United States Government Accountability Office

Report to the Committee on Armed Services, U.S. Senate

October 2014

DOD SPACE SYSTEMS

Additional Knowledge Would Better Support Decisions about Disaggregating Large Satellites

GAO Highlights

Highlights of GAO-15-7, a report to the Committee on Armed Services, U.S. Senate

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DOD SPACE SYSTEMS

Additional Knowledge Would Better Support Decisions about Disaggregating Large Satellites

Why GAO Did This Study

Fiscal constraints and growing threats to space systems have led DOD to consider alternatives for acquiring space-based capabilities, including disaggregating large satellites into multiple, smaller satellites or payloads (see graphic). A Senate Armed Services Committee report mandated GAO to assess the potential benefits and drawbacks of disaggregation and examine if it offers decreased costs and increased survivability for selected DOD satellite systems.

This report (1) describes potential benefits and limitations of disaggregation, and (2) assesses the extent to which DOD is ready to make informed decisions regarding disaggregating these systems. GAO reviewed documents and interviewed officials from over 35 offices within DOD, civilian agencies, contractors, and third parties to compile a list of factors relating to potential impacts of disaggregation. GAO used these factors, along with prior GAO work on best practices and space acquisitions, as criteria for evaluating DOD's work to date on assessing disaggregation.

What GAO Recommends

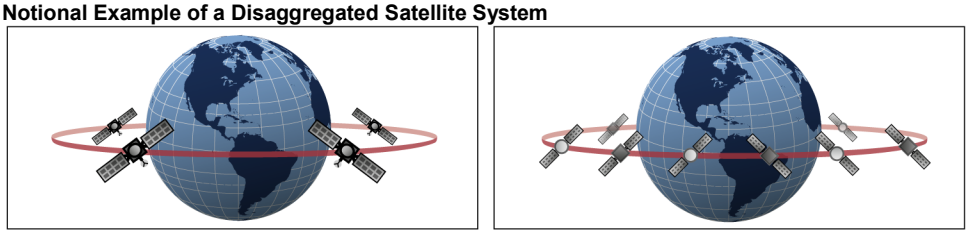
Before making decisions to disaggregate DOD space systems, DOD should (1) comprehensively examine the full range of potential effects of disaggregation, (2) develop common measures for resilience, and (3) expand demonstration efforts to examine the operational feasibility of disaggregation. DOD concurred with the first two recommendations and partially concurred with the third. GAO continues to believe DOD should demonstrate the operational feasibility of disaggregation.

View GAO-15-7. For more information, contact Cristina Chaplain at (202) 512-4841 or chaplainc@gao.gov.

What GAO Found

It is not yet known whether and to what degree disaggregation can help the Department of Defense (DOD) reduce acquisition costs and increase the resilience of its satellite systems. Experts GAO spoke with identified an array of benefits and limitations. For example, acquiring smaller, less complex satellites may require less time and effort to develop and produce. On the other hand, a larger number of satellites may be needed to provide the same level of capability, and the transition from existing system designs could increase costs. Experts agree that decisionmaking would benefit from assessments that look beyond a single satellite program and consider the broad range of potential effects of disaggregation. Benefits and limitations aside, there are longstanding barriers to implementation. For instance, disaggregation could exacerbate delays in the delivery of user equipment and ground systems. As GAO has reported, such delays, tied to management and oversight shortcomings, have resulted in expensive satellites being in orbit for years with limited use.

Notional Example of a Disaggregated Satellite System



Example of aggregated satellite system

Example of disaggregated satellite system

Satellite with strategic and tactical capabilities

Satellite with strategic-only capabilities

Satellite with tactical-only capabilities

Source: GAO (data and images); MapResources (maps). | GAO-15-7

Note: For purposes of this graphic, strategic capabilities may refer to those needed for major operations, such as those involving nuclear weapons. Tactical capabilities may refer to those needed for more localized operations.

DOD is examining whether disaggregation should be used for some of its space systems, but significant uncertainty—including how to quantify a broad range of potential effects—remains. For example, DOD has initiated and completed studies and demonstrations, including Analyses of Alternatives that examine disaggregated concepts for certain systems. These studies can provide initial insights, such as rough order of magnitude costs of selected disaggregated scenarios, but they are not intended to comprehensively assess the effects of disaggregation. Moreover, DOD does not have common measures for resilience—a key space system consideration—which may limit the effectiveness of these assessments. Additionally, while technology demonstrations are providing an avenue for gaining knowledge about disaggregation, they have been limited, concentrating more on technical than operational feasibility. Focusing more on operational feasibility would help to empirically quantify the effects of disaggregation and address implementation barriers. Until more knowledge is gained, disaggregation will not only remain inconclusive, but poorly informed decisions could be made in the interim.

Contents

Abbreviations

AEHF	Advanced Extremely High Frequency
ALASA	Airborne Launch Assist Space Access
AOA	Analysis of Alternatives
CHIRP	Commercially Hosted Infrared Payload
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
HoPS	Hosted Payload Solutions
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
OPIR	Overhead Persistent Infrared
SBIRS	Space Based Infrared System
SENSE	Space Environmental NanoSatellite Experiment
WSF	Weather System Follow-on
XS-1	Experimental Spaceplane

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
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October 30, 2014

The Honorable Carl Levin
Chairman
The Honorable James Inhofe
Ranking Member
Committee on Armed Services
United States Senate

Each year, the Department of Defense (DOD) spends billions of dollars to develop, produce, and launch space systems. These systems provide the government with communication methods, critical intelligence information, weather data, and other capabilities vital to military and civilian agencies and commercial operations. DOD is rethinking its approach to building large, complex, multi-mission satellites. As satellites have become more complex, they have required larger investments of money and time to develop, produce, and launch. In addition, these satellites face growing threats from adversary attacks, such as anti-satellite weapons and communications jamming, to environmental hazards, such as orbital debris. A single launch failure, on-orbit problem, or adversary attack on one of these large satellites could result in the loss of billions of dollars of investment and a significant loss of capability. The time it takes to develop and construct a complex satellite can also be very lengthy. Some satellites, which have taken more than a decade to develop, contain technologies that have become obsolete by the time they are launched.

To address these challenges, DOD has begun considering alternative approaches for acquiring space-based capabilities and plans to decide on an acquisition approach over the next two to three years. One such approach involves disaggregating, or breaking up, large satellites into multiple, smaller satellites or payloads. Given preliminary indications that DOD intends to pursue disaggregation to potentially reduce costs and make satellite constellations more survivable, the Senate Armed Services Committee, in its report accompanying S. 1197, a bill for the National Defense Authorization Act for Fiscal Year 2014, mandated that we assess the potential benefits and drawbacks of disaggregating key military space systems and examine if disaggregation offers decreased acquisition and lifecycle costs and increased survivability of a satellite constellation

compared to more traditional acquisition approaches.[1, 2] In particular, the Committee mandated that we examine disaggregation concepts for capabilities provided by three military space systems:

- Advanced Extremely High Frequency (AEHF), which provides protected (survivable, jam-resistant, and secure) satellite communications;
- Space Based Infrared System (SBIRS), which provides missile warning, missile defense, technical intelligence, and battlespace awareness capabilities; and
- Weather System Follow-on (WSF), which is to provide space-based environmental monitoring (WSF has not yet begun product development).

Because DOD has only recently begun assessing the concept of disaggregation and a variety of unknowns remain, we were not in a position to definitively determine the benefits and drawbacks of disaggregation, including impacts on acquisition and lifecycle costs and survivability. Consequently, we focused our review on (1) describing the potential benefits and limitations of disaggregating military space systems and (2) assessing the extent to which DOD is ready to make informed decisions regarding disaggregating AEHF, SBIRS, and WSF.

To identify and describe potential benefits and limitations of disaggregating military space systems, we reviewed reports, assessments, and publications related to disaggregation produced by DOD, civilian agencies, industry, and third-party research organizations. We also interviewed a non-generalizable sample of representatives from these agencies and organizations, collectively referred to as experts for the purposes of our report, on the potential impacts of disaggregation. Based on these document reviews and discussions, we compiled a list of potential benefits and limitations that experts determined to be important

[1] A satellite constellation is a group of satellites acting in concert to perform a specific mission.

[2] S. Rep. No. 113-44, at 165 (2013). In its report accompanying S. 1197, a bill for the National Defense Authorization Act for Fiscal Year 2014, the Committee mandated that we report on the results of our engagement by March 31, 2014. As agreed with Committee staff, we satisfied this reporting requirement by including preliminary results of this engagement in our written statement for a March 12, 2014 hearing on military space issues before the Subcommittee on Strategic Forces, Senate Committee on Armed Services (see GAO, *Space Acquisitions: Acquisition Management Continues to Improve but Challenges Persist for Current and Future Programs,* GAO-14-382T (Washington, D.C., Mar. 12, 2014)), to be followed by this report.

factors for consideration regarding disaggregation and subsequently verified the list with those experts.

To assess the extent to which DOD is ready to make informed decisions regarding disaggregating AEHF, SBIRS, and WSF, we identified criteria based on the factors identified by experts and prior GAO work regarding early acquisition planning and development efforts to minimize cost and schedule growth. We then evaluated DOD's work to date on assessing disaggregation against these criteria to determine the extent to which DOD's efforts may provide the information necessary for sound decisionmaking. Additional details on our scope and methodology are provided in appendix I.

We conducted this performance audit from November 2013 to October 2014 in accordance with generally accepted government 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.

