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SPACE ACQUISITIONS

DOD's Goals for Resolving Space Based Infrared System Software Problems Are Ambitious

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SPACE ACQUISITIONS

DOD's Goals for Resolving Space Based Infrared System Software Problems Are Ambitious

GAO Accountability · Integrity · Reliability

Highlights

Highlights of GAO-08-1073, a report to Congressional Committees

Why GAO Did This Study

In 1996, DOD initiated the Space Based Infrared System (SBIRS) to replace the nation's current missile detection system, and to provide expanded missile warning capability. Since then, SBIRS has been restructured several times to stem cost increases and schedule delays, including revising program goals in 2002, 2004, and 2005. These actions were partly due to the challenges of developing sophisticated technologies and software. In 2007, SBIRS had a major setback when flight software for the first satellite underwent testing and failed, a failure caused by design issues. DOD developed a plan for resolving these issues, and revised its cost and schedule goals. GAO has assessed (1) the approach used to mitigate the problems, and (2) the cost and schedule risks and challenges of that approach. To conduct our work, GAO has contacted, met with, and performed detailed work at numerous DOD and contractor offices; and reviewed technical documents on flight software.

What GAO Recommends

GAO recommends that the Secretary of Defense revise cost and schedule goals commensurate with acceptable risk to increase the confidence of success, and require the contractor to adhere to disciplined software practices as a priority to reduce risk. DOD partially concurred with the first recommendation to revise the cost and schedule estimates, and concurred with the recommendation to prioritize adherence to software practices.

To view the full product, including the scope and methodology, click on GAO-08-1073. For more information, contact Cristina T. Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

To mitigate the SBIRS flight software problems, DOD has assessed various alternatives and developed a way to implement the software redesign and oversee its development. In April 2008, DOD approved the redesign effort, which addressed problems with the original design that affected the timing of stored programs, distribution of control between processors, and failure at the hardware interface level. Six review teams comprised of 70 personnel in all evaluated the designs to ensure the technical solutions, development approach, and readiness of test facilities were adequate. DOD and its contractor are now implementing the simplified architecture, developing new software, and testing elements critical to the integration and test of systems. DOD is also improving its program oversight and better managing the SBIRS development, by acting on the recommendations of an Independent Program Assessment; addressing weaknesses in management responsibility, accountability and organizational structure; and establishing a central execution team.

DOD has estimated that the SBIRS program will be delayed by 15 months and cost $414 million in funding to resolve the flight software problems, but these estimates appear optimistic. For example, confidence levels—based on the program's ability to develop, integrate, and test software in time to meet the schedule goal—have been assessed as low.

Confidence Level to Produce Software in Time to Meet First Satellite Launch Goal

Confidence level	Contractors	Estimated launch goal
Less than 10 percent	Aerospace Corporation	December 2009
5 percent	Galorath, Inc.	December 2009
50 percent	Lockheed Martin	December 2009

Source: U.S. Air Force (data); GAO (analysis and presentation).

Further, the review teams who approved the designs to start coding software report that the program's aggressive schedule is a major challenge because it allows "little margin for error." DOD has also introduced risk by granting waivers to streamline the software development processes to meet the aggressive schedule. These allow the program to deviate from disciplined processes in order to compress the schedule and meet the goal. In addition, some software elements are behind schedule, and thousands of software activities and deliverables remain to be integrated. Delay by these other programs could create unintended consequences for the SBIRS launch goal. If DOD should need additional time or encounter problems beyond what was planned for, more funds will be needed and launch of the first satellite in December 2009 could be jeopardized.

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Abbreviations

DOD	Department of Defense
FFRDC	federally funded research and development center
GEO	geosynchronous earth orbit
HEO	highly elliptical orbit
IPA	Independent Program Assessment
OSD	Office of the Secretary of Defense
RFSW	reusable flight software
SBIRS	Space Based Infrared System

GAO
Accountability * Integrity * Reliability

United States Government Accountability Office
Washington, DC 20548

September 30, 2008

Congressional Committees

In 1996, the Department of Defense (DOD) initiated the Space Based Infrared System (SBIRS), a satellite missile warning system, to replace the nation's current missile detection system and to provide expanded capabilities to support intelligence, surveillance, and reconnaissance. Since its inception, SBIRS has been burdened by underestimated software and technical complexities, poor oversight, and other problems that have resulted in cost overruns and years in schedule delays. DOD had expected to field SBIRS by 2004 at a cost of $4.2 billion; however, SBIRS is now estimated to cost over $10.4 billion, and the first satellite launch is expected in 2009—a 7-year delay.

In 2006, you requested that we review the SBIRS program. In response, we reported on an array of problems the program was still facing, particularly with respect to software development, the expenditure of management reserves, and deferred requirements.[1] Subsequent to our work, SBIRS experienced another major setback in January 2007 when the flight software for the first satellite underwent testing and failed. The flight software controls and monitors the satellite's health and status and is considered a critical component of the satellite. In April 2007, DOD determined that the software failure was caused by design issues that affected the timing of stored programs, among other problems. DOD also developed a plan for resolving the issues, and associated cost and schedule goals.

Given the importance of flight software to the first SBIRS satellite and its cost and schedule impact on the SBIRS program, we agreed to follow up on our work and assess the software management, development, and mitigation efforts. Specifically, we (1) identified DOD's approach to mitigate the SBIRS flight software problems, and (2) assessed the cost and schedule risks and challenges of that approach.

To conduct our work for this report, we contacted the Office of the Secretary of Defense (OSD), Air Force, and contractor offices. We also

[1]GAO, *Defense Acquisitions: Space Based Infrared System High Program and its Alternative*, GAO-07-1088R (Washington, D.C.: Sept. 12, 2007).

conducted detailed work and held discussions with both the Air Force and Lockheed Martin on their efforts to manage, mitigate, and redesign the flight software that is to operate, control, and monitor the satellite's health, status, and safety. We reviewed technical software plans, assessments, analyses, and independent reviews pertaining to the flight software's redesign, and held discussions with key Air Force and contractor officials on various aspects of the flight software development for SBIRS. In addition, we drew from our body of past work on weapon systems acquisitions practices and used disciplined software practices as criteria.[2] We conducted this performance audit from April 2008 to August 2008 in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives. Appendix I further discusses our scope and methodology.

