology Readiness Level (TRL) or flight heritage and a large budget or schedule; or
- Low TRL or flight heritage and configuration management processes that required a higher level of support than anticipated or available; or
- High risk posture and a large budget or schedule; or
- More than four primary partners involved in the design and fabrication of the instrument.

Based on this definition, a total of 25 of the 41 instruments were determined to be more complex developments. Once the instruments were binned into the two groups, each group was assessed based on the problems they encountered as well as their cost, schedule, and technical performance.

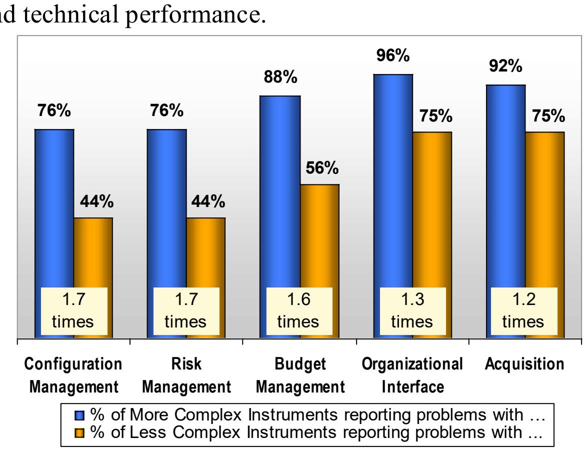

Figure 3. Problem areas with highest differentials between more and less complex instruments.

Figure 3 shows the percentage of more complex and less complex instrument developments that reported problems in the areas shown. It also shows the differential between the two groups. The problem area with the largest differential, or the one reported more often by complex instruments, was configuration management. More complex instruments were 1.7 times more likely to report problems in this area. One of the configuration management issues complex instruments reported more often was that multiple versions of documentation were being implemented at the same time.

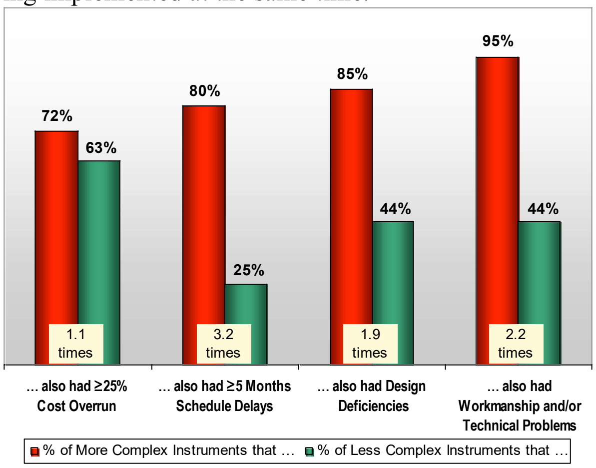

Figure 4. More and less complex instruments versus the primary success indicators.

Figure 4 shows the performance of the more and less complex instruments versus the primary success indicators. It is interesting to note that while there was only a minor correlation between complexity and cost overruns, there was a major correlation between complexity and schedule delays. More complex instrument developments were 3.2 times more likely to have schedule delays of 5 months or more. Technical performance is represented by those populations citing design deficiencies or workmanship/technical problems contributing to cost growth and/or schedule delays. Complex instruments were approximately twice as likely to experience problems in these areas as well.

The data showed correlations between the complexity of instrument development and an increased likelihood of encountering problems with configuration management, risk management, budget management, organizational interfaces, and acquisition. The data also showed that more complex instruments were more likely to have schedule delays of 5 months or more and experience design deficiencies or workmanship/technical problems. This information increases awareness of these types of issues for complex instruments and allows projects to outline potential mitigations in case the issues are realized.

3.5 Higher versus Lower Risk Instrument Developments

Instruments typically are viewed as higher risk mission elements compared to spacecraft, launch vehicles, or ground systems because many are unique, first time developments, and they often possess technologies with low TRLs. The Study team viewed instrument risk as an important characteristic and thus decided to define risk populations from the IS data to enable an understanding of the differences between higher and lower risk instrument developments. In addition, the Study team plotted the higher versus lower risk populations against the technical, cost, and schedule parameters to further evaluate these populations.