Background

DOD is considering alternative approaches—including disaggregation—to providing space-based capabilities to address challenges related to high-cost satellite programs and increasing threats to its space system capabilities. The size, capability, and complexity of DOD's satellites have tended to increase over the years, making them more costly to build. For example, Milstar, the protected communications satellite that preceded AEHF, weighed about 10,000 pounds, whereas the AEHF satellite weighs about 13,600 pounds and provides ten times the communications capacity. Additionally, SBIRS satellites are more capable than the Defense Support Program satellites they are to replace, offering greater sensor sensitivity and supporting a broader set of missions. According to DOD officials, it has made economic sense to maximize satellite capabilities as much as launch vehicle constraints would allow to fully utilize the capacity of the selected launch vehicle—which can cost well over $100 million for the vehicles DOD primarily uses. Additionally, certain requirements were consolidated to more efficiently provide capabilities, that is, fewer but more capable satellites could execute more missions than in the past.

This approach of building large, multifunctional satellites also increased acquisition risks since the design and manufacturing of satellites became

more complex.[3] Total acquisition costs for the AEHF satellite constellation, for example, have more than doubled, from $6.7 billion at program inception in 2001 to $14.5 billion currently.[4] This was partially due to the acquisition of an additional satellite, but also due to technical challenges and associated schedule delays of about 6 years for the launch of the first satellite. Our reports over the years have found that the significant cost and schedule growth for AEHF, SBIRS, and the environmental satellites DOD was acquiring in a similar fashion were partly due to design and manufacturing complexity.[5] We also reported that DOD's tendency to build large, monolithic satellites limited its ability to provide capabilities sooner and contributed to higher costs through developing extensive new designs, custom-made spacecraft, and payloads to meet the needs of multiple users. At the same time, other issues drove up costs for these programs including immature technologies, requirements instability, concurrent development and production, poor management and oversight, and reduced testing.[6] We have reported that DOD has taken actions to address many of these issues, and in recent years, DOD has largely overcome cost and schedule problems for the programs currently in production, and additional satellites of the same design are now being launched.[7]

[3] See GAO, *Military Space Operations: Common Problems and Their Effects on Satellite and Related Acquisitions,* GAO-03-825R (Washington, D.C.: June 2, 2003) and GAO-14-382T.

[4] Costs are in fiscal year 2015 dollars and based on DOD data contained in its December 2002 and December 2013 Selected Acquisition Reports for AEHF.

[5] Specifically, the environmental satellites referred to were for the National Polar-orbiting Operational Environmental Satellite System, a tri-agency program managed by DOD, the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA).

[6] See GAO-03-825R; *Defense Acquisitions: Space System Acquisition Risks and Keys to Addressing Them,* GAO-06-776R (Washington, D.C.: June 1, 2006); *Space Acquisitions: DOD Needs to Take More Action to Address Unrealistic Initial Cost Estimates of Space Systems*, GAO-07-96 (Washington, D.C.: Nov. 17, 2006); *Space Based Infrared System High Program and its Alternative*, GAO-07-1088R (Washington, D.C.: Sept. 12, 2007); *Briefing on Commercial and Department of Defense Space System Requirements and Acquisition Practices*, GAO-10-315R (Washington, D.C.: Jan. 14, 2010); and *Polar-Orbiting Environmental Satellites: Agencies Must Act Quickly to Address Risks That Jeopardize the Continuity of Weather and Climate Data*, GAO-10-558 (Washington, D.C.: May 27, 2010).

[7] See GAO-14-382T; *Space Acquisitions: DOD Is Overcoming Long-Standing Problems, but Faces Challenges to Ensuring Its Investments Are Optimized,* GAO-13-508T (Washington, D.C.: Apr. 24, 2013); and *Space Acquisitions: DOD Faces Challenges in Fully Realizing Benefits of Satellite Acquisition Improvements,* GAO-12-563T (Washington, D.C.: Mar. 21, 2012).

Reducing acquisition cost and risk are not the only reasons DOD is considering new approaches. According to Air Force Space Command, U.S. space systems face intentional and unintentional threats, which have increased rapidly over the past 20 years. These include radio frequency interference (including jamming), laser dazzling and blinding, kinetic intercept vehicles, and ground system attacks. Additionally, the hazards of the already-harsh space environment (e.g., extreme temperature fluctuations and radiation) have increased, including numbers of active and inactive satellites, spent rocket bodies, and other fragments and debris. In response, recent governmentwide and DOD strategic and policy guidance have stressed the need for U.S. space systems to be survivable or resilient against such threats.[8]

The decisions DOD plans to make over the next two to three years to address these affordability and threat-based challenges have the potential for making sweeping changes to DOD's space systems' top-level designs—or architectures—of the future.[9] For example, DOD may decide to build more disaggregated systems, including dispersing sensors onto separate satellites; using multiple domains, including space, air, and ground, to provide full mission capabilities; hosting payloads on other government or commercial spacecraft; or some combination of these.[10] Figure 1 shows a notional example of a disaggregated satellite system compared to one with fewer, but larger, multifunctional satellites. Last year, we reported that hosted payload arrangements in which government instruments are placed on commercial satellites may provide opportunities for government agencies to save money, especially in terms of launch and operation costs, and gain access to space.[11] However, the

[8] Office of the President of the United States, *National Space Policy of the United States of America* (June 28, 2010); *National Security Space Strategy, Unclassified Summary (Jan.2011)*; DOD, *Quadrennial Defense Review 2014* (Mar. 4, 2014); DOD Directive 3100.10. *Space Policy* (Oct. 18, 2012) (hereinafter cited as DODD 3100.10 (Oct. 18, 2012)).

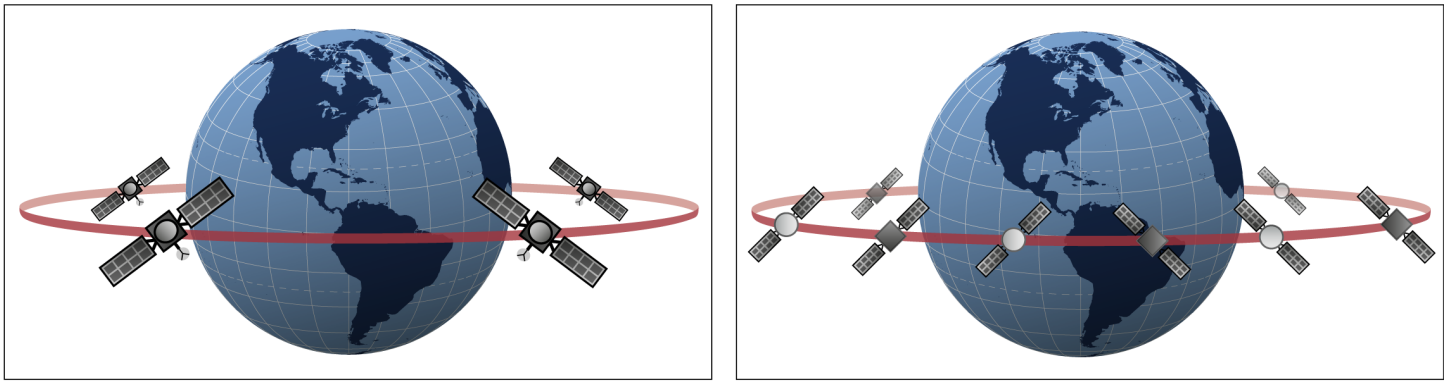
[9] According to the Air Force, to maintain protected satellite communications, SBIRS, and space based environmental monitoring capabilities, new satellites and/or payloads would be needed beginning in 2024, 2025, and 2015, respectively.

[10] Air Force Space Command defines space disaggregation as "[t]he dispersion of space-based missions, functions or sensors across multiple systems spanning one or more orbital plane, platform, host or domain." Programs may consider disaggregation in the future because it allows for options within a system's design to drive down cost, increase resilience and distribute capability. Air Force Space Command, *Resiliency and Disaggregated Space Architectures, White Paper* (Aug. 21, 2013).

[11] GAO, *2013 Annual Report: Actions Needed to Reduce Fragmentation, Overlap, and Duplication and Achieve Other Financial Benefits*, GAO-13-279SP (Washington, D.C.: April 9, 2013).

impacts of decisions could reach far beyond the space segment, affecting ground control systems, satellite user equipment, and communications networks.

Figure 1: Notional Example of a Disaggregated Satellite System



Example of aggregated satellite system

Example of disaggregated satellite system

Satellite with strategic and tactical capabilities

Satellite with strategic-only capabilities

Satellite with tactical-only capabilities

Source: GAO (data and images); MapResources (maps). | GAO-15-7

Note: For purposes of this figure, strategic capabilities may refer to those needed for major operations, such as those involving nuclear weapons. Tactical capabilities may refer to those needed for more localized, theater-level operations.

While this report is focused on the concept of disaggregation, it is important to note that DOD officials we spoke with stressed that disaggregation is only one of a number of approaches DOD is considering for its future space system designs. For example, in addition to disaggregation, DOD is considering the possibility of making satellites more maneuverable and building in defense capabilities to protect themselves as a means to increase survivability. Another approach under consideration is to evolve, or enhance, the capabilities of the large multifunctional satellites DOD is currently building. According to these officials, the primary considerations for studying these approaches and making decisions on which to use relate to finding the right balance between:

- Affordability—the determination that the life cycle cost of a program is in line with long-range plans;

- Resilience—the ability of a system to support the functions necessary for mission success in spite of hostile action or adverse conditions;[12] and
- Capability—the ability to execute specified actions.