Results in Brief

DOD has assessed various alternatives for mitigating SBIRS' flight software problems and developed a way forward to implement the program's software redesign and oversee its development. In April 2008, DOD approved the overall software redesign effort which was to address problems with the original design that affected the timing of stored programs, distribution of control between processors, and failure at the hardware interface level. Review teams—comprised of personnel from the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics; Aerospace Corporation; Lockheed Martin Corporate; Air Force Space and Missiles Systems Center Wing; and Software Engineering Institute—evaluated the designs to ensure the technical solutions, software requirements, development approach, and readiness of the test facilities were of adequate quality. Currently, DOD and the contractor are

[2]CMMI® (Capability Maturity Model® Integration) is a collection of best practices that helps organizations improve their processes. It was initially developed by product teams from industry, government, and the Software Engineering Institute for process improvement in the development of products and services covering the entire product life cycle from conceptualization through maintenance and disposal. Following the success of CMMI models for development organizations, a CMMI model that addresses the acquisition environment was developed; and can be found within *Guidelines for Successful Acquisition and Management of Software-Intensive Systems: Weapon Systems Command and Control Systems Management Information Systems*, Department of the Air Force, Software Technology Support Center, (Condensed version) (February 2003).

working to implement the simplified architecture, develop additional software, and test elements critical to the integration and test of systems. DOD has also undertaken several initiatives to improve its program oversight and to help it better manage the development, such as acting on several recommendations identified in an Independent Program Assessment to address weaknesses in management responsibility, accountability, and organizational structure, and establishing a dedicated execution team with a focus on managing the first satellite effort.

DOD has estimated that the SBIRS program will be delayed by 15 months and cost $414 million in funding to resolve the flight software problems, but these estimates appear too optimistic. For example, the productivity estimates that are based on the program's ability to develop, integrate, and test software in time to meet the schedule have been assessed as low—by technical contractors—ranging from 5 to 50 percent in confidence for meeting the schedule goal. Further, the review teams who approved the designs to start coding software report that the program's aggressive schedule is a major challenge because it allows "little margin for error." In addition, DOD has introduced program risk by requesting and receiving waivers for the purpose of streamlining important software development processes to meet the aggressive schedule. The waivers will allow the program to deviate from disciplined processes in order to compress the schedule and meet the goal. Finally, some program elements are already behind schedule, and thousands of software activities and deliverables remain that must be integrated without significant consequence across the broad spectrum of development elements, such as integration with ground, space, and database systems. Also, the launch range needed by SBIRS to launch the first satellite is scheduled for use by other satellite programs prior to SBIRS. Delay in these other satellite programs could create unintended consequences. Should DOD need additional time or encounter problems beyond what was marginally planned for, more funds will be needed and launch of the satellite in December 2009 could be in jeopardy.

We are making recommendations to the Secretary of Defense regarding the development of realistic cost and schedule estimates commensurate with acceptable program risk to increase the confidence of success, and adherence to disciplined software practices. DOD partially concurred with our recommendation to revise the cost and schedule estimates based on more realistic assumptions, and concurred with our recommendation to require the contractor to make adherence to disciplined practices a priority. On the recommendation to develop realistic cost and schedule estimates, DOD stated that the current goals are executable on the basis of

available management reserve and schedule margin, as well as additional funds that have been approved by Congress in the event of any unforeseeable problems or delays. DOD further stated it would consider modifying the cost and schedule goals based on the results of an ongoing flight software assessment. While DOD's plan to assess software and its willingness to revise the cost and schedule goals appear plausible, we believe this approach falls well short of a more reasonable approach to revise the estimates based on realistic assumptions to increase the confidence of success. In light of the program's risks, poor performance history, and technical challenges expected during integration, we maintain that developing goals based on realistic assumptions would place DOD in a position to achieve cost and schedule goals with greater confidence.