The Study team developed criteria for higher risk instruments based on thorough discussions of the Study surveys, and general knowledge of instrument development and risk. The criteria for higher risk instruments were defined as those that reported:

- Low TRL/flight heritage and cost/schedule "pressure" (aggressive or unrealistic), or
- Requirements too complex, or
- Medium risk posture and cost/schedule “pressure” (aggressive or unrealistic), or
- A "high" risk posture.

A total of 25 out of 41 instruments were defined as higher risk based on the criteria above. Once the instruments were split into higher risk and lower risk populations, each group was assessed based on the problems they encountered as well as their cost, schedule, and technical performance.

A comparison of the higher versus lower risk instruments was analyzed across the instrument development processes. The top five problem areas with the highest differentials between the higher and lower risk instruments are shown in Figure 5. The problem area with the highest differential was contract management. Higher risk instruments were 3.5 times more likely to report problems in contract management than lower risk instruments. Instrument survey respondents also reported issues with contract management.

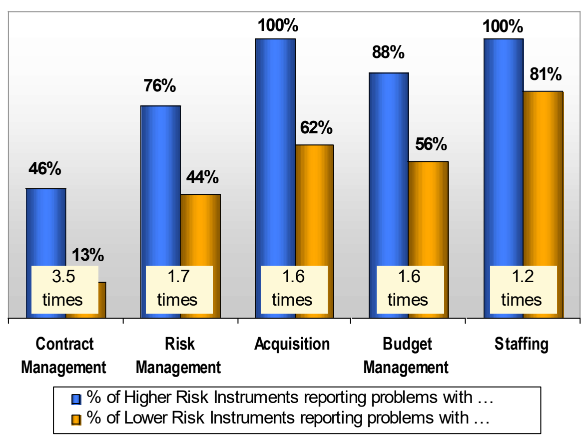

Figure 5. Problem areas with highest differentials between higher and lower risk instruments.

Figure 6 shows the performance of the higher and lower risk instruments versus the primary success indicators: cost, schedule, and technical performance. Higher risk instrument developments were more than twice as likely to experience cost overruns and more than 3 times as likely to experience schedule delays. In addition, higher risk instrument developments were more likely to experience design deficiencies and workmanship/technical problems contributing to cost growth/schedule delays compared to lower risk instruments.

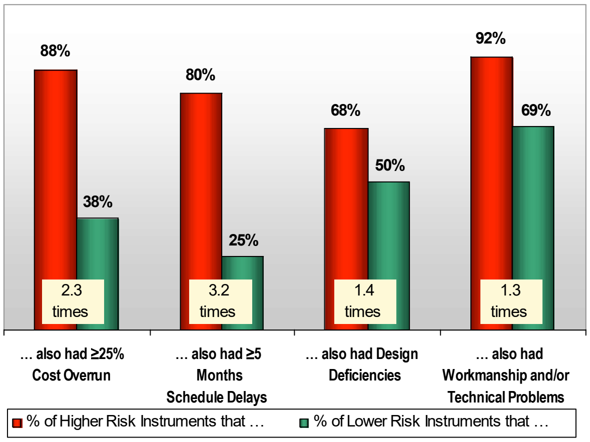

Figure 6. Higher and lower risk instruments versus the primary success indicators.

The data showed that higher risk instrument developments had an increased likelihood of encountering problems with contract management, risk management, acquisition, budget management, and staffing. The Study data also shows that higher risk instrument developments were 2 to 3 times more likely to have cost overruns and schedule delays compared to the lower risk instruments. In addition, higher risk instrument developments were more likely to experience design deficiencies and workmanship/technical problems. This data provides a snapshot of the types of problems that higher risk instrument developments encountered. Future instrument teams may decide to use this information as part of a risk mitigation strategy.

3.6 Challenged versus Successful Instrument Developments

This section shows the top five cross-cutting problem areas by correlation with cost and schedule as reported by the instruments. This is followed by the top specific issues within these problem areas. These relationships were identified by using two instrument populations, challenged and successful, as defined below:

- Challenged instruments: ≥25% cost overrun and ≥5 months schedule delays
- Successful instruments: <25% cost overrun and ≤4 months schedule delays

A total of 20 out of 41 instruments were defined as challenged and a total of 9 out of 41 instruments were defined as successful. Twelve instruments were excluded because they did not meet both criteria in the challenged or successful populations.