To build consensus, and to conduct a more rigorous analysis of options, DOD is currently conducting studies that will consider future system architectures. Among these are Analyses of Alternatives (AOAs) that compare the effectiveness, suitability, risks, and estimated costs of alternatives for future protected satellite communications, SBIRS, and space-based environmental monitoring.[13] Determining which system design and components to pursue is critical because most of a program's total life-cycle cost is influenced by decisions made before it is approved to start development.

Disaggregation Offers an Array of Benefits and Limitations, but Significant Barriers to Implementation Exist

It is not yet known whether and to what extent disaggregation, on a broad scale, can enable DOD to reduce acquisition costs and increase the resilience of its satellite systems. DOD has had limited experience with disaggregating satellites and is still in the relatively early stages of quantifying the costs and benefits of disaggregating its satellites. The potential benefits of disaggregation, such as reduced costs associated with shorter development cycles and simpler designs, have been discussed in various Air Force publications. But less has been said about potential limitations, such as changes that would need to be made to interconnect systems—such as ground stations, user equipment, and communications networks—and the investment those changes would require. Moreover, many potential benefits can also be accompanied by

[12] Current DOD Space Policy defines resilience as the ability of a system to support the functions necessary for mission success with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats, in spite of hostile action or adverse conditions. DODD 3100.10 (Oct. 18, 2012) Glossary. During the course of this review, officials stated that DOD was in the process of developing a new definition for resilience. In commenting on a draft of this report, DOD stated the Defense Space Council—a senior-level DOD advisory group for space matters—has approved the above definition of resilience as it relates to the space domain.

[13] An Analysis of Alternatives (AOA) is a review in the DOD acquisition process that compares the operational effectiveness, suitability, and lifecycle cost of solutions to satisfy documented capability needs. Factors considered in the AOA include effectiveness, cost, schedule, concepts of operations, and overall risk of each alternative. The AOA is normally conducted during the Materiel Solution Analysis phase of the Defense Acquisition System to support a Milestone A decision to begin technology development for a preferred solution.

drawbacks. For instance, with capabilities distributed across multiple platforms, rather than centralized onto just a few satellites, it may be more difficult for an adversary to target all assets to attack full system capabilities. However, with increased numbers of satellites, the space environment becomes more congested, increasing risk of radio frequency interference and the potential for on-orbit contact with and damage from debris or other assets. Given the breadth of impacts disaggregation can have, it may not be possible to have complete knowledge of its effects. But experts agree that decisionmaking would benefit from assessments that look well beyond a single satellite program.

Further, even if DOD concludes disaggregation would have net positive effects, there are significant longstanding barriers to implementation. For instance, our work continues to find that there are time gaps—sometimes years—in aligning the delivery of satellites with associated user equipment and ground systems, which means that satellites may be in orbit for a long time with limited use. Without resolving the leadership, management, and oversight issues that have led to these delays, time gaps may well be exacerbated by disaggregation. Furthermore, disaggregation may require a more complex infrastructure and additional investments to support the satellites.

Disaggregation Offers a Range of Potential Benefits and Limitations

DOD, civilian agencies, industry officials, and researchers have identified a broad range of potential benefits and limitations associated with disaggregating military space systems that span numerous aspects of space systems acquisitions and operations. Views on the potential benefits and limitations are widely distributed among the various experts, even within DOD. Because these potential effects are dependent on various disaggregation approaches and have not yet been validated in practice for large, complex space systems, some points may appear to contradict one another. Further, some potential effects may not be unique to disaggregation, but may also apply to other changes from the current approach. Tables 1 through 5 describe the potential benefits and limitations in terms of affordability and life cycle costs, resilience, capability, the acquisition process, and the industrial base identified by experts. The contents of the tables are not exhaustive, but each of the potential benefits and limitations included were identified by more than one expert as important considerations for deciding whether to pursue a disaggregated approach.

Affordability and Life Cycle Costs

Affordability—the feasibility of producing and supporting a program throughout its life cycle and within budget—is one of the key drivers behind considering disaggregation as an option, according to experts.[14] Disaggregation may offer a more affordable approach to providing capabilities because of the potential for reduced per-satellite costs over the long term. Acquiring smaller, less complex satellites may require less time and effort to develop and produce, for example. This may be in part due to improved requirements discipline, as more frequent production rates may allow program managers to delay new requirements to the next production cycle instead of incorporating them into ongoing timelines mid-stream. However, a larger number of small satellites may be needed to provide the same level of capability overall, and the transition from existing system designs to disaggregation could increase costs in the near term. Additionally, given the current budget environment facing DOD, the transition to a new approach may be cost prohibitive, as resources may not be available to maintain and operate a legacy system and develop and field a new system at the same time. Table 1 describes how affordability could be impacted by disaggregation.

[14] The life cycle costs of a program include all direct and indirect costs that may be attributed to the program, such as research and development, investment, operation and support, and disposal costs.

Table 1: Potential Effects of Space System Disaggregation on Affordability and Life Cycle Costs

Potential benefits: affordability and life cycle costs	Potential limitations: affordability and life cycle costs
• Demand for more satellites may stimulate new entrants and competition to lower acquisition costs. • Smaller, less complex satellites may shorten development and production schedules and avoid delays that contribute to cost overruns. • A more continuous satellite production rate could reduce per-unit costs and provide a more predictable program baseline. • Smaller satellites may allow for lower-cost launch options, such as greater use of commercial launch vehicles, as available, and combining lighter, smaller payloads onto a single launch vehicle or attached to a host satellite. • Less complex satellites may reduce risk in technology research and development, integration, and launch, thereby reducing overall costs. For example, the Department of Defense (DOD) may be able to accept shorter satellite lifetimes and save on costs associated with rigorous mission assurance requirements and government reviews.[a] • If disaggregation involves splitting strategic and tactical capabilities onto separate payloads, the more demanding and costly requirements associated with strategic capabilities, such as the ability to survive a nuclear attack, may be isolated and allow DOD to leverage the commercial market for potentially less demanding and less costly tactical capabilities. As a result, overall costs may be reduced.[b]	• Transitioning from existing satellite system designs to disaggregation may increase costs in the near-term to support interoperability between—and potentially duplicate ground systems to support—legacy and new systems simultaneously. In constrained budget environments, the costs of transition may be prohibitive. • More satellites may require more or more complex ground systems—including user terminals—and more frequent updates to ground systems, adding to life cycle costs. • Increased numbers of satellites or payloads may require more launches and increase overall launch costs. • Using smaller, less complex satellites may require a high enough number of satellites to achieve the same level of capability such that the overall system is more costly. • More numerous satellites may result in multiple, simultaneous programs and contracts, leading to increased overall costs for non-recurring engineering.[c] • Use of hosted payloads may involve fees and/or penalties to reposition host satellites and reschedule launch opportunities if the payload is not ready on time.

Source: GAO analysis of documents from and interviews with DOD, NASA, NOAA, industry officials, and representatives of other knowledgeable organizations. | GAO-15-7

[a]DOD defines mission assurance as a process to protect or ensure the continued function and resilience of capabilities and assets—including personnel, equipment, facilities, networks, information and information systems, infrastructure, and supply chains—critical to the execution of DOD mission-essential functions in any operating environment or condition. DOD Directive 3020.40, *DOD Policy and Responsibilities for Critical Infrastructure* (Jan. 14, 2010, incorporating change 2, Sept. 21, 2012).

[b]For purposes of this report, strategic capabilities may refer to those needed for major operations, such as those involving nuclear weapons. Tactical capabilities may refer to those needed for more localized, theater-level operations.

[c]Non-recurring engineering costs refer to one-time costs for design engineering.

Resilience

Another main driver experts cited for examining disaggregation is the potential for increased resilience—the ability of a system to support the functions necessary for mission success in spite of hostile action or adverse conditions, according to one DOD definition—of space systems. Distributing capabilities across more satellites will increase the number and diversity of potential targets for an adversary and may make it more difficult for an adversary to decide which assets to attack, though some argue an adversary may be more likely to attack disaggregated satellites because they may be considered lower risk in terms of escalating

hostilities. Potential effects of disaggregation in terms of resilience are listed in table 2.

Table 2: Potential Effects of Space System Disaggregation on Resilience

Potential benefits: resilience	Potential limitations: resilience
• With capabilities distributed across multiple platforms rather than centralized onto just a few satellites, it may be more difficult for an adversary to target all assets to attack full system capabilities. • The loss of one smaller satellite or payload may result in less capability loss than damage to, or loss of, a large multifunctional satellite. • Smaller, more easily produced satellites or payloads may increase the ability to quickly reconstitute a lost satellite or payload. • If disaggregation involves international partnerships, adversaries may be less likely to attack shared assets because it would involve an attack on multiple governments and be more likely to quickly escalate a conflict.	• Adversaries may be more likely to attack small tactical satellites because they may be viewed as lower risk with regard to escalating hostilities. • More satellites or payloads create more space and ground assets for the Department of Defense (DOD) to protect from attack. Further, the cost of attacking multiple satellites may not be prohibitive for an adversary. • With increased numbers of satellites, the space environment may become more congested, potentially creating additional sources of debris that can damage other assets in orbit. • DOD may face additional information assurance challenges with hosted payloads. For example, DOD may need to take additional steps to ensure data processed from a DOD payload hosted on a foreign- or commercially-owned satellite is secure.