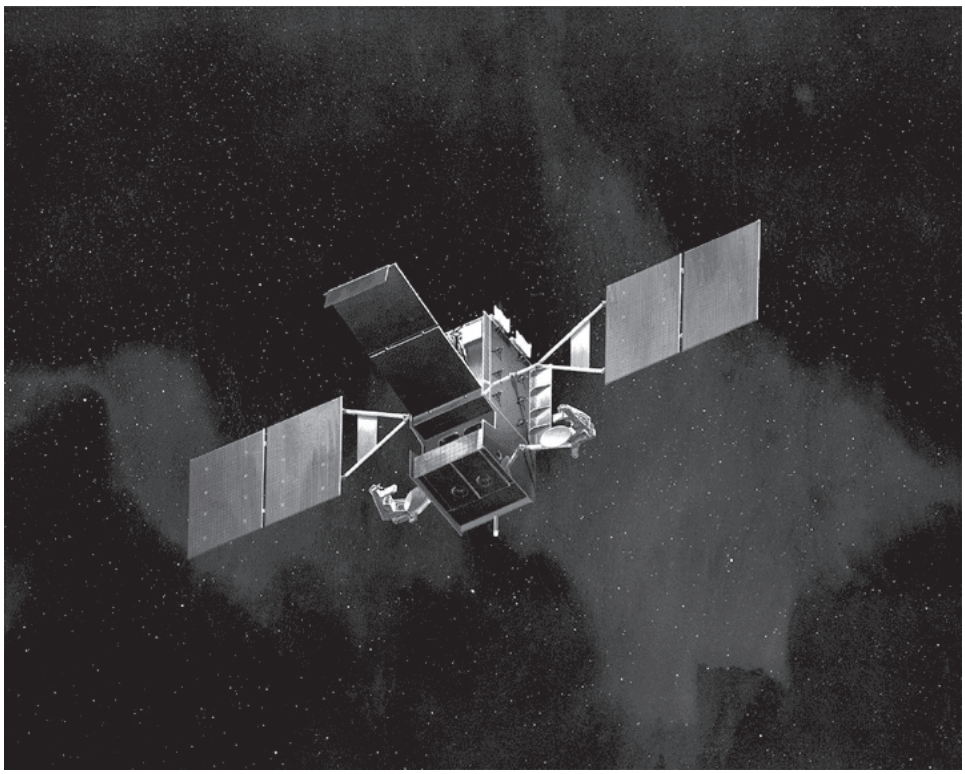
Background

DOD initiated the SBIRS program to meet all military infrared surveillance requirements through a single, integrated system, and to provide better and timelier data to the Unified Combatant Commanders, U.S. deployed forces, U.S. military strategists, and U.S. allies. SBIRS is to replace the existing infrared system, the Defense Support Program, which has provided early missile warning information since the 1970s. The SBIRS program was originally conceived as having high- and low-orbiting space-based components and a ground segment for mission-data processing and control to improve current capabilities. In 2001, the SBIRS Low component was transferred from the Air Force to the Missile Defense Agency and renamed the Space Tracking and Surveillance System. The Air Force continued developing SBIRS High (herein referred to as "SBIRS"). It, along with its associated ground segment, is one of DOD's highest priority space programs.

The SBIRS program originally consisted of four satellites to operate in geosynchronous earth orbit (GEO), plus one spare, an infrared sensor placed on two host satellites in highly elliptical orbit (HEO)—known as "HEO sensors"—and a ground segment for mission-data processing and control.

The SBIRS GEO satellite is designed to support two infrared sensors—a scanning sensor and a staring sensor. The first GEO satellite is commonly referred to as GEO 1. Figure 1 shows the GEO satellite that is to operate in space.

Figure 1: SBIRS Satellite



Source: Lockheed Martin Space Systems Company, Sunnyvale, California. © 2007 Lockheed Martin Corporation.

As a result of past technical and program difficulties experienced during sensor and satellite development, the SBIRS program has encountered cost and schedule increases. These difficulties have led DOD to restructure the program multiple times, including revising program goals in 2002, 2004, and 2005. For example, in 2002, the program faced serious problems with software and hardware design progress and, in the Conference Report accompanying the National Defense Authorization Act for Fiscal Year 2002, conferees recommended cutting advance procurement funding due to concerns about program developments and the unclear status of the SBIRS program. At that time, the first satellite launch slipped from 2002 to 2006. In late 2005, SBIRS was restructured for a third time which stemmed from a 160 percent increase in estimated unit

cost, triggering a fourth Nunn-McCurdy[3] breach, which again postponed the delivery of promised capabilities to the warfighter.

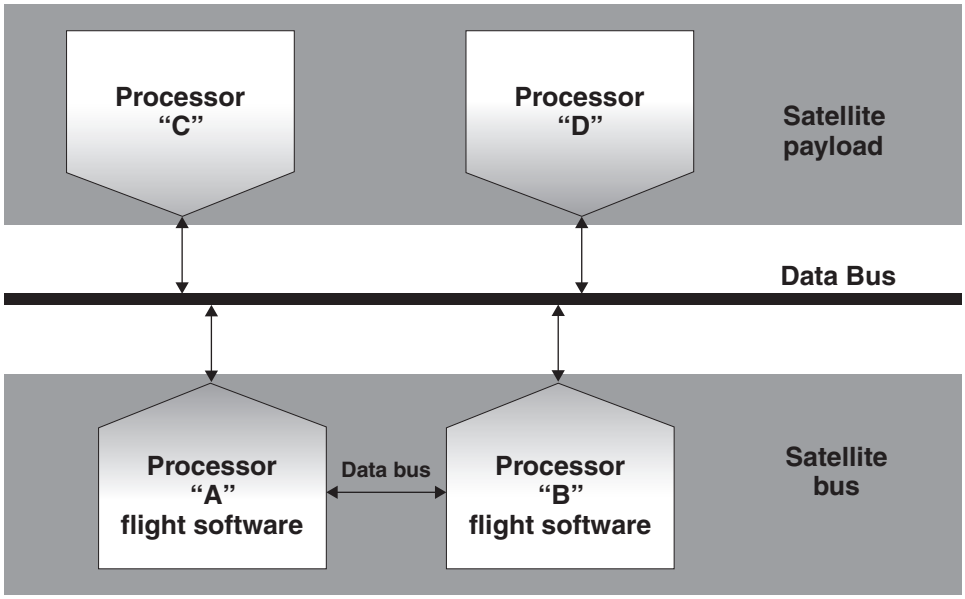
Flight Software

The flight system software is expected to control the GEO satellite's mission critical functions and activities. Unlike other software programs that can be deferred and uploaded to the satellite after launch, the flight software cannot be deferred because it is critical to the satellite's operation and function. The flight software is expected to operate, control, and monitor the GEO satellite's health, status, and safety. Based on the original design, the flight software was to operate on two of four computer processors onboard the satellite and perform important functions and operations, such as telemetry, thermal control, power management, and fault detection activities.[4] Figure 2 shows a simplified diagram of the original flight software design.

[3]10 U.S.C. § 2433, commonly known as "Nunn-McCurdy," generally requires DOD to review programs and report to Congress whenever certain unit cost growth thresholds are reached.

[4]Satellites primarily consist of the payload and the bus. Currently, DOD's buses are custom-made for each space program.

Figure 2: Simplified Diagram of Original Flight Software Design



Source: Lockheed Martin (data); GAO (analysis and presentation).