As shown in Figure 7, the risk management problem area was cited 3.6 times more often by the challenged instruments than the successful instruments.

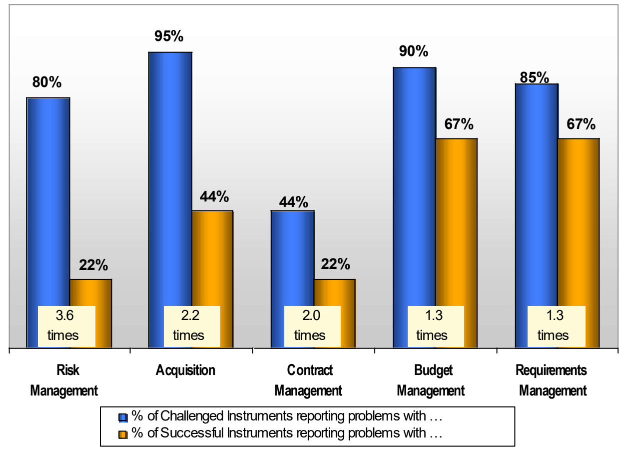

Figure 7. Problem areas with highest differentials between challenged and successful instruments.

4 Findings and Recommendations

The analysis of all of the results culminated in the development of five over-arching study themes: staffing, acquisition, systems engineering, instrument management, and testing issues. Common issues or threads, and their impacts, were examined within each of the themes and these threads were then evaluated across all of the themes to develop the overall Study findings and recommendations.

4.1 Finding 1

Instrument developments lack the resources and authority to successfully manage to cost and schedule requirements.

4.1.1 <u>Recommendations</u>

1. Implement changes to policy to define and elevate instrument management requirements and authorities in a manner similar to project-level management.
2. Assign NASA instrument managers full authority and responsibility to manage their cost and schedule reserves and hold them accountable.
3. Require 30% to 50% cost reserves for instrument developments (>$10 Million) to account for the fact that most instrument developments are highly complex, single builds.
4. Require 1½ to 2 months per year of schedule reserve for instrument developments (>$10 Million).
5. Require dedicated level of support staff (configuration management, schedule management, risk management and budget management) for instrument developments (>$10 Million).

4.1.2 Rationale

Instrument developments are uniquely complex, often one-of-a-kind, and, as such, require a higher level of visibility, authority, and support than normal spacecraft subsystems.

Transition of authority to the lower levels is necessary to permit informed management and mitigation of risks before they turn into more expensive problems.

The typical rule of thumb of 25% cost reserve and 1 month per year schedule reserve does not appear to be sufficient for instrument developments. This is corroborated by the data which indicated that ~70% of the instruments reported 25% or more cost overruns and ~60% of the instruments reported schedule delays of 5 months or more.

4.2 Finding 2

Instrument developments are lacking the critical skills, expertise, or leadership to successfully implement these unique (one-of-a-kind), high technology developments.

4.2.1 Recommendations

1. Expedite the planned enhancement of the NASA Engineering Network People, Organization, Project, Skills (POPS) expertise locator to enable instruments to address critical skills shortages by drawing upon personnel from other NASA centers.
2. Add capability to the POPS locator to include data sources external to the NASA workforce.
3. Require the addition of a deputy instrument manager position (similar to a deputy project manager), for instrument developments with a budget >$10 Million.

4.2.2 Rationale

Expediting the POPS expertise locator enhancement will allow instrument projects to locate critical skills in the near term mitigating staffing issues, which is one of the top five problems reported in this Study. POPS allows instruments to draw from a wider pool of potential expertise.

Given the complexity and scope of instrument developments, the addition of a deputy instrument manager position is warranted. This position creates a mechanism for transfer of corporate knowledge, training and mentoring, and provides critical support to the instrument manager. Finally, it ensures continuity, should leadership transitions occur.

4.3 Finding 3

There are significant process problems in the area of requirements formulation, reviews, and management.

4.3.1 Recommendations

1. Require NASA instrument team leadership to take requirements formulation/management training, e.g., "Requirements Development and Management (APPEL-REQ)," prior to requirements development [2].
2. Require instrument teams to conduct Peer Reviews of requirements (for each instrument subsystem), in preparation for instrument Systems Requirements Reviews (SRR).
3. Require draft mission Level 1 and 2 technical requirements to be controlled and provided to instrument managers prior to the instrument SRR. Also, notify instrument managers of any changes to the draft requirements so that impact assessments can be performed.