Source: GAO analysis of documents from and interviews with DOD, NASA, NOAA, industry officials, and representatives of other knowledgeable organizations. | GAO-15-7

Capability

Experts also cite capability—the ability to execute specified actions—as a key driver for considering disaggregation. Some experts assert disaggregation will offer enhanced space-based capability, largely due to increased opportunities to insert new technologies, while others argue that disaggregation may reduce capability overall by losing the combined capacity achieved by operating multiple payloads on a single satellite. Table 3 details the range of potential benefits and limitations of disaggregation with respect to capability.

Table 3: Potential Effects of Space System Disaggregation on Capability

Potential benefits: capability	Potential limitations: capability
• More, smaller satellites or payloads may create regular, planned technology insertion points and reduced time to deploy enhanced capabilities. • Mixed constellations of small distributed capabilities and more robust systems hardened against nuclear attack or other threats may allow individual payloads to be more tailored to specific requirements. • Producing less complex satellites quickly may provide the ability to respond to emerging needs more effectively, with more flexibility in providing capabilities when and where they are needed. • Building more, less-complex satellites may provide the Department of Defense (DOD) the opportunity to use commercial products and systems that have already been tested in the market. For example, DOD may use commercial off-the-shelf technologies, such as satellite control operations software systems and networks to bolster DOD systems. • The potential use of multiple suppliers for disaggregated satellites and payloads may help prevent systemic failures across a constellation—a latent defect in one payload or piece of equipment may be isolated to a small portion of a constellation.	• More satellites and frequent technology insertion may exceed the capacity of existing user equipment and ground systems that provide satellite control and data processing, potentially limiting delivery of increased capabilities to end users. For example, it may be more difficult to identify the source of, integrate, and distribute data to the appropriate end user. • Some systems may not be simplified to fit on smaller satellites without losing capabilities. For example, some capabilities require higher power and inherently complex components—such as crycoolers, which ensure sensors used for missile detection, for example, are kept at an appropriately cool temperature range—that smaller satellites would not be able to accommodate. • If payloads are separated, systems may lose capabilities provided by large, multifunction systems. For example, strategic payloads may no longer be able to support multiple missions, and tactical payloads may lose some of the protection provided by radiation-hardened strategic satellites. • Interoperability between legacy and new systems during the transition period to a new system may be limited, potentially limiting delivery of increased capabilities to end users. • DOD's existing primary launch infrastructure—the Evolved Expendable Launch Vehicle system—may not be able to accommodate the more frequent launches of smaller satellites associated with disaggregation. For hosted payloads, finding a host opportunity could be difficult due to a lack of available commercial satellite launches to specific orbits. • Adding more satellites and new technology may complicate efforts to synchronize satellite, terminal, and ground system schedules, limiting delivery of capabilities to end users. • With ground systems for current programs still in development, system capabilities have not yet been fully discovered and exploited. Moving to a new system may preempt the use of additional capabilities available in existing systems. • When a government payload is hosted on a commercial satellite, the government does not control the satellite and consequently may have to accept a lower level of capability and/or information assurance. In addition, sensors and host satellites may face compatibility challenges that limit capability. • With increased numbers of satellites, availability of radio frequency bandwidth for military communications may become constrained, and coordinating frequencies may become more difficult. Similarly, radio frequency interference between satellites—especially communications satellites—may become more common.

Source: GAO analysis of documents from and interviews with DOD, NASA, NOAA, industry officials, and representatives of other knowledgeable organizations. | GAO-15-7

Acquisition Process

The acquisition process—the way DOD buys, develops, and produces defense systems to provide capabilities to the warfighter—is another area that may be impacted by disaggregation.[15] According to some experts, disaggregation may allow DOD to implement new business practices, though others are concerned about the ability of the existing process to manage smaller, more frequent acquisitions. Table 4 expands on the potential benefits and limitations of disaggregation related to DOD's acquisition process.

Table 4: Potential Effects of Space System Disaggregation on DOD's Acquisition Process

Potential benefits: acquisition process	Potential limitations: acquisition process
• The Department of Defense (DOD) may be able to use innovative business practices—such as fixed price contracting and service leasing—more frequently and potentially improve overall acquisition performance. • DOD may be able to solicit competition separately for payloads and satellite buses to enable more tailored acquisition.[a] • Smaller programs with stable production rates may allow for stable funding profiles, avoiding large funding spikes typical of large programs that sometimes result in budget cuts to pay for other priorities in constrained budget environments.	• Disaggregation could require more rapid requirements development and vetting—to support, for example, more frequent technology insertion and commercially hosted payloads—than the current requirements process allows. • DOD may need to acquire multiple satellites rather than one, which may make it more difficult to manage acquisition schedules. In addition, potentially more development and production contracts may result in more complexity for program offices to manage, requiring increased oversight of contractors. • Commercial providers may be discouraged from pursuing contracts with DOD to host government payloads or provide satellite-based services due to lack of guaranteed funding and/or uncertainty regarding future funding investments. • More numerous, smaller acquisition programs may complicate DOD's ability to coordinate oversight efforts and prevent overlap and duplication.

Source: GAO analysis of documents from and interviews with DOD, NASA, NOAA, industry officials, and representatives of other knowledgeable organizations. | GAO-15-7

[a]The satellite bus is the body of the satellite. It carries the payload and is composed of a number of subsystems, like the power supply, antennas, telemetry and tracking command, and mechanical and thermal control systems. It also provides electrical power, stability, and propulsion for the entire satellite.

Industrial Base

Experts identified various potential effects on the industrial base—the capacity to produce and maintain U.S. military services and equipment—due to disaggregation. Some stated disaggregation may provide greater stability for the industrial base, while others said it may be more

[15] DOD refers to its acquisition process as the Defense Acquisition System—the management process by which the department provides effective, affordable, and timely systems to the users. The system is intended to manage the nation's investments in technologies, programs, and product support necessary to achieve the National Security Strategy and support the United States Armed Forces. DOD Directive 5000.01, *The Defense Acquisition System* (May 12, 2003, certified current as of Nov. 20, 2007).

disruptive, especially for existing suppliers. Details on potential benefits and limitations for the industrial base due to disaggregation are provided in table 5.

Table 5: Potential Effects of Space System Disaggregation on the Industrial Base

Potential benefits: industrial base	Potential limitations: industrial base
• More stable demand and higher production rates may provide business stability, stimulate innovation, and incentivize new companies to enter the marketplace. • Increased production may be distributed over multiple contractors—including traditionally lower-tier contractors—to foster more competition.[a] • With shorter acquisition time frames, engineers and program managers may experience the full project cycle more quickly and frequently, allowing enhanced skill development.	• The lower-tier supply base may not have the capacity or knowledge base in the near term to produce disaggregated satellites at higher and more regular production rates. • Shifting to greater use of lower-tier suppliers may be disruptive to traditional providers in the current industrial base and spread limited government funds too thinly across contractors. Further, the skills and experience of large prime contractors who know how to build needed systems may be lost.

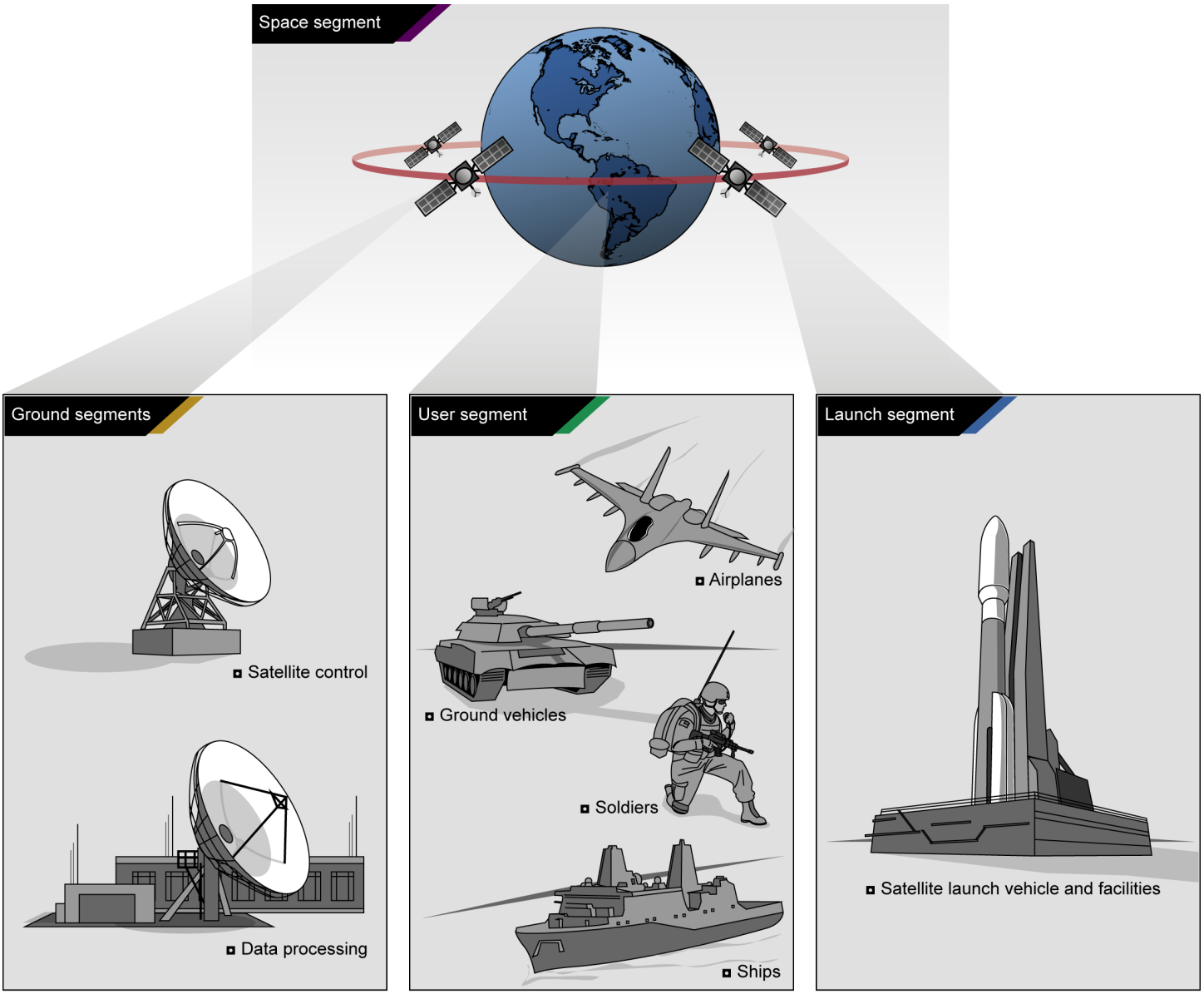
Source: GAO analysis of documents from and interviews with DOD, NASA, NOAA, industry officials, and representatives of other knowledgeable organizations. | GAO-15-7