Origin and Chronology of Flight Software Events

In 1996, development of the flight software began as an independent research and development project by Lockheed Martin—referred to as reusable flight software (RFSW)—to be used for multifunctional "bus" purposes.[5] In 2004, the RFSW was provided to the SBIRS program for development as the flight system software to operate, control, and monitor the GEO satellite's health, status, and safety. At that time, the software needed to address 1261 requirements in order to satisfy the specific flight software system needs for the GEO satellite. From 2005 to 2006, the Air Force and Lockheed Martin conducted detailed requirements reviews that resulted in the delivery of flight software that was integrated into the satellite's computers.

In January 2007, the flight software underwent testing in a space representative environment called thermal vacuum testing and experienced a higher number of unexpected and unexplained failures. By April 2007, in additional tests, the number of problems escalated well

[5]The bus is the platform that provides the power, attitude, temperature control, and other support to the satellite in space.

beyond what was expected. At this time, Lockheed Martin notified DOD of the seriousness of the problem. From April 2007 to July 2007, the Air Force and Lockheed Martin analyzed the problems and developed two options:

- modify the existing software or
- redesign the software by simplifying the architecture, developing more software, and increasing the robustness of the fault management system.

The Air Force chose to redesign the software architecture and began its work with Lockheed Martin on detailed software designs from September 2007 to December 2007. In March 2008, the new design underwent Incremental Design Review Block 1 and was approved by the program review board for the revised cost and schedule baseline. In April 2008, six independent review teams examined the Block 2 design during the Systems Engineering & Incremental Design Review and authorized the Air Force and Lockheed to proceed with formal software coding under the redesign.[6]

DOD Is Taking Steps to Mitigate Software Problems, Including Initiatives to Improve Program Oversight

To mitigate the software problems, DOD has assessed various alternatives and developed an approach for implementing the software redesign effort and overseeing its development. DOD and the SBIRS contractor are taking steps to address problems, among others, with the original software architecture. DOD has redesigned the architecture, and is in the midst of developing additional software, and testing elements critical to the integration and test of systems. DOD has also undertaken several initiatives to improve its program oversight and to help it better manage the development, including addressing weaknesses in program management responsibility, accountability, and other areas.

[6]FSS v1.5 Block 2 Systems Engineering & Incremental Design Review, Lockheed Martin Space Systems Company, Sunnyvale, California.

Steps Have Been Undertaken to Address Poor Software Architecture

To address the software's poor architectural design that ultimately resulted in the unexpected loss of telemetry and commanding for extended periods and unexpected hardware errors, a trade study was conducted by Lockheed Martin to examine options for redesign. Table 1 shows the trade study options considered, and recommendations made.

Table 1: Trade Study Options and Recommendations on Software Architecture

Option	Recommendation
Distributed applications (synchronous)	Not recommended due to complexity and risk
Distributed applications (asynchronous)	Not recommended due to complexity and risk; has the highest impact to ground systems
All applications on processor "B"	Not recommended due to complexity and risk
All applications on processor "A"	Recommended as best fit with component and fault management system designs

Source: Lockheed Martin (data); GAO (analysis and presentation).

As indicated in table 1, the trade study recommended a simplified architecture that places all the software applications on a single processor, processor "A", rather than using distributed applications because it represents the best fit with system designs. Lockheed Martin officials stated that the simplified software architecture will address a number of areas that were problematic with the original design, such as the timing of stored programs that failed during thermal vacuum tests. Among other elements, the new design will involve the development of additional software that will also increase the robustness of the fault management system.

Major Redesign Approved for Coding Software

Approved in April 2008, the new designs have undergone numerous reviews, the last of which was subjected to comprehensive and detailed examination involving six independent review teams. Teams comprised of personnel—from the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics; Aerospace Corporation, a federally funded research and development center (FFRDC)[7]; Lockheed Martin

[7]FFRDCs are unique independent nonprofit entities sponsored and funded by the. government to meet specific long-term technical needs that cannot be met by existing in house or contractor resources. The Aerospace Corporation's FFRDC is sponsored by the Air Force, and provides objective technical analyses and assessments for space programs that serve the national interest. As the FFRDC for nation-security space, Aerospace supports long-term planning and the immediate needs of our nation's military and reconnaissance space programs.

Corporate; Air Force Space and Missiles Systems Center Wing; and the Software Engineering Institute[8]—evaluated the technical solutions, development approach, and readiness of the test facilities, among other elements.

The objective of the design review was to authorize the start of formal software coding. For the incremental design review, independent review teams were provided detailed information about software issues on the original design, including the severity of the issues and the status of each. Other information included DOD's approach in managing risk, resolution of critical issues, disposition of deficiency reports, requirements volatility, and integration with ground systems. Technical data included diagrams of the simplified architecture, operating system interface design, and lines of software code that would be impacted from earlier designs. Other information about the software included designs of subsystems, schematics, integration and delivery schedules, and productivity and sizing estimates.