4.3.2 Rationale

In order to fix the requirements problems reported in the Study, a wide range of recommendations should be implemented. These recommendations include a greater emphasis on training to provide instrument teams a better understanding of how to formulate and manage requirements. The recommendations also provide an improved requirements review process to account for the fact that instrument SRRs occur much earlier than mission SRRs which often leads to requirements changes, as well as traceability issues. Finally, a recommendation is added to provide instruments with top level requirements early in formulation to allow for a more thorough requirements development and management process.

4.4 Finding 4

Unrealistic caps, overly optimistic estimating, and externally directed changes correspond to a significant increase in the likelihood of overrunning cost and schedule.

4.4.1 Recommendations

1. Develop an Agency-level historical cost and schedule database of instruments to provide information that would allow for higher fidelity cost caps.
2. Review cost credibility evaluation and scoring criteria for accuracy and flow-down to the proposal selection process (for use by Technical Management and Cost or project Source Evaluation Board).
3. Establish a Peer Review prior to PDR for instruments >$10 Million to assess budget and schedule baseline credibility and increase the emphasis on cost and schedule assessment at PDR.

4. Ensure that instrument managers are made aware of externally driven changes in a timely manner and afforded the opportunity to discuss any impacts prior to implementation of changes.

Note: The NICS team did not develop a recommendation for cost estimating problems since this issue is currently being addressed by a multi-Agency team (The Space Systems Cost Analysis Group, co-chaired by NASA). This group is sponsoring a Baseline Realism Team.

4.4.2 Rationale

The costing database will be useful in: establishing higher fidelity cost caps; evaluating government and contractor instrument proposals; and assessing progress during implementation. Furthermore, a data exchange between NASA, NOAA, and DoD on instrument development cost data would allow for a more thorough data set.

Improved cost credibility criteria support a more robust and thorough source selection.

Adding a budget and schedule baseline credibility Peer Review prior to PDR will increase confidence going into the Confirmation Review.

Early communication of externally driven changes (e.g., budget or schedule changes) down to the instrument level minimizes the impact to the instrument development.

4.5 Finding 5

NASA needs a method to continue answering basic questions pertaining to the instrument development process to identify any emerging or persisting issues.

4.5.1 Recommendations

1. Require all instrument managers to take the IS upon delivery of their instrument.
2. Maintain survey results in a historical database.

4.5.2 Rationale

The aggregated data could provide the Agency information regarding trends, persistent issues, and emerging issues.

5 Concluding Remarks

The NASA Instrument Capability Study has established a foundation for objective instrument development analysis. A strict process was followed to ensure integrity and confidentiality across all Study elements. Quantitative data has been collected and analyzed, which indicates that the instrument developers are indeed facing challenges that impact the capability to design and build quality instruments. These challenges focus on lack of resources and authority to successfully manage these instruments, lack of critical skills or expertise to implement these one-of-a-kind developments, significant problems in the area of requirements (formulation, reviews, and management), and issues with unrealistic caps, overly optimistic/unrealistic cost estimating, and externally directed changes impacting cost and schedule. The Study team recommended top-level changes in the way the Agency views and implements instrument development. The Study team also recommended improvements to key instrument development processes, such as project staffing and acquisition. The recommendations to address the Study findings should be implemented as soon as possible, with the highest level of priority. Since the NICS team only scratched the surface of problems impacting the capability to develop instruments, recommendations for continued data analysis were also provided.

Acknowledgments

The NICS team included members from NASA Headquarters, Goddard Space Flight Center, Jet Propulsion Laboratory, Johnson Space Center, NOAA, and DoD. The team also consulted, as necessary, with representatives of Johns Hopkins University/Applied Physics Lab, The Aerospace Corporation, and support contractors to obtain individual viewpoints. The Review Board participants provided invaluable input throughout the assessment.

NASA acknowledges the contributions of representatives from government agencies and aerospace companies that supported this assessment by: responding to the NICS surveys, participating in the industry workshop, or providing feedback during focus groups. Their efforts were instrumental in the Study team's completion of this tri-Agency assessment of instrument development capability.

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