[a]Lower-tier contractors refer to those that supply products or materials to a first-tier, or prime, contractor or supplier.

DOD Faces Significant Longstanding Barriers to Implementation

Benefits and limitations aside, there are significant, persistent barriers to implementing a disaggregation approach. Most of these relate to leadership shortcomings over systems and assets that need to work together to deliver space-based capabilities, such as satellite control and data processing facilities, user terminals, and satellite launch vehicles and facilities. Figure 2 depicts these interdependent segments. For each of these segments, DOD is already facing considerable management and oversight challenges that disaggregation could well exacerbate.

Figure 2: Segments Involved in Delivering Space-Based Capabilities



Source: GAO (data and images). | GAO-15-7

Fragmented Leadership

Disaggregation could require DOD to make significant cultural and process changes in how it acquires space systems—for instance by relying on new contractors, relinquishing control to providers who host government payloads on commercial satellites, using different contracting

methods, and executing smaller but more numerous and faster-paced acquisition programs. It will likely require DOD to be more flexible and agile when it comes to satellite acquisitions, especially with regard to coordinating satellite delivery with interdependent systems, such as user equipment. Yet, we have reported that DOD's culture has generally been resistant to changes in space acquisition approaches and that fragmented responsibilities have made it very difficult to coordinate and deliver interdependent systems.[16] At present, although some improvements in leadership have been made, there is still no single person or organization that is held accountable for balancing needs against wants, ensuring coordination among the many organizations involved with space systems acquisitions, and ensuring that resources are directed where they are most needed.[17] These challenges pose barriers for even the best-run efforts and they likely will be exacerbated and pose significant implementation barriers if DOD decides to disaggregate its space systems.

Gaps in the Delivery of Satellites, Ground Systems, and User Terminals

One of the principal, persistent outgrowths tied to fragmented leadership is that development of satellites often outpaces that of ground systems and user terminals (such as those on airplanes, ground vehicles, and ships), leading to underutilized on-orbit satellites and delays in getting new capabilities to end users. In some cases, gaps in delivery can add up to years, meaning that a satellite is launched but not effectively used for years until ground systems become available. One reason DOD has been unable to align the delivery of space system segments is because budgeting authority for the segments is spread across the military services and there is no single authority to ensure programs are funded in a manner that would align their deliveries. There are other reasons that have contributed to gaps in the delivery of space system segments, including poor acquisition management (requirements instability, underestimation of technical complexity, and poor contractor oversight),

[16] GAO-14-382T and *Space Acquisitions: Challenges in Commercializing Technologies Developed under the Small Business Innovation Research Program*, GAO-11-21 (Washington, D.C.: Nov. 10, 2010).

[17] GAO-14-382T; *2012 Annual Report: Opportunities to Reduce Duplication, Overlap and Fragmentation, Achieve Savings, and Enhance Revenue*, GAO-12-342SP (Washington, D.C.: Feb. 28, 2012); *Space Acquisitions: Development and Oversight Challenges in Delivering Improved Space Situational Awareness Capabilities,* GAO-11-545 (Washington, D.C.: May 27, 2011); and *Space Acquisitions: DOD Poised to Enhance Space Capabilities, but Persistent Challenges Remain in Developing Space Systems*, GAO-10-447T (Washington, D.C.: Mar. 10, 2010).

program funding instability, and changing information security requirements.[18] These challenges could intensify with the potentially larger numbers and novel configurations of satellites, payloads, and other components of a disaggregated approach.

Stove-Piped Satellite Control Networks

Over the past decade, DOD has increasingly deployed standalone satellite control operations networks, which are designed to operate a single satellite system, as opposed to shared systems that can operate multiple kinds of satellites. Dedicated networks can offer many benefits to programs, including possible lower risks and customization for a particular program's needs. However, we have reported they can also be more costly and have led to a fragmented, and potentially duplicative, approach which requires more infrastructure and personnel than shared operations. Moreover, DOD has not embraced practices and technologies that could reduce satellite control costs and increase efficiency.[19] By introducing more satellites developed by a potentially broader base of suppliers, DOD risks increasing its reliance on standalone satellite networks, especially since it has lacked a long-term plan for satellite control operations.

Satellite Launch Costs

In theory, disaggregation can enable DOD to reduce launch costs because satellites would no longer require the heaviest, most expensive launch vehicles to get to orbit. However, the vehicles DOD primarily relies on to deliver its satellites to orbit are designed to carry heavier satellites. Without changes to the current architecture, DOD may well find itself having to rely on launch vehicles that are more capable and expensive than needed. Or, it may need to make changes to its approach to launching satellites so that it can rely on smaller launch vehicles or multiple smaller satellites on a single launch vehicle. Transitioning to these approaches may require additional investment to ensure they are fully developed and reliable. DOD is also in the midst of introducing competition into its launch acquisitions. While this could open up avenues to acquiring smaller launch vehicles, the current process for introducing

[18] GAO, *Defense Acquisitions: Challenges in Aligning Space System Components,* GAO-10-55 (Washington, D.C.: Oct. 29, 2009).

[19] GAO, *Satellite Control: Long-Term Planning and Adoption of Commercial Practices Could Improve DOD's Operations,* GAO-13-315 (Washington, D.C.: April 18, 2013).

competition is focused on the larger launch vehicles DOD primarily uses for its satellites.[20]

DOD Has Begun to Examine Disaggregation for Its Space Systems but Has Yet to Verify Effects

DOD has initiated and completed studies and demonstrations, including AOAs that examine disaggregated concepts for certain systems. While AOAs and other studies can provide initial insights, such as rough order of magnitude costs of selected disaggregated scenarios, they are not intended to comprehensively assess the effects of disaggregation. Moreover, the lack of common measures for key factors such as resilience may limit the effectiveness of these assessments. Technology demonstrations are providing an additional avenue for gaining knowledge about disaggregation, but demonstrations to date have been limited, concentrating more on technical feasibility and less on operational feasibility.

DOD is Beginning to Develop Knowledge on Disaggregation but Lacks Key Assessment Measures

DOD has multiple ongoing and completed efforts to examine aspects of disaggregation (see table 6). These include AOAs—which are designed to identify a range of solutions that could provide needed capability and support a decision on the most cost effective solution—as well as other studies and demonstrations that assess the potential for applying disaggregation concepts. We have reported on the important role of AOAs in establishing a sound basis for initiating programs, including providing insight into the technical feasibility and costs of alternatives.[21] AOAs carry significant weight in the decisionmaking process, in part because they involve participation and oversight by all military services. Many of the other studies and demonstration projects related to disaggregation are Air Force efforts with a focused application to Air Force missions or programs.

[20] GAO, *The Air Force's Evolved Expendable Launch Vehicle Competitive Procurement*, GAO-14-377R (Washington, D.C.: March 4, 2014).

[21] GAO, *Defense Acquisitions: Many Analyses of Alternatives Have Not Provided a Robust Assessment of Weapon System Options*, GAO-09-665 (Washington, D.C.: Sep. 24, 2009).