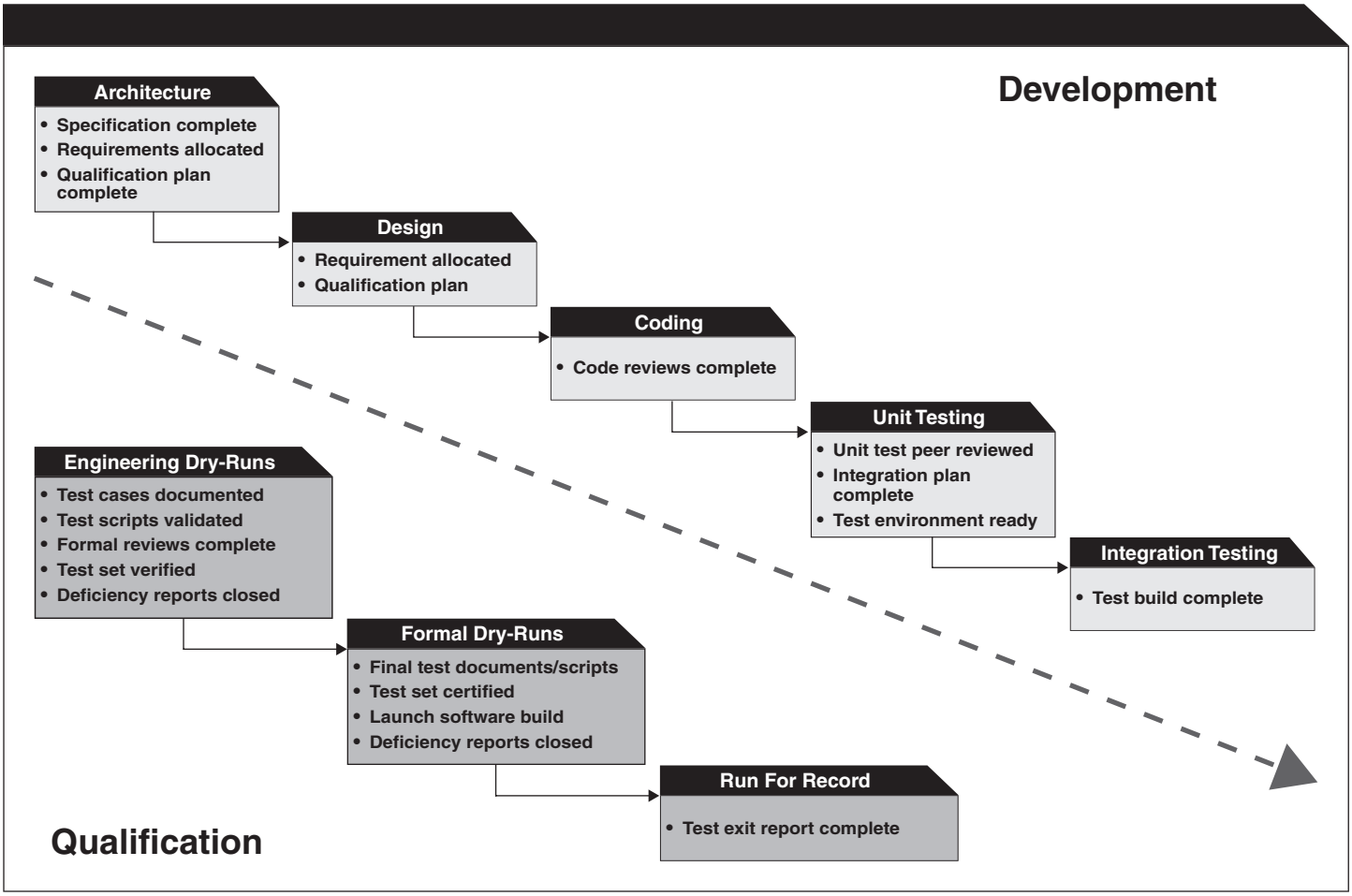
Progress Is Being Made to Develop Software and Conduct Tests

DOD is making progress to develop needed software and conduct tests of elements that are critical to the first satellite system, called GEO 1. For example, in June 2008, DOD held a design review on software for the fault management system that elicited concurrence from external stakeholders to proceed with coding activities. At the same time, they held a space technical interchange meeting that provided consensus on the methodology and a plan for complete space vehicle testing, including the flight software. In July 2008, Lockheed Martin delivered 63,000 of the projected 67,000 source lines of code for the space vehicle and ground software integration effort, including a database that provided data so that development efforts could continue on ground software and testing activities.

According to Lockheed Martin, software development efforts followed a disciplined process, except in those cases where waivers were requested and granted by the software engineering process group. Figure 2 shows Lockheed Martin's process for developing and qualifying flight software.

[8]The Software Engineering Institute is a FFRDC that works closely with defense and government organizations, industry, and academia to continuously improve software intensive systems. The Institute's core purpose is to help organizations to improve their software engineering capabilities and to develop or acquire the right software, defect free, within budget and on time.

Figure 3: Flight Software Development Process



Source: Lockheed Martin (data); GAO (analysis and presentation).

Risks Reduced by Funding Additional Test Resources

DOD has taken steps to fund critical test bed resources that are needed to adequately test, model, analyze, and simulate software functions as a means to reduce integration and test risks, in response to lessons learned from the failed software that identified the need to add and upgrade their simulation and test bed resources. For example, an evaluation of the software problems found several contributory factors that prevented them from identifying the software problems earlier. These include:

- test beds that had matured in parallel with the flight software and hardware, making it difficult to distinguish between test bed and software issues;
- oversubscription of test beds and lack of simulation resources that precluded them from checking out high-risk areas (timing, and stored programs); and
- insufficient modeling of timing, and analysis of stored program implementation, which might have shed light earlier on lack of robustness.

In May 2008, the additional test bed and simulator was brought online and is currently in use.

Actions Have Been Undertaken to Address Program Weaknesses, and Improve Oversight of GEO Development

DOD and Lockheed Martin have undertaken several initiatives to address areas of program risk, such as efforts to improve oversight of GEO 1 and flight software development. These include acting on recommendations made in an Independent Program Assessment (IPA) that was conducted to ensure the validity of the technical, cost, and schedule baselines. As part of the assessment, the IPA study assessed contractor performance, evaluated program risk areas, and made recommendations on where program improvements could be made. In November 2007, officials from the Air Force, Lockheed Martin, and Aerospace Corporation reported the IPA findings. Table 2 shows the IPA findings, recommendations, and status of implementation efforts.

Table 2: IPA Findings, Recommendations, and Status of Implementation

Finding	Recommendation	Implemented? (as of April 2008)
1. Lockheed Martin's program process discipline is poor	• Engage Lockheed Martin functional areas and ensure that processes are being followed	Yes
2. Air Force has limited management control over SBIRS	• Amend contract to provide necessary management control	Yes
3. Adversarial relationships exist between Air Force and Lockheed Martin	• Fix responsibility, accountability, and authority disconnects	Yes
4. Government organizational structure is flawed because cost and schedule responsibilities are separated.	• Combine in a single office the review of contractor cost and schedule data	Yes
5. Focal point for FSS completion is needed	• Designate a program manager within flight software system • Establish giver/receiver relationships	Yes

Source: Aerospace Corporation (data) and U.S. Air Force (data); GAO (analysis and presentation).

As indicated in table 2, the Air Force and Lockheed Martin have taken actions to address areas of risk. Among others, these actions included deliberately emphasizing the software development process where adherence to process disciplines was lacking, and enhancing the interaction between cost and schedule functions where the Air Force organization structure was found to be flawed because it did not mirror the contractor's more traditional approach where these functions are combined for better program control.

To improve the oversight and management of the GEO 1 satellite and software development, the Air Force and Lockheed Martin established a dedicated execution team with a focus on overseeing the test, integration, and assembly of software and hardware, and ensuring delivery of the GEO 1 satellite. The execution team is a joint effort that includes the Air Force, Lockheed Martin, and Aerospace Corporation. As part of the management approach, the execution team is responsible for conducting daily meetings to review "inch stone" metrics and to resolve issues. The execution team also meets weekly with the Executive Program Management leadership to provide early insight on issues and resolve organizational weaknesses, and conduct monthly reviews with senior executives to provide consistent communication and allow opportunity for guidance. According to DOD officials, the execution team not only improved oversight of software development and management of the GEO 1 effort, but also addressed weaknesses identified in the IPA study. For example, these weaknesses included, among others, the need to fix the program's responsibility, accountability, and authority disconnects. Officials reported that the execution team helped alleviate the strained relationships that had existed between the Air Force and Lockheed Martin where adversarial relationships and morale problems were evident.

DOD's Plan for Resolving the Software Problem Is Optimistic

While DOD has estimated that the SBIRS program will be delayed by 15 months and cost $414 million to resolve the software problems, those estimates appear too optimistic, given the cost and schedule risks involved. For example, SBIRS contractors' report low confidence that software can be produced in time to meet the December 2009 satellite launch goal. Further, DOD and the contractor face significant challenges and risks that could result in more time and money being required to meet program goals, to include the bypassing of some disciplined software practices that add risk to cost and schedule. Finally, as of August 2008, DOD reported that SBIRS was already behind schedule on some software development efforts, and thousands of activities remain that must be integrated and tested across various systems, with cost and schedule implications, if problems or unintended consequences occur.

Low Confidence That Software Can Be Produced to Meet Cost and Schedule Goals

A major concern is the infeasibility of producing the software in time to meet the estimated launch goal. For example, technical contractors—Aerospace Corporation, Galorath Inc., and Lockheed Martin—estimated the confidence to be "low" that software can be developed within the tight time frames. These estimates are based on widely accepted models (System Evaluation and Estimation of Resources, Software Estimating Model, and Risk Assessment) that take into account the effective size of the software, staffing of the effort, complexity, volatility of software requirements, and integration and risk of anticipated rework and failure in system tests. Using DOD's self-imposed baseline schedule goal, software productivity estimates show very low confidence levels that the schedule goal can be met. Table 3 shows the confidence in meeting the GEO 1 launch goal in December 2009 (various models used).

Table 3: Confidence Level to Produce Software to Meet GEO 1 Schedule

Confidence level	Contractors	Estimated launch goal
Less than 10 percent	Aerospace Corporation	December 2009
5 percent	Galorath, Inc.	December 2009
50 percent	Lockheed Martin	December 2009

Source: U.S. Air Force (data); GAO (analysis and presentation).

As indicated in table 3, one estimate shows only a 5 percent confidence that the software can be produced in time to meet the schedule goal, while the other estimate shows a less than 10 percent confidence level. Lockheed's own software productivity estimate shows a 50 percent confidence level in meeting the December 2009 launch schedule, but its

estimate assumes (1) a higher productivity than has been demonstrated, and (2) the software will require less effort, which has not been the program's experience. According to DOD's Cost Analysis Improvement Group, if productivity on software does not materialize, or problems occur during testing and integration beyond what was marginally planned for, then it could cost an additional $400 million for each year of schedule slippage.

Major Challenge and Risks to the Redesign and Development Effort Still Exist

Based on an April 2008 review of the revised software designs and software development approach, the independent review teams—comprised of personnel from the Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics; Aerospace Corporation; Lockheed Martin Corporate; Air Force Space and Missiles Systems Center Wing; and the Software Engineering Institute—concluded that the program should proceed with formal software coding, but also expressed concern about the ambitious schedule. Specifically, the review teams cited the program's aggressive schedule as a major challenge because it allows "little margin for error" and concluded the program faces high risk of not meeting the schedule. Table 4 shows the weaknesses and risks to software development.

Table 4: Weaknesses and Risks to Software Development

Weaknesses
• Schedule pressure, and alignment of code and designs
• Code complexity impacting unit testing
• Late integration with ground software
• Significant amount of work remaining
Risks
• Concurrent systems engineering and software development
• Code development requiring more labor than estimated
• Additional system or software testing required beyond plans
• Qualification of test products behind schedule
• Systems engineering completion may require more effort

Source: Lockheed Martin (data); GAO (analysis and presentation).

Although the Air Force and Lockheed Martin are committed to the effort and have built in a 120-day margin to fix unexpected and unforeseeable problems, a computer engineer from the Defense Contract Management Agency who is familiar with the program believes that the margin is

insufficient because the planned schedule considers only routine development activities, and that additional time will likely be needed to address any unanticipated problems.

Bypassing Disciplined Software Practices Adds Risk

Further, to meet the cost and schedule goals, the program is using approaches that will increase program risk. These risks stem from waivers, which were requested by Lockheed Martin, as specified by software provisions in the program's software development process. In following the SBIRS Software Development Plan, for Flight Software System 1.5, waivers were generated and approved by a software engineering process group so that developers could deviate from the established processes. These deviations from the disciplined development process allowed the program to shortcut important processes in order to meet the ambitious schedule goal, rather than follow a disciplined process to develop software. For example, a waiver was granted for software design to be done in parallel with the software specification activity. However, according to DOD, the risk is that requirements could be rejected and that rework may be required in coding or design. Another waiver was granted for software unit integration testing to be done in parallel with formal unit testing. According to DOD, the risk is that formal unit testing may find problems that were not identified during prior informal (developer) unit testing, thereby necessitating possible rework.