Table 6: Examples of DOD Efforts Related to Disaggregation

Effort and lead organization	Purpose, applicability to disaggregation, and status as of October 2014
Analyses of Alternatives (AOA)	
Protected Satellite Communications Services AOA Office of the Undersecretary of Defense for Acquisition, Technology and Logistics	Conduct analysis required to ensure the Department of Defense (DOD) pursues the most suitable alternative for providing space-based protected satellite communications services following the current Advanced Extremely High Frequency (AEHF) program. The AOA will assess a disaggregated scenario among multiple other options. Status: Ongoing. Final report expected March 2015, according to a DOD official.
Space Based Infrared System (SBIRS) Follow-On AOA Air Force Space Command and National Reconnaissance Office	Provide analytical basis for determining an approach for providing launch detection and missile tracking capabilities following the current SBIRS program. The AOA will assess a disaggregated scenario among multiple other options. Status: Ongoing. Final report expected December 2014, according to a DOD official.
Space-Based Environmental Monitoring Capabilities AOA Air Force Space Command	Conduct analysis of alternative solutions that can provide environmental monitoring capabilities following the current Defense Meteorological Satellite Program and other meteorological satellite programs. The AOA was designed to assess a disaggregated scenario among multiple other options. Status: Ongoing. According to officials, the report has been completed, was approved by the Joint Requirements Oversight Council September 3, 2014, and is awaiting final release as of October 2014.
Other Studies	
Review of threats to national security space systems National Research Council, in arrangement with the Secretary of Defense and the Director of National Intelligence	Conduct a review of the range of options to address near- and long-term threats to national space systems and identify specific strategies, such as disaggregation, and planned architectures.[a] Status: Not yet started pending funding.
Various joint operations studies of alternatives for future systems Various agencies, including the Office of Cost Assessment and Program Evaluation, the DOD Executive Agent for Space, Air Force Space Command, and the National Geospatial-Intelligence Agency	Assess options for providing future protected satellite communications and overhead persistent infrared (OPIR) capabilities, which include disaggregated options.[b] Specific studies that have been completed include: • 2011 Resilient Basis for Satellite Communications in Joint Operation Study • 2012 Joint OPIR Integrated Space Trade Study • 2010 Joint OPIR Ground Architecture Study Status: Completed.
Microsatellite Mission Applications Study Air Force Scientific Advisory Board	Assess the potential for microsatellites—satellites that weigh less than 300 kilograms—to provide military weather; space situational awareness; position, navigation, and timing; missile warning, and satellite communications capabilities.[c] Status: Completed. Final results of the study were reported in 2013.
Project on Effects of Satellite Constellation Disaggregation on Launch Enterprise RAND Corporation, Project AIR FORCE	Help the Air Force investigate the impact of satellite constellation disaggregation on the cost and mission effectiveness of the launch enterprise. Status: Ongoing, with planned completion in fall 2014.

Effort and lead organization	Purpose, applicability to disaggregation, and status as of October 2014
Technology Development Demonstrations	
Projects under Space Modernization Initiative Air Force Space Command, Space and Missile Systems Center	The Space Modernization Initiative is intended to develop affordable approaches to maintain and evolve current military capabilities. The AEHF and SBIRS programs have specific projects that may support disaggregation, including demonstrations of separate protected tactical and strategic capabilities for AEHF and data exploitation, infrared sensors, and hosted payload projects for SBIRS. Status: Ongoing.
System F6 Defense Advanced Research Projects Agency	Demonstrate fractionation—the decomposition of a system into modules which interact wirelessly to deliver the capability of the original monolithic system—in a constellation of free-flying satellites. Status: Discontinued in 2013.
Airborne Launch Assist Space Access (ALASA) and Experimental Spaceplane (XS-1) Projects Defense Advanced Research Projects Agency	Develop lower cost and rapid launch opportunities for small satellites. In particular, ALASA seeks to develop a complete launch vehicle requiring no recurring maintenance or support and no specific integration to prepare for launch, enabling launches of 100 pounds for less than $1 million. XS-1 is intended to demonstrate a reusable first stage launch vehicle that costs less than $5 million for launching an operational system. Status: Ongoing.
Commercially Hosted Infrared Payload (CHIRP) Flight Demonstration Air Force Space Command, Space and Missile Systems Center	Test new infrared sensor technology and demonstrate hosting a government payload on a commercial satellite bus. Status: Discontinued in 2013 due to budgetary constraints.
Tests of Alternative Acquisition Approaches	
Space Environmental NanoSatellite Experiment (SENSE) Air Force Space Command, Space and Missile Systems Center	SENSE seeks to demonstrate affordable and rapid deployment of small satellites as well as monitoring and forecasting environmental changes.[d] SENSE leverages commercial off-the-shelf electronics, enables quick production of large quantities of satellites, and utilizes an automated ground architecture that requires minimal operator oversight. Status: Ongoing.
Hosted Payload Solutions (HoPS) Program Air Force Space Command, Space and Missile Systems Center	Develop an affordable and reproducible process for acquiring access to space with commercial industry acquisition timeframes of two to three years. The Air Force recently awarded contracts to 14 companies to support the development of an on-orbit hosted payload system and integrated ground system to deliver government payload data to end users.[e] Status: Ongoing.

Source: GAO summary of information from DOD documents and interviews with officials. | GAO-15-7

[a]This review was mandated by the National Defense Authorization Act for Fiscal Year 2014. Pub. L. No. 113-66, § 912 (2013).

[b]OPIR capabilities support four main missions: missile warning, missile defense, technical intelligence, and battlespace awareness.

[c]Air Force Scientific Advisory Board, Microsatellite Mission Applications Study Abstract (2013).

[d]Two SENSE satellites were among multiple payloads launched on the Operationally Responsive Space-3 “Enabler Mission” on November 19, 2013.

[e]The 14 awards were firm-fixed price, indefinite delivery/indefinite quantity contracts, intended to create a pool of qualified vendors to meet the government’s needs for various hosted payload missions. The Air Force may issue delivery orders under these indefinite delivery/indefinite quantity contracts within a five year period.

It is too early to determine the extent to which the AOAs will assess disaggregation for AEHF, SBIRS, and WSF because the AOAs are ongoing. While DOD plans to assess a disaggregated scenario in each of the AOAs for the mission areas of these programs, it is not yet clear how thorough the assessments will be in terms of the potential benefits and limitations experts identified. However, the intent of the AOAs is not to examine the merits of disaggregation on its own, but rather as one of the many options that may or may not provide solutions. The additional studies beyond the AOAs have been useful in providing results to inform the ongoing AOAs, officials told us, though some have been regarded as inconclusive because they were not conducted with sufficient analytical rigor or did not consider the capabilities, risks, and trades in a holistic manner. For example, according to the Office of the Secretary of Defense's Office of Cost Assessment and Program Evaluation, one study of satellite communication architectures contained insufficient data to support the conclusion that one architectural approach was more resilient than others. In addition, the study's cost estimates did not consider important factors, such as ground control and user terminal costs, in calculating the implications of changing architectures. Other studies on specific applications and system components of disaggregation may provide useful information in those narrow areas, though they are not set up to cover a broader range of potential impacts of disaggregation.

Further, DOD lacks common measures for resilience that can be used consistently in AOAs and other analysis. DOD leaders have emphasized resilience as a priority when considering future systems. For example, officials told us DOD is conducting an internal review on various aspects of space resilience in the strategic portfolio, which includes disaggregation as one potential method for affecting resilience in the space segment. Officials acknowledge the need for measures and DOD is taking steps to develop them. For example, in February 2014, DOD hosted a forum convening DOD and industry experts to discuss resilience and work toward developing an agreed-upon taxonomy. The Space and Missile Systems Center, under Air Force Space Command, is also working to develop a standard assessment methodology to quantify the resilience of proposed enhancements to certain systems, including overhead persistent infrared (OPIR) and satellite communications systems. These efforts may not be completed in time to apply common measures across alternatives in the AOAs in our review; instead, resilience will be assessed on a relative basis by comparing alternatives and determining which is more or less resilient than another, Air Force officials told us. Without a consistent method to measure resilience that

can be used across DOD, though, it may be difficult to determine how much resilience is needed and whether an alternative meets that need.

Demonstration Projects Are Helping to Build Knowledge but Have Not Concentrated on Operational Aspects

Demonstration projects related to disaggregation have provided technological insight and valuable lessons that DOD may use in future projects. For example, the CHIRP program demonstrated how new infrared sensor technology can be applied in OPIR missions and whether the capability of commercial spacecraft technologies could support mission needs. For future hosted payloads, DOD learned that it is better to finish payload upgrades before contracting for launch and integration services to prevent schedule delays and take advantage of cost savings. DOD also learned that conducting the necessary up-front systems engineering to better configure the payload for the host vehicle could help ensure the payload's performance without harming the host. The Defense Advanced Research Projects Agency's (DARPA) System F6 project also provided a lesson learned with regard to the utility of efforts not in direct support of a mission. DARPA officials said the lack of a driving mission behind System F6—which was initiated with technology development as a goal rather than support of a specific mission—limited its ability to directly inform operational systems. The project did provide useful outcomes that could be applied to future disaggregated architectures, though, such as the development of data management protocols for managing multiple satellites.

While technology demonstrations have been playing an important role in assessing the technical feasibility of disaggregation, they have not focused on operational feasibility, that is, how to introduce a disaggregated approach into a program of record and make it work from a holistic perspective. This would include assessing, for example,

- how a potential technical or design change would impact contracting and program management;
- how it would impact interconnected systems such as ground terminals and control stations and the extent to which changes would be needed to these systems;
- how data from disaggregated satellites would be integrated and shared; and
- how information assurance would be maintained with hosting operational payloads on commercial or foreign satellites.

In addition to studies and technology demonstrations, officials we interviewed emphasized the importance of testing the operational viability

of disaggregation—to provide real data to assess the effectiveness of the concept—and gaining practical experience by disaggregating a mission system. Along these lines, we have previously recommended that DOD follow an incremental path toward introducing significant advancements or changes into weapon programs and ensure critical technologies are proven to work.[22] Though disaggregation may not be introducing revolutionary technology changes, it may be introducing design, architectural, and operational changes that could have far-reaching effects.

Conclusions

Disaggregation of satellites may offer a viable option for addressing affordability and resilience challenges that DOD is facing. But it is not a simple solution. The changes to satellite designs that are being contemplated could have far-reaching effects on requirements, supporting infrastructure, management and oversight of acquisitions, industry, and other areas. They could also require upfront investments—which, under DOD's current fiscal constraints, may not be feasible—and more leadership attention. DOD does not yet have the knowledge it needs to make changes on a wide scale nor has it addressed underlying challenges to space acquisition that could be exacerbated by disaggregation. Without a determined and disciplined effort to develop information about the full range of disaggregation issues—including operations—decisions on future space capabilities could be under-informed and opportunities missed. For example, a premature decision to pursue a large-scale disaggregated design could lead to a poor investment. Alternatively, aspiring programs could overlook the benefits of disaggregation in favor of status-quo approaches.

DOD is taking steps to gain knowledge, particularly in terms of technical feasibility, costs, and technical alternatives. The ongoing studies, including the AOAs for protected satellite communications, SBIRS, and space-based environmental monitoring, if comprehensively conducted, should help to determine some of the impacts of changing DOD's current space system designs and find the right balance among system characteristics of affordability, capability, and resilience. However, until resilience measures are developed and agreed upon, resilience

[22] GAO, *Space Acquisitions: DOD Faces Substantial Challenges in Developing New Space Systems*, GAO-09-705T (Washington, D.C.: May 20, 2009).

assessments—whether as part of the AOA studies or not—will be of limited value. Further, even when these studies are completed, there may still be significant uncertainties about how disaggregation could work and there will still be significant risks in implementation if key challenges, such as aligning satellite and ground systems, are not addressed. Because most of DOD's knowledge about disaggregation resides in paper studies and a limited number of demonstration efforts, continued or expanded demonstration efforts—including those to provide operational capabilities or otherwise aimed at quantifying the benefits, limitations, and feasibility of space system disaggregation—conducted before wide-scale change is implemented could go a long way towards gaining empirical data to help DOD develop quantifiable estimates and verify the wide range of potential benefits and limitations disaggregation may yield.

Recommendations for Executive Action

Before making decisions on whether to disaggregate DOD's protected satellite communications, SBIRS, or environmental monitoring satellite systems, we recommend that the Secretary of Defense direct the Under Secretary of Defense for Acquisition, Technology and Logistics to take the following three actions:

1. Comprehensively examine—either through the AOA studies or through other assessments—the full range of disaggregation issues, including those that go beyond the satellite systems themselves;
2. Develop common measures for resilience; and
3. Expand demonstration efforts to examine the operational feasibility of disaggregation by empirically quantifying its benefits and limitations as well as addressing longstanding barriers that could hinder its implementation.

Agency Comments and Our Evaluation

We provided a draft of this report to DOD for comment. In its written comments, DOD concurred with our first two recommendations and partially concurred with our third recommendation. The comments are reprinted in appendix II. DOD also provided technical comments which we incorporated as appropriate.

In concurring with our first recommendation, DOD agreed that the extent to which disaggregation could help reduce costs and increase the resilience of satellites is not yet known, and AOAs and other forms of assessments should comprehensively examine the range of disaggregation issues. DOD reiterated that alternatives for future satellite

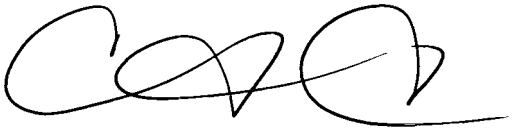
constellations must balance required capability, affordability, and resilience. Additionally, DOD stated that it continues to examine how different architectural alternatives affect its acquisition process, its relationship with industry partners, and the space industrial base as a whole.

In concurring with our second recommendation, DOD agreed that developing a common definition and measures for resilience is important. During the course of our review, DOD officials we interviewed stated that a consensus on a definition for resilience had not yet been achieved. However, in commenting on this recommendation, DOD stated that its Defense Space Council has approved a definition of resilience, contained in its October 2012 Space Policy. In response, we revised our recommendation to focus on the need for common measures for resilience. DOD stated it is beginning to implement resilience measures into space systems requirements and acquisition processes, and that it agrees the development of metrics to measure space system resilience is needed.

In partially concurring with our third recommendation, DOD agreed that disaggregation requires continued analysis as one method of providing increased space system resilience and emphasized that disaggregation is just one approach. DOD stated the challenges of a disaggregated ground system are well-known and demonstrated in existing architectures. However, our work found that multiple stakeholders—including DOD officials—are concerned about the unknown impacts of disaggregation on ground systems, such as whether existing systems could support it. Further assessment of the potential effects on the ground system—including how interconnected systems could be impacted and whether changes would be needed—will be necessary to ensure DOD has a complete understanding of the challenges it may face. DOD also stated it is well-versed in managing constellations with many satellites and networks with diverse users. However, disaggregation, depending on how it is carried out, could represent a significant departure from DOD's current space system architectures, operational experience, as well as acquisition strategy and oversight. Consequently, we continue to maintain that gaining experience on the operational feasibility of disaggregation through expanded demonstrations could provide DOD with valuable knowledge for deciding a way forward for its space system acquisitions.

We are sending copies of this report to the appropriate congressional committees and the Secretary of Defense. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact me at (202) 512-4841 or chaplainc@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix III.



Cristina T. Chaplain
Director
Acquisition and Sourcing Management

Appendix I: Objectives, Scope, and Methodology

The Senate Armed Services Committee, in its report, 113-44, accompanying S. 1197, a bill for the National Defense Authorization Act for Fiscal Year 2014, mandated that we assess the potential benefits and drawbacks of disaggregating key military space systems—to include the use of hosted payloads—with a focus on whether disaggregation offers decreased acquisition and life cycle costs and increased survivability compared to more traditional approaches to acquiring capabilities.[1, 2] The report mandated that we examine disaggregation for three military space systems in particular: Advanced Extremely High Frequency (AEHF), Space Based Infrared System (SBIRS), and Weather Satellite Follow-on (WSF). This report (1) describes the potential benefits and limitations of disaggregating military space systems, and (2) assesses the extent to which DOD is ready to make informed decisions regarding disaggregating AEHF, SBIRS, and WSF.[3]

To identify and describe potential benefits and limitations of disaggregating military space systems, we reviewed reports, assessments, and publications related to disaggregation produced by DOD, civilian agencies, industry, and third-party research organizations. We also interviewed a non-generalizable sample of representatives from over 35 organizations and offices, collectively referred to as experts for the purposes of our report, on the potential benefits and limitations of disaggregation. Specifically, we spoke with DOD officials from the Secretary of Defense, including the Office of Cost Assessment and Program Evaluation and the Offices of the Undersecretary of Defense for Acquisition, Technology and Logistics and for Space Policy; Chief

[1] S. Rep. No. 113-44, at 165 (2013). In its report the Senate Armed Services Committee mandated that we report on the results of our engagement by March 31, 2014. As agreed with Committee staff, we satisfied this reporting requirement by including preliminary results of this engagement in our written statement for a March 12, 2014 hearing on military space issues before the Subcommittee on Strategic Forces, Senate Committee on Armed Services (see GAO, *Space Acquisitions: Acquisition Management Continues to Improve but Challenges Persist for Current and Future Programs,* GAO-14-362T (Washington, D.C., Mar. 12, 2014)), to be followed by this report.

[2] Other approaches might include incremental technological improvements of existing space systems and the use of block buy or fixed price contracting.

[3] Because DOD has only recently begun assessing disaggregation and a wide variety of unknowns—including how to quantify the effects of disaggregation, which would largely depend on the specific option being pursued—remain, we were not in a position to definitively determine the benefits and drawbacks of disaggregation, including impacts on acquisition and life cycle costs and survivability. The particular impacts of disaggregation depend largely on the specific option being pursued and the specific mission it supports, which are yet to be determined as DOD's studies are ongoing.