Cost and Schedule Goals Are at Risk Because Some Software Elements Are Behind Schedule, and Complex Integration and Other Activities Remain

Some of the flight software's elements are already behind schedule and a significant amount of activities remain to be done, posing concern to DOD. For example, DOD reported that, as of August 2008, the software qualification test case and script development effort was already a month behind schedule. Also, final delivery of the Block 2 flight software is now forecasted to be at least 2 weeks late. Other problems that could set back SBIRS are the thousands of integration and coordination activities that must take place as they ramp up. For example, Lockheed Martin reports that the schedule has more than 14,500 tasks that will occur, beginning in January 2008, across multiple systems. This means that the flight software test activities and integration efforts must all be integrated in a "single-flow" without consequence across a broad spectrum of systems, such as integration with ground, space, and database systems, among others. Software experts, independent reviewers, and government officials acknowledged that the aggressive schedule, when combined with the significant amount of work that remains, is the biggest challenge facing the program.

Still, there are external factors that could create schedule impacts for meeting the SBIRS schedule goal. For example, DOD reports that the GEO 1 satellite launch could be affected by other satellites scheduled to launch prior to the SBIRS launch. Essentially, these launch activities use the same launch range resources that will be required to launch the GEO 1 satellite, and delays in any of these events could create unintended consequences to the SBIRS GEO 1 launch goal.

Conclusions

Given the technical complexity of the program and SBIRS' poor program history, it is unwise for DOD to pursue such ambitious goals for resolving the flight software problem. More than 12 years after its inception, the SBIRS program continues to face major challenges that have proven technically challenging and substantially more costly than originally envisioned. The testing failure of the flight software is further proof that sophisticated technology and inherent complexities related to software continue to be underestimated. To its credit, DOD has instilled greater discipline by involving outside experts, regaining control of development activities, and dealing with the poor relationships that had existed for some time. To ensure that such steps can lead to success, adherence to disciplined software practices should be made a priority over steps or measures taken to compress the schedule for the sake of meeting the self-imposed launch goal. Prioritizing such disciplines will improve efforts to acquire a better product, increase executability of the program, and reduce program risk. In turn, establishing goals that are synchronized with such priorities will allow DOD to achieve expectations and program deliverables with greater reliability. Essentially, these will position the leadership to better direct investments by establishing goals with greater confidence that they can be achieved.

Recommendations for Executive Action

To better ensure that SBIRS can meet the cost and schedule goals for resolving the flight software problems as well as launch the first satellite on schedule, we recommend that the Secretary of Defense

- revise the cost and schedule estimates based on more realistic assumptions to increase the confidence of success, and
- require that the contractor make adherence to disciplined software practices a priority to reduce program risk.

Agency Comments and Our Evaluation

DOD provided us with written comments on a draft of this report. DOD partially concurred with our recommendation to revise the cost and schedule estimates based on more realistic assumptions, and concurred with our recommendation to require the contractor to make adherence to disciplined practices a priority. DOD's comments appear in appendix II.

In its comments, DOD partially concurred with the recommendation that the cost and schedule estimates be revised based on more realistic assumptions to increase the confidence of success. DOD noted that the current goals are executable on the basis of available management reserve and schedule margin. In the event that the program encounters any unforeseeable problems that may cause further delays, DOD stated that Congress has approved an additional $45 million in funding to mitigate any future launch delays. The department pointed out that OSD is working with the SBIRS program to hold a more specific review of the flight software. Based on the results of this review, DOD stated it would consider them in any decision to modify the cost and schedule estimates. DOD expects these assessments to be complete by the end of the 2008 calendar year.

As indicated in our report, SBIRS has been restructured several times because it underestimated the technical complexity and inherent challenges associated with software, among other technical elements. Neither the software assessment conducted to determine the confidence of producing software nor the independent reviewers who examined the redesign approach indicated that the current goals were executable. Rather, as we noted, software experts, independent reviewers, as well as the government officials we interviewed expressed concern over the aggressive schedule and questionable schedule margin, which the Defense Contract Management Agency believes is insufficient. Moreover, as we previously reported and noted in this report, the expenditure of management reserves has been particularly problematic because these funds were being rapidly spent. Further, while OSD's plan to assess software and its willingness to revise the cost and schedule goals appear plausible, we believe this approach falls well short of a more reasonable approach to increase the confidence of success for the reasons we cited. In light of the program's risks, poor performance history, and technical challenges expected during integration, we maintain that establishing goals that are based on more realistic assumptions would place DOD in a better position to achieve cost and schedule goals with greater confidence.

DOD concurred with the second recommendation stating that adherence to disciplined software development processes improves the quality and

predictability of the software development while reducing the amount of rework. DOD further states that the program office and the contractor jointly accepted two process waivers to streamline the process, but that these waivers have had no adverse impact on the software development effort. In order to keep the focus on quality software deliveries, DOD noted that the program would disapprove any waivers which might compromise the team's ability to complete the development.

We are encouraged by DOD's efforts to adhere to disciplined software processes to improve the quality and predictability of development. In this endeavor, DOD states that it would disapprove any waivers that could compromise the development effort. However, it is unclear exactly what criteria DOD will use to determine whether a waiver will compromise development efforts. Without this, there is no mechanism to ensure that any waivers that are granted will not have a material effect on software development.

We also received technical comments from DOD which have been addressed in the report, as appropriate.

We are sending copies of this report to the Secretary of Defense; the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics; the Secretary of the Air Force; and the Director, Office of Management and Budget. Copies will also be made available to others on request. In addition, the report will be made available at no charge on the GAO Web site at http://www.gao.gov.