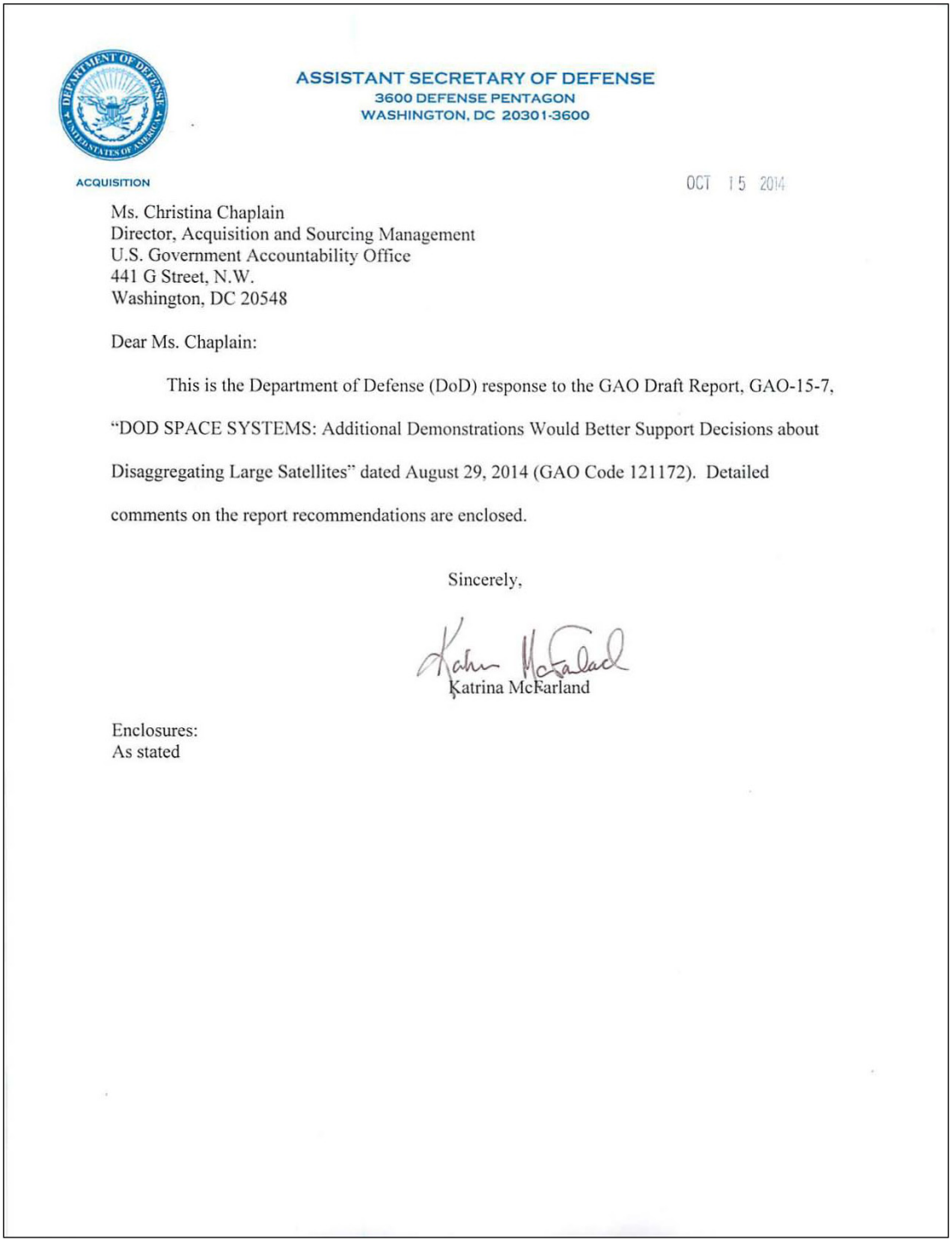
Information Officer; Joint Chiefs of Staff; U.S. Strategic Command; military service headquarters, including the Offices of Executive Agent for Space Staff, the Assistant Secretary of the Air Force (Acquisitions-Directorate of Space Programs), and the Office of the Chief of Naval Operations; Air Force Space Command; applicable program offices at the Air Force Space and Missile Systems Center; Naval Research Laboratory; the Defense Advanced Research Projects Agency; the Air Force Scientific Advisory Board; and the National Geospatial-Intelligence Agency. Outside of DOD, we met with government officials from the Department of Commerce, including the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration. We also interviewed representatives from contractors representing work in a range of mission areas (e.g., satellite communications, weather monitoring, etc.), product and service types (e.g., building satellites, integrating systems, etc.), and level of involvement in military space systems within the scope of our review. In addition, we spoke with third-party organizations such as non-profit research and industry organizations. Based on these document reviews and discussions, we compiled a list of potential benefits and limitations that experts determined to be important factors for consideration regarding disaggregation and subsequently verified the list with those experts. Each of the potential benefits and limitations identified in our report are supported by statements from at least two experts, generally representing multiple types of organizations (i.e., DOD, civilian agency, industry, and third-party). Further, we reviewed prior GAO work to determine if longstanding space system acquisition challenges pose potential barriers to implementing a disaggregated approach.

To assess the extent to which DOD is ready to make informed decisions regarding disaggregating AEHF, SBIRS, and WSF, we reviewed prior GAO work on DOD space systems acquisitions and identified criteria for early acquisition planning and development efforts to minimize cost and schedule growth. We interviewed officials from the DOD offices responsible for conducting and reviewing the ongoing AOAs in the scope of our review, as well as contributing offices, and reviewed available guidance for conducting each of the AOAs. We also reviewed available documentation about and interviewed the relevant DOD officials involved in previous or ongoing studies and demonstrations related to disaggregation. We assessed the completed and ongoing efforts—to include the AOAs, other studies, and demonstrations—against the criteria from prior GAO work and the potential benefits and limitations identified by experts to determine the extent to which these efforts provide a

comprehensive assessment of disaggregation and prepare DOD to make an informed decision.

We conducted this performance audit from November 2013 to October 2014 in accordance with generally accepted government 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 II: Comments from the Department of Defense



ASSISTANT SECRETARY OF DEFENSE
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WASHINGTON, DC 20301-3600

ACQUISITION

OCT 15 2014

Ms. Christina 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-15-7, "DOD SPACE SYSTEMS: Additional Demonstrations Would Better Support Decisions about Disaggregating Large Satellites" dated August 29, 2014 (GAO Code 121172). Detailed comments on the report recommendations are enclosed.

Sincerely,

Katrina McFarland

Enclosures:
As stated

GAO Draft Report Dated AUGUST 29, 2014
GAO-15-7 (GAO CODE 121172)

"DOD SPACE SYSTEMS: ADDITIONAL DEMONSTRATIONS WOULD BETTER SUPPORT DECISIONS ABOUT DISAGGREGATING LARGE SATELLITES"

DEPARTMENT OF DEFENSE COMMENTS TO THE GAO RECOMMENDATION

RECOMMENDATION 1: The GAO recommends that the Secretary of Defense direct the Under Secretary of Defense for Acquisition, Technology and Logistics to comprehensively examine – either through AOA studies or through other assessments – the full range of disaggregation issues, including those that go beyond the satellite systems themselves.

DoD RESPONSE: CONCUR. The DoD concurs with comprehensively examining the range of disaggregation issues, including those areas that go beyond the satellite systems themselves. This will take place through Analysis of Alternatives (AoA) studies and other forms of assessments.

Recommendation 1 is consistent with the concept that for the DoD to sustain space services, the United States must consider architectural alternatives for future satellite constellations. These alternatives must balance required capability, affordability and resilience. The DoD is actively studying several options—disaggregation is one. The DoD agrees that it is currently not known if, and to what degree disaggregation could help reduce costs and increase the resiliency of its satellites.

Ongoing AoAs are already positioned to examine life-cycle cost, performance, resilience, and operational risks of potential architectures, including disaggregated architectures. The culmination of these activities will inform architecture decisions for the space, ground and user segments for both follow-on protected communications systems, missile warning systems as well as other platforms. Furthermore, the Protected Satellite Communication (SATCOM) System AoA has already broadened its scope to include non-space (air and ground) systems which will enhance the disaggregation analysis and go beyond the satellite systems themselves per this recommendation.

Additionally, the department continues to look at how different architectural alternatives affect the DoD acquisition process, the department's relationship with industry partners and the space industrial base as a whole.

RECOMMENDATION 2: The GAO recommends that the Secretary of Defense direct the Under Secretary of Defense for Acquisition, Technology and Logistics to develop a common definition and measures for resilience.

DoD RESPONSE: CONCUR. The DoD concurs with this recommendation to develop a common definition and measures for resilience. To that end, the Department's Defense Space

Council has approved a definition of resilience as it relates to the space domain. This definition was codified in DoDD 3100.10, Space Policy (dated 18 October 2012) which states resilience is "the ability of an architecture to support the functions necessary for mission success with higher probability, shorter periods of reduced capability, and across a wider range of scenarios, conditions, and threats, in spite of hostile action or adverse conditions. Resilience may leverage cross-domain or alternative government, commercial, or international capabilities."

The DoD acknowledges that current space architectures are vulnerable to attack. Our adversary's counterspace capabilities and actions continue to grow in sophistication, number and employment with the intent to hold our space systems at risk. Metrics to measure resilience, lethality, and survivability already exist within other warfighting domains. Now that the space domain is increasingly contested, congested and competitive, the DoD is beginning to implement resiliency measures into the space systems requirements and acquisition processes. The DoD agrees that the development of metrics (i.e., time to restore, reconstitution, survivability) to measure space system resilience is needed.

RECOMMENDATION 3: The GAO recommends that the Secretary of Defense direct the Under Secretary of Defense for Acquisition, Technology and Logistics to expand demonstration efforts to examine the operational feasibility of disaggregation by empirically quantifying its benefits and limitations as well as addressing longstanding barriers that could hinder its implementation.

DoD RESPONSE: PARTIALLY CONCUR. The DoD agrees that as a strategy, disaggregation requires continued detailed analysis and mission-specific assessment as one method to provide a greater level of space system resiliency. Given the vulnerability inherent in current space architectures, combined with the danger of an escalating threat, our future architectures demand a thorough examination of the potential benefits of disaggregation. As an approach to resilience, disaggregation is just one method, and it is resilience in the space domain that bears further examination.

The operational, acquisition, and integration challenges of disaggregated ground systems are well-known to the department. For example, both the nuclear command and control architecture and the integrated threat warning and attack assessment architecture are disaggregated. Both architectures rely on systems in multiple (air/space/ground) domains and are designed with a measure of resilience in mind.

The DoD should continue incorporation of resilience assessments into wargaming and theater exercises including disaggregation as one method. It will allow opportunities to explore and test ways to enhance the quantitative and also qualitative aspects of resiliency of existing and potential future space mission architectures and associated hardware. The department however is well-versed in managing constellations with many satellites (e.g. GPS) as well as managing networks with numerous and diverse users (e.g. AEHF, WGS), attributes which would be inherent in future disaggregated systems.

Appendix III: GAO Contact and Staff Acknowledgments

GAO Contact

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Staff Acknowledgments

In addition to the contact named above, key contributors to this report were Art Gallegos, Assistant Director; Jenny Chanley; Brenna Guarneros; Kristine Hassinger; Rich Horiuchi; Carol Petersen; Jeff Sanders; Roxanna Sun; Bob Swierczek; Jay Tallon; and Oziel Trevino.