If you, or your staff, have any questions concerning this report, please contact me at (202) 512-4589. Contact points for our offices of Congressional Relations and Public Affairs may be found on the last page of this report. The major contributors are listed in appendix III.

Cristina T. Chaplain
Director
Acquisition and Sourcing Management

List of Congressional Committees

The Honorable Bill Nelson
Chairman
The Honorable Jeff Sessions
Ranking Member
Strategic Forces Subcommittee
Committee on Armed Services
United States Senate

The Honorable Ellen Tauscher
Chairwoman
The Honorable Terry Everett
Ranking Member
Strategic Forces Subcommittee
Committee on Armed Services
House of Representatives

Appendix I: Scope and Methodology

To identify the Space Based Infrared System's (SBIRS) approach to mitigate the flight software problems, we reviewed the plans and alternatives the Department of Defense (DOD) put in place to mitigate the software problem. We also interviewed Air Force, Defense Contract Management Agency, and Lockheed Martin officials who were responsible for management and oversight of the software development effort. We also examined technical reports, studies, and analyses about the factors that contributed to the flight software problems, as well as planning documents and alternatives that were considered in fixing the software problem.

To assess the cost and schedule risks and challenges of the way forward, we held discussions with both the DOD and Lockheed Martin on their efforts to assess the program risks and challenges, including their approach to manage, mitigate, and redesign the flight software that is to operate, control and monitor the satellite's health, status, and safety. We also reviewed schedules, risk reports, analyses, program assessments, and independent review reports pertaining to the flight software's redesign, and selected assessments by independent sources that were used, in part, as basis for selecting December 2009 as the launch goal for the GEO 1 satellite. We also interviewed Air Force and contractor officials responsible for developing and executing the redesign, including a contractor hired for their expertise in estimating software productivity.

We conducted this performance audit at the Office of the Secretary of Defense, Washington D.C.; Space and Missile Systems Center, Los Angeles Air Force Base, California; and Lockheed Martin and the Defense Contract Management Agency, Sunnyvale, California from April to August 2008 in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. In addition, we drew from our body of past work on weapon systems acquisition practices and disciplined software practices. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Comments from the Department of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
TECHNOLOGY
AND LOGISTICS

SEP 29 2008

Ms. Cristina Chaplain
Director, Acquisition and Sourcing Management
U.S. Government Accountability Office
441 G Street, N.W.
Washington, DC 20548

Dear Ms. Chaplain:

This is the Department of Defense (DoD) response to the GAO draft report GAO-08-1073, "SPACE ACQUISITIONS: DoD's Goals for Resolving Space Based Infrared System Software Problems Are Ambitious," dated August 22, 2008, (GAO Code 120761). Detailed comments on the two report recommendations are enclosed.

Sincerely,

Joshua T. Hartman
Director,
Space & Intelligence Capabilities

Enclosure:
As stated

GAO Draft Report Dated August 22, 2008
GAO-08-1073 (GAO CODE 120761)

"SPACE ACQUISITIONS: DOD'S GOALS FOR RESOLVING SPACE BASED INFRARED SYSTEM SOFTWARE PROBLEMS ARE AMBITIOUS"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATIONS

RECOMMENDATION 1: The GAO recommends that the Secretary of Defense, revise the cost and schedule estimates based on more realistic assumptions to increase the confidence of success. (Page 17/GAO Draft Report)

DOD RESPONSE: Partially concur. While the current contractor cost and schedule baseline is aggressive and contains risks, we believe the remaining Flight Software Subsystem (FSS) development is still executable within the available management reserve and schedule margin. Congress has approved an additional $45M in Omnibus funding to provide mitigation against a future launch date delay as a result of any unforeseen program problems, to include Flight Software development and qualification delays. The Wing has recently completed an integrated baseline review of the program. In addition, the program office is working with OSD to hold a more specific review of the FSS effort. These results will be considered in any decision to modify FSS cost and schedule estimates. These assessments will be complete by the end of the calendar year.

RECOMMENDATION 2: The GAO recommends that the Secretary of Defense require that the contractor make adherence to disciplined software practices a priority to reduce program risk. (Page 17/GAO Draft Report)

DOD RESPONSE: Concur. The DoD agrees adherence to disciplined software development processes, as outlined in the SBIRS Software Development Plan, improves the quality and predictability of the software development while reducing the amount of rework. To date, the program office has jointly, with the contractor, accepted the two minor process waivers mentioned in the report to streamline the development process and reduce the schedule risk associated with the December 2009 projected launch date. Those waivers have had no adverse impacts to the FSS development. To keep focus on quality software deliveries in support of space vehicle testing and operations, the program office will disapprove any waivers which compromise the team's ability to complete the development.

Appendix III: GAO Contact and Staff Acknowledgments

Contact

Cristina T. Chaplain, (202) 512-4859 or chaplainc@gao.gov

Acknowledgments

In addition to the individual named above, Arthur Gallegos, Assistant Director; John M. Ortiz Jr.; Claire A. Cyrnak; Madhav S. Panwar; Bob S. Swierczek; and Alyssa B. Weir made key contributions to this report.

Related GAO Products

Space Acquisitions: Major Space Programs Still at Risk for Cost and Schedule Increases. GAO-08-552T. Washington, D.C.: March 4, 2008.

Space Acquisitions: Space Based Infrared System High Program and Its Alternative. GAO-07-1088R. Washington, D.C.: September 12, 2007.

Defense Acquisitions: Assessments of Selected Weapon Programs. GAO-07-406SP. Washington, D.C.: March 30, 2007.

Space Acquisitions: Actions Needed to Expand and Sustain Use of Best Practices. GAO-07-730T. Washington, D.C.: April 19, 2007.

Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems. GAO-07-96 (DATE?)

Space Acquisitions: Improvements Needed in Space Systems Acquisitions and Keys to Achieving Them. GAO-06-626T. Washington, D.C.: April 6, 2006.

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Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes. GAO-01-288. Washington, D.C.: March 8, 2001.